Aalto University
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Modeling supply chain costs in the automotive manufacturing industry

The case of Valmet Automotive

Logistics

Master's thesis

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2015

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Abstract of master's thesis

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Title of thesis Modeling supply chain costs in the automotive manufacturing industry – The case of Valmet Automotive

Degree Master of Science in Economics and Business Administration

Degree programme Information and Service Economy

Thesis advisor(s) Markku Kuula

Year of approval 2015 **Number of pages** 114 **Language** English

Abstract

This thesis examines mathematical modeling as a means to improve profitability. The research is focused on studying supply chain cost drivers and their potential in regard to cost reduction in the automotive manufacturing industry, where the role of supply chain management is significant because of the capital intensive, fast paced, and high volume nature of the business. Hence, supportive tools for decision making are highly valuable. Therefore, the objective of this study is to develop a total supply chain costing model that can be used to add value to business primarily in the automotive manufacturing sector.

Despite its significance, surprisingly little research has been published on the subject of supply chain costs in manufacturing in general, let alone modeling of supply chain costs in the automotive manufacturing industry. Research into costing has been published in management accounting literature, but supply chain management is rarely represented. Simulation and optimization models have been developed, even in the automotive sector, but they are usually very case specific, and discuss mostly manufacturing or distribution related modeling problems. Therefore, this thesis aims to contribute to filling the research gap in modeling total supply chain costs in automotive manufacturing by extending the knowledge of both modeling methods and supply chain cost drivers in the automotive sector.

This research is conducted as a case study of a Finnish automotive contract manufacturer, Valmet Automotive Inc., that expressed the need to develop a supply chain costing model to streamline its supply chain processes and generate cost savings through improved understanding and control of its supply chain cost drivers. A literature review of the topic informs the theoretical basis for constructing the costing model. In addition to theory, the mechanics and mathematical formulas of the model are developed based on participant observations and informal interviews with supply chain professionals at the case company. Moreover, verification and validation of the costing model is carried out together with the case company's supply chain managers.

The output of this thesis is a validated total supply chain costing model that was taken into use at the case company. Experimentation proved that the developed model can be used to add value to the case company's business in forms of cost saving, supply chain process streamlining and performance follow up. Moreover, supply chain managers can utilize the costing model as a strategic planning tool and as a supportive tool for decision making. Lastly, by providing an innovative case study of modeling supply chain costs in the automotive manufacturing industry, this thesis has contributed to the research into supply chain cost drivers and their modeling in the automotive manufacturing context.

Keywords Valmet Automotive, industry, Finland, supply chain management, logistics, cost management, cost driver, costing, mathematical modeling, process streamlining

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Maisterintutkinnon tutkielman tiivistelmä

Tekijä Lauri Koivula

Työn nimi Toimitusketjukustannusten mallintaminen autoteollisuudessa
– Tapausyhtiönä Valmet Automotive

Tutkinto Kauppatieteiden maisteri

Koulutusohjelma Tieto- ja palvelutalous

Työn ohjaaja(t) Markku Kuula

Hyväksymisvuosi 2015 **Sivumäärä** 114 **Kieli** Englanti

Tiivistelmä

Tässä gradututkielmassa tutkitaan yrityksen kannattavuuden parantamista matemaattisen mallinnuksen avulla. Tutkielma keskittyy toimitusketjukustannustekijöiden ja niiden kustannussäästöpotentiaalin kartoittamiseen autoteollisuudessa. Päätöksentekoa tukevat työkalut ovat tarpeellisia erityisesti alalla, jossa investoinnit ovat suuria ja tilanteet vaativat nopeaa päätöksentekokykyä. Tämän tutkielman tavoite onkin kehittää päätöksenteon tueksi toimitusketjun kokonaiskustannuksia mallintava työkalu, jolla voidaan luoda liiketoiminnallista lisäarvoa erityisesti autoteollisuudessa toimiville valmistajille.

Aiheen merkityksellisyydestä huolimatta autoteollisuuden kustannustekijöistä ja niiden mallintamisesta on julkaistu yllättävän vähän aiempaa tutkimusta. Simulointi- ja optimointimalleja on kehitetty, mutta ne ovat yleisesti ottaen hyvin tapauskohtaisia ja käsittelevät usein tuotantoon ja jakeluun liittyvien ongelmien mallintamista. Siispä tämä gradututkielma pyrkiikin edistämään tutkimusta toimitusketjun kokonaiskustannusten mallintamisesta autoteollisuudessa kasvattamalla tietämystä autovalmistajien toimitusketjukustannustekijöistä ja kustannusten mallintamismenetelmistä.

Tutkielma toteutetaan empiirisenä tutkimuksena yhdessä autoalan sopimusvalmistajan Valmet Automotive Oy:n kanssa, joka esitti tarpeen toimitusketjukustannustensa mallintamisesta. Mallinnustyökalun avulla Valmet Automotive pyrkii tehostamaan toimitusketjuprosessejaan ja luomaan kustannussäästöjä paremmin ymmärtämällä ja hallitsemalla toimitusketjukustannustekijöitään. Menetelmät kustannuslaskentamallin kehittämiseksi perustuvat kirjallisuuskatsaukseen aiheesta, sekä tutkijan havaintoihin Valmet Automotiven toimitusketjuprosesseista että epämuodollisiin haastatteluihin yhtiön toimitusketjualan ammattilaisten kanssa. Laskentamallin oikeellisuuden vahvistaminen toteutetaan yhdessä Valmet Automotiven toimitusketjujen hallinnasta vastaavien esimiesten kanssa mallinnuskirjallisuudessa esiteltyjä menetelmiä käyttäen.

Gradututkielman lopputuloksena kehitettiin kokonaiskustannuslaskentamalli, joka otettiin käyttöön Valmet Automotiven toimitusketjujen hallinnassa. Tutkielman empiiriset kokeet osoittivat, että mallinnustyökalulla voidaan luoda lisäarvoa yhtiölle kustannussäästöjen muodossa toimitusketjuprosesseja tehostamalla. Lisäksi kustannuslaskentamallia voidaan hyödyntää yhtiön päätöksenteon tukena ja strategisena suunnittelutyökaluna. Tämä gradututkielma on onnistunut myös edistämään akateemista tutkimustyötä toimitusketjujen kustannustekijöistä ja niiden riippuvuussuhteiden mallintamisesta autoteollisuudessa innovatiivisen tapaustutkimuksen avulla.

Avainsanat Valmet Automotive, autoteollisuus, Suomi, toimitusketjujen hallinta, logistiikka, kustannusten hallinta, kustannustekijä, kustannuslaskenta, matemaattinen mallintaminen, prosessien tehostaminen

Acknowledgements

First of all, I would like to thank Valmet Automotive Inc. for providing and financing this research opportunity. Throughout the writing process of this thesis I have been able to extend my knowledge of the automotive industry, supply chain management, and modeling techniques, of which I am grateful to Valmet Automotive. Moreover, I am pleased to know that this research has proven to be of value for Valmet Automotive, and that the developed tool has been taken into use.

I appreciate the support of my thesis supervisors: professor Markku Kuula from Aalto University and Mrs. Marita Saarinen from Valmet Automotive. Thank you for your encouragement and constructive feedback throughout the writing process of my thesis. Furthermore, I want to thank Mrs. Saarinen for her time and advice throughout the process of developing the costing model.

In addition, I would like to thank Mr. Heikki Kivijärvi from Valmet Automotive, who acknowledged the need to carry out this research, and trusted me with the research opportunity in the first place. Besides, I give thanks to Mr. Teppo Siivonen from Metso Corporation, who connected me with this research opportunity at Valmet Automotive and also gave me valuable feedback on my thesis.

I thank all the people who contributed to my thesis by participating in the informal interviews, helping in the development of the costing model, proofreading, and providing comments to my written work. I especially want to thank my colleague Mr. Mikko Luoma, who encouraged me in the early stages of the research process and provided me with literature on the research topic. In addition, I thank Mr. Luoma for always having time for my questions and phone calls, and sharing his professional experience and knowledge with me.

Lastly, completion of this thesis would have been difficult without my friends and colleagues who helped me commute between my home in Helsinki and Valmet Automotive's office in Uusikaupunki. In addition, these very friends offered me a place to stay overnight whenever I was visiting Uusikaupunki. I give my sincere thanks to these helpful people. Moreover, I am thankful to my dear family and friends for all your support, understanding and encouragement throughout the completion of this thesis. You cheered me up whenever I needed it, and finally, we are able to celebrate this achievement together.

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List of Abbreviations

3PL	Third party logistics service provider
ABC	Activity-based costing
BI	Business Intelligence
BOM	Bill of materials
CAO	Computer assisted ordering
CT	Control Tower
DPM	Defects per million
EBIT	Earnings before interests and taxes
EDI	Electronic data interchange
EOQ	Economic order quantity
EOI	Economic order interval
ERP	Enterprise resource planning
ETL	Extracting, transforming and loading
FIFO	First in, first out inventory management method
FTL	Full truck load
GDP	Gross domestic product
JIS	*Just-in-sequence* supply chain management
JIT	*Just-in-time* supply chain management
KPI	Key performance indicator
LDM	Loading meter
LSP	Logistics service provider
LFL	Lot-for-lot ordering
LTL	Less than truck load
M&S	Modeling and Simulation
MOQ	Minimum order quantity
MRP	Material requirements planning
MTR	VA's custom-built MRP software
OLAP	Online analytical processing
RFID	Radio-frequency identification
SC	Supply chain
SCM	Supply chain management
SKU	Stock keeping unit
TCO	Total cost of ownership
UI	User interface
VA	Valmet Automotive Inc.
VATG	Valmet Automotive Transport Gateway
VBA	Visual Basic for Applications programming language
WACC	Weighted average cost of capital
WOW	Warehouse on wheels

1. Introduction

The concept of supply chain management (SCM) is gaining increased importance in today's economy due to its impact on companies' competitive advantages (Bottani & Montanari 2010). Supply chain management is put under pressure by companies striving to maintain high customer service levels while being forced to cut costs and maintain profit margins (Altiparmak et al. 2009). The automotive industry is ever changing, fast paced and capital intensive. Supportive tools for decision making, strategic planning, and cost reduction are highly valuable. Every situation is unique and demands a model that is customized to match the particular situation and purpose of the company in question (D'este 2001, p. 534).

Very little research has been published on the subject of supply chain (SC) costs in automotive manufacturing and in manufacturing industry in general. However, research into costing and the factors that affect costs in organizations has been published in management accounting literature, but the context of supply chain management is rarely embodied. This is rather surprising considering the significance of SCM and its potential for improving profitability especially in the field of manufacturing. On the other hand, because of the comprehensive nature of SCM, the data on SC costs is typically fragmented in various places in the organization, which may lead to poor understanding and poor control of SCM cost drivers, and ultimately result in underestimating the significance of SCM and its potential for improving the profitability of organizations. Thus, in the worst case, SCM may be considered merely as a necessary cost.

1.1 Background and motivation for the research

This research is commissioned by a Finnish automotive contract manufacturing company, Valmet Automotive Inc. (VA), where the author had worked prior to the initiation of this thesis. Developing a tool to calculate and model total SC costs has been one of the company management's interests for a couple of years before conducting this study. At VA, the tool is referred to as the *total cost of ownership* (TCO) model, and it should be able to measure SC costs and key performance indicators (KPI) on a part number, supplier number, and an overall level. However, the TCO model is not about supplier selection, which the TCO term is usually referred to. Instead, the TCO model is used to increase understanding and provide the means to improve VA's SCM, which is a meaningful use of TCO analysis, as Ellram and Siferd (1998), the founders of the TCO term, bring out in their study. Furthermore, in this thesis the modeling tool is referred to both as TCO model and as *costing model*.

The model ought to utilize data from VA's database and provide information in support of management decision making in SCM, and especially in procurement and logistics. Furthermore, a supportive tool for fact based decision making should ultimately help management make better decisions, and thus increase the case company's net profit through decreased total SC costs. Besides bringing out monetary savings, the research shall help VA obtain a better understanding and control of their SC cost drivers as well as introduce possible areas for development in order to make SCM more effective.

Academic research can also benefit from the unique problem of this case study: the methods created and results achieved in calculating and modeling SC costs of the case company. Automotive manufacturing industry is highly complex, competitive and labor intensive, yet it can still strive even in a somewhat isolated and up market country like Finland, which makes the study particularly interesting. Besides, car production requires large capital investments, which necessitate well founded decision making, i.e. data management and advanced supportive tools for decision making are essential. Because of the complexity and development potential within the industry, this research in Finnish automotive manufacturing sector should form an interesting line of study for the researcher as well as the academic sector.

Earlier research on SC models exists, yet no similar case to VA's process optimization and costing model development was found. Numerous previous studies in the field of SC modeling and simulation have been conducted, and some of them include e.g. models for materials planning in the automotive industry (Mula et al. 2014), modeling a manufacturing assembly line (Kekre et al. 2003), automotive distribution network (Turner & Williams 2005), automotive transportation and inventory optimization (Mula et al. 2013), the bullwhip-effect (Bolarín & Mcdonnell 2008), automotive supply chain resilience (Carvalho et al. 2012), and supply chain cost analysis on an aggregate level (Bottani & Montanari 2010).

However, the previous studies are very case specific and offer neither universal solutions nor a working solution suitable for the study of this thesis. Moreover, very little research has been published on the subject of SC costs in manufacturing. All in all, no previous study of modeling total SCM costs in the automotive manufacturing industry appeared. Therefore, the academic motivation for conducting this thesis is to contribute to filling the research gap in modeling total SCM costs especially in the automotive manufacturing industry.

1.2 Research questions and objectives

This thesis consists of three research questions. The primary research question is to determine:

(1) *How to create a tool for calculating and modeling supply chain costs?*

And the two sub questions examine:

(2) *What are Valmet Automotive's key supply chain cost drivers, and how are they correlated?*

(3) *How can the costing model be used to add value to Valmet Automotive's business*?

The practical objective of this study is to contribute to the knowledge of VA regarding the modeling of total supply chain costs by identifying and describing the key supply chain cost drivers and key performance indicators. The study aims to improve visibility within VA's SC operations, and disclose the relations between key SC cost drivers. The added value of the TCO model will be evaluated: whether the theoretical model is valid in practice and is able to provide reliable and useful support for management decision making, and whether the possible benefits make it worthwhile to develop and maintain such a model. In addition, the aim of the research is to help VA find reasonable means to achieve cost savings and streamline the case company's SC operations, while maintaining a low risk of production disruptions and upholding high service quality.

This is an example of so-called action research as described by Kaplan (1998), and thus its objective regarding theoretical contribution is to *modify and extend the emerging theory in light of knowledge gained through experience*. However, as already discussed in the previous part of this chapter, there is very limited research published on the subject of modeling total SCM costs in the automotive manufacturing industry. Therefore, instead of modifying the existing theory, this thesis aims to extend the emerging theory of modeling SCM costs. Furthermore, the benefit of understanding existing theories regarding the studied topic is to ensure that the theoretical basis in building the TCO model and selecting the key cost drivers is sound. In addition, VA's current SC operations will be evaluated based on the theories relating particularly to the automotive manufacturing industry, such as lean supply chain management. On the other hand, existing theories of SCM, modeling and automotive manufacturing industry in general can be challenged and enriched with the findings of this empirical case study and the mathematical tool developed for calculating and modeling supply chain costs.

1.3 Research methods, framework and limitations

This research is an innovative and practice oriented case study, as described by Dul and Hak (2008, p. 217), consisting of the development of mathematical modeling methods. The study will include participant observations as well as informal interviews with SCM professionals at VA and at a third party logistics service provider's site. Besides, data will be retrieved from VA's database and documented files. Theoretical part of the thesis will be based on a literature review.

Empirical experimentation will be carried out as scenarios run by the costing model after it has been verified and validated. Analysis of results will be based on logic models, such as sensitivity analysis, which can reveal causality and patterns in the case company's SCM. Additionally, empirical evidence and management's interpretations will be taken into account in the results analysis phase.

This thesis is limited to studying VA's SC operations regarding its current manufacturing contract with Daimler AG. Moreover, the scope of this research is limited to modeling SC costs associated with the case company only, and thus inter-enterprise SC performance or its costs are not taken into account. This limitation is due to the concern of the case company to focus on optimizing its own operations.

This research adopts the Product-Relationship-Matrix framework proposed by Seuring (2002b, p. 18) as the most applicable to the study. Seuring's (2002b) SCM framework is divided into four phases as shown in Figure 1. As product and network design (I, II and III) are on Daimler's responsibility, VA is left with only the last field of the matrix to work on: (IV) *process optimization in the supply chain.* Indeed, SCM process optimization and streamlining is a key motivation for conducting this research and developing the TCO model and, at the same time, one of the limitations to the scope of this thesis.

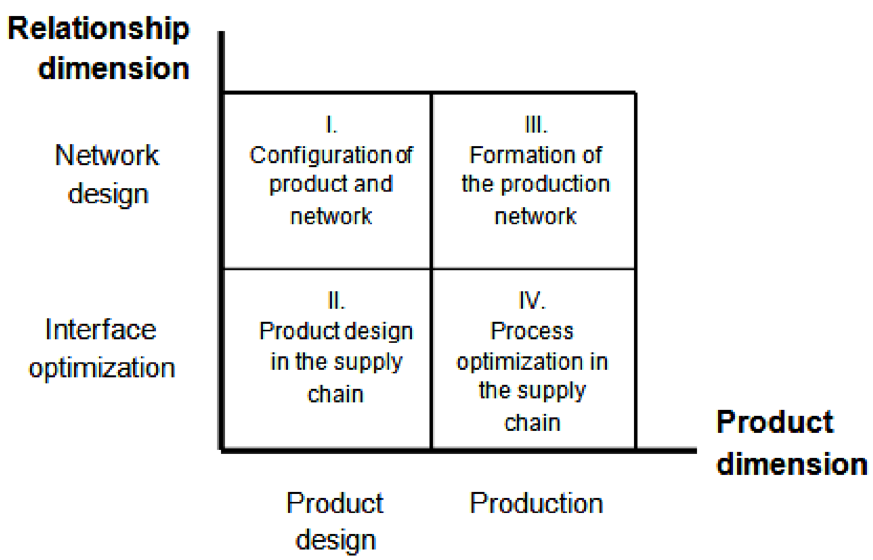


Figure 1. The Product-Relationship-Matrix of Supply Chain Management (Seuring 2002b, p. 18)

Furthermore, the scope of this research is restricted to studying only VA's indirect SC costs, as the case company has no power over some direct costs, such as the cost of components. Component costs are, however, included in the costing model as a point of comparison to other SCM costs. Other direct costs, such as manufacturing costs, are excluded too because their consideration would widen the scope of this research excessively, and are not among the case company supply chain managers' focus in this study.

Moreover, although manufacturing operations are not included in this research, the author acknowledges the importance of manufacturing related risk management, and the cost of possible stock out and production disruptions. Nevertheless, consideration of such risks is left to the responsibility of VA personnel using the costing model.

1.4 Structure of the study

An overview of the thesis' structure is displayed in Table 1 below. After this introduction, the concepts of supply chain management, cost management and modeling are discussed in the literature review part of this study. A short overview of the case company is also provided, followed by a description of the case company's supply chain operations.

After understanding the case company's SC operations and the theory underlying the construction of a costing model, the different stages of developing the model are discussed in Chapter 6. Once the model is developed, it is followed by a verification and validation process conducted in Chapter 7, which includes scenario experiments as well as analysis of their results. Lastly, Chapter 8 consists of a conclusion of the study, with discussion of managerial implications and suggestions for future research.

Table 1: Structure of the study

Chapter	Objective
I	Introduction and background
II	Literature review
III	
IV	
V	Description of the case company
VI	Developing the costing model
VII	Experimentation and analysis of results
VIII	Discussion and conclusions

2. Description of main supply chain functions

The objective of this chapter is to describe the main supply chain functions and key performance indicators that could be studied in the case company, and further applied in the development of the costing model. Examples of SCM characteristics in the automotive industry are then discussed. But first the author will present an overview of the concept of supply chain management.

According to the Council of Supply Chain Management Professionals (CSCMP 2014), the concept of supply chain management is defined as:

> *Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies.*

In other words, SCM is the management of material and information flows, and the management of relationships between supply chain members (Seuring 2002a, p. 2). In addition, a broader definition of SCM includes also financial flows (Stemmler 2002, p. 166-167). Therefore, the concept of supply chain management is defined in this thesis as the management of material, information and financial flows, including the management of relationships between supply chain participants as well.

An overview of SC participants, functions and business processes is presented in Appendix 1. The objective of SCM is to operate cost-effectively by minimizing total costs across the entire SC, while maintaining a high level of service. However, system wide cost-effectiveness can be difficult to achieve since the objectives of different SC functions can be conflicting in the first place. However, SC participants should not try to operate on the expense of other SC functions, as transferring the costs will end up with the consumer, and ultimately impairs the competitiveness of all SC functions (Christopher 1992, p. 13; Mentzer et al. 2001).

Logistics functions form a large part of SCM costs and have typically accounted for some 5 to 10 per cent of a company's total sales (Maununen 2000; McKinnon 2001, p. 164). In a more recent study of Finnish manufacturing companies Solakivi et al. (2012) discovered that on average logistics costs equaled 12 per cent of company annual turnover. Logistics itself can be divided into four different segments: (1) inbound logistics that include logistics functions related to moving items from supplier to manufacturer, (2) internal logistics including logistics functions within manufacturer's premises, (3) outbound logistics involving functions in moving products from manufacturer to customer and (4) reverse logistics that include functions in moving items from customer back to manufacturer or from manufacturer back to supplier (Cooper et al. 1997; Miemczyk & Holweg 2004).

Furthermore, the term cost driver in this research is defined as anything that creates costs without adding value to the customer (Kajüter 2002, p. 44). Three major logistics cost drivers are commonly considered to be *transportation*, *warehousing* and *inventory holding costs*, which cover some 80 per cent of total logistics costs, others being e.g. ordering and administration costs (Christopher 1992, p. 61-62; Solakivi et al. 2012; Tyndall & Bushner 1985). These main logistics functions will be discussed next in more detail.

2.1 Inventory management

A supply chain with minimum inventories is the goal of inventory management, but having no inventory is rare in reality. Inventory can appear in several forms, such as (1) raw materials, (2) work-in-progress and (3) finished products. Typically, inventories are held to be able to deal with seasonality and unexpected changes in demand, uncertainty in supply and delivery, or because of a trade-off to achieve cost savings through economies of scale in transportation and procurement. Also, because of long lead times, due to growing distances between global suppliers and manufacturers, safety stocks need to be kept in order to cover demand and its variation during lead time, see Figure 2. (Richards 2011, p. 9-15; Simchi-Levi et al. 2008, p. 31-32; Waters 2001, p. 195-197.)

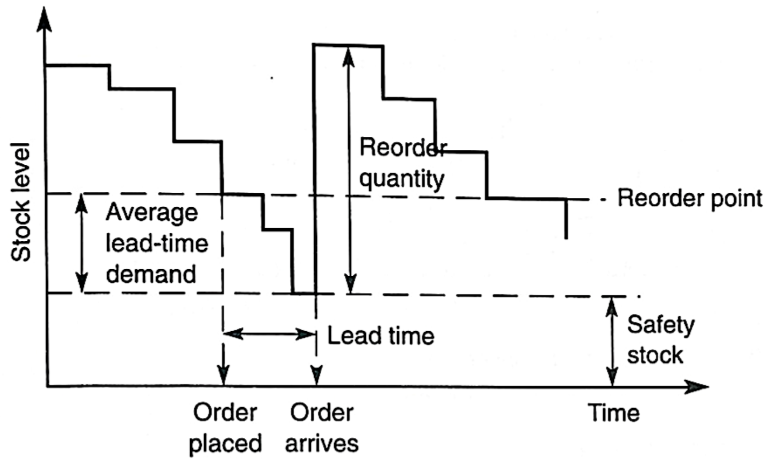


Figure 2. Safety stock and reorder point method in inventory control (Christopher 1992, p. 155)

As stated by Christopher (1992, p. 62), there is a hidden cost in SCM that few management accounting systems separately identify. This hidden cost is the interest charged on inventory holding, which is based on an interest rate for capital and on the average value of inventory. Timme and Williams-Timme (2003) recommend using the weighted average cost of capital (WACC) as the interest rate for calculating opportunity cost, as WACC represents the opportunity cost for a company's average risk investment. Furthermore, when calculating the average inventory value, inventory in transit also known as warehouse on wheels (WOW), ought to be considered as part of the inventory (Krüger 2002). However, it is not only the opportunity cost or cost of capital that defines inventory holding cost. Inventory holding cost should also take into account the costs of obsolete and deteriorated material, taxes, insurance costs of stored items and inventory management costs. It is estimated that inventory holding costs account for some 20 to 25 per cent of average annual inventory value, and usually form 20 to 30 per cent of total SCM costs (Solakivi et al. 2012).

Obsolescence is the risk of an item losing value because of shifts in styles or consumer preferences, i.e. decreased demand for a product (Tersine 1994, p. 14). According to Taylor (2001, p. 216), obsolete material in the automotive industry usually derives from component changes within car models or the complete change of a car model, which takes place every few years. However, overenthusiastic purchasing, forecast errors or inventory record keeping errors may lead to excess inventory even in cases where the product's life cycle is known (Tersine 1994, p. 293). Tersine (1994) adds that any kind of excess inventory is a dead weight to a company; it uses valuable storage space and depletes working capital, and should be sold or salvaged if possible.

The major reduction of logistics costs in recent decades has been acquired through reduction in inventory levels, which has been significantly furthered by the move to so-called *just-in-time* (JIT) replenishment (McKinnon 2001, p. 164), which will be further discussed in this chapter. According to Richards (2011, p. 124), companies that are world-class in using JIT techniques have an inventory turnover ratio over 150, meaning that their inventory is sold over 150 times per year. Richards (2011, p. 124) observes that typical European manufacturing companies' inventory turnover ratio is between 10 and 30. Moreover, inventory turnover ratio can be increased e.g. by reducing safety stock, i.e. reducing the average inventory level, or increasing sales. Richards (2011, p. 124) further defines the formula for calculating inventory turnover ratio as:

$$Inventory\ turnover\ ratio = \frac{Cost\ of\ goods\ sold}{Average\ cost\ of\ goods\ stored} \tag{1}$$

Furthermore, once the inventory turnover ratio is calculated, it can be used to calculate the approximate inventory throughput time. As defined by Tersine (1994, p.23), throughput time is the average time the inventory is in an organization. Furthermore, Tersine (1994, p.23) describes the formula for calculating inventory throughput time as:

$$Inventory\ throughput\ time = \frac{Operating\ days\ per\ year}{Inventory\ turnover\ ratio} \tag{2}$$

Minimizing inventory throughput time improves cash flow, decreases capital tied up in inventory and also enables a quick response to possible changes in the SC or customer requirements. The target for any organization should be to reduce lead times at every stage of the SC as close to zero as possible. Imagine a pipe full of oil: now if a change of requirement occurs in the end of the pipeline, all the material within the pipe at that time needs to be pumped out before the new material can come through, and the longer the pipeline, the bigger the markdown and the longer it takes the new material to reach the point of demand. The same applies to automotive manufacturing, where the longer the lead time, the higher the combined value of obsolete material should part requirements change.

To conclude, the main inventory trade-offs are between inventory holding costs, inventory space and customer service level and, again, the penalty of not holding inventory when it is needed (Richards 2011, p. 28). For instance, in the automotive industry, an average vehicle consists of 2 000-4 000 components, many of which are customizable by color, size and style, and hence, traditional stock holding would be extremely costly (Miemczyk & Holweg 2004). The challenge of inventory management is to find the best balance between these trade-offs, although continuously striving to achieve them all.

2.2 Warehousing operations

Although warehouses can be different in type, functionality, ownership and size, the principal processes are similar (Richards 2011, p. 43-45). The main warehouse processes are:

- *Pre-receipt*. Agreeing with the supplier on the required packaging and labeling compatible with the storage facility as well as agreeing on the transportation mode and delivery frequency.
- *Receiving*. Offloading and checking; to ensure that the correct products have arrived in the correct quantity, required condition, at the right time and at the right place.
- *Put-away*. Moving the unloaded goods to storage or dispatch area.
- *Storage*

- *Picking*. Order picking and delivery to production line. Picking is typically considered the most labor intensive, and thus the most cost intensive function of all warehouse operations.
- *Replenishment*. Ensuring that the right products and right quantities are in the right pick locations.
- *Value-adding services*. Labeling, repacking, subassembly and repairing services.
- *Dispatch*. Forwarding goods to the customer.

Furthermore, warehouse operation costs can be divided into three groups, as explained by Simchi-Levi et al. (2008, p.88):

1. *Handling costs* consist of costs such as receiving and order picking. These costs include labor and equipment utility costs, and are dependent on the annual flow of material through the warehouse.
2. *Fixed costs* include costs that are related to the warehouse building itself, and are not proportional to annual material flow.
3. *Storage costs,* such as cost of capital tied up in inventory, obsolescence costs and insurance costs of inventory are proportional to the average inventory levels. However, in this research storage costs are considered as inventory holding costs, instead of part of warehousing costs, based on the division proposed by Lambert (1994, p. 273).

According to Richards (2011, p. 212), warehousing costs average usually between 1 and 5 per cent of total sales of the company, and around 20 per cent of the company's total logistics costs, depending on the industry. Similar findings were also published in a study of Finnish manufacturing companies conducted by Solakivi et al. (2012). Moreover, Richards (2011) indicates that warehousing costs are usually:

1. 60 per cent labor related, e.g. wages, overtime, bonuses, safety wear, and welfare.
2. 25 per cent space related, e.g. rent, electricity, heating and building depreciation.
3. 15 per cent equipment related, e.g. rent, depreciation and running costs.
4. Overhead costs, such as information technology hardware and software.

Furthermore, Figure 3 displays a distribution of warehouse operation costs (Richards 2011, p. 44). However, these costs can vary remarkably depending on how the warehouse is operated. For example, in the automotive manufacturing industry, a warehouse operated in a lean manner usually has low storage costs because of the low inventory level, but may instead have higher receiving and picking costs because of frequent deliveries and pick-ups. Nevertheless, as receiving, picking and dispatching operations are labor intensive, they are commonly some of the major warehousing operation costs, and their importance is also apparent from the figure.

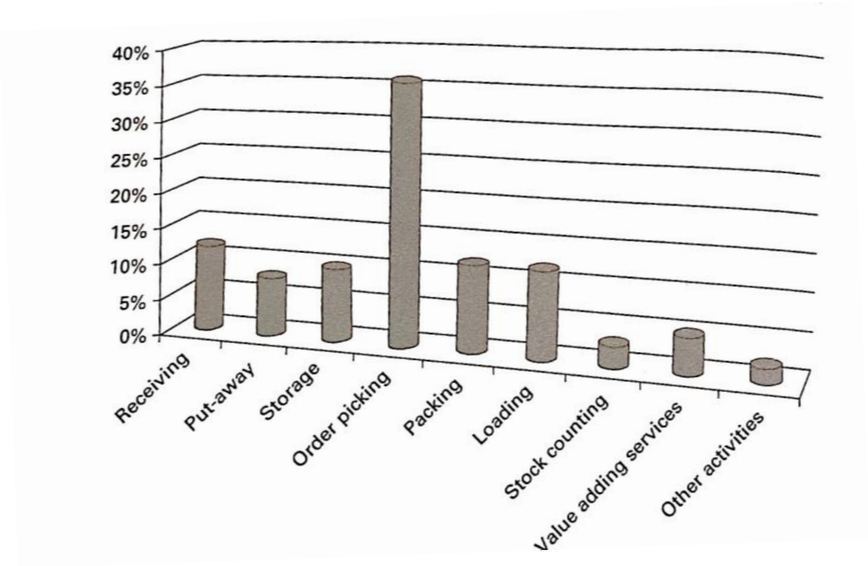


Figure 3. Warehouse activities as a percentage of total warehousing cost (Richards 2011, p. 44)

2.3 Transportation

Perhaps the most common cost that is considered as a logistics/SCM cost is transportation, along with the inventory and inventory-keeping related costs, as these have been mentioned as long ago as in 1930 (Ostlund 1930) as part of operations costs. Together with warehousing and inventory costs, transportation costs accounted for some 80 per cent of total logistics operations costs in most companies by the 1980s (Tyndall & Bushner 1985). In a more recent study of Finnish manufacturing companies, transportation costs accounted on average for 30 to 50 per cent of total logistic costs (Solakivi et al. 2012).

Transportation involves functions such as shipping, freight consolidation, freight bill auditing, and freight payment (Bardi & Tracey 1991). As transportation is considered as one of the major SC cost drivers in Finnish manufacturing companies, it is a function likely to be outsourced (Solakivi et al. 2012). Outsourcing may occur if the principal company does not have the required expertise or a third party can perform transportation functions at a lower cost. Bardi and Tracey's (1991) research indicates that the trend of outsourcing transportation functions, which prevails today (Solakivi et al. 2012), was realized in the early 1990s.

Usually, freight costs increase linearly with transport distance, independent of transport mode, be it road, rail, air or sea (Simchi-Levi et al. 2008, p. 85-86). However, the freight rate per transported unit varies depending on freight volume. Full truck loads (FTL) have the least expensive freight rate per unit, as full capacity is utilized. Otherwise, where freight is less than truckload (LTL), freight rate can be based on weight, cubic meters or loading meters, so that increased volume decreases costs per unit. Smaller volumes are relatively expensive to transport by road because of high fixed handling and terminal costs that form a large part of total freight costs per unit for a small volume freight.

Krüger (2002, p. 312-313) adds that longer distances result in longer lead-times, add uncertainty to planning and increase the risk of production disruption. Uncertainty in the SC results in higher inventories and holding costs, reduced flexibility, and declined in overall reliability of the logistics operations. Transport mode of freight is commonly determined based on the distance to be covered, freight rate and a transit-time based interest rate on held inventory, as well as value, weight and volume of products. For instance, items of high value ought to have a transport mode with short transit time such as air transit, if possible, to minimize the cost of interest on the items in transit.

2.4 Packaging

According to Simchi-Levi et al. (2008, pp. 342-343) efficient packaging is one way to reduce both transportation and warehousing costs e.g. by using more compact, lighter or stackable packaging to by minimize space and weight per unit. Furthermore, space saving both in transportation and warehousing reduces the overall logistics costs per unit.

However, when designing packages one must keep in mind the main function of packaging, which is to protect the product inside, and not to pursue transport and warehousing cost savings at the risk of damaging products, as this may result in additional special freight costs and quality costs (Pålsson et al. 2013). For example, in the automotive industry components need to be well protected during transportation, and more often than not, items are packed in expensive, custom-made steel cages. Some of the components such as car engines are especially heavy, and thus need heavy-duty packaging. On the other hand, air bags require shell-proof packages that ensure safety during transportation, should an air bag explode. Even plastic containers have to be carefully designed to ensure that the handling of packages is optimized in warehouse and manufacturing operations.

Packages are a multi-million, or even multi-billion, investment especially in the automotive industry (Twede & Clarke 2004; Rosenau et al. 1996). Operating a closed-loop system with reusable packaging material requires a large investment in buying the packaging material itself in the first place, but also in creating a system to track the packages and managing the return transports, and therefore third parties (3PLs) are often used to supply and manage the flow of packaging materials (Coia 2013). Twede and Clarke (2004) add that significant costs may occur if packaging logistics are poorly managed; packaging might be misdirected, late or lost completely, resulting in suppliers being unable to deliver components, which may ultimately cause production disruptions.

Purchase of reusable packaging is recommended when return distances are short. Otherwise, if closed loop logistics cycle times are long, packaging material related costs become high as more material is tied up in the pipeline. As for return transport, packaging material is usually collapsible when empty, which decreases return transport costs (Coia 2013). However, waiting for an FTL transport lengthens the logistics cycle time, which in turn results in more packages being needed in the pipeline. Twede and Clarke (2004) state that cycle time variations need to be kept in mind so that sufficient inventory of packaging material is always on hand to cover peak demand or disturbances in the SC.

Moreover, although Gudehus and Kotzab (2009, p. 131) argue that packaging costs are merely material costs, and hence not actually part of SCM operation costs, the author justifies including packaging material as a cost driver in this research, as packaging material in transporting components from suppliers to manufacturer creates costs without adding value to the customer, and thus fits the description of a cost driver. Indeed, as mentioned by Twede and Clarke (2004) and Rosenau et al. (1996), packaging is a critical and considerable investment in the automotive industry, and thus, should be recognized as an important cost factor when calculating total SCM costs.

To conclude, logistics/SCM costs arguably account for some 10 per cent of manufacturing company annual turnover (Maununen 2000; McKinnon 2001, p. 164; Solakivi et al. 2012). Furthermore, four main SC cost drivers were identified from the literature. In general, freight costs were found to be the major cost driver accounting for as much as 50 per cent of total SCM costs (Solakivi et al. 2012; Bardi & Tracey 1991). Second to freight costs came warehousing costs that form on average 20 per cent of SCM costs (Richards 2011, p. 212; Solakivi et al. 2012). Combined with inventory holding costs, these three cost drivers contribute approximately 80 per cent of total SCM costs (Christopher 1992, p. 61-62; Solakivi et al. 2012; Tyndall & Bushner 1985). In addition, packaging material costs were identified as a key SCM costs driver especially in the automotive manufacturing industry, which will be discussed next in more detail.

2.5 SCM characteristics in the automotive industry

The automotive industry is one of the largest manufacturing industries in the world. It is highly competitive and has been in constant transition during the last decades, and yet continues to grow. According to MarketLine (2014) data, in 2013 the global automotive industry had total revenues of 1 145 billion EUR with a total production of 144,5 million units, 44,1 per cent being passenger cars. It is expected that by the end of 2014, global sales of passenger cars will reach 72,2 million units (Statista 2014). In the US, automotive industry contributes on average 3,5 per cent to the country's gross domestic product (GDP) (Autoalliance 2014), whereas in Europe the auto industry represents as much as 6,9 per cent of the EU GDP (Acea 2014). The value of the industry has grown globally 9,1 per cent annually between 2009 and 2013, and is expected to grow 7,2 per cent annually for the next five years.

Car manufacturing was revolutionized by Henry Ford, who came up with the assembly line technique of mass production in 1913, which enabled Ford Motor Company to manufacture a car affordable for middle-class people. Since then, car manufacturing has become ever more efficient thanks to (among other things) the concept of lean SCM, which was initially introduced by Toyota in Japan as the Toyota Production System (Ohno 1988, p. 2). Nowadays, efficiency is still a fundamental principle in the manufacturing sector, but it has been integrated with the concept of sustainability (Rebitzer 2002, p. 128).

The early 2000s was an especially interesting time in the automotive industry. The industry's profitability averaged only 4 per cent earnings before interest and taxes (EBIT). Something needed to change (Holweg & Miemczyk 2003). It was thought that Henry Ford's concept of mass production was coming to its end as such, and the quest for regaining profitability had begun. Inevitably, the transition would have wide implications for the automotive supply chain, which are discussed next in more detail.

2.5.1 Automotive supply models

As a vehicle typically consists of 2 000 to 4 000 components that can vary in terms of color, size and style, the demand of one part number can radically differ from another's (Miemczyk & Holweg 2004). Indeed, a study by Bhatnagar and Chee-Chong (2009) highlights the variety of possible component combinations in a vehicle; some 850 vehicles are produced every day at a car factory in Germany, yet on average only 1,5 cars leave the factory with the exact same components, annually.

In order to supply the range of thousands of components, several hundred suppliers are typically involved in the automotive SC. Different supply methods are used in order to control the material flow from suppliers; see Figure 4. Supply methods can vary depending on the pick-up frequency, delivery volume, and physical as well as geographical factors. Typically, inbound transportation accounts for some 1-2 per cent of the total costs of a finished vehicle (Miemczyk & Holweg 2004).

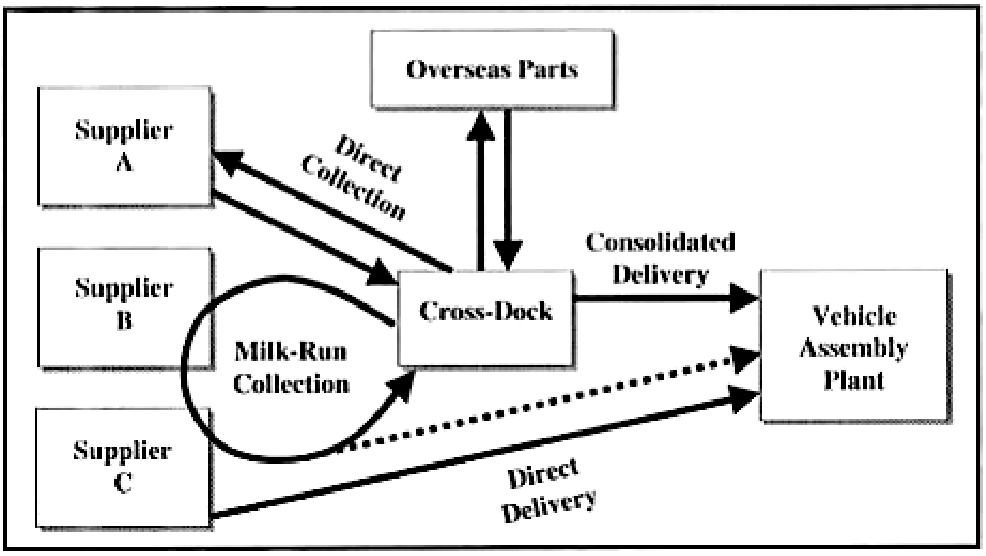


Figure 4. Inbound logistics process in the automotive industry (Miemczyk & Holweg 2004)

Direct deliveries from supplier to manufacturer carry only the components of one supplier, and represent typically the case of only a few high-volume suppliers. The most common arrangement, however, is a milk-run collection, in which the truck visits more than one supplier collecting components that are delivered directly to the manufacturer or to a consolidation center (Volling et al. 2013). Each stop at subsequent suppliers incurs a stoppage cost, but on the other hand, trailer utilization is high and only one trip is needed for the collection. Consolidation at the cross-dock center, where the shipments are arranged and combined before final dispatch, incurs further handling costs, but pays back as shipping to manufacturer is with a higher trailer utilization rate. Should a supplier be remotely located or have high volumes, direct collection from supplier to consolidation center can be arranged. (Miemczyk & Holweg 2004.)

Furthermore, Miemczyk and Holweg (2004) discuss the transition in the automotive industry of moving from Henry Ford's mass production paradigm, i.e. push-based supply, to a pull-based supply, where actual customer demand determines the manufacturing of cars. This transition is to cut the several billions of dollars tied up in finished goods inventory in the marketplace. However, pull-based supply has been struggling with long order-to-delivery (OTD) times. Therefore, reducing the OTD lead time is crucial, and strategies have already been implemented (Zhang et al. 2007). For instance, Renault introduced an order-to-delivery target of 14 days, but because their outbound logistics could not cope with such a short time frame, the OTD target was increased to 21 days, which is still much better than the industry average OTD of 40 days. One key finding in Miemczyk and Holweg's (2004) study was that the so-called lean SCM is a key philosophy in being able to meet the shorter order-to-delivery targets. The concept of lean SCM will now be discussed in more detail.

2.5.2 Lean supply chain management

The concept of *lean* comes from the automotive manufacturing industry, and is associated with the Japanese automaker Toyota. The lean concept is also known as the Toyota Way of operating production and supply chains. The main idea behind lean principles is to remove any activities that absorb resources without creating value for the end customers (Womack & Jones 1996, p. 16). Non-value adding activities that cause (1) waiting, i.e. time delays, (2) defects, (3) process variation, (4) excessive inventory, (5) overproduction, (6) unnecessary transportation and (7) unnecessary motion are considered as the seven wastes (*Muda* in Japanese) of the Toyota Production System, and the objective of lean SCM is to cut out this waste (Womack & Jones 1996, p. 15; Hall & Braithwaite 2001, p. 87). Brunt and Butterworth (2001, p. 84) add that today's new waste types, such as wasted power and energy, environmental pollution and overcomplicated IT systems, are also considerable types of waste that will reduce total costs if cut out. All in all, striving to eliminate waste has already had and will continue to have a significant role in the development of automotive SCM. (Richards 2011, p. 301; Kajüter 2002, p. 45.)

In examining the performance of supply chains it is often found that many SC activities, such as warehousing, add more cost than value, and actually only few SC activities can make the product more saleable (Christopher 1992, p. 136). Value adding activities are rather easy to point out, but it is more difficult to see all the waste that surrounds them. Hines et al. (2001, p. 173) argue that commonly in manufacturing, only 5 per cent of activities actually add value, 35 per cent are necessary non-value adding activities and the last 60 per cent of activities add no value at all, and could thus be removed. Commonly, eliminating this 60 per cent of non-value adding activities offers the biggest opportunity for performance improvement and cost reduction. Moreover, once non-value adding activities are minimized or eliminated, only then should the next objective be to reduce the costs of value adding activities (Kumar & Zander 2007, p. 3).

Elimination of waste requires that at each point of the production process, only the products that have actual demand are made, and in the exactly required quantity, without creating any form of waste, as described above (Hall & Braithwaite 2001, p. 88). Any activity that deviates from this ideal should be refined accordingly. Lean is an endless quest for perfection that no one will ever reach, but practicing it will continuously drive the company to minimize waste and improve its operations (Taylor & Brunt 2001, p. 4). Hall and Braithwaite (2001) contend that although the operational changes sound radical in theory, they are usually rather small and incremental in practice. For example, instead of seeking economies of scale, lean manufacturers seek economies of scope, i.e. greater variety, and more responsive production systems through shorter set-up times.

An example of comparing Japanese lean automotive production to traditional mass production in the US is given by Kawahara (1997, pp. 195-196). Kawahara (1997) states that because of their lean production, Toyota was able to produce a car in half the time, with a 66 per cent lower defect rate and requiring 60 per cent less space in production line compared to GM in the US. Quite remarkable is also that Toyota had only stock worth two hours' production. Japanese suppliers were located close to the car manufacturer, and were also closely involved in research and development with their clients. Besides, suppliers constantly monitored the quality of their own products, which decreased defect rates and workload at the car manufacturer as inspection need not to be done. Such efficient processes were developed due to the highly competitive domestic automotive manufacturing industry in Japan, which stipulated constant improvement of the companies in order to survive. As declared by Kawahara (1997, p. 207) *without* (domestic) *competition, lean production would never have been developed*.

However, it is not simple to determine what kind of SCM strategy best suits an automotive manufacturer after all. Simchi-Levi et al. (2008, p. 288) state that SCM of a functional product with predictable demand, as defined by Fisher (1997), ought to be efficient and is typically focused on minimizing total landed costs. In contrast, innovative products with unpredictable demand match with responsive SCM that is focused on maximizing flexibility and reducing lead times (Fisher 1997). For this reason, Turner and Williams (2005) argue that automotive manufacturers are typically in the inconvenient position of combining both features of functional and innovative products. Therefore, it may not be straightforward for a car manufacturer to decide whether to pursue efficient or responsive SCM. However, Naylor et al. (1999) argue that the division between lean (efficient) and agile (responsive) SCM is too simplistic. Instead, companies should pursue "leagility", which is carefully combining both the lean and agile SCM paradigms, i.e. operating one part of the SC in a lean fashion and another part in an agile fashion.

Switching from mass production to lean production requires re-engineering of SCM operations, such as logistics, to find cost-effective means of operating with smaller quantities and more frequent deliveries. The topic of frequent deliveries is discussed in more detail in the next part of *just-in-time* materials management.

2.5.3 Just-in-time and just-in-sequence materials management

Just-in-time (JIT) is a significant philosophy as much as it is a technique in lean SCM (Bhamu & Sangwan 2014; Hall & Braithwaite 2001, p. 89). JIT is a pull-based SCM concept where demand at the end of the pipeline pulls products and the flow of components towards the market. Moreover, JIT is focused on costs, and its principal idea is that, if possible, no activity should take place in a system until there is a demand for it (Taylor 2001, p. 213). Therefore, according to JIT philosophy, no products should be made and no components ordered until there is a downstream requirement (Christopher 1992, p. 153).

The fundamental principle of JIT SCM is to ensure that all elements of the chain are integrated and that shipping and replenishment requirements are identified early on. Goods should be delivered at the right quantity and at the right place immediately in advance of their consumption (Hall & Braithwaite 2001, p. 89). However, low quality components arriving at the production line on time is not adequate for JIT; instead there is a great emphasis on perfect delivery in all aspects every time (Taylor 2001, p. 213). Achieving and maintaining perfect deliveries comes down to highly disciplined planning (Christopher 1992, p. 163). Furthermore, according to Christopher (1992), the effects of JIT can result in a company achieving:

- Consistent top quality with zero defects, no incoming inspection
- Low inventories, reliable and continuous deliveries
- Short lead times and much flexibility
- Absolute trust in the transportation service level
- Long partnership and open communication with suppliers and carriers
- Fewer but better suppliers
- Commitment to decisions

According to Taylor (2001, p. 215-216) there are several reasons why an automotive company is especially well suited to JIT production. Firstly, a car is such a complex product that it requires excellence in the manufacturing process. Each product is assembled from thousands of parts that undergo numerous processes. A problem with any of these processes would have a major and costly impact on the overall production process. Therefore, component and process quality has to be uncompromisingly high. Secondly, flexibility is needed, as variation on the automotive production line is vast both because of the range of different models and their variations, and also because of the fluctuation in the demand for each variation. Thirdly, there are often component changes within a model and, moreover, vehicles are completely remodeled every few years, which would cause costs in the form of inventory obsolescence, if lead times were long and inventory levels high.

As the JIT philosophy's requirement is for small and frequent shipments that meet the time requirements of the production line, the challenge for SCM is to find ways to deliver small timely shipments without an uneconomic escalation of costs. Although trade-offs, e.g. between freight costs and trailer utilization rate, are inevitable, the overall goal of JIT must be to improve the total SC cost-effectiveness. One way to achieve JIT without excessive costs is through consolidated transportations.

Consolidated deliveries can be further sequenced in a consolidation center, thus making it a *just-in-sequence* (JIS) delivery. The principle of JIS is that the items are received at the factory in the right quality, time, and quantity – just like in JIT – but on top of that also in the correct sequence according to the production schedule (Wagner & Silveira-Camargos 2011). Wagner and Silveira-Camargos (2011) go on to argue that in complex assembly operations, prior sequencing of parts is essential, and therefore JIS is a familiar concept especially in the automotive manufacturing industry, where JIS sourcing enables the cost efficient manufacturing of customized products. Typically, valuable and large parts, such as seats, exhausts and bumpers, with a variety of hundreds or thousands of options within a category are synchronized according to specific car orders (Christopher 1992, p. 165).

In the automotive manufacturing environment, JIT-delivered racks of singular variants reach its limits as warehouse space, stock levels, risk of obsolescence, and handling costs start to increase exponentially when the number of component variants grows (Wagner & Silveira-Camargos 2011). The difference between the cost of JIT and JIS regarding component variety is illustrated in Figure 5. As shown in the figure, after a few variants in a component, it is more cost-efficient to use JIS instead of JIT.

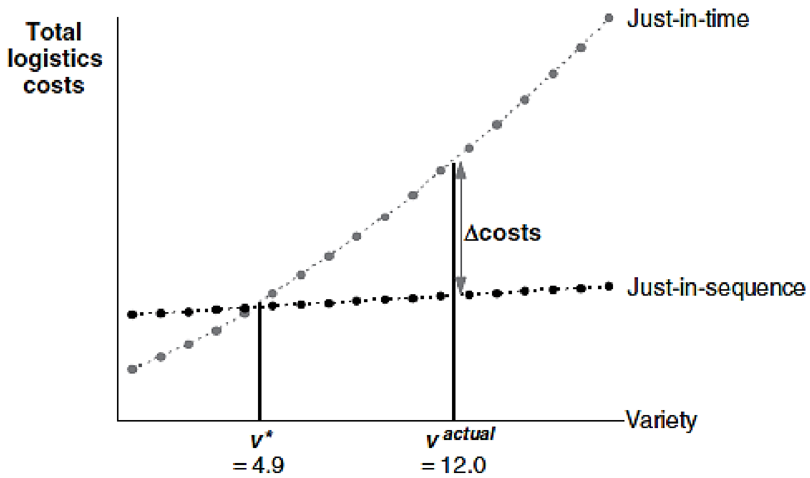


Figure 5. Cost savings through JIS implementation (Wagner & Silveira-Camargos 2011)

Wagner and Silveira-Camargos (2011) add that, on average, even 40 per cent of car components are JIS-delivered in the automotive industry. The Ford Motor Company in Valencia, for example, has its parts delivered in a stockless, JIS manner from overhead tunnels fed by conveyors from suppliers located less than one kilometer away from the car factory (Hall & Braithwaite 2001, p. 90). This enables the cost-efficient manufacturing of mass customized cars, while keeping inventories and handling costs to the minimum, and maintaining a fast throughput time.

Lastly, Christopher (1992, p. 48) contends that JIT and JIS deliveries require flexibility from suppliers when it comes to minimum order quantities. Manufacturers want to operate in a lean fashion with a minimum inventory level in order to achieve cost savings. Therefore, manufacturers desire flexible order sizes that fit their changing demand. However, there is a contradiction here as suppliers desire economies of scale in production and are not willing to manufacture any kind of a lot size, but define a minimum order quantity (MOQ) instead, hence ensuring their own profitability.

3. Supply chain cost management

The purpose of this chapter is to discuss different types of cost levels, supply chain cost drivers and cost management methods found in the literature that could be applied in the SCM costing model to be developed. Discussion of SCM cost management methods will focus on concepts of activity-based costing and total cost of ownership. However, first, the author presents a brief motivation for using cost management in managing supply chain operations.

> *Traditionally it has been suggested that the main route to cost reduction was by gaining greater sales volume… However, it must also be recognized that logistics* [and supply chain] *management can provide a multitude of ways to increase efficiency and productivity and hence contribute significantly to reduced unit costs.* (Christopher 1992, p. 4.)

Indeed, this quote by Christopher (1992) is also supported by Brunt et al. (2001, p. 98) who use the automotive industry as an example of markets nowadays determining the selling price. Thus, the traditional approach, where selling price was determined by costs and a desired profit, has now changed to profits determined by selling price and costs. Hence, if selling price is fixed, reducing costs is the only concrete way to increase profits per unit. Furthermore, the potential of cost reduction has driven more attention to supply chain cost management.

According to Christopher (1992, p. 53), problems in SCM integration derive from the lack of appropriate cost information. Traditional cost management systems group costs into broad categories that do not allow the detailed analysis necessary to identify the true SCM costs and key cost drivers. Indeed, Cokins (2001) brings out that companies are actually not even able to directly manage their incurred costs, but only the cost drivers, which are the causes of the incurred costs. Moreover, Christopher (1992, p. 53) adds that, without the facility to analyze aggregated cost data, it becomes impossible to reveal the potential cost trade-offs between total costs and sales revenue within SCM.

Given that SCM's ultimate concern is to meet customer service requirements in the most cost-effective way, it is essential that those responsible for SCM have the most accurate and meaningful data possible (Christopher 1992, p. 79). However, Christopher (1992, p. 189) goes on to assert that the problem in SC cost management is the lack of cost transparency. Material flow costs across different functions are not easy to measure. Costs may be measured on a functional level, such as total transportation or inventory holding costs, but this cost information remains too aggregated. Therefore, the objective is that broadly defined costs, such as total transportation costs, could be further evaluated among suppliers and components.

However, cost management was not initially designed from an SCM perspective, but with a management accounting approach, and thus these two concept platforms need to be integrated. Seuring (2002b) underlines that SC costs do not only consist of costs created by material and information flows, but also costs of relationship management, such as communications. Because identification and evaluation of SC costs is complex, only a few viable SC accounting systems have been developed and thus costs are usually presented with a wide range, depending on the overall level of understanding of SCM (Kotzab et al. 2002, p. 236-238). While concepts such as activity-based costing and total cost of ownership have been established for cost management, only few guiding principles for implementing these exist so far.

Furthermore, Seuring (2002b, p.23) presents an approach in which SC costs are divided into three levels:

1. *Direct costs*, such as material and labor costs that are directly related to the manufacturing of a product.
2. *Indirect / Activity-based costs*, which are not directly related to a product itself but arise from other indirectly related processes, such as transportation and inventory holding.
3. *Transaction costs*, such as the cost of making a contract, which arise from interactions with other SC participants.

Integrating these three cost levels into the SCM framework presented in Chapter 1.3, a framework for SC costing is developed. The four fields of the product-relationship-matrix are integrated with the three cost levels and displayed in Figure 6. As mentioned earlier in Chapter 1.3, this research is focused on process optimization that addresses single measures for cost reductions in the SC, which Seuring (2002b) integrates with the two cost levels of direct costs (such as SCM labor) and activity-based costs. As stated earlier, this study is focused on indirect and activity-based costs, which is the costing method to be discussed next in more detail.

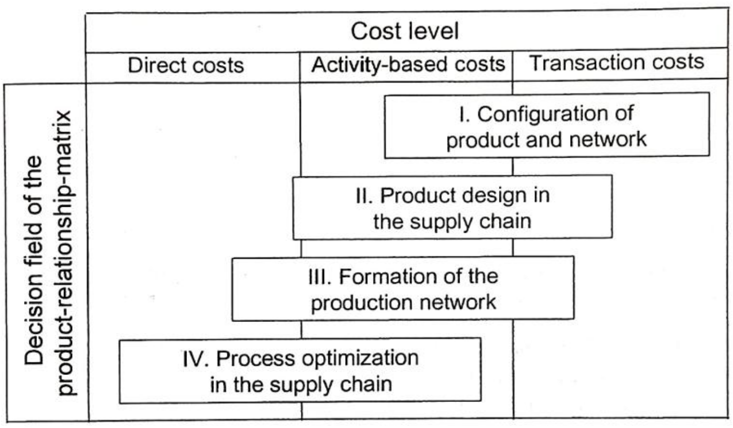


Figure 6. Principal cost levels within the Product-Relationship-Matrix (Seuring 2002b, p. 27)

3.1 Activity-based costing

Activity-based costing (ABC) is a relatively new but increasingly recognized procedure in cost management. Unlike traditional costing, overhead costs are not allocated arbitrarily in ABC. Instead, indirect costs are allocated to processes in a way which accurately reflects how the costs are incurred. ABC measures the cost of products that consume activities by assigning resource costs to activities, and further allocating activity costs to products (Cooper & Kaplan 1991; Constantin et al. 2009; Kumar & Zander 2007, p. 2). ABC is a useful method when overhead costs are significant, multiple or complex products are produced, or if variation between high and low volume products is notable (Kuula 2014a), which are all aspects found in the automotive industry.

The concept is summarized in Figure 7. In principle, customers buy products, which consume activities that require resources, which cost money. Furthermore, these activity costs are assigned to cost objectives, i.e. products that customers buy. As an example, insurance costs can be allocated according to the value of the component, and storage rent costs can be allocated according to the space required by the component.

Figure 7. Activity-based costing model, modified from Kumar and Zander (2007, p. 2)

The first step is to determine the activities in the process, such as receiving or warehousing, and the way they interact with each other. The next step is to categorize the activities into homogenous cost pools that have costs assigned to them, which can be further broken down into departments or functions, such as quality department costs, inspection function costs or storage costs. The third step is to determine cost drivers, such as time consumed, distance covered or space required, into which cost pools are allocated. The last step is to determine cost pool rates, i.e. divide cost pools by cost drivers to determine the pool rate, e.g. warehouse cost per square meter, and then allocate the costs to particular products, which consume time, space or distance in different amounts. (Kumar & Zander 2007, p. 61-62.)

Implementing ABC requires a thorough understanding of a company, its operations and the roles of its personnel. The disadvantage of using ABC is that it requires sophisticated IT systems to provide accurate data about operations. Besides, much time as well as manual work is required in order to collect accurate data about operations and overhead costs (Constantin et al. 2009).

Collecting information can be conducted by observing and recording operations, and also by asking the employees about the critical cost drivers. (Richards 2011, p. 217-220.)

However, because implementing ABC is such an expensive and time consuming process, it should first be implemented only to processes which management considers most critical. Moreover, it is suggested that ABC not be implemented at all if overhead costs are less than 15 per cent of total costs of the company as the cost of implementing ABC overruns the added value of using the method. (Kumar & Zander 2007, p. 58, 66.)

3.2 Total cost of ownership

> *To minimize total costs, a firm must be able to measure those costs or at least to understand the general way in which the costs are affected by the decision at hand.* (Waller, Fawcett 2012)

Traditionally companies have tried to optimize the costs of the whole firm through optimizing single functions, such as minimizing logistics costs or procurement prices (Cavinato 1992). Nevertheless, although each part of the company would optimize its functions, it does not necessarily optimize the total costs of the firm unless a manager is responsible for several linking functions.

Total cost of ownership (TCO) is another common costing method in SCM, besides ABC. The concept of TCO was proposed by Ellram and Siferd in 1993, although the general idea has been around since 1980 under different names. TCO analysis can help a company identify its key cost drivers, which, in fact, are often poorly recognized. According to Ferrin and Plank (2002), this finding appears in several TCO and ABC studies.

According to Ellram (1994), TCO modeling was initially designed as a supportive tool for purchasing to help gain understanding of the "true" total costs of doing business with different suppliers. However, it can well be used for other purposes such as measuring ongoing supplier performance and identifying key cost drivers (Ellram & Siferd 1998), which is the intended use of TCO in this study. Moreover, the benefits of using TCO are notable:

1. Improved supplier performance measurement; a tool for benchmarking.
2. Improved purchasing decision making; trade-offs are quantified.
3. Improved internal and external communications; involving other functions in purchasing.
4. Better insight into purchased goods; data for cost analysis.
5. Supports continuous improvement; forces managers to look at internal issues.

TCO is defined as including all internal costs associated with the activities of procurement, use and maintenance of an item. The costs are collected based on activity analyses described in the previous part of this chapter. These three activities are further broken down into six cost categories: (1) quality, (2) management, (3) delivery, (4) service, (5) communications and (6) price. Typical costs in these categories are administrative costs, supplier audits, inspection, rework, customer returns, lost sales, warranty, field failures, maintenance, scrap, environmental fees for disposal, labor, purchase orders, material, transportation, production and storage costs. (Kumar & Zander 2007, p. 56, 58, 68.)

Cavinato (1992) collected several SCM cost drivers for his total cost/value model. Among the 10 cost drivers introduced in Cavinato's (1992) study, some of the most relevant for this thesis are:

- *Traditional Basic Input Costs* representing the initial purchase price of components.
- *Supply Relational Costs* representing the costs of creating and maintaining supplier relationships including travel, education and establishing EDI links. Supplier quality and long-term costs should also be considered.
- *Logistics costs* representing transportation, receiving (un-/re-packing, inspection), handling and storage costs.
- *Indirect financial costs* representing payment terms to suppliers (interest on capital).

Besides the traditional cost drivers, Ferrin and Plank (2002) support Ellram's (1994) finding in their conclusion that there can be countless unique TCO models that consist of different cost drivers individually defined by each company. Unique models take more time to develop and implement compared to using a standard TCO model. On the other hand, unique models offer the ability to tailor the model according to a company's needs, and thus can outweigh the additional time and resources taken (Ellram 1994). Ellram (1994) adds that TCO modeling does not have to be exhaustive, because Pareto's law that 20 per cent of issues make 80 per cent of the costs is accurate enough.

In their study, Ferrin and Plank (2002) identified a staggering 135 different cost drivers used across companies. As in a factor analysis, 13 cost driver categories were deduced from these 135 cost drivers:

1. Operations (cost and speed)
2. Quality (downtime)
3. Customer-related (satisfaction)
4. Logistics (freight, packaging)
5. Technological advantage (agility)
6. Initial price (price stability)
7. Opportunity cost (cost of capital)
8. Supplier reliability (payment terms)
9. Maintenance (preservation of assets)
10. Inventory (turnover, obsolescence)
11. Transaction costs (agreements)
12. Life cycle costs (long term usage)
13. Miscellaneous (disposal, taxes)

Despite the large number of cost drivers defined in Ferrin and Plank's study (2002), the overall outcome was that certain cost drivers are applicable to nearly every TCO model (those presented in brackets in the list above). Besides the core cost drivers, modular sets of cost drivers could be identified, and together with the core cost drivers it would be possible to estimate the TCO for any item. Most of the cost drivers are quantifiable, but cost drivers such as *trust* and *capability to change* remind us that purchasing should look beyond quantifiable costs as well when determining total costs.

Possible barriers to the implementation of TCO include corporate culture which is resistant to change and may be stuck with the orientation of thinking only about the initial price of products and services. Besides, TCO may be regarded as a tool too theoretical, and quantifying "soft" issues may be frustrating. Moreover, identifying relevant cost drivers may be challenging and time-consuming especially when there is a lack of readily accessible data and support systems. (Ellram 1994, Ellram & Siferd 1998.)

To conclude, supply chain cost management is a rather unpracticed concept which, however, is gaining more and more attention due to the pressure, and its potential, for cost reduction. Some SCM cost management methods exist, but their implementation is case specific, time-consuming, and requires proper information systems as well as SCM understanding. However, using cost management methods such as activity-based costing and total cost of ownership can add value to business by helping optimize SCM processes and decision making.

4. Modeling and simulation

The purpose of this chapter is to describe different modeling and simulation techniques found in the literature that could be applied in developing the supply chain costing model for this research. In addition to modeling techniques, this chapter will provide information about the model development process as a whole. Next, the author describes different modeling and simulation applications, and motivates the use of modeling in this research.

Optimization of decision making has become essential for modern companies. Although data warehouses provide past data for analysis, they alone are not capable of anticipating the future and its impacts on the corporation (Golfarelli & Rizzi 2009). In order to evaluate the impacts of a decision, managers need reliable predictive and descriptive systems, such as analytical models and simulation tools (Brooks & Tobias 1996).

Modeling and simulation (M&S) was initially used as a training mechanism for the military. Nowadays M&S is used in different domains such as logistics, crowd modeling, emergency management and engineering design, to name just a few. The primary use of M&S applications in academia and business is for analysis, training and experimentation purposes. Moreover, industrial organizations have used M&S as a decision support methodology since the late 1940s. (Sokolowski & Banks 2009, p. 15, 198.) Jay Wright Forrester was the first to introduce simulation to SCM in the mid-1950s by developing the approach known as system dynamics, which helped to identifying the concept of demand amplification, also known as the bullwhip-effect (Turner & Williams 2005).

M&S can be a powerful method for analyzing supply chains. The process starts with constructing mental models of the SC, allowing for possible events and their impacts on the SC. However, as observed earlier in this thesis, supply chains are complex systems, and both the capacity and accuracy of a mental model is limited. Therefore, the mental map becomes soon so large that sole intuition is not sufficient to reliably model all the causality of the dynamic SC functions. A better alternative is to build a mathematical model that reliably imitates SCM in reality. The model can take care of managing data and performing required calculations while leaving the user to concentrate on developing SCM scenarios, interpreting results and making decisions. (D'este 2001, p. 521.)

Moreover, besides constructing mental models, a scientific modeling process is composed of organized steps that form the basis of model development (Brooks & Tobias 1996). As defined by Tersine (1994, p. 509), the seven steps of a modeling process are:

1. Problem formulation
2. Construction of a conceptual model
3. Data collection
4. Developing the executable model
5. Model verification and validation
6. Experimentation
7. Analysis of results

D'este (2001, p. 533) explains that almost all SCM modeling tools are implemented on a computer using general or purpose-built software tools. Spreadsheets are one very common general software tool used especially in financing, but in logistics as well, see e.g. Manunen's (2000) study on activity-based logistics costing. However, spreadsheets can be difficult to integrate with the bulk of historical data (Golfarelli & Rizzi 2009). Besides, spreadsheets may become heavy to use or even unmanageable with large and complex models. In the case where spreadsheets run out of capacity, specialized software packages provide a working alternative. Nevertheless, spreadsheets are more flexible and configurable than off-the-shelf software packages. Customized software packages offer the most capable solution, but are also the most expensive solution.

However, no matter how sophisticated the platform, what really matters is the input data the model is based on. As declared by D'este (2001), quality models and decisions come from quality inputs. For efficient SCM, organizational parameters should be known. Without this information managers need to make decisions in situations determined by uncertainties and risks, not completely knowing the effects of their decisions (Kaczmarek & Stüllengberg 2002, p. 275). Sokolowski and Banks (2009, p. 4) add that to be able to model real life processes it is imperative to conduct some research to better understand the processes and steps involved before creating the model. Models are driven by data, and therefore data collection should be done with great accuracy. Collecting data is an important phase also in regard to understanding the processes in reality in order to be able to accurately model them.

The practical advantages of modeling are, for example, the saving of time and money as experiments do not take place in real time and do not occupy actual resources. Also, models are flexible tools as different designs and strategies can be easily compared to each other, which helps choose the most promising options. Besides, modeling is safer than full-scale testing, and may even be the only possible option; risks are minimized, as model experiments have no direct effect on actual operations. For example, modeling can be used to reveal bottlenecks in SCM, model the impact of new SC requirements, or anticipate the effects of possible changes in ordering patterns, and so on. Lastly, modeling can improve a business's understanding of SCM by visualizing complex systems and visually explaining cause and effect relations between SC functions. It is also a powerful tool for explaining and selling ideas. (D'este 2001, p. 521-522; Kaczmarek & Stüllengberg 2002, p. 276-278.)

D'este (2001, p. 522) asserts that modeling is a valuable tool especially when the SC system is integrated with complex relationships between components and provides a multitude of options, but available resources are limited. Understanding of the SCM system gained by the modeler and user is therefore an important benefit of using modeling techniques (Brooks & Tobias 1996). Modeling has a key role in planning as it can be used at all planning levels: strategic, tactical, and operational. Firstly, in long-term strategic planning, modeling can help in designing and re-engineering SC systems. Secondly, tactical planning can involve incremental adjustments to transport arrangements, inventories, and storage capacity over an intermediate period of days or months. Thirdly, modeling can assist in daily operational planning by optimizing operational procedures and allocating daily resources.

Overall, modeling can help the business identify available opportunities and take advantage of them e.g. by finding the lowest-cost approach to meeting desired service levels or evaluating cost trade-offs such as lower transport costs compared with secondary warehousing costs (D'este 2001, p. 523). According to Christopher (1992, p. 56), an SC costing model should be capable of separating cost analyses based on certain segment, supplier or customer selections. Otherwise if only total or average values are looked at, the substantial variation that may occur in reality is left out and the analysis is too aggregated.

Common approaches to modeling SC systems are mathematical optimization and simulation modeling, which are discussed next in more detail.

4.1 Mathematical optimization

Optimization is a mathematical modeling technique especially useful for large and complex strategic and tactical planning problems in SCM. The optimization technique is designed to find the best possible solution subject to constraints, which determine what is feasible or necessary under prevailing conditions. For example, mathematical optimization can be used to find the least-cost SCM strategy (Jula & Leachman 2011). However, optimization can be used to minimize or maximize any other factor or combination of factors under given constraints that may represent limited available resources or required levels of performance. The main purpose of constraints is to impose realistic conditions that exclude unfeasible options from generated solutions. (D'este 2001, p. 523-524.)

D'este (2001, p. 524) explains that both the objective function, such as total SCM costs to be minimized, and the constraints are expressed mathematically in terms of decision variables and parameters. Decision variables represent specific activities, such as the production rate, that can be varied by the user. Discreetly adjusting the decision variables corresponds to different scenarios and strategies. Parameters, on the other hand, represent known characteristics of the SC, such as transport costs per unit. Typically, parameters are measures of the costs in regard to performing activities.

Simchi-Levi et al. (2008, p. 91) support the idea that mathematical techniques enable finding the optimal least-cost solutions. However, Mazzuto et al. (2012) as well as Kaczmarek and Stüllengberg (2002, p. 276) argue that supply chains are such complex systems in reality that they are virtually impossible to solve mathematically. This limitation is realized by the researcher; the costing model to be developed is theoretical, and cannot take into account all the stochastic dimensions of reality. The model will represent the long-run steady-state behavior of the system, and thus might not be absolute in the short-term but rather suggestive instead, and this will be taken into account in the verification phase of the model.

In addition, as a result of expressing everything mathematically, subtle constraints and decision variables that cannot be quantified will be omitted from the model, which somewhat reduces its accuracy and reality. Inevitably, some parts of the modeling, such as taking unquantifiable variables into account, will be left to heuristics methods, i.e. human judgment and experience rather than mathematical theory (D'este 2001, p. 530).

4.2 Simulation modeling

As defined by Kaczmarek and Stüllengberg (2002, p. 276) supply chain simulation *is the imitation of a system with its dynamic processes in a model in order to get knowledge for designing supply chains, which are portable to reality*. Simchi-Levi et al. (2008, p. 91) state that simulation models are a *mechanism to evaluate specified alternatives created by the designer.* D'este (2001, p. 526) supports both ideas by stating that simulation modeling is about mimicking the system, and testing and comparing alternatives.

According to D'este (2001, p. 526), simulation models use mathematical and logical relationships to represent interactions between SC components, and are especially useful for tactical and operational planning problems. A simulation model is like a computerized laboratory version of the real world as it accurately describes the SC components and the way they interact according to operating rules.

Building a simulation model includes the steps of identifying items, such as deliveries, that are being processed in the simulation and all the different processes, such as pick-up, transport and warehousing, that are involved with the item to be simulated. Obviously, the degree of detail in including the involved processes will determine the complexity of the simulation model (Brooks & Tobias 1996). Thirdly, simulation models include the rules that govern the processes, such as available warehouse space or maximum trailer capacity. Lastly, varying performance of SC components, such as transportation time, can also be included in the simulation model. In fact, the last aspect is what makes simulation models stochastic. (D'este 2001, p. 526-527.)

Transportation times and other performance measures are not always fixed; instead there are random events with different probabilities that cause variability, which is not captured by the optimization model that has an average long-run perspective to operations. Therefore, the output of a simulation is a sample from all the possible outcomes of the model. The idea is to run the simulation several times to be able to get an idea of the typical as well as unusual behavior of the system, and reveal the robustness of the SC. (D'este 2001, p. 527)

However, dynamic simulations require a large amount of data and much computational power, which, after all, results in being able to consider only few alternatives when using a simulation model (D'este 2001, p. 527). As a simulation model is not able to find the best scenario, simulation is not really meant for optimization but is more useful in characterizing the performance of a particular configuration. Nevertheless, mathematic modeling and simulation can also be used together, drawing on the strengths of both. A mathematical optimization model can be used to generate least-cost solutions on a macro level, and these solutions can be evaluated in more detail on the micro level with a simulation model. (Simchi-Levi et al. 2008, p. 94.)

According to Tersine (1994, p. 509), simulation models can be divided into two basic categories: stochastic and deterministic models. Stochastic or probabilistic models have key variables defined by probability distribution, whereas in deterministic models the variables are continuous and their relationships are stable. These two types of simulation models will be discussed in more detail in the following parts of this chapter.

4.2.1 Stochastic Monte Carlo simulation model

Monte Carlo is a stochastic type of simulation model that is used to develop a solution to a problem by sampling from a random process (Fu & Liqun 2002). It is a useful model especially for modeling a waiting line problem, and a multiphase assembly line problem and for inventory management problems. In a Monte Carlo simulation, variables do not need to be continuous and their relationships can vary. Probability distributions are assigned to each variable and data is obtained through different scenarios that are created based on the given probability distributions of variables. In more detail, scenarios are created by using random numbers that trigger events, which take place based on the probabilities of the variables. (Tersine 1994, p. 510, 512.)

Statistics are used to determine the model's average outcome and its variability. Since it is a random model, each time the simulation is run the results may be different (Simchi-Levi et al. 2008, p. 423). Decisions are made based on solutions that result from following the generation of data through several experiments and using analytical computations to analyze the simulated data. Developing the probability theory is the most critical part of creating a Monte Carlo simulation model and, unless the distributions are well chosen, the value of the simulation model is questionable (Tersine 1994, p. 512).

4.2.2 *What-if* analysis

What-if analysis is a data-intensive modeling method with the goal of modeling the behavior of some complex system under given scenarios (Golfarelli & Rizzi 2009). What-if analysis can be used as a deterministic equations-based method where the relations between variables are determined and no probabilities are applied, unlike in stochastic simulation models (Wallace 2000). Typical uses of what-if analysis appear in profitability analysis in commerce, promotion analysis in marketing and effectiveness analysis in manufacturing.

The application measures how incremental changes in independent decision variables impact a set of dependent variables in a simulation model, which is the center of a what-if analysis. Prediction of the what-if scenario is obtained by assigning values for the business variables and scenario parameters, and then executing the model. A simple illustration of the what-if analysis process is given in Figure 8. (Golfarelli & Rizzi 2009.)

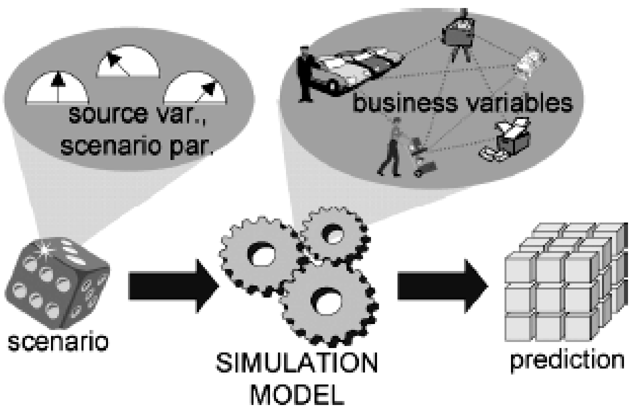


Figure 8. What-if analysis at a glance (Golfarelli & Rizzi 2009)

Moreover, Figure 9 illustrates a business intelligence (BI) pyramid presented by Golfarelli and Rizzi (2009). The different steps of transforming data into information and further into knowledge are described, and different BI processes are assigned to the steps accordingly. As indicated in the figure, *What-if analysis* is close to the top of the pyramid representing its importance in supporting decision making by transforming information into knowledge. Christopher (1992, p. 55) states that the incremental cost difference is the relevant information for decision making, and therefore costs must be viewed in incremental terms, which is the change of total costs caused by the change in the system that can be modeled through *what-if* scenarios.

Figure 9. The business intelligence pyramid (Golfarelli & Rizzi 2009)

4.3 Data analysis

There are basically two ways to analyze data from decision support systems. The first is to use some business analytic tools to analyze data extracted from ERP systems. Techniques such as queries, statistical analysis, data mining and online analytical processing (OLAP) tools can be used to ask specific questions about the data, determine trends and patterns, or hidden relationships in data, and navigate across dimensions of data using rollup and drill-down operations (Chaudhuri & Dayal 1997).

Another possibility for analyzing data is to use decision support systems that can e.g. create reports based on defined problems. These kinds of systems include calculators that can conduct total cost calculations or find optimal solutions based on exact algorithms, and simulation models that take into account complex dynamics of several variables, simulate different scenarios and provide their outcomes. By discreetly adjusting input parameters, different outcomes and decisions can be compared. Simulation models, however, are typically time consuming and require much computational power in order to be run, which can make comparison a time consuming task. Often the used analytical tools are a combination of the techniques described, and the used methods are also dependent on the type and complexity of the problem to be solved. (Simchi-Levi et al. 2008, p. 422-424.)

4.4 Model verification and validation

The importance of model validation cannot be overstated. However, before validation, the model must be verified. Both verification and validation should be completed as soon as possible, i.e. when the model is constructed and when its results can be compared to actual data (Sokolowski & Banks 2009, p. 130). Verification means determining whether the developed model is consistent with its specifications, whether it satisfies the requirements of its intended use and works as intended (Brooks & Tobias 1996). Furthermore, Carvalho et al. (2012) state that verification determines whether the idea in the conceptual model is correctly transferred and implemented in the executable model, i.e. it tries to find out whether the model was built correctly. According to Sokolowski and Banks (2009, p.126), the verification process typically includes answering to questions such as:

1. *Does the program code of the executable model correctly implement the conceptual model?*
2. *Does the executable model satisfy the intended uses of the model?*
3. *Does the executable model produce results when it is needed and in the required format(s)?*

Sokolowski and Banks (2009) continue that model validation, on the other hand, is the process of determining how accurately the model represents the simuland, i.e. the object(s) being modeled. Carvalho et al. (2012) simplify the purpose of validation by asking whether the correct model was built. The validation process typically involves answering questions such as:

1. *Is the executable model a correct representation of the simuland, i.e. does the model make sense?*
2. *Under what range of inputs are the model's results credible and useful?*
3. *Is the data consistent?*
4. *Can the modeled results be fully explained?*
5. *Was sensitivity analysis performed?*

(Simchi-Levi et al. 2008, p. 91; Sokolowski & Banks 2009, p. 126.)

Brooks and Tobias (1996) summarize that model validation is about comparing the output of the model with historical data. Similarly, Simchi-Levi et al. (2008, p. 90) state that a model can be validated, e.g. by reconstructing the model according to existing actual configuration and comparing the output of the model to existing data, such as the company's accounting information. By doing this, data defects, problematic assumptions and modeling flaws can be identified, which helps the user to understand the current operations and can also help generate ideas to improve the model and the actual operations. Simchi-Levi et al. (2008) continue by asserting that management involvement in validation is desirable, as managers often have a good intuition of what the effect of changes to the system should be, and therefore can easily identify errors in the model. However, intuition is not so reliable when radical changes are to be implemented, but can work well for small-scale changes.

Finally and furthermore, Sokolowski and Banks (2009, p. 130-134) add close to a hundred different model verification and validation methods, which can be grouped into four main categories:

1. *Informal* methods are mostly qualitative and rely on subjective evaluation. Examples of informal methods include *inspection*, which is similar to what Simchi-Levi et al. (2008) present as a comparison method.

2. *Static* methods are more often used by developers and technical experts as they are able to analyze programming language code, which is involved in using static validation and verification methods. Examples of static methods include *data analysis* and *cause-effect verification*, whose purpose is to ensure that data is defined properly, and that data dependency and cause-effect relationships are modeled correctly.

3. *Dynamic* methods are often quantitative, and include evaluating numerical results and data, i.e. statistics, of the executable model. Examples of dynamic methods include *sensitivity analysis*, which was also mentioned by Simchi-Levi et al. (2008, p. 91) as one of the available validation methods. Sensitivity analysis is an analysis of the range and variability in the model's results, which can be compared to the simuland's behavior using the same input values, if sufficient data regarding the simuland is available.

4. *Formal* methods include mathematical proofs of the accuracy and characteristics of the model. Methods such as *inductive assertion* involve mathematical verification of the logic of the input-to-output relations of the model, i.e. it is mathematically proven that the path from the beginning assertion through execution of instructions implies the truth of the end assertion.

According to Golfarelli and Rizzi (2009), the main issue in simulation modeling is to achieve a good balance between model credibility and complexity. However, a model's credibility comes with a cost, and 100 per cent credibility is perhaps not even a justified goal, as illustrated in Figure 10 by Sokolowski and Banks (2009). If model credibility is desired, it requires sufficient investments of time, effort and resources in model development, verification and validation.

Nevertheless, even though the credibility of the model would be low, it can still prove to be valuable to its user. (Sokolowski & Banks 2009, p. 137-138.)

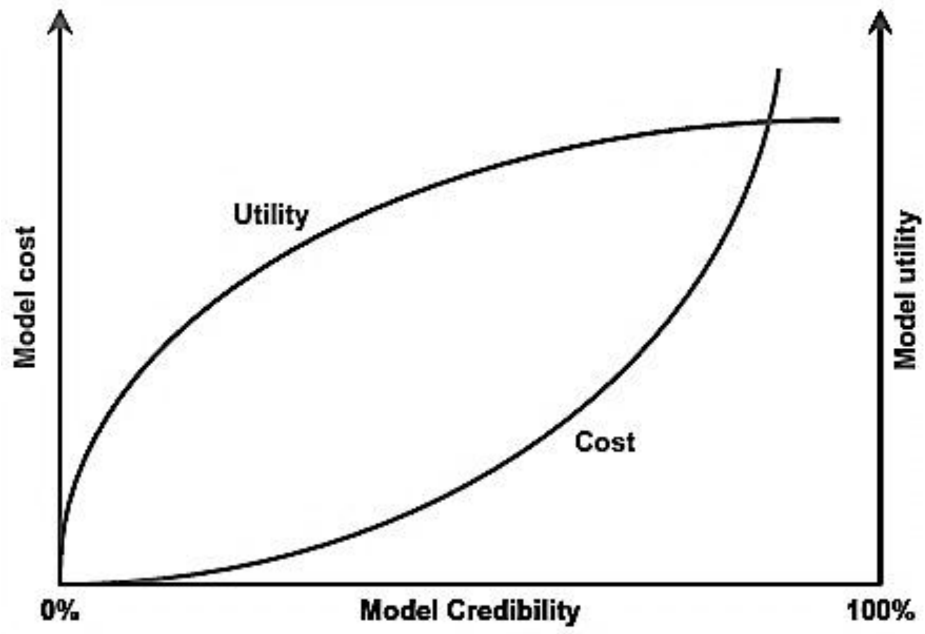


Figure 10. Relationship between model cost, credibility and utility (Sokolowski & Banks 2009, p. 137)

To conclude, modeling can be a powerful tool to support SCM decision making. Models can be mathematical optimization tools, dynamic simulation tools or combinations of both types. Typical steps in model development include construction of a conceptual model, development of the executable model, verification of the model, validation of data and the executable model, experimentation and analysis of results. Careful planning and validation of the model is critical for its usability. Moreover, although an invalid model can still provide useful information, it should not be used for more than it is credible for.

5. Supply chain management at Valmet Automotive

As mentioned earlier in Chapter 1.1, this is a case study of a Finnish automotive contract manufacturing company, Valmet Automotive Inc. (VA), where the author had worked prior to the initiation of this thesis. The purpose of this chapter is to give an overview of the case company and its supply chain management to form the basis of what can be measured in VA's SCM. Finally, Chapter 6 will describe the development of the SCM costing model.

5.1 Description of the case company

Valmet Automotive Inc. is an automotive engineering and contract manufacturing company located in Uusikaupunki, Western Finland, being the only manufacturer of passenger cars in the country (Pesonen 2014). In fact, VA is one of only two automotive contract manufacturers left in Europe. With annual revenues of over 200 million EUR and proving work for 2 000 employees, VA is considered a large company in Finland. The ownership of VA is currently divided between Finnish Industry Investment, Pontos, and VA executives.

VA has a long history in automotive manufacturing starting with the production of Saab cars in 1969. With acquired expertise in engineering and manufacturing, VA has focused especially on manufacturing premium cars, electric vehicles and convertibles. In fact, out of over 1,1 million cars manufactured by VA, as many as 30 per cent have been convertibles. This expertise has also made VA one of the leading suppliers of convertible roof systems in the world.

Today VA describes itself as a "first-class service provider for the automotive industry", with customer references to Mercedes-Benz (Daimler), BMW, Lamborghini, Fisker and Porsche. Its current manufacturing contract with Daimler started in 2013 and is signed until 2016. During this period of time, VA ought to manufacture 100 000 Mercedes-Benz A-class automobiles (Valmet Automotive 2012). Production of an A-class automobile is illustrated in Figure 11.

Figure 11. Production of Mercedes-Benz A-class automobile at Valmet Automotive (VA database)

5.2 Valmet Automotive's supply chain model

VA strives to minimize its SCM costs by practicing efficient and lean supply chain management. For example, freight costs per unit are minimized by optimizing the load planning of trailers, and inventory holding costs are minimized by having minimal safety stock levels and supplying components *just-in-time* and *just-in-sequence.* However, although trailer capacity and inventories are optimized, VA needs to balance and make trade-offs, as inventory ties up capital and contains a risk of obsolescence, but it can also protect VA from production disruptions. Therefore, to achieve high trailer fill rates, VA aims to optimize transport routes, order sizes and pick-up frequencies in addition to load planning. Moreover, the amount of required packaging material in VA's SC is minimized by pursuing fast cycle times, which will be discussed in more detail in Section 5.2.7.

5.2.1 Suppliers of Valmet Automotive

The components associated with the production of the Mercedes-Benz A-class automobile are divided between suppliers that are mostly located in Central Europe, where VA's current client is based as well. Although the range of suppliers is rather extensive, the number of actively used suppliers is relatively low, as fewer than 20 per cent of all the suppliers provide 80 per cent of the components used in the production of the A-class automobile.

However, in comparison to other automotive manufacturers, VA has generally speaking a longer distance between the car factory and its suppliers. According to Miemczyk and Holweg's (2004) study of Japanese automotive manufacturers, the average distance between the assembly plant and its suppliers was only 130 kilometers. Moreover, even another European automotive contract manufacturer's (Magna Steyr located in Austria), distance to most of its component suppliers is only some hundreds of kilometers, whereas the distance from VA to its suppliers is generally at least 1 000 kilometers, which inevitably increases logistics costs and lead times. Therefore, particular effort to optimizing the logistics functions and minimizing its cost is aspired at VA.

5.2.2 Material requirements planning and ordering at VA

Material requirements planning (MRP) is a technology used to assist in the management of inventories and the procurement of components. MRP systems take the production schedule for a given period of time and identify the requirements for different materials based on the bill of materials (BOM) of each product in the master production schedule. Should inventory records indicate that materials on hand for any scheduled production is inadequate, the MRP system generates orders taking into account the ordering and delivery lead times to ensure that materials are delivered prior to the start of production. (Whiteing 2001, p. 410.)

For planning and placing orders, VA uses its own computer-assisted ordering (CAO) system, Oracle-based MRP software named MTR. MTR is used by VA's material planners who look after their designated suppliers and are responsible for having components in house when needed. The software is used in particular to control inventory levels and timely dispatch of material orders.

VA does not pay any separate ordering cost as such, apart from the computers' EDI calls on each pick-up, but these data flow costs are considered minimal (Saarinen). Therefore, the only costs in regard to ordering are the order related components themselves, which have a fixed price independent of ordered quantity, and transportation costs, which are based on VA's own contracts with its carriers. VA can request delivery frequencies optimized according to VA's SCM strategy, as long as the supplier is able to deliver according to the given schedule.

5.2.3 Lean inventory management at VA

As practically no ordering costs exist, theories of economical order quantities (EOQ), which are partly based on ordering costs, are not applied to optimize VA's SCM practices as such. Nevertheless, EOQ principles are pertained to procurement but solely on the supplier's point of view, i.e. VA's procurer and supplier agree on an order quantity that is still economic for the supplier to produce. In VA's procurement, this agreed value is used as the part number's minimum order quantity (MOQ) that can be ordered in multiple batches at a time. Moreover, as VA's production demand is fairly deterministic, because Daimler provides confirmed orders for a certain period of time in advance and daily demand forecasts thereafter, VA can procure goods based on a combination of economic order interval (EOI) and lot-for-lot (LFL) ordering. In this ordering system, the order quantity is based on the part number's demand between placing the current and the subsequent order taking into account the part number's minimum order quantity (Tersine 1994, p. 133, 180). The interval between orders is determined by the most cost-effective pick-up frequency regarding VA's cost of transport, inventory holding cost and cost of packaging material.

JIT materials management is conducted by using the LFL ordering method, in which inventory level, inventory holding costs, and inventory throughput time are minimized, while inventory turnover ratio and cash flow are maximized. However, the optimal LFL order size does not always equal the demand during the order interval, as e.g. the MOQ constraint may increase the order size over the actual demand. Besides, initial inventory may sometimes be high enough, and thus a smaller order size in line with the MOQ constraint or even no order at all is enough to cover the demand until the following pick-up.

Furthermore, an illustration of pick-up frequency's impact on inventory level is shown in Figure 12. As can be seen from the figure, a supplier's (A, B and C) average weekly inventory level is considerably lower when the supplier's weekly supply is divided into three deliveries instead of delivering the weekly supply all at once. However, increased pick-up frequency usually results in higher transportation costs. Nevertheless, the inventory – transportation trade-off can be overcome by conducting milk-runs via several suppliers as illustrated in the figure, and still achieve high trailer fill rate while minimizing average inventory value.

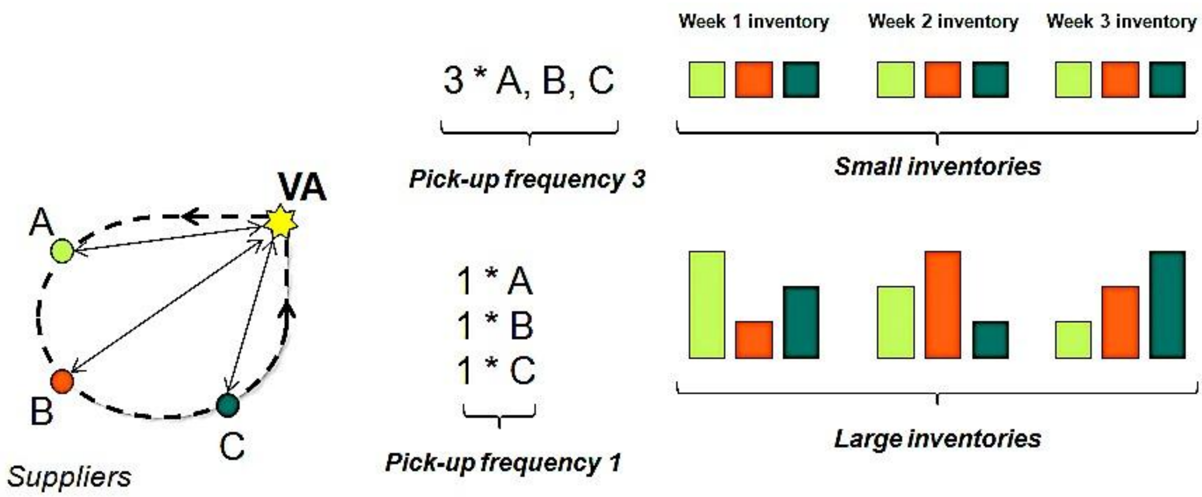


Figure 12. Example of pick-up frequency and inventory level

However, as VA's first tier suppliers (direct suppliers to the manufacturer) need orders in advance before pick-up, VA is not always able to place its orders based on confirmed orders from Daimler, but on Daimler's forecast data instead, which creates a slight variance in inventory levels. Forecasts of the absolute number of cars to be produced is practically the same as the actual demand, but e.g. the share of certain colors or specific models of cars can vary, depending on which orders Daimler decides to take from their order pool. Possible means to reduce the risk of stock-out and production disruption due to differences in forecasted and actual demand are e.g. to increase safety stock levels or use special freight, most commonly air freight, to reduce transit times. (Saarinen.)

At VA, safety stock is determined as the number of production days multiplied by the forecasted daily demand. VA's safety stock categories follow generally the so-called ABC analysis where products are divided into different inventory categories based on their value (Ng 2007). As in the ABC categorization, 20 per cent of VA's part numbers (3 per cent of inventory stock keeping units (SKU)) account for roughly 80 per cent of the total value of components. The first 20 per cent that form the A-group have short safety stocks as they tie up much capital, and thus also create an expensive risk of obsolescence because of high total value. On the other hand, B-, C- and D-category parts have longer safety stock as they are more affordable, and taking the risk of production disruption due to an inexpensive part would be uneconomical.

5.2.4 Sequenced supply of components

One third of VA's parts are delivered on a JIS basis, meaning that these items have no safety stock, but are delivered to the factory according to the production sequence, and installed only to specific order numbers (cars) arranged in a planned queue. Based on observations, the benefits of JIS parts are that the SC remains lean; there is no need to rearrange parts further at VA, thus time and money is saved. Besides, inventories are practically non-existent and some parts can be taken directly to the production line as such after they arrive. Also, less packaging material is needed as packages are not tied up in inventory, and floor storage space is released quickly as full packages are emptied at once.

However, the leaner the SC is, the higher the risk of stock-outs and production disruption, due to delivery or quality issues. If parts are not delivered in time, incomplete orders need to be removed from the production line, and the production queue needs to be rearranged, which slows down the production, and creates additional work and inventory at the production line.

5.2.5 VA's internal logistics service provider

VA uses a third party logistics service provider (LSP) for its internal logistics operations. The LSP is responsible for receiving, handling, repacking, storing and distributing delivered items. The

LSP and its warehouse are located on the same plot of land with VA, and its warehouse is directly connected to the car factory.

The LSP is paid a fixed amount based on the number of cars produced during a certain period of time. However, the LSP is developing a system to monitor their own operating times and costs on a part number level, but until this activity based “plan for every part” cost system is implemented, VA will have to content itself with having the LSP costs on an aggregate level linked to a production rate index (Karvanen).

At the moment, the service payment covers the costs of blue and white collar personnel of the LSP, the costs of the warehouse building, and all warehouse operations. Personnel salaries alone account for almost two-thirds of the total LSP costs, which was also brought out earlier by Richards (2011) in Chapter 2.2. Besides, VA is gradually redeeming the warehouse and its equipment from the LSP to itself, which is included in the payment as well. To summarize, all the internal logistics functions and warehousing operations are outsourced to the third party LSP, and thus payment of their services covers all the internal logistics costs of VA. (Karvanen.)

5.2.6 Control Tower operator

VA has outsourced some of its transport operations to a control tower (CT) operator which is paid a fixed amount for performing services associated with the management of VA’s daily transportations (Luoma). More specifically, and according to the agreement: “The main purpose of Control Tower Services is to monitor, measure and manage transport movements across the supply chain of Valmet Automotive. Control Tower is also a link between Valmet Automotive and transportation companies and all communication concerning transport operations will be carried out between Valmet Automotive and Control Tower.” This includes transport planning and freight optimization such as planning effective milk-run routes.

5.2.7 Closed-loop logistics, transportation and packaging

SC design at VA is a closed-loop including inbound, internal, reverse and outbound logistics. As illustrated in Figure 13, some of the components from first tier suppliers (inbound logistics), i.e. sequenced JIS parts, are distributed directly to collection or the production line after unloading from a trailer, while other components go first to storage and are transferred to the production line when ordered (internal logistics).

As discussed already in Section 5.2.1, most of VA’s first tier suppliers are located in Europe, and thus the majority of freight is road transportation; mega trailer trucks are used to transport goods from suppliers to the factory in Uusikaupunki. Moreover, because Finland is logistically more or less an island, part of VA's freight is intermodal transportation, i.e. trucks carried on vessels or trains.

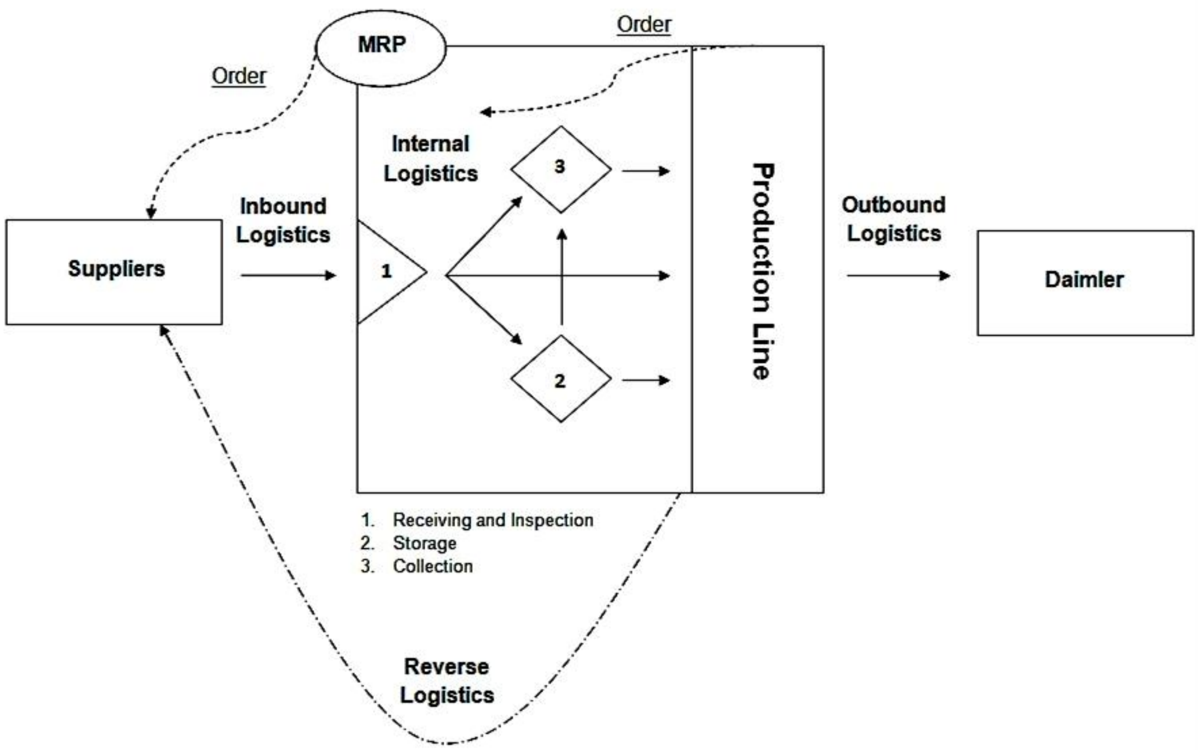


Figure 13. VA's closed-loop logistics (Revised from Salminen 2012, p. 14)

The function of VA's reverse logistics is to return empty packaging material to component suppliers. After unloading their cargo at VA's factory, trucks are loaded with empty packages that are transported back to the first tier suppliers for the next delivery of components. Instead of purchasing traditional corrugated fiberboard packaging material and disposing of them, or renting packaging material from suppliers and 3PLs, VA designs and procures its own reusable packaging material, which is optimized according to VA's internal logistics and production. Currently, however, the alternative cost to optimizing packaging material according to the objectives of internal logistics and production is the slightly negative effect on average trailer fill rates in transportation, as all packaging material is not designed to utilize trailer space in the most efficient way. Nevertheless, design of packaging material is continuously improved to meet the needs of both inbound and internal logistics.

The significance of packaging in SCM may be easily underestimated, but it is of great importance as packaging directly affects transportation costs, quality costs and warehouse operations costs. Based on observations in the case company, management of reusable packages requires efficient operation of reverse logistics and the SCM manager's holistic understanding of the supply chain, and sufficient resources (packaging material and labor) to ensure operational efficiency.

Furthermore, efficient management of reverse logistics can refrain the company from having SC bottlenecks that can, in the worst case, lead to production disruptions unless empty packaging material is delivered back to suppliers in time.

Special transportation, i.e. express door-to-door delivery, takes place when delivery to or from VA needs to be arranged differently to what has been agreed with the supplier, client or carrier. Most commonly, express delivery occurs due to a supplier's inability to dispatch items on a given pick-up date. Suppliers may have e.g. quality or capacity related problems. However, special transportation may be used in reverse logistics operations as well, if needed.

Also, should the LSP of internal logistics cause an accident, e.g. damage items required for production, the LSP is responsible for covering the costs of replacement parts and paying a premium to cover other costs, such as transportation. If special transportation is needed, this is also covered by the LSP. An essential part of risk management, when dealing with external parties such as carriers and other LSPs, is to have well-thought contracts in place that clearly dictate liabilities of the contract partners. (Karvanen.)

Lastly, VA operates outbound logistics as well. The function of outbound logistics is to transport finished products (cars) from VA's factory to its client. Outbound transportation includes road freight from VA's factory to the nearest port, from where the finished products are carried by sea freight to the destination port.

5.2.8 Maintaining a positive cash flow

According to VA's SCM director (Kivijärvi), maintaining a positive cash flow is a key condition in the company's SCM practices, and thus also an important element to be measured in the costing model. The principal idea of maintaining a positive cash flow is that the component's cycle time from a first tier supplier (component supplier) to the customer (Daimler) does not exceed the payment term to the supplier. In other words, cash flow is positive when payment of the delivered car is received from Daimler before VA pays the suppliers for installed car parts. Therefore, it is essential that items move swiftly enough throughout the SC, and do not create unnecessary inventories that slow down the throughput time.

5.3 Business intelligence in VA's SCM

Christopher (1992, p. 122) summarizes the essence of global logistics and SCM as follows: "The management of global logistics is in reality the management of information flows." An information system is the mechanism in which the complex flow of materials and finished products can be coordinated in a cost-effective manner. Substituting information for inventory should be a prime objective of every company, as time lapses in information flows translate directly into inventory and further into costs.

VA currently has separate enterprise resource planning (ERP) software for finance and SCM. The ERP used in SCM is named MTR. It was initially custom-built for VA's contract manufacturing purposes in the 1990s. The software is still being continuously reconfigured according to new client and product requirements. As operational environments change, areas for development in regard to VA's ERP software environment are acknowledged. (Saarinen.)

In addition to developing the supportive SCM tool under this research, VA has recently implemented another SCM tool named Valmet Automotive Transport Gateway (VATG) which is a system for freight booking and trailer load planning. VATG is linked to MTR, and thus it can access the information on delivery schedules and order quantities, as well as component packaging data. Therefore, as suppliers who are registered in VATG receive VA's orders, VATG automatically sends them a pick-up proposal including pick-up date and time, carrier name and a load plan to ensure cost-effective loading of the ordered material. Suppliers can accept the proposal or modify it if needed, but after the pick-up has been accepted information is automatically sent to VA's CT who manages the transportation from there onwards.

CT arranges an effective route to minimize transport costs, after which it informs the assigned carrier about the pick-up(s). VATG's load planning is an advanced feature which optimizes the space utilization in a trailer to minimize transportation costs, and can also provide information on how many trailers are needed and estimates the cost of the freight. In order for these kinds of features to work properly, basic data, e.g. data on packaging material, should be of sufficient quality. Otherwise, if basic data is incorrect, an order may be created for too many or too few trailers for the pick-up, which results in additional costs if the error proceeds unnoticed.

6. Development of the SCM costing model

The purpose of this chapter is to describe the process of developing the SCM costing model. The researcher approaches the development of the costing model based on Tersine's (1994) seven steps in model development, as described earlier in Chapter 4. The first four steps will be covered in this Chapter 6, leaving validation, experimentation and analysis of the results to the following Chapter 7. As a reminder to the reader, the seven steps of a modeling process include:

1. Problem formulation
2. Construction of a conceptual model
3. Data collection
4. Developing the executable model
5. Model verification and validation
6. Experimentation
7. Analysis of results

6.1 Problem definition and development of the conceptual model

The purpose of the costing model is to improve understanding and control of VA's SCM cost drivers and KPIs, and help streamline as well as improve the cost efficiency of SCM processes. The approach is to calculate SCM costs, identify the key cost drivers and the correlation between them. In addition, the model should help SCM decision making by providing the capacity to conduct what-if scenarios, i.e. model the cost effects of adjusting certain SCM decision variables.

When the researcher was first given the opportunity to develop a tool to model VA's total SCM costs, the principal idea was to determine the effects of altering a few SCM variables, such as pick-up frequency and minimum pick-up quantity, and to observe the causality between SCM variables of freight costs and inventory value. Also, it was desired that variables could be changed individually for multiple part numbers, supplier numbers and regions. The initial concept of the model is presented in Figure 14.

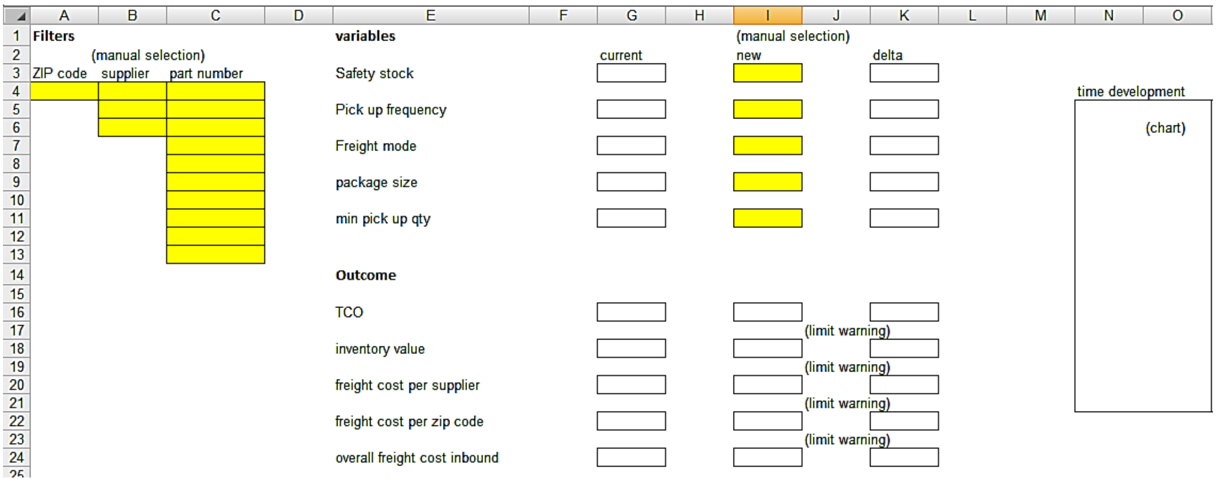


Figure 14. Initial concept of the costing model

The first version of the model was drafted by the author soon after starting the project (see Appendix 2). Together with Mrs. Saarinen (main supervisor of this project at VA) it was decided that certain costs, such as manufacturing costs, taxes, warranty and R&D would not be included in the scope of the model. The draft version was true to the initial version by including the possibility of adjusting variables for multiple part numbers and suppliers at the same time. Also, as in the concept model, it was possible to alter the variables of a certain pick-up region.

There were two main displays in the draft version. The idea of showing all current values on an overall, per vehicle, supplier and part number level in one display, and the new values after adjusting parameters in another display was approved by Mr. Kivijärvi and Mrs. Saarinen, the supervisors of the project at VA. Another modification to the initial version was to include the possibility of adjusting the daily production rate and the length of the modeling period.

Further additions included the capacity to change the throughput time of selected part numbers, calculate different warehousing costs, and measure inventory fill rate as well as supplier performance in regard to delivery accuracy and quality. Two other displays were used to show the difference between the current situation and the modeled situation in terms of money and percentage indicating the difference by colors of red and green. However, these were mere ideas of what the final model could be. The draft version was not functioning, as no formulas were in place and the version was based on dummy values. Nevertheless, the draft version visualized the researcher's understanding of the desired tool, and furthered the execution of the actual model.

6.2 Data collection and the ETL process

Data collection for the model started at grass roots by getting familiar with the automotive factory and its processes. As mentioned earlier in the SC costing Chapter 3.1, it is important to gain practical knowledge of the processes involved in the SC to know what to measure in the process, and how to measure it. Getting to know the process flows and all the exceptions required much time and observation as well as discussions with VA's SCM professionals. Understanding the process proved to be vital in order to grasp the relations between the SCM functions and to develop the logic for the costing model. Moreover, when moving on to the electronic data collection phase and using VA's custom-built ERP applications to retrieve data, understanding the terminology and key data sources was essential and saved much time later on in the development process.

The process of extracting data from data source(s), transforming the data and loading it into a data warehouse or some other target is called the extracting-transforming-loading (ETL) process, see Figure 15 (Song & Liu 2011). Song and Liu (2011) explain the common steps in the ETL process as (1) selecting the data source(s) for extraction, (2) transforming the source data,

(3) joining the source data, (4) selecting the target into which data is loaded, (5) mapping source data according to the target structure, and (6) loading data into the target.

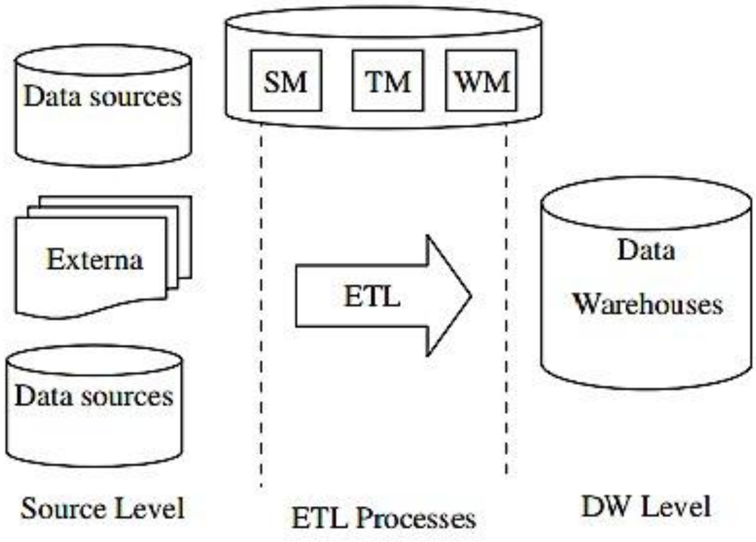


Figure 15. ETL architecture (Song & Liu 2011)

Griesemer (2011, p. 169) remarks that the source data can be staged, i.e. stored in a temporary location, before transforming and loading it into the target structure. The transformation phase before loading may include filtering and cleaning of the source data. In addition, calculations can be performed on the data to further transform it before moving on to the loading step (Griesemer 2011, p. 167). Griesemer (2011) states that data cannot be directly taken from the source and placed in the destination as-is, but the data has to be manipulated when it is copied. Depending on the needed manipulations, it can be a complex task, which should therefore be automated with some programming code.

When retrieving SCM data for the costing model, the researcher used the above-described methods presented by Griesemer (2011) and Song and Liu (2011). At first, the plan was to extract data directly from the company's Microsoft SQL server. This attempt was developed together with VA's IT personnel. Even at that stage it was known that the required data was in different sources, and thus everything could not be extracted from the SQL server. For example, certain finance data and packaging data were kept only on separate Excel spreadsheets.

The same data (all components and suppliers involved in the production of the Mercedes A-class automobile) that was supposed to be extracted from SQL could also be extracted through VA's Oracle-based Discoverer application that was used for the task after all. The downside of extracting through an application was that the data was not as integrated as it could have been when extracting from the SQL server. Therefore, data extraction was initially a laborious process and required much data integration. However, once the data query was completed and saved, the updated data can be easily extracted again with the same Discoverer query.

The Discoverer application allows the user to select and extract from multiple data sources, but often the data sources cannot be linked, or some data may be lost. For example, component information and supplier information are separate queries. Therefore the main query includes some 20 individual queries that are conducted at the same time. Each query can also have certain constraints applied to it, e.g. include a certain client's components only.

The query is extracted in Excel format including each query as a separate spreadsheet. Data from different queries is later on loaded, joined and transformed in the costing model through Visual Basic for Applications (VBA) coding. The purpose of the code is to remove old data sheets and import new ones from the Excel file extracted by means of a Discoverer query. This ensures easy updating of the raw data in the model. Furthermore, the VBA code joins the data from 20 spreadsheets into one sheet, where the data is combined. After joining the data, numerous calculations take place to map and transform the data into information down to the part number level. At first, the expectation was that this point could have been reached directly through SQL extraction without the described intermediate step involving a Discoverer query and joining of part number data in the model.

6.3 Construction of the executable model

Based on the needs of the case company, and recommendations in the modeling literature (e.g. D'este 2001), the researcher decided to use a mixture of strategic and tactical approaches in modeling, i.e. develop a model for long-term planning with incremental adjustment possibilities. The model is based on a combination of mathematical calculation and mechanical *what-if* modeling techniques, which were described by D'este (2001, p. 533) as an effective strategy for modeling SC systems. As a strategic planning model, it is able to reproduce the overall system mechanics, i.e. the interactions between decision variables and SCM cost drivers; the model is able to mimic the overall pattern of SC activities. Moreover, the model supplies greater detail for certain aspects of VA's SCM, such as cash flow, and can thus be considered as a tactical planning tool as well.

Taking into account the experimental nature of the study and both the available resources and expertise for the task, a mathematical spreadsheets model was considered the most suitable basis for conducting the project. Spreadsheets offer a good deal of flexibility and can with relative ease be synchronized with VA's data sources. The obvious downsides in using Excel spreadsheets are the high required computing power and the difficulty of use, such as version control, compared to commercial modeling software. As the model consists of 41 Excel spreadsheets, over 900 000 formulas and some 700 lines of Visual Basic code, it is rather slow to run the modeled scenarios and calculations. However, using the model should be relatively straightforward, as the user needs only one sheet, the main display, to operate the model. An overview of the model's main display is presented in Figure 16 on the next page.

The model and its mechanics are based on the following assumptions:

- Lead times are deterministic
- Demand is deterministic
- No production disruptions can occur
- Zero defects from suppliers
- No initial inventory exists
- SCM is lean; no excess inventories exist

As the model is supposed to provide information with a sufficient level of accuracy, i.e. not perfect accuracy, it does not take all SCM aspects into account. In other words, the model is not stochastic, and therefore it does not capture the probabilistic variation of events.

Modeling can be restricted by given constraints, e.g. storage space, maximum pick-up frequency, minimum safety stock level, and so on. Scenarios such as total costs with different production rates can also be modeled using a deterministic what-if analysis method. While the model is based on deterministic calculations, it does also reveal the SC functions' cause and effect relationships when decision variables are discreetly adjusted. The formulas that drive the interaction mechanics between SC functions are based on the understanding achieved when familiarizing oneself with the process flow of VA's SCM. SCM functions and the application of their calculation methods to the model will be discussed next in more detail.

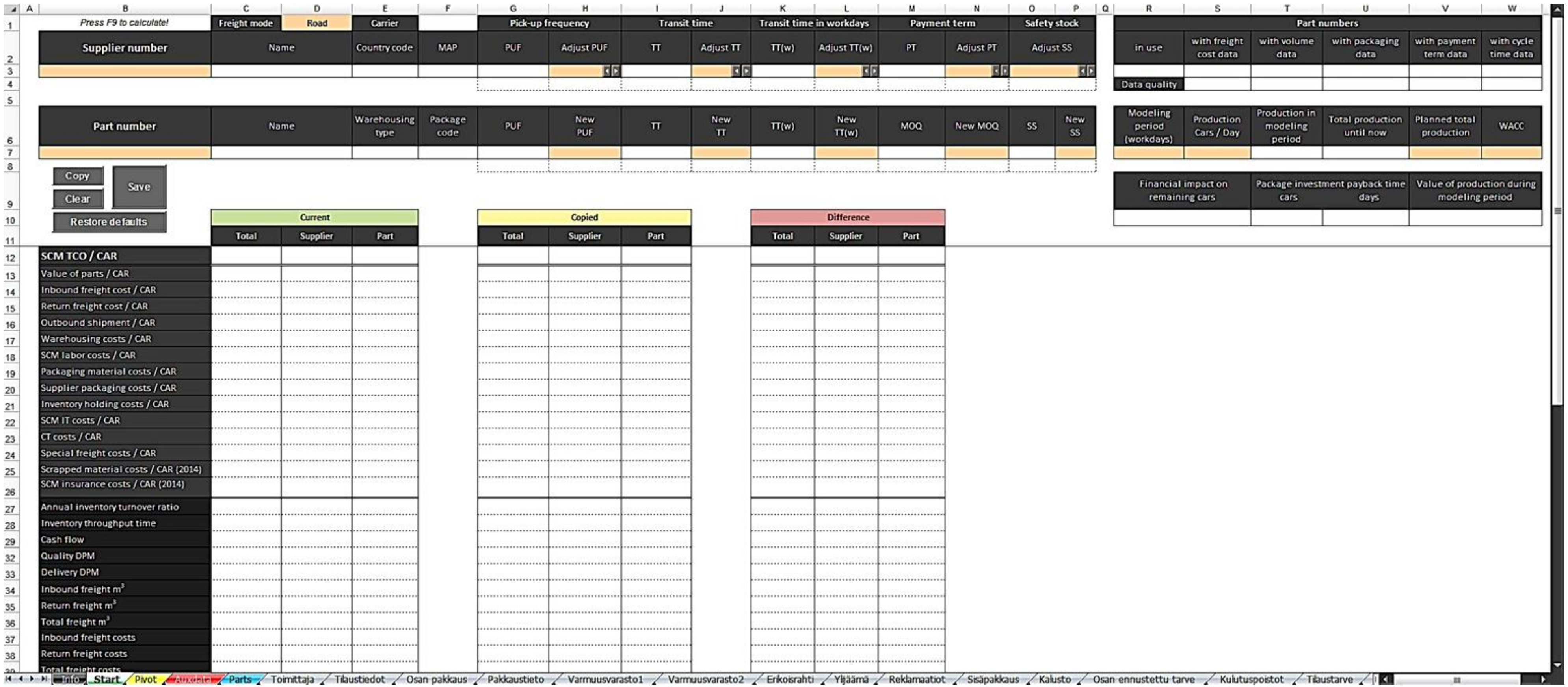


Figure 16. Overview of the main display in the costing model

6.3.1 Choosing SCM cost drivers and decision variables for the model

As discovered in the data collection phase, and also discussed in several SCM modeling articles (Altiparmak et al. 2009; Bottani & Montanari 2010; Carvalho et al. 2012; Manunen 2000; Mula et al. 2013; Paksoy et al. 2013), transportation, warehousing, and inventory holding costs proved to be some of the major SC cost drivers. Therefore, it is justifiable to include these key cost drivers in the costing model of this study. Manufacturing, ordering and stock-out costs are some other major SC cost drivers which emerged from the literature review on the topic. However, these cost drivers are not applicable, or for other reasons are not considered in this research, as discussed earlier in this text in Chapter 1.3 and Chapter 5.2.2.

In addition to the above-mentioned cost drivers, packaging material was found to be a significant cost driver at VA. Furthermore, including the value of components in a car puts the other SCM costs into perspective, and is therefore useful information to be included in the model. Examples of transaction costs that can be included in the calculation model are e.g. those of CT and LSP, the internal logistics service provider.

Besides cost drivers, different key performance indicators (KPI) are to be measured. KPIs in the model include cash flow, inventory turnover ratio, throughput time, quality and delivery defects per million opportunities (DPM), data quality, and average inventory value and inventory fill rates.

Lastly, after the SCM costs and KPIs are calculated, it is also desired that the user can alter certain decision variables, which would provide re-modeled SCM costs and KPIs. Decision variables in the model include: daily production rate, planned overall production, length of modeling period, weighted average cost of capital, safety stock level, payment term length, minimum order quantity, transit time, pick-up frequency, and freight mode. Moreover, the results should be shown per vehicle on an overall, supplier and part number level.

6.3.2 Designing the user interface

The user interface (UI) of the model should be clear and intuitive. Although the model consists of several spreadsheets, the user should be able to get by with only the main display, the *Start* sheet. The main display of the model, presented in Figure 16, consists of the supplier selection panel, part number selection panel, data quality panel, financial panel, and production panel. Decision variables that can be altered are indicated with orange cells.

The adjustable orange cells in the supplier panel include supplier number, freight mode, pick-up frequency, transit time in calendar as well as in production days, payment term and safety stock. Adjusting any of these cells affects a supplier number level, except that if different adjustments are made to a supplier's part number in the part number panel, as then the part number adjustments overrule the effects of adjustments on the supplier number level for that particular part number. Each supplier number is listed in a drop down list, and also an option for "all suppliers" is available. Therefore, if *all suppliers* is selected, adjustments such as "safety stock -0,5", affect all suppliers' safety stocks by a reduction of 0,5 days if possible, as 0 is the lowest end value.

The adjustable cells in the part number panel include a list of part numbers available based on the selected supplier. Other variables are the same as in the supplier panel, except that the part number panel does not include a payment term, but includes a minimum order quantity instead. Variables in the part number panel are not adjusted like in the supplier panel by increasing or decreasing the previous value. Instead, variables in the part number panel are replaced by the input method.

Besides information on data quality, the panels on the right (see Figure 16) display measures of production and financial parameters. For instance, if the total SCM costs per car are changed, the impact of the change is multiplied by the remaining number of cars to be produced, thus calculating the overall impact of the change, which is displayed in the financial panel. Also, if total costs decrease while packaging investment increases, the payback time of the packaging investment is displayed in terms of days and cars to be produced. To put other cost measures into perspective, the total value of production during the modeling period is also calculated. Moreover, adjustable decision variables in the panels on the right side include variables such as daily production rate, total production quantity, WACC, and length of modeling period.

In addition to adjustable panels, there are three "scoreboard" displays on the main screen. The one on the left displays figures according to the current or given conditions. The display in the middle shows the values according to the previous or original parameters. The display on the right indicates the difference between the current situation and the previous situation. In addition, if costs or KPIs are changed, the effect of the change will be color coded, and the title of the item on the left will be highlighted with its color code indication. Values are shown on an overall level, supplier number level, and part number level. Costs are calculated per produced car.

The UI provides four ActiveX control buttons named "Copy", "Clear", "Restore defaults" and "Save". Clicking a button performs a simple macro which either copies the current data from the scoreboard on the left to the one in the middle, or clears the copied data. *Restore defaults* empties the orange cells in the supplier and part number panels. *Saving* the data performs a "printing" macro, which copies all the data from the main display and pastes the values to a new workbook, enabling the user to save and compare different scenarios.

Lastly, before the main sheet, there is an *Info* sheet, which instructs for the use of the costing model. The Info sheet explains the functions of the costing model, instructs for the adjustment of decision variables, and briefly explains the cost drivers and KPIs. Moreover, the process of updating basic data in the costing model is also explained on the Info sheet.

The logic of formulating the reviewed SCM cost drivers, KPIs and variables will be discussed next in more detail.

6.3.3 Calculating and modeling freight costs

Freight costs are expected to be the major SCM cost driver at VA. In this study, there are a few different freight costs to be modeled. Firstly, there are inbound freight costs from component suppliers to VA. As described earlier, components may be transported directly, via terminal or as a milk-run shipment. Secondly, there are return freight costs of empty packaging material from VA to suppliers. Like the inbound freight, also return freight is delivered either as direct, via terminal or as a milk-run shipment. Thirdly, there are outbound freight costs, i.e. transporting the finished products to the client (Daimler). Lastly, there are also special freight costs, which include express deliveries besides normal air freight costs.

In the literature, freight costs were often simply based on distance or zone pricing and freight volume. Moreover, the freight cost models usually deal with total freight volumes within certain freight lanes and e.g. compare the costs in case the total freight volume was nominated to another lane, i.e. origin-destination combination. Instead of total freight volume, VA is interested in calculating freight costs per pick-up on an overall, supplier and part number level, and taking the sum of individual pick-up costs.

Although VA's transport costing is also based on given transport rates that vary between different pick-up regions, modeling of freight costs is not so straightforward, as VA's freight costs are based on loading meters instead of volume. A mega-trailer has 13,6 meters of available loading space, where 1 loading meter equals 1 meter in length of goods in a trailer. Therefore, to minimize freight costs, the aim is to use each loading meter as efficiently as possible by maximizing the height of each loading meter in a trailer.

However, when modeling freight costs, it is challenging to model trailer load planning according to what is the most efficient method to load a trailer with differently sized packages given the constraints of stacking, and so on. Fortunately, besides loading meters, VA's freight rates are given also in weight (per 100kg) and in full trailer loads (FTL). It is known that the maximum volume of a mega trailer is approximately 100m^3 and maximum load is 24 000kg.

Also, the demand for each part number over a given period can be found out, as well as the total number of cars to be produced in that given period of time. Dividing the component demand by car production, an average usage of components per car can be derived. For each part number, packaging information can be retrieved, from which volume information is generated. As part number data is linked to supplier data in the model, total supplier inbound volume in the modeling period can be generated. Moreover, as the length of the modeling period and the supplier's pick-up frequency are known, the total number of pick-ups per supplier during the modeling period can be calculated.

From total volume and total number of pick-ups, an average volume per pick-up for each supplier is calculated. As production rate is stable throughout the modeling period, average volume per pick-up is sufficient for modeling pick-up costs. Nevertheless, when calculating the total order quantity per part number during the modeling period, minimum order quantity constraints are taken into account, i.e. if total demand of a certain component is 410, but the minimum order quantity is 100, then the total order amount is rounded up to 500. No initial inventory is considered to exist in the model.

With known volumes per part number and supplier number, freight costs can be calculated. Direct and milk-run shipments are based on FTL rates multiplied by volume, which is divided by VA's average FTL load. Condition (volume limit) for direct shipment can be adjusted in the model. By following the ABC method, freight costs are allocated to part numbers based on their use (volume) of the full trailer capacity. Therefore, the higher the part number's volumetric share of the supplier's total volume, the higher the freight costs allocated to the part number.

However, freight via terminal is priced differently. As in direct shipment, the conditions for terminal shipment can be modified, however, the general condition is that freight volume less than 10m^3 and weight less than 2 500kg is directed through a terminal. Freight rate to terminal is based on maximum chargeable weight, i.e. whichever is higher, the volumetric weight or the actual weight of goods.

The conversion rate of cubic meters to kilograms depends on the type of goods, and it can be adjusted in the model. First, an average value of 150kg / 1m^3 was used in calculating volumetric weight on road transportation. From terminal to VA, freight costs are based on given *terminal to VA* FTL rates, and the costs are calculated as in direct and milk-run shipments: freight volume divided by average trailer fill rate multiplied by FTL freight rate. This calculation method is justified for terminal and milk-run shipments because milk-run trailers and trailers from terminals are delivered as full trailer loads to VA.

Moreover, freight cost calculation includes the option of freight mode selection. By default, freight rate is calculated as normal road freight, but freight mode can also be changed to *road courier* or *air courier* mode. Different freight rates apply for each courier mode, and the cost calculation is based on maximum chargeable weight, as in terminal freight rate. Volumetric weight in courier modes is set by the carriers at 200kg / 1m^3 for the air courier, and 250kg / 1m^3 by the road courier.

The following self-made equation is used to calculate inbound freight costs in the costing model:

$$If\ \ M_f = AC \quad \rightarrow \quad MAX(C_{V_s * CW_{AC}};\ C_{Wa_s}) * (1 + FS) \tag{3}$$

$$If\ \ M_f = RC \quad \rightarrow \quad MAX(C_{V_s * CW_{RC}};\ C_{Wr_s}) * (1 + FS)$$

$$If\ AND(W < 100kg;\ V * CW < 100kg) \ \rightarrow \quad P_{min} + \frac{P_{Ti}}{\overline{FR}_i} * V$$

$$If\ \ AND(W \leq W_T;\ V * CW \leq W_T; V \leq V_T) \ \rightarrow \quad MAX(\,P_W; P_{V*CW}) + \frac{P_{Ti}}{\overline{FR}_i} * V$$

$$If\ \ V < V_D \quad \rightarrow \quad \frac{P_{FTLi} + C_s * 2}{\overline{FR}_i} * V$$

$$If\ \ \ V > \ \overline{FR}_i \quad \rightarrow \quad P_{FTLi} * \left\lfloor \frac{V}{\overline{FR}_i} \right\rfloor + \frac{P_{FTLi} + C_s * 2}{\overline{FR}_i} * (V - \left\lfloor \frac{V}{\overline{FR}_i} \right\rfloor * \ \overline{FR}_i)$$

$$OTHERWISE$$

$$C_f = \frac{P_{FTLi}}{\overline{FR}_i} * V$$

Where M_f denotes freight mode, AC is air courier, RC is road courier, $C_{V_s * CW_{AC}}$ is freight rate from the air courier pricing sheet based on supplier's inbound volume and volumetric weight rate, $C_{Wa_s}$is freight rate from the air courier pricing sheet based on supplier's actual inbound freight weight, $C_{V_s * CW_{RC}}$ is freight rate from the road courier pricing sheet based on supplier's inbound volume and volumetric weight rate, $C_{Wr_s}$is freight rate from the road courier pricing sheet based on supplier's actual inbound freight weight, FS is fuel surcharge, V is pick-up volume, CW is cubic meter weight, V_T is maximum terminal volume, W is pick-up weight, W_T is maximum terminal weight, P_{min} is minimum terminal rate, P_{Ti} is FTL freight rate from terminal to VA, $\overline{FR}_i$ is average inbound trailer capacity, P_W is terminal rate based on weight, P_{V*CW} is terminal rate based on volumetric weight, P_{FTLi} is FTL inbound rate from supplier to VA, C_S is milk-run stoppage cost (two additional stoppages on average), V_D is minimum direct shipment volume, and C_f indicates freight cost.

A similar formula applies also to calculating return freight cost, which, of course, is calculated with return freight volumes, average trailer fill rate, and return freight rates. Return volumes are based on the return ratio of packaging material, which is usually 35, 50 or 100 per cent of the original inbound volume, as some packaging material is collapsible when empty. However, return freight calculations are based only on volumetric weight of the packages and do not include courier freight cost calculation option, as all return freight is normal road freight.

Besides inbound and return freight, VA's freight costs include outbound and special freight costs. However, calculating these require no formulas, as they are either fixed or records extracted from VA's database. The cost of outbound shipment of finished cars to Daimler is fixed and based on VA's contract with its sea freight carrier.

Special freight costs include normal air freight, but also special express deliveries. This information is extracted from the database, and costs are historical instead of modeled in the costing tool. The formula for special freight costs is simply special freight costs incurred during the contract with Daimler divided by the number of Daimler cars produced so far. This data can be retrieved on a part number level and therefore on a supplier number level as well. As the formula looks back in time, special freight costs per produced car will change only when the basic data of the model is updated.

6.3.4 Modeling average inventory value and inventory fill rates

As explained by Kuula (2014b), the equation for calculating average inventory is:

$$\bar{I} = \frac{I_{max} + I_{min}}{2} \tag{4}$$

Where $\bar{I}$ denotes average inventory value, I_{max} is the maximum inventory value, and I_{min} indicates the minimum inventory value.

In regard to the costing model's calculation method, where inventory value is measured at the same time every morning, maximum inventory comprises safety stock, components for the day's demand, and delivered components, whereas minimum inventory consists of safety stock and components for the day's demand. Thus, the self-made equation for average inventory value is:

$$\bar{I} = \sum_{i=1}^{n}((\frac{Q_{max_i} + SS_i * \overline{DD}_i * 2}{2} + \overline{DD}_i) * P_i) \tag{5}$$

Where Q_{max} denotes maximum pick-up quantity, SS is safety stock (days), $\overline{DD}$ is average daily demand, P is price, n is the number of different part numbers, and i indicates the part number.

Maximum pick-up quantity is the part number's total demand during the modeling period divided by the number of pick-ups, which is rounded up to the next minimum order quantity (MOQ). For example, if average pick-up quantity was 260, but MOQ is 50, then Q_{max}would be 300. However, $\bar{I}$ covers only average inventory on hand, although as discussed in Chapter 2.1, average inventory value should include the value of inventory in transit as well. Based on VA's inventory value follow ups, the value of inventory in transit accounts on average for the value of components over the next 4,3 production days. Therefore, the equation for calculating average total inventory value is:

$$\bar{I}_T = \bar{I} + \sum_{i=1}^{n} C_{dc_i} * 4{,}3 \tag{6}$$

Where C_{dc_i} denotes daily consumption value of a part number, which takes into account the daily production rate and value of the part number.

After calculating the average total inventory value, the KPI of annual inventory turnover ratio can be calculated. Inventory turnover is based on the total production, the average value of a finished product, and average inventory value, as explained in Chapter 2.1. Moreover, the KPI of throughput time can be derived after knowing the inventory turnover ratio, as also explained in Chapter 2.1.

VA's SCM is also interested in having the inventory fill rate as a constraint in the costing model. Furthermore, VA's inventory is divided into (1) "miniload" inventory, (2) logistics center inventory, (3) inventory at welding department, (4) inventory at assembly line and (5) floor inventory. The miniload inventory is divided into three sections. Different part numbers belong to their assigned inventory types and this information is available from the database. Also, the maximum capacity of each inventory is known. As the part number's volumetric data, packaging data, average inventory level, and inventory type as well as the inventory type's maximum capacity are known, average inventory fill rate can be modeled. The self-made equation for average inventory fill rate is:

$$\overline{f_x} = \frac{\sum_{i=1}^{n} \frac{\bar{I}_{q_i}}{Q_{p_i}}}{Ca_x} \tag{7}$$

Where $\bar{f}$ denotes average inventory fill rate, x is inventory type, n is the number of different part numbers, i is part number, $\bar{I}_{q_i}$ is average inventory quantity of the part number, Q_{p_i} is components per package, and Ca_x indicates package capacity of inventory type.

However, the equation for calculating floor storage fill rate is not similar to that of shelf storage. Volumetric data of part numbers has to be converted into square meters on the floor storage. For this calculation, an established equation by Marttila is used. According to Marttila, cubic meters can be converted to storage square meters with the following formula:

$$CBM_{m^2} = \frac{V}{S * FR * \bar{H}} \tag{8}$$

Where V denotes total volume, S is share of usable space for storage out of total floor area, FR is fill rate of usable storage space, and $\bar{H}$ indicates average height of inventory stacks.

To calculate floor storage fill rate, the volume summation of part numbers that are stored on the floor is first converted to square meters with the above equation. Finally, the fill rate is calculated by dividing the occupied area with the available floor storage area.

6.3.5 Calculation of warehousing and inventory holding costs

Although warehousing and inventory holding costs were not included in the first concepts of the costing model, in the SCM literature they were considered as some of the key SCM cost drivers, and should thus add value if included in the model. As discussed in the previous chapter, VA's warehousing operations are outsourced to a third party, LSP. Currently the warehouse costing is based on agreed cost per produced car, which correlates negatively with the daily production rate, i.e. the more cars that are produced, the lower the warehousing operation costs per car.

Warehousing costs in the model are simply based on the daily production rate applied in the model. As a result of a discussion with the LSP representative, the best approximate distribution of total warehousing costs between part numbers is based on their volume; the more and the bigger the packages, the more handling costs are incurred. Handling costs account for 75 per cent (60 per cent labor and 15 per cent equipment costs) of total warehousing costs, and thus form the majority of warehousing costs, which makes volume a justified basis for cost distribution. Average inventory of a part would not be as good a basis for cost allocation, as storage cost accounts only for some 25 per cent of total warehousing costs, as described by Richards (2011) earlier in Chapter 2.2.

As discussed in Chapter 2.1, inventory holding costs can include opportunity cost, inventory management cost, insurance cost, and cost of obsolescence. The costing model can help VA to minimize its inventory holding costs which appear mainly as opportunity costs. Opportunity costs are formed whenever inventory is held, as the inventory could be sold immediately and the money could be invested until the goods are needed in production. Therefore, the average inventory value, including inventory on hand and in transit, could, at least in theory, be invested.

As recommended by Timme and Williams-Timme (2003), weighted average cost of capital (WACC) is used as the interest rate for opportunity cost in the costing model. WACC determines the firm's cost of capital based on the share of equity and debt, and their costs (Nyberg, 2011). According to Nyberg (2011), the equation for WACC is:

$$WACC = \frac{E}{E+D} * Re + \frac{D}{E+D} * Rd * (1-T) \tag{9}$$

Where E denotes equity, D is debt, Re is cost of equity, Rd is cost of debt, and T indicates tax rate.

Cost of obsolescence is calculated separately from inventory holding costs in the model. As obsolescence is influenced by unpredictable future events, such as changes in car models, it is not to be modeled, but instead a value of actual obsolescence per car is given as a piece of information that can be compared to other SCM costs. Initially, the value to be used in the model is the value of scrapped components in 2014 divided by the number of cars produced during that year. This information can be distributed between suppliers.

SCM insurance costs are also calculated separately from the inventory holding costs. The insurance costs cover transportation insurance as well as inventory insurance costs. Nevertheless, insurance costs cannot be modeled in the costing model as the model does not support the dynamics of future insurance cost development, which is subject to several matters, such as the number, nature and scale of previous losses, agreed terms and liabilities, production volumes as well as external factors, e.g. the competition at the insurance market and general attitude towards risk taking (Julin). Thus, an actual value of 2014 insurance costs divided by the amount of produced cars in that year will be used in the costing model as a reference. Insurance costs can be further divided between part numbers based on their share of value in a finished product.

As insurance and obsolescence costs are calculated separately from the inventory holding cost, the two remaining inventory holding cost factors are the opportunity cost and inventory management cost, which is the sum of material planners' annual salaries and wages. However, because material planners' salaries are rather included in the sum of SCM labor costs (see Chapter 6.3.9), the equation for inventory holding cost during the modeling period is:

$$C_{ih} = WACC * \bar{I}_T * \frac{d}{D} \tag{10}$$

Where C_{ih} denotes inventory holding cost during modeling period, $WACC$ is weighted average cost of capital, $\bar{I}_T$ is average total inventory value, d is production days in the modeling period, and D indicates production days in a calendar year.

6.3.6 Modeling Control Tower operation costs

CT costs are fixed weekly costs that can be allocated to part numbers e.g. according to their share of total freight costs, which is a justifiable allocation method as the CT is paid for transport management. Compared to freight volume, freight costs are a better allocation condition, because a delivery of a small volume can be relatively costly and require much transport management work as the delivery is arranged via a terminal or as a milk-run transportation. The self-made equation for CT cost is:

$$C_{CT} = \frac{\frac{d}{5} * CT}{Z} \tag{11}$$

Where C_{CT} denotes control tower operations cost per produced car, d is production days in the modeling period, CT is fixed weekly CT operating costs, and Z indicates production of cars during the modeling period.

6.3.7 Cash flow calculation method

The equation for calculating cash flow is based on the part number's cycle time and the payment term to supplier. In addition, the part number's value and daily consumption are included in the calculation. Firstly, to describe the part number's cycle time, a process flow is presented in Figure 17. The cycle time that affects cash flow begins in the phase of pick-up at supplier. As VA's freight is shipped according to the FCA Incoterms[1], the risk and ownership of goods is transferred from supplier to VA when goods are loaded onto VA's nominated carrier. Therefore, the payment term time starts on the day of pick-up.

The next step in the process flow is the transport time through origin and destination ports to VA, and then unloading the goods at the warehouse. Some parts go directly to the production line whereas others include safety stock time in their cycle time. Waiting time at the production line is calculated based on the average daily consumption of a certain part number and its batch

[1] Incoterms help traders avoid costly misunderstandings by clarifying the tasks, costs and risks involved in the delivery of goods from sellers to buyers (International Chamber of Commerce 2010).

size. In addition, depending on the stage of production at which the part is installed, a throughput time on the production line is added to the cycle time.

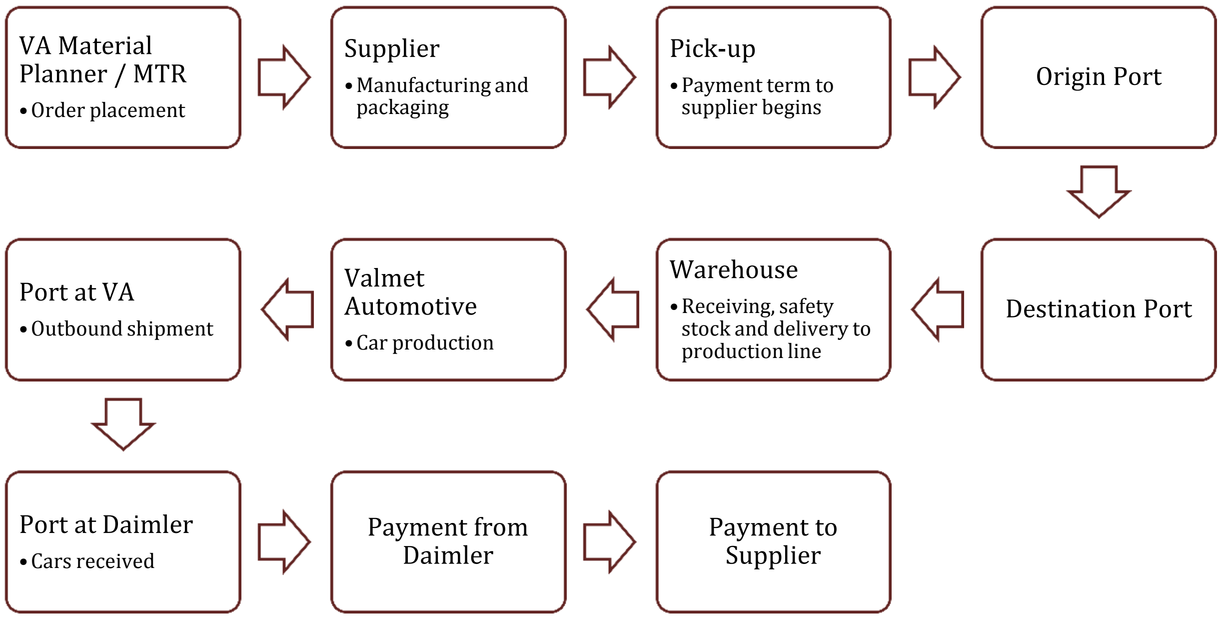


Figure 17. VA's order-to-delivery process flow

Finished products are shipped according to a regular schedule. Some installed parts in finished products wait at the port longer than others that had been installed closer to the outbound shipment day. Therefore, an average waiting time at the port is calculated and added to the fixed shipping time. After delivering finished goods to the destination port, payment from Daimler is received in a fixed period of time. When payment from Daimler is received, the cycle time of a part number has reached its finale. However, some values, such as safety stock and throughput time, are given in production days, and thus a "weekend add-on" is added to the cycle time. The cycle time of each part number is then compared to its supplier's payment term, which defines whether cash flow is positive or negative (Julin).

Not only does the model define whether cash flow is positive or negative, it also calculates the quantity of positive or negative cash flow. The formula first calculates how many days the cycle time is below or above the payment term, which is then multiplied by the monetary value of the part number's daily consumption. The value of daily consumption multiplied by payment term undercut in days denotes how much money could be invested before the parts must be paid to the supplier. On the other hand, if the cycle time exceeds the payment term, the value of daily consumption multiplied by exceeded days would denote the loan amount that should be taken to be able to pay for the components.

Finally, it is calculated how many times this cycle and payment term takes place during the modeling period by dividing the number of modeling days by the payment term, e.g. if modeling period was 100 days and payment term 50 days, the calculated cash flow would be multiplied by 2. In the form of an equation, cash flow is calculated according to the following self-made formula:

$$CF_i = (Pt_s - Ct_i) * C_{dc_i} * \frac{d}{Pt_s} \tag{12}$$

Where CF_i denotes cash flow of a part number, Pt_s is supplier' s payment term, Ct_i is cycle time of a part number, C_{dc_i} is daily consumption value of a part number, and d indicates days in the modeling period.

6.3.8 Calculating quality and on-time delivery deficiencies

Supplier and carrier performance can be measured as a KPI in the costing model in terms of quality and delivery deficiencies. Deficiencies are commonly calculated using the defects per million (DPM) method, which indicates how many defective items there are in a sample of one million items. As explained by Vepsäläinen (2014), the equation for calculating DPM is:

$$DPM = \frac{Q_d}{Q_T} * 1\,000\,000 \tag{13}$$

Where Q_d denotes the number of defective parts and Q_T indicates the total number of parts.

The total number of delivered components as well as the total number of defective components, in terms of quality and delivery, can be gathered on a part number level from VA’s database. DPM rates can be followed up and compared between suppliers. A suitable rate is dependent on the desired level of quality determined by VA and Daimler, but as an example, the DPM rate for six Sigma quality would be 3,4 and quality of five Sigma would be achieved with a DPM rate of 233. In terms of percentage, the highest quality level, six Sigma, results in 99,9997 per cent perfect quality, and five Sigma accounts for 99,977 per cent perfect quality.

Quality deficiency can be due to a supplier’s quality problem or damage during transportation. Moreover, it is not only poor quality that can cause problems in SCM, but delivery deficiencies as well. Late deliveries may cause the need to arrange special freight and may result even in production loss. However, it is not only late deliveries that cause problems. Early deliveries cause unexpected extra work in warehouse operations and may interfere with the normal and expected operations. In addition, early deliveries reserve storage space and extend cycle times, and thus negatively affect cash flow and inventory turnover ratio, and cause a higher risk of obsolescence as well. Early deliveries occur for example if suppliers deliver more components than ordered, or even because one trailer may contain a mixture of early items and urgent items that need to be off-loaded, in which case the early items are off-loaded as well (Marttila).

6.3.9 Administrative SCM labor and IT upkeep costs

Although lean principles suggest that inspection cannot add quality into products and should thus be left out (Tersine 1994, p. 421), VA has seen the need to inspect arriving goods to some extent. VA's personnel perform quality inspection on every delivered package whenever there is a reason to suspect occurrence of external damage to delivered goods. If items need to be scrapped because of transportation damage, the carrier is liable to cover the cost of damaged goods, transportation cost of replacement parts, and the possible cost of production loss. Although the responsible party or insurance company refunds VA's loss, inspection labor costs are not generally compensated for (Luoma). In addition to quality inspectors' own observations of external damage, components of poor quality can be directed also from the production line to quality inspection (Saarinen). Indeed, quality issues are not only external damage caused by carriers, as poor quality may be supplier related as well.

Quality inspection is a functional part of VA's SCM, and thus also included in the sum of SCM labor costs, i.e. salaries and wages of SCM personnel. In addition to quality inspection, other SCM functions that comprise SCM labor costs at VA include:

- *Inventory management*, which covers the labor costs of material planning and material bookkeeping
- *Sourcing*, which covers the labor costs of sourcing production and non-production materials
- *Supplier development*
- *SCM and logistics development*
- *Transportation and packages*, which covers the labor costs of transportation planning, forwarding, and packaging engineering
- *Warehousing*, which covers VA's labor costs of warehouse management, excluding 3PL

SCM labor costs are included in the costing model as a per car value. Overall 2014 SCM labor costs are divided by production days in 2014, which gives the average cost of SCM labor per production day. The average daily SCM labor cost is multiplied by the number of production days during the modeling period, which is then divided by the number of cars to be produced during the modeling period, hence resulting in an average SCM labor costs per car.

The equation for SCM labor costs is:

$$L_{SCM} = \frac{L_{2014}}{D} * \frac{d}{Z} \tag{14}$$

Where L_{SCM} denotes SCM labor costs per car, L_{2014} is SCM labor costs in 2014, D is production days in a calendar year, d is production days in the modeling period, and Z indicates the amount of cars to be produced during the modeling period.

It is justifiable to use the 2014 based average value in modeling, as SCM labor costs are not expected to increase when daily production rate is increased. For example, according to Mrs. Saarinen, no additional SCM personnel are recruited for the upcoming 20 per cent ramp up of production. Indeed, a higher production rate should not increase the working hours of SCM personnel, who are not directly interconnected with manufacturing. Manufacturing labor costs, however, would increase as the daily production rate increases.

SCM IT costs cover the upkeep costs of the main SCM software, MTR and Discoverer, as well as the transport booking and trailer load planning software VATG. IT upkeep costs are fixed monthly costs, and thus the IT costs per produced car can be mechanically modeled. Weekly IT costs can be derived from the monthly costs, and IT costs per car can be calculated similarly to CT costs described earlier:

$$C_{IT} = \frac{\frac{d}{5} * IT}{Z} \tag{15}$$

Where C_{IT} denotes SCM IT upkeep cost per produced car, and IT indicates fixed weekly IT upkeep costs.

6.3.10 Calculation of packing operation and packaging material costs

Data on packing costs at supplier is available on part number level for some 25 per cent of the components, or no packing cost is applied to the rest of the components. Packing costs are either per one item or per 100 items, and thus the costs have to be mapped to represent packing cost per one item. As some packing costs are announced in different currencies, exchange rates need to be applied as well. After mapping the data, calculating packing costs per car on a part number level is to multiply the packing cost by the average amount of that certain part number installed into a car.

Packaging material costs were realized to be a key SCM cost driver at VA during this research, and a potential cause of bottlenecks in the supply chain. As no explicit packaging material calculation method was found in the literature, until late into the project, much of the researcher's effort was at first focused on creating a method to calculate the amount of required packaging material, and further to develop a tool for the task. Because a great deal of data manipulation was required, the packaging calculation tool could not be attached to the costing model as such, but had to be developed separately. However, the developed calculation method and formulas are included in the costing model, and its packaging calculations can be used as a suggestive reference. Still, the results of the costing model are not as accurate as in the separate packaging calculation tool because of the lack of manual data manipulation. This data manipulation cannot be applied to the costing model because the idea of the costing model is to be easily updatable with new data from the database.

The mathematical method for calculating required packaging material and the development of the separate calculation model are discussed next in more detail.

6.4 Developing a model to calculate required packaging material

According to Twede and Clarke (2004), initial investment in the packaging fleet depends on the length of the logistics cycle time, and the number of items in a box, i.e. the holding capacity of the package. Furthermore, Rosenau et al. (1996) add that the size of packaging investment depends also on the number of daily-consumed components, and therefore, required packages per day. These late-found definitions describe precisely the packaging calculation method already developed by the researcher. Therefore, theory supports the self-made calculation method, which in simple form is:

$$Q_p = Ct_p * q_p \quad (16)$$

Where Q_p denotes total required quantity of a certain package, Ct_p is cycle time of the package, and q_p indicates daily consumption of the package.

The method developed for calculating the cycle time of packaging material is presented in Figure 18. Firstly, all time measurements in the equation should be calculated in production days, as daily consumption of a package is calculated initially in production days. If calendar days were used, daily consumption should be recalculated including production-free weekends and public holidays. However, the simpler way is to use production days only.

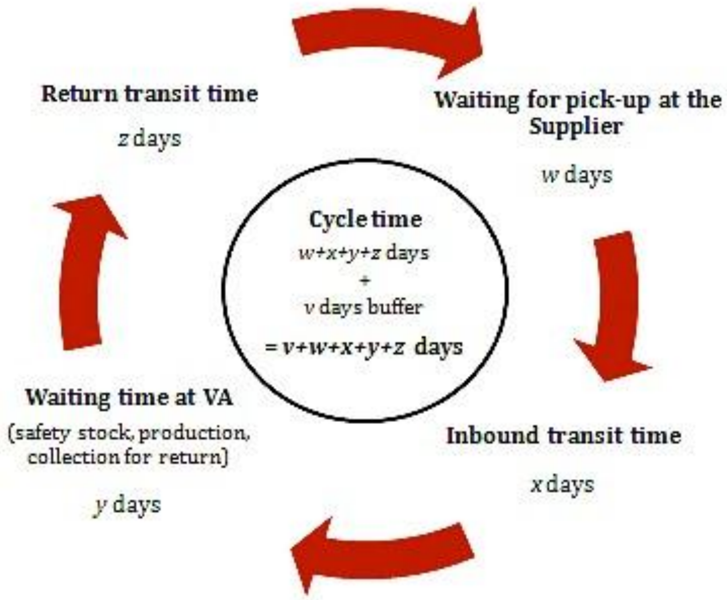


Figure 18. Cycle time of packaging material

The cycle time of a package includes inbound transit time from supplier to VA as well as return transit time from VA to supplier. In addition, dependent on the part number's safety stock, average waiting time of a package at the production line, return rate of the package and the supplier's pick-up frequency, the package remains at VA's premises for a certain period of time. For example, if the supplier's pick-up frequency is once a week, packages will be returned once a week, and thus the package will remain at VA for five production days, unless the package content is not consumed within this time. Indeed, daily package consumption is dependent on the daily consumption of the components and the holding capacity of the package. Furthermore, if the return ratio of a package is 1, the package will leave when possible, i.e. after 5 production days or later when the content of the package is consumed, but if the return ratio is below 1, i.e. the package is collapsible, the package may skip one or more dispatches in order that VA's packaging engineers can dispatch a maximal trailer load of goods to minimize freight costs. The same applies to waiting time at supplier; if packages arrive in bigger lots, some of the packages wait for their turn until enough components are produced.

As a remark, transit times from VA's database should not be used as such, because they do not count the pick-up day as part of the transit time. Therefore, e.g. some Finnish suppliers may have a transit time of 0 days in the original data, but if the pick-up day is not counted as a production day in the model, the consumption of packages during this day is not included, which skews the total required quantity of packages. Therefore, to achieve more realistic results, one day should be added to the original transit times, and this applies to return transit time as well. Furthermore, to be better prepared for demand peaks, package losses, uneven distribution of packaging material between suppliers and other disturbances in the SC and return logistics, the researcher included the option to add a small buffer to the calculated package cycle time, as indicated in Figure 18.

So far, the same calculation principles are applied in the costing model. However, the packaging calculation tool was developed as a separate tool for the purposes of packaging material procurement. Calculations needed to be precise to ensure purchase of correct quantities, and therefore, a fair bit of manual data manipulation was required. Some examples of data manipulation include correcting package types for part numbers, manually adjusting cycle times for suppliers with special arrangements, and correcting package information, such as holding capacity. For one reason or another, these corrections could not be made at the data source, and thus the data had to be manually corrected in the model. However, for the packaging calculation to work properly in the costing model, data should be corrected at the source.

The packaging material calculation tool developed by the researcher was successfully utilized together with the packaging engineers' implicit knowledge in the procurement of packaging material. As the order lead times of packaging material were generally several months, it was still possible to reduce or cancel some of the initially placed unnecessarily large orders, and thus excess spending was avoided with the help of the packaging calculation tool. In addition, further orders were placed with better knowledge, and investments were computationally justified.

7. Empirical study

This chapter on empirical study will first discuss the process of verification and validation of the costing model. Further experiments with the model will be conducted after the model validation is complete. Finally, the results of the empirical study and added business value of the model will be analyzed in the last parts of this chapter.

7.1 Model verification

Before final model validation is the step of model verification. Verification of this costing model is based on the three model verification questions posed by Sokolowski and Banks (2009) earlier in Chapter 4.4. Although initially designed for a simulation model, the verification questions are also applicable for this mechanical costing model.

1. *Does the program code of the executable model correctly implement the conceptual model?*

According to Carvalho et al. (2012), this question can be interpreted as whether the idea in the conceptual model is correctly transferred and implemented in the executable model, i.e. was the model built correctly. As we can see from the earlier presented Figures 14 and 16 representing the conceptual and executable model, and understand from their discussed features, the executable model is more extensive and complex than the conceptual model. The executable model successfully implements the idea of measuring SCM costs on a part number, supplier number and overall level, and provides the capacity to model *what-if* scenarios and adjust different SCM decision variables. The model also successfully indicates the difference between the original and the new-modeled situation. However, although the executable model transferred the main idea and provided many more useful features the conceptual model did not consider, it still could not realize everything that was designed in the conceptual model.

The executable model fails to model scenarios on a regional level. Also, selecting multiple supplier numbers or part numbers is not supported. These features would probably not be difficult to implement, but it would likely make the already-heavy costing model unusable, if features were built with cell formulas, as done so far in the costing model. Perhaps a lighter solution would be to use VBA macros, but the problem of using a macro is that it would replace the original data, which would make back and forth changes and comparisons with the original data more difficult. Nevertheless, the macro solution could work, if original data was stored separately; the adjusted data could be overwritten by original data using another macro. However, it is difficult to estimate how slow and problematic a solution this would be, perhaps rather complex as well. Besides, due to the lack of experience in using cell formulas with such large data quantities, it was not expected that the formula solution would be computationally such a heavy method.

However, even with the cell formulas used in the model, it is currently possible to select and model scenarios with *all suppliers*. In addition, all part numbers of a certain supplier are included whenever a supplier is selected, unless a specific part number is also selected. Besides, it is possible to model regions, multiple suppliers, and part numbers with the current model, if need be, but not simultaneously. To model e.g. a region of suppliers, the calculations have to be done one supplier at a time, save the results of each run, and sum the results to see the overall impact. Of course, this method is not as straightforward as intended in the conceptual model. Moreover, information on country, regional, multiple supplier and part number level can be accessed also through the pivot table on the third sheet of the costing model. Pivot table filters can be applied to observe selected data in different perspectives e.g. to find suppliers and part numbers that encompass a potential for cost reduction and streamlining of VA's SCM processes.

Nevertheless, the researcher believes that the level of detail and the extensive scope of the executable model will provide a better overview of SCM costs, which was the main objective of developing the costing model. Thus, more valuable information and criteria for SCM decision making is provided compared to the conceptual model, where only few decision variables and aggregate measurements of inventory and freight were included.

2. *Does the executable model satisfy the intended uses of the model?*

The intended use of the model was to increase understanding and provide an overview of VA's SCM cost drivers, which the executable model successfully satisfies by providing per produced car level information of all SCM costs. Besides, the model also provides information on some of the main SCM KPIs, such as inventory fill rates, inventory turnover rate, and throughput time and cash flow, which are pieces of information that add value to SCM decision making. Therefore, the model satisfies and even exceeds the conceptual model's intended use to increase understanding of VA's SCM costs.

Another intended use of the model was to be able to model different SCM scenarios to support SCM decision making. Except for the fact that multiple suppliers cannot be adjusted and modeled simultaneously, the costing model satisfies the given modeling requirements by providing all the other desired, and even additional, adjustable decision variables that were included in the conceptual model. Moreover, besides modeling different scenarios, the executable model can to some extent be used to optimize VA's SCM, one supplier at a time, although optimization was not an intended use of the model. In addition, the model provides the possibility to save the results of different SCM scenarios' modeled outcomes. Furthermore, updating the basic data is straightforward and consumes little time, as desired already in the planning phase of the costing model.

Lastly, included in the conceptual model, there was a possibility of changing freight mode e.g. from road to air. Although basically all of VA's normal freight is currently road transportation (the small amount of normal air freight is included in special freight costs), VA is planning to transfer some suppliers from using normal road freight to using either road or air courier freight. Courier freight, be it road or air, could be a cost efficient solution for suppliers with small freight volumes that are currently transported via terminals. Although courier freight rates were acquired in a late stage of developing the model, the feature of modeling freight costs with different freight modes was successfully included in the costing model.

3. *Does the executable model produce results when it is needed and in the required format(s)?*

Although the model is rather slow in calculating, because of the large number of cell formulas and data sheets included, it does produce results after it is instructed to calculate. Depending on the type of activity, calculation times vary. For instance, after selecting a supplier or a part number, Excel calculates for 20 seconds on the researcher's computer (2,7 GHz; 8 GB RAM), whereas adjusting the daily production rate, or altering freight mode takes only a few seconds. However, initially the calculation took 2,5 minutes when selecting a supplier or a part number, but the calculation time could be significantly reduced by fine-tuning the cell formulas. In addition, the researcher did experiments e.g. by removing the option of choosing *all suppliers*, which shortened a large number of formulas. However, the time saving of this was only one or two seconds when selecting a supplier. Therefore, as time saving was not significant in comparison to the added value of the feature, the researcher decided to keep the option of *all suppliers* in the model. Lastly, the model produces results in the required format, e.g. SCM costs per car and KPIs on supplier number and part number level. It is also possible to save the results into a new workbook using an Excel VBA macro.

All in all, as discussed above, verification of the costing model is not perfectly successful, but it is considered sufficient taking into account the intended uses of the model, and the available knowledge and resources for the task. Indeed, the fact that the model is able to fulfill several intended uses, such as providing as good an overview of SCM costs as possible, and still being able to model radical adjustments with several adjustable variables, is a considerable achievement in itself. However, simultaneous modeling with multiple selected suppliers and part numbers remain a task for the future. In addition, to implement all the desired features without exceeding the user's patience and the calculation capacity of Excel creates a further constraint. Therefore, in retrospect, the intended use of the model should have been narrowed down and defined more clearly in the conceptual phase of developing the model. Nevertheless, the executable model does succeed in providing an extensive overview of SCM costs and KPIs, and is also able to perform several modeling scenarios, and thus the verification is considered sufficient.

7.2 Model validation

When validating a model, the idea is to determine how accurately the model represents the objects being modeled. As instructed by Simchi-Levi et al. (2008, p.90) and Brooks and Tobias (1996), one way to validate a model is by reconstructing the model according to existing actual configurations and comparing the output of the model to existing and historical data. Therefore, costing model parameters are set to represent the conditions at the time when actual data of modeled objects is collected, and comparison of outputs is conducted. Moreover, support for validation was received from VA's SCM managers.

However, before moving on to model validation, it must be realized that although modeling methods were valid, the model could still produce erroneous results. Erroneous results can be caused e.g. by the poor quality of input data. As earlier mentioned by D'este (2001, p. 533), quality models and quality decisions come from quality inputs. Therefore, the quality and availability of input data should be inspected first before model validation is undertaken.

7.2.1 Data validation

Mostly, the basic data in the database is of high quality. Data validation of the costing model proved that around 90 per cent of the required basic data exists (see Table 2). However, although Table 2 indicates that e.g. 93,7 per cent of part numbers have packaging data, the existing data is not necessarily correct data. Therefore, instead of referring to part numbers' *data quality* in Table 2, perhaps a more truthful description would be to use *data availability*.

As a principle, data manipulation was to be avoided in the costing model. However, although the raw data from the database was mostly of good quality/availability, highly accurate calculations were required for the packaging procurement process, which necessitated some data manipulation in a separately developed packaging material calculation model.

Indeed, part numbers may have wrong packaging codes, and the packaging data itself can be incorrect as well. For instance, sometimes the holding capacity of a package was discovered to be erroneous. Part of this problem is caused by the fact that some part numbers have outer and inner packaging. Holding capacity may be given either according to the outer box or inlay information, although they should both be taken into account. Still, sometimes the information of correct holding capacities can be retrieved only from VA's packaging engineers. However, majority of the packaging information is still correct and reliable, and thus the packaging material calculation also in the costing model can be taken as useful and suggestive information, although not as accurate as in the separate packaging model.

Table 2: Data quality in the costing model

Part numbers					
in use	with freight cost data	with volume data	with packaging data	with payment term data	with cycle time data
xxxx	xxxx	xxxx	xxxx	xxxx	xxxx
Data quality	**87,9 %**	**95,0 %**	**93,7 %**	**90,6 %**	**99,9 %**

As can be seen from the table above, basically all part numbers have cycle time data, which is dependent on safety stock, transit time, daily consumption and minimum order quantity data. However, safety stock data in the costing model is manipulated with a formula so that if the part number is a JIS, i.e. a *synchronized* part, it will automatically have a safety stock of 0. By default JIS parts' safety stock information is not updated because the information is not required or used in any other applications at VA. Nevertheless, the safety stock information is relevant in the costing model even for synchronized components. In addition, as indicated in the table above, cash flow could be calculated for 90 per cent of the part numbers, as some part numbers were lacking their supplier's payment term data. Moreover, supplier's payment term data is retrieved from a different data source than most of the data that is extracted through the Discoverer query.

However, as indicated with red color in Table 2, freight cost data is an issue in data quality, as this piece of data is missing from 12 per cent of part numbers. Freight cost data requires packaging volume data, which is missing from 5 per cent of part numbers. The reason why packaging *volume* data quality is better than packaging data quality is because part numbers may have packaging volume data (95 per cent), but packaging data is not considered complete without packaging procurement information (93,7 per cent), i.e. information on the cost and procured quantity of packages. In addition to the lack of packaging volume data, another reason for missing freight cost data is the fact that there is a small amount of part numbers without supplier information in the basic data. Without supplier information, there can be no location data and thus no freight rate available for the part number. Also, there are some deficiencies in freight rate data, i.e. freight rates are missing for some countries. For instance, freight costs from Finnish suppliers cannot be calculated because of missing freight rates, and thus, freight costs from Finnish suppliers are left out of the costing model. Finnish suppliers alone represent some 5 per cent of total freight volume, but obviously their freight costs would be relatively inexpensive compared to foreign suppliers, which are located further away.

As a note, synchronized JIS part numbers that have their packaging holding capacity set to zero are not included in the freight cost data quality measurement, because these parts are combined under one synchronized part number. For instance, different colors of armrests exist in the data with unique part numbers, but the data of armrests that are within a box is given only to one of the part numbers. Data may indicate that there are 20 black armrests in a package, but in reality there might be five of each four different colors, i.e. five of each four unique part numbers.

Finally, taking into account the quality of data, modeled results cannot represent reality with absolute accuracy. Knowing the quality of data, however, it is possible to allocate some of the error margin on data quality. At the same time, it is acknowledged that data quality is generally of high quality and it is not to be blamed should the model validation fail.

7.2.2 Validation of freight cost modeling

Modeling of freight costs is part of the key intended uses of the costing model, and because freight is a major SCM cost driver at VA. Therefore, it is of high importance to validate the process of freight cost modeling with particular accuracy.

Actual freight cost data is retrieved from invoices. In addition, modeled inbound freight costs can be compared to inbound freight costs calculated by VATG. However, not all suppliers use VATG yet, hence VATG can calculate freight costs only for the suppliers included in the system. Besides, return freight costs are not included in VATG, and thus VATG cannot be used in validating return freight costs. Moreover, VATG does not currently support courier freight cost calculation, and because courier freight modes were not yet in use at the time of developing the costing model, no invoices of air or road courier freight costs were available for validation purposes. Nevertheless, modeling of courier freight modes was validated in collaboration with logistics planners at VA, who had performed initial freight cost calculations. Modeled results were found to be similar to those calculated by VA's logistics planners.

Actual production cases were selected and the model parameters were set to mimic a similar scenario, after which the results were compared. Firstly, freight costs were measured on an overall level, studying the average freight costs over different periods from one week to 25 weeks. Validation started with positive results, as modeled control tower operating costs per car were precisely the same as the actual CT costs.

However, modeled total freight costs were 8 to 14 per cent below actual total freight costs, as shown in Table 3. Furthermore, modeled inbound freight costs were some 12 to 20 per cent deficient, whereas return freight costs differed only ±4 per cent of the actual freight costs during different study periods. While modeled inbound freight costs were clearly underestimated, return freight costs seemed to be very close to the actual return freight costs.

Table 3: Accuracy of modeled freight costs using different study periods

Freight	1 week	2 weeks	5 weeks	25 weeks	
Inbound	88%	86%	81%	80%	% of actual freight costs
Return	100%	96%	103%	100%	
Total	92%	90%	88%	86%	

Local transportation, i.e. freight from Finnish suppliers, was excluded from the actual freight costs, so the inbound cost difference could not be explained by the lack of freight rates in Finland. Nevertheless, Finnish freight costs would have accounted for only 0,1 per cent of total inbound freight cost, which became evident when studying actual freight cost data. Furthermore, freight from other countries without freight rate data contributed only 0,5 per cent towards the total freight volume, which would not explain much of the inbound cost difference either. And most of the freight from foreign countries without freight rates was probably air freight that is included in special freight costs. Therefore, no critical reason for the cost difference was found, yet.

However, when VATG was included in the cost comparison, and recent freight costs were investigated on a shipment level rather than an overall weekly level, further understanding of the modeled cost difference was achieved. Tables 4 and 5 present actual inbound freight scenarios that are compared to modeled data as well as data from VATG.

Table 4: Actual milk-run inbound freight including 2 suppliers

Source	Freight cost	Fill rate m^3	Fill rate LDM
Actual	FTL	39 %	46 %
VATG	57 %	39 %	46 %
Model	45 %	40 %	?

Table 5: Actual direct inbound freight including 1 supplier

Source	Freight cost	Fill rate m^3	Fill rate LDM
Actual	FTL	90 %	96 %
VATG	100 %	90 %	96 %
Model	84 %	78 %	?

As can be seen from Table 4 and Table 5, VA is paying the FTL price regardless of the trailer's fill rate, except for some 5 per cent of cases where freight costs are divided between several buyers. Table 4 represents a case where the trailer's fill rate in cubic meters is only 39 per cent, yet the payment is for a full trailer load. In this case, the trailer was half empty because the trailer's weight limit was reached. As freight calculations both in VATG and in the costing model expect the consolidated milk-run transport to utilize full trailer capacity, the modeled freight costs for the two suppliers are far behind the actual costs. In other words, the modeled costs did not take into account the possibility of low trailer fill rates. Lastly, as VATG is able to calculate freight costs based on loading meter (LDM) fill rate (46 per cent), which is higher than the cubic meter fill rate (39 per cent), and is the actual pricing method, VATG's calculated freight cost can be more accurate than that of the costing model.

Table 5 displays a case where actual freight *volume* is higher than that estimated by the costing model, and hence also the actual freight costs are 16 per cent higher. Sometimes, when compared to a single shipment, the estimated volume by the model is higher or lower than actual, because the model is based on average freight volumes, whereas in reality there is some variation among individual shipments from the same suppliers. Therefore, due to using average values, the model may use an inbound volume of $70m^3$ (78 per cent when 90 m^3 is the average trailer fill rate), although based on the minimum order quantity constraint, the supplier's inbound freight volume would actually be $90m^3$ for one shipment and $50m^3$ for the next shipment, thus averaging $70m^3$ per pick-up.

Furthermore, Tables 6 and 7 represent return freight data. Table 6 presents a case where daily return freight of five suppliers is calculated. From transport data, the researcher found out that the empty packaging material for these five suppliers was transported in seven trailers that were paid in full. Based on modeled data of the same five suppliers, freight volume exceeded the maximum capacity of seven FTLs by 10 per cent, and similarly the cost of seven FTLs was exceeded by 10 per cent. Therefore, the actual return freight was somewhat less than the model's average estimation. However, considering total daily return freight of five suppliers and daily variation, the error margin is not alarming.

Table 6: Actual milk-run return freight including 5 suppliers

Source	Freight cost	Fill rate m^3	Fill rate LDM
Actual	7 * FTL	?	?
Model	110 %	110 %	?

Table 7: Actual milk-run return freight including 3 suppliers

Source	Freight cost	Fill rate m^3	Fill rate LDM
Actual	FTL	?	?
Model	100 %	99 %	?

Furthermore, as can be seen from Table 7, the model estimated the freight cost of one shipment including packaging material for three suppliers with 100 per cent accuracy. However, at times modeled freight costs are also below actual costs, which is inevitable as in reality shipment volumes and costs vary daily. All in all, it can still be said that even on shipment level, modeled return freight costs are similar to the actual costs.

However, modeled inbound freight cost accuracy varied a good deal, which made the researcher reconsider the set average FTL fill rate in the costing model. As explained earlier in Chapter 6.3.3, freight cost calculations are affected by the estimated average fill rate of a trailer, i.e. how many cubic meters are expected to be on average in a trailer paid in full. Initial fill rate was set to 90 m^3. However, this was a rather subjectively evaluated value. Another subjective estimation in the freight cost formula was the average weight of one cubic meter of freight, which was set to 150kg based on information from VA's SCM personnel. Experimentation on changing the cubic meter weight to 100kg or 200kg did not have any significant impact on the freight costs, because of the relatively small amount and small expense of terminal freight compared to direct and milk-run freight. On the other hand, altering the inbound FTL fill rate had a substantial impact on the modeled costs.

After taking the volume of more than 5 000 received trailers, the average inbound fill rate turned out to be somewhat less than the assumed 90m^3. Nevertheless, the adjusted fill rate may still not be absolutely correct, as some 6 per cent of the data was invalid, possibly due to incorrect packaging data, as trailer fill rates exceeded their maximum capacity of 100m^3. Still, the adjusted inbound fill rate is based on a rather large sample, and should thus produce more reliable results than that based on an assumption. Unfortunately, because of poor return freight data quality, average return trailer fill rate could not be calculated, and hence the original estimation of 90m^3 remained as the average fill rate for return freight.

Furthermore, it is not only because of inefficient transport management or load planning that the average inbound fill rate is lower than expected, but also because of the trailers' maximum weight limit. For instance, 6 per cent of inbound trailers had a low fill rate because the trailers' maximum weight limit was reached. In addition to weight limits, average trailer fill rates are hampered because of the inefficient design of some packaging material in regard to optimizing trailer space utilization. Still, it was discovered that some carriers occasionally use lower capacity trailers although they have agreed to use high capacity mega trailers in normal road transportation of goods to VA.

While studying the volumetric information for received trailers, it was also found that one cubic meter of freight weighed 165kgs on average, which decreased total freight costs by 0,1 per cent, when changed from 150kgs. With the new average inbound trailer fill rate, modeled inbound freight costs increased by some 20 to 25 per cent. Results of updated freight cost comparisons can be seen from the tables below.

Table 8: Accuracy of modeled freight costs using different study periods (updated inbound fill rate)

Freight	1 week	2 weeks	5 weeks	25 weeks	
Inbound	106%	103%	102%	101%	% of actual
Return	100%	96%	103%	100%	freight
Total	104%	101%	102%	101%	costs

Table 9: Actual direct inbound freight including 1 supplier (updated inbound fill rate)

Source	Freight cost	Fill rate m^3	Fill rate LDM
Actual	FTL	90 %	96 %
VATG	100 %	90 %	96 %
Model	102 %	95 %	?

Results with the new fill rates propose that modeled inbound freight costs now represent actual costs significantly better; the difference between modeled and actual inbound freight costs is on average only some +3 per cent, depending on the study period. The longer the study period is, the closer the modeled costs come to the actual costs, which indicates that the model represents well the average freight costs over longer periods of time. Results also highlight the overestimated modeled inbound freight cost when the study period covers only one or two weeks, which is due to the lack of initial inventory in the costing model. In addition, as the model calculates average values, comparison to actual values of one or two weeks may not be long enough to represent average actual freight costs, as there is always some variation in actual freight between production weeks. This is illustrated in Table 8, where two weeks' actual return freight is relatively high in comparison to other study periods (and to the modeled costs), and then again a few percentage points lower in a study period of 5 weeks.

With the new inbound fill rate, the modeled inbound freight cost of a single shipment is also now closer to the actual cost and that calculated by VATG, as shown in Table 9. Lastly, with the updated fill rate, the error margin of modeled total freight costs to actual costs is on average only some 2 per cent, as demonstrated in Table 8.

All in all, although slightly overestimated by a couple of percentage points, modeling of freight costs is of high accuracy and validation of freight cost modeling can be considered successful. These results are especially accurate when modeled costs are compared to actual long-term averages. However, it must be taken into account that pre-determined trailer fill rates used in modeling may still not represent the absolute truth, although the modeled results now represent actual costs more accurately. Current fill rate calculation is based on the assumption that data of weight, package size, and volume is correct in the database, which is still known to have some errors, as became evident in the process of determining average trailer fill rates.

7.2.3 Validation of freight volume modeling

Modeling of freight volume is validated by comparing modeled total inbound freight volume to actual volume with different study periods and production rates. Unfortunately, actual data for return freight volume is too dispersed to give realistic results of weekly freight volumes, and thus the validation can only be conducted for inbound freight. Furthermore, Figure 19 displays two charts of different production rates within various study periods comparing actual and modeled inbound freight volumes.

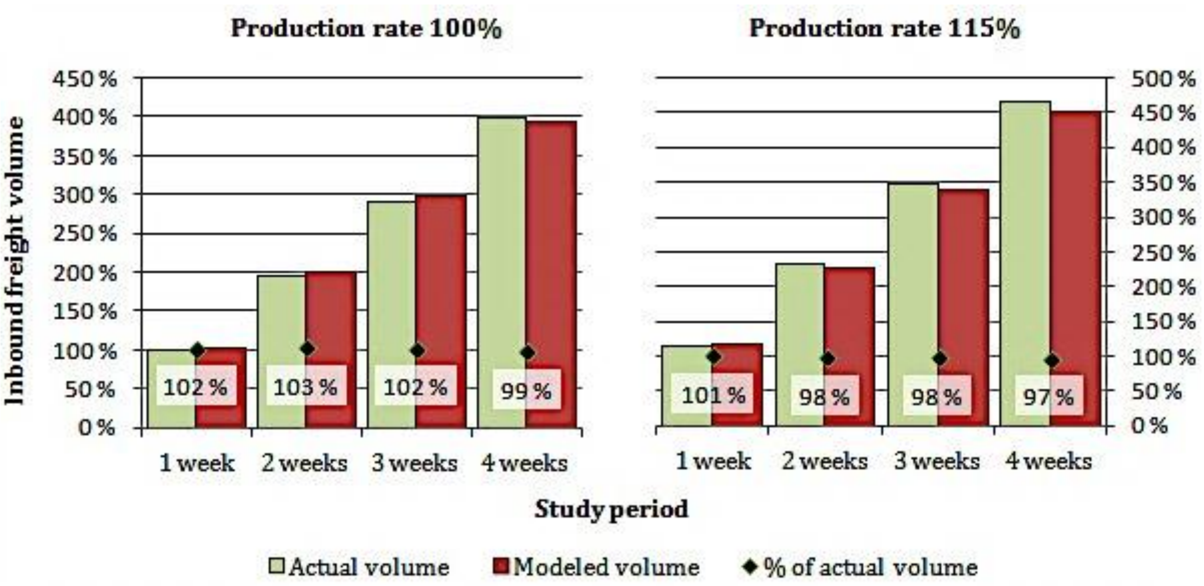


Figure 19. Inbound freight volume with different study periods and production rates

The chart on the left is based on freight volumes with a certain production rate, whereas volume data in the chart on the right is from a time with 15 per cent higher daily production rate. As can be seen from the figure, freight volume accumulates as the study period extends. The first week's freight volume on the left-hand chart is used as an index value of 100 per cent, to which all other volumes in both charts are compared. The growth of freight volume seems fairly linear when production is stable; each week the total freight volume is increased by approximately 100 per cent. A positive remark is that the modeled freight volume is initially only 2 per cent higher than that of actual, and grows similarly to the actual volume ending a mere 1 per cent below the actual volume at the end of the study period in the left-hand chart.

Model's accuracy remains high also when daily production rate is increased as in the chart on the right side. Modeled freight volume is initially 1 per cent above the actual, and ending with a 3 per cent deficit of the actual volume. From the chart, it is also evident that the 15 per cent increase in daily production rate results in some 15 to 20 per cent increase in freight volume, when values of the chart on the right are compared to the values in the left chart. All in all, freight volume modeling is successful; the model's accuracy is close to reality and the behavior of the model is logical.

7.2.4 Validation of modeling average inventory value

Validation of modeled average inventory value is conducted by aligning the daily production rate in the model to the actual production rate at the time of study, and comparing modeled inventory values to the actual bookkeeping values. Results of inventory value modeling are shown in the following table.

Table 10: Inventory value and model accuracy

Source	Inventory on hand	Inventory in transit	Surplus material	Total
Actual	100 %	129 %	2 %	231 %
Model	96 %	127 %	0 %	223 %
% of actual	96 %	98 %	0 %	97 %

In the validation process, the value of actual inventory on hand, excluding surplus and rejected material, represents the index value of 100 per cent, as shown in the above table. All other values are compared to this index value. As can be seen from the table, the accuracy of modeled inventory value is high and ranges from 96 to 98 per cent, depending on the inventory type. Actual inventory on hand includes some 2 per cent of surplus and rejected material, which is not included in the calculations of the costing model. However, this surplus was removed from the index value, and thus it only affects the accuracy of modeled total inventory value, which is 97 per cent.

Nevertheless, although modeled inbound freight volume was of very high accuracy as proven in the previous part of this chapter, some of the difference in modeled *inventory on hand* value is explained by the fact that the costing model assumes components are consumed to safety stock level before the next shipment arrives, whereas in reality there often is some inventory besides the safety stock level. Moreover, actual inventory value includes components that have arrived too early. On the other hand, late deliveries are missing from the inventory value, which balances the difference. All in all, it can be confirmed that modeling of average inventory value is still of high accuracy, with a deficit of some 2 to 4 per cent.

7.2.5 Validation of modeling average inventory fill rates

Actual data of floor storage fill rate is not available, but records of shelf storage fill rates are kept by VA's SCM personnel, and thus the shelf storage fill rate modeling could be validated. Validation was performed for different inventory types during different production rates. As there was much variation in actual inventory fill rates, longer periods of production were studied, for which average fill rates were calculated. Results of inventory fill rate validation are shown in Table 11.

Table 11: Inventory fill rates and model accuracy

Production	LC	Model	WS	Model	AS	Model	T1, T2	Model	T3, T4	Model	T5	Model
100 %	76 %	61 %	81 %	63 %	50 %	45 %	88 %	80 %	62 %	59 %	25 %	18 %
117 %	82 %	72 %	73 %	77 %	57 %	53 %	77 %	66 %	64 %	64 %	47 %	45 %
138 %	92 %	85 %	85 %	92 %	70 %	62 %	79 %	77 %	78 %	75 %	65 %	52 %
Average	83 %	73 %	80 %	77 %	59 %	53 %	81 %	74 %	68 %	66 %	46 %	38 %
% of actual	87 %		97 %		90 %		91 %		97 %		84 %	

As can be seen from the results displayed in Table 11, depending on the inventory type, modeled fill rate accuracy ranges on average from 84 to 97 per cent. Modeled fill rates are generally deficient of the actual fill rates, except for welding storage, where the model may overestimate the fill rate. The accuracy of the model is based on the assumption that the part number inventory type and package holding capacity data are correct in the database.

Moreover, some of the costing model's deficit can be explained by the fact that actual inventory includes obsolete material, which is not part of the costing model's inventory fill rate calculation. As the fill rate records are older than the data used in validating inventory value modeling, not as much obsolete material was scrapped yet at that time, and hence the surplus would be more than the 2 per cent identified in inventory value validation. At the time of validating inventory fill rate modeling, fill rate data of inventories with the 2 per cent surplus material was not available. Nevertheless, the researcher estimates that if surplus material would be removed from actual inventories, the model's overall fill rate accuracy would become close to 95 per cent. Nevertheless, slight inaccuracy in inventory fill rate modeling is not critical, as inventory fill rate modeling is not the primary intended use of the costing model.

Still, the accuracy of fill rate modeling is fairly high and behavior of the model makes sense, i.e. inventory fill rates increase as daily production rate increases. Indeed, as can be seen from Table 11, in general the higher the production rate is, the higher the actual inventory fill rates are, and this correlation applies to the modeled fill rates as well. However, some inventory rearrangements have been made to T1 and T2 inventories after a production ramp up, which can be seen as a decrease in inventory fill rate when moving from the index production rate to the increased production rate of 17 per cent. Simultaneously, T5 inventory's fill rate increased significantly. This was due to the effort of balancing the overall fill rate of the miniload inventory.

7.2.6 Validation of cycle times

The cycle time of part numbers and packaging material can be validated from supplier pick-up time to the time when items are delivered to the production line based on actual data records. However, cycle time data of a certain part number waiting at the production line to be installed, or a package waiting to be released, is not available. Calculated waiting time at production line is an estimation based on daily consumption rate and lot size.

Also, if actual cycle time of packages was desired, packages should be marked and manually tracked, as there is no package follow up system in place. However, as discussed with one of VA's packaging engineers, validation of packaging cycle times would be virtually impossible, because each package and supplier is a unique case containing much variation in cycle times. For instance, although packages would come with direct transit from supplier, they can be returned via terminal, which increases the calculated cycle time significantly. Secondly, although it would be known that packages for a certain supplier are returned once a week, the weekday is not set, and thus cycle times can vary from one week to another. Thirdly, if a package was manually tracked, it is not known whether the suppliers would cycle packages by the first-in-first-out (FIFO) method, and thus cycle times could be misleading. Therefore, because of the lack of a packaging tracking system and records of waiting time at production line, the validation of cycle times will be incomplete, and thus cash flow and packaging material requirement calculations pose a possibility of error, although they are modeled based on the most accurate data and calculation methods available at the time.

Table 12 presents the results of comparing modeled transit times and total lead times from suppliers to the production line against actual values. As can be seen from the table, on average, modeled transit times are slightly longer than actual transit times. On the other hand, modeled total lead times are shorter than actual lead times, and have quite a high variance of 27 percentages. As indicated in the table, 74 per cent of the part numbers have a modeled lead time between 50 and 100 per cent of the actual total lead time.

Table 12: Modeled lead time accuracy

Accuracy	Transit time		Total lead time	
% of actual lead time	% of part numbers	Cumulative %	% of part numbers	Cumulative %
0-5%	0 %	0 %	0 %	0 %
5-25%	0 %	0 %	0 %	0 %
25-50%	1 %	1 %	8 %	8 %
50-75%	10 %	11 %	51 %	59 %
75-100%	44 %	55 %	23 %	83 %
100-125%	30 %	85 %	5 %	87 %
125-150%	8 %	93 %	4 %	91 %
150-200%	6 %	99 %	4 %	96 %
>200%	1 %	100 %	4 %	100 %
Average % of actual lead time	104 %		86 %	
Variance	13 %		27 %	

The differing results recall that lead times are stochastic in reality, whereas the model is based on deterministic lead times. Evidence that modeled lead times are somewhat shorter than actual lead times should be taken into account when making decisions concerning cash flow and packaging material requirements, as they may be slightly optimistic. In fact, packaging material calculations have already taken this into account by adding some buffering into the cycle times.

Modeling of packaging material calculation is further validated on an aggregate level against the actual procured amount of packaging material for a certain daily production rate. When the costing model is configured with the same production rate that packaging material has been procured for, the model deficit is 16 per cent of the actual packaging material costs. As packaging material is procured based on the same calculation method as in the costing model, the cost deficit is explained mostly by the lack of data manipulation, i.e. special supplier arrangements are not included, and packaging type and holding capacity information on part number level is incorrect to some extent in the costing model. However, although not necessarily accurate for all part numbers, the costing model's packaging calculations are still suggestive and useful on an aggregate level.

Validation of cash flow calculation could not be quantified, as actual data for part numbers' cash flow was not available. However, Julin was able to confirm that the calculation method was fair, and that the trend for cash flow was correct. Nevertheless, as discussed above, modeled cash flow may be slightly optimistic, because of underestimated lead times.

Moreover, validation of the costing model is concluded by briefly answering the five questions included in a validation process, which were introduced in Chapter 4.4. Although the validation questions were initially designed for the validation of a simulation model, they are applicable to the validation of the developed mechanic costing model as well. As mentioned by Simchi-Levi et al. (2008, p. 91) and Sokolowski and Banks (2009, p. 126), the validation process typically involves answering questions such as:

1. *Is the executable model a correct representation of the simuland, i.e. does the model make sense?*

In general, the model makes sense and correctly represents the modeled objects. However, modeled lead times could be more accurate. Nevertheless, there is always some lead time variation in reality, which would require more dynamic modeling methods to be correctly modeled. Yet, the modeled lead times are still sensible. Moreover, cycle times of packages and part numbers could not be fully validated due to the lack of tracking data, and thus it is not known whether the model accurately represents these objects. However, and most importantly, as became evident in the validation process of freight costs, freight volumes and inventory values, these objects are correctly modeled, which is of high importance in regard to the model's intended use.

2. *Under what range of inputs are the model's results credible and useful?*

Modeled results are generally credible and useful, although they depend on the type of inputs. For instance, if the modeling period is no longer than one week, freight costs and volume are usually overestimated by a couple of per cent. However, to ensure accurate modeling of freight costs, one should first carefully determine the trailer fill rates. Indeed, FTL fill rates are perhaps some of the most critical inputs in the model.

Moreover, warehousing costs per car are given by the 3PL warehousing company only until a certain production rate is reached. Therefore, modeling with production rates higher than the ones included in the pricing sheet does not have any further impact on the warehousing costs, whereas in reality warehousing costs per produced car are expected to decrease as the production rate increases.

Furthermore, as the model operates mostly on average values, its results are most accurate in the long term and on an average level. However, values can still be measured on a part number level. The model best represents reality when modeled results are compared to average actual values over a period of one week or more, as there can be some daily variation in reality, which is not considered in the deterministic costing model. Moreover, the costing model works well with different inputs of production rate and modeling period. Also, decision variables such as transport time, safety stock level and pick-up frequency can be adjusted as long as the values do not go below zero, i.e. are realistic.

3. *Is the data consistent?*

For the most part, the basic data used in the model is consistent. However, as discussed earlier, there are some flaws in the basic data, especially when it comes to packaging data. However, in general, the quality of basic data is acceptable, and it does not invalidate the model. Moreover, data produced by the model is consistent and logical.

4. *Can the modeled results be fully explained?*

The validation process was conducted together with the support of VA's SCM managers and other SCM personnel. It was commonly agreed that the modeled results make sense and can be explained. For instance, an accuracy deficiency in inventory fill rate modeling can mostly be explained by obsolete material in actual inventory. Another minor variation in accuracy is explained by the fact that in reality there is always some irregularity, whereas the model is completely deterministic.

5. *Was sensitivity analysis performed?*

Sensitivity analysis was performed several times with different production rates and study periods. Results of sensitivity analyses were consistent. Behavior of the costing model is logical when parameters are changed.

As discussed earlier in Chapter 4.4, the verification and validation of a model is a key step in the modeling process. The usability and credibility of a model is only known through thorough testing of the model. If verification or validation of the model is incorrect, but the results are still accepted, using the model is considered a more serious type II user error, as described by Sokolowski and Banks (2009, p. 134), see Table 13. Improper "management-by-numbers" can result in seriously erroneous decision making if an incorrect model is used. Moreover, should the model be valid, but the verification and validation process is insufficient and model is not used, it is a less serious model builder's type I error. The only correct use of a model is to use it if it is proven valid and results are accepted. Otherwise, the model should not be used.

Table 13: Verification and validation errors (Sokolowski & Banks 2009, p. 134)

	Model valid	Model not valid	Model not relevant
Results accepted, model used	Correct	**Type II error** Use of invalid model; Incorrect V&V; Model user's risk; **More** serious error	**Type III error** Use of irrelevant model; Accreditation mistake; Accreditor's risk; **More** serious error
Results not accepted, model not used	**Type I error** Non-use of valid model; Insufficient V&V; Model builder's risk; **Less** serious error	Correct	Correct

Fortunately, however, performed verification and validation of the model indicate that the costing model is valid for its main intended use of modeling supply chain costs. Nevertheless, as the model includes measures such as part number and packaging material cycle times that could not be fully validated, the model should not be considered completely valid and reliable in modeling these particular objects. However, even though modeling of these objects could not be fully validated, cash flow and packaging material calculations are considered to be suggestive and informative for SCM decision making support. Nevertheless, decisions should not rely solely on the modeled information for these two objects.

Moreover, the model was also designed to display actual SCM cost data that is not modeled, such as SCM labor, insurance, IT, packing, special freight, CT, and scrapped material costs. The model is considered valid in calculating these measures from combined data records. Although the model is already generally valid, see the dotted circle in Table 13, the validation process should be continued, especially when courier cost data can be used to validate the modeling of courier freight modes.

7.3 Experimentation and analysis of results

After successful validation of the costing model, further experimentation was conducted. The modeling period was set at 10 weeks during experimentation in order to achieve balanced results. Scenarios with different production rates, pick-up frequencies, safety stock levels, minimum order quantities, and freight modes were executed to find out the relations between SC cost drivers. The development of KPIs and total costs per car was also examined while scenarios were carried out. The results and analysis of the experiments are shown in the following tables and figures.

7.3.1 Experiments with different production rates

SCM total costs per car, with 100 per cent as a starting value to denote the production rate, is used as an index value that all other values in Table 14 are compared to. The value of components per car, which would cover some 90 per cent of total SCM costs, is excluded from the modeled values to highlight the significance and relation of primary SCM cost drivers.

Table 14: Modeled SCM cost driver values on overall level with different production rates

SCM cost driver | Production rate	67 %	83 %	100 %	113 %	117 %
SCM total costs / CAR	104,8 %	102,1 %	100,0 %	99,5 %	99,4 %
Inbound freight cost / CAR	39,7 %	39,0 %	38,4 %	38,2 %	38,1 %
Return freight cost / CAR	16,7 %	16,5 %	16,1 %	15,9 %	15,9 %
Outbound shipment / CAR	14,0 %	14,0 %	14,0 %	14,0 %	14,0 %
Warehousing costs / CAR	14,3 %	13,4 %	12,8 %	12,8 %	12,8 %
SCM labor costs / CAR	6,7 %	5,3 %	4,4 %	3,9 %	3,8 %
Packaging material costs / CAR	2,9 %	3,7 %	4,4 %	5,0 %	5,1 %
Supplier packaging costs / CAR	3,1 %	3,1 %	3,1 %	3,1 %	3,1 %
Inventory holding costs / CAR	3,4 %	3,3 %	3,3 %	3,3 %	3,3 %
SCM IT costs / CAR	1,1 %	0,9 %	0,7 %	0,7 %	0,6 %
CT costs / CAR	0,8 %	0,6 %	0,5 %	0,4 %	0,4 %
Special freight costs / CAR	0,3 %	0,3 %	0,3 %	0,3 %	0,3 %
(2014) Scrapped material costs / CAR	1,6 %	1,6 %	1,6 %	1,6 %	1,6 %
(2014) SCM insurance costs / CAR	0,3 %	0,3 %	0,3 %	0,3 %	0,3 %

One of the research questions of this study was to determine VA's key SC cost drivers and the correlation between them. Different cost drivers' share of total SCM costs can be retrieved from the table above. After removing the value of installed components, the highest SCM costs per car are generated by the inbound freight cost, which accounts for some 39 per cent of total costs. Furthermore, return and outbound freight costs are the second and third highest costs after inbound freight cost. Therefore, all freight costs total to almost 70 per cent of all SCM costs, which is considerably more than the 50 per cent found in studies by Solakivi et al. (2012), and Bardi and Tracey (1991). The difference may be due to the fact that VA's transportation costs include also return freight, whereas transportation costs commonly consist only of inbound and outbound freight costs. On the other hand, VA's other SCM costs can be low, which increases the share of freight costs.

The fourth major cost driver is warehousing, which accounts for some 14 per cent of total SCM costs. This value is slightly less than the 20 per cent mentioned by Richards (2011) and Solakivi et al. (2012) in Chapter 2.2. The rest of the cost drivers are less significant; SCM labor, packaging material, and packaging labor at supplier each accounting for some 3 to 4 per cent of total SCM costs. Rather surprisingly, inventory holding costs equal only a few per cent of total SCM costs, whereas in their study of Finnish manufacturing companies, Solakivi et al. (2012) discovered that inventory holding costs accounted for some 20 to 30 per cent of total SCM costs. The difference may be explained by VA's lean inventory management practices and high inventory turnover ratio, but also partly due to the fact that insurance, scrapped material, labor and IT costs of inventory management are calculated separately from the inventory holding cost value. Nevertheless, even if combined in inventory holding costs, their total share would not exceed even 10 per cent. Furthermore, of the five smallest SCM cost drivers, scrapped material is rather significant by accounting for the sum of IT, CT, insurance and special freight costs per car.

From the results in Table 14, it can be also noticed that total SCM costs per car slightly decrease as the production rate increases. Packaging material cost per car seems to be the only one cost that increases when the production rate grows, which is logical as daily consumption of part numbers and thus packaging material increases while total production of cars remains the same. When the model is run with 17 per cent higher production rate, the largest cost savings per car are in SCM labor costs that decrease by 0,6 percentage units, and inbound freight cost, which decreases by 0,3 percentage units. Production rate seems to have very little impact on inventory holding costs per car because of the high inventory turnover ratio.

Table 15: Modeled SCM KPI values on overall level with different production rates

KPI | Production rate	67 %	83 %	100 %	113 %	117 %
Annual inventory turnover ratio	99 %	99 %	100 %	100 %	100 %
Inventory throughput time	101 %	101 %	100 %	100 %	100 %
Cash flow	66 %	83 %	100 %	113 %	117 %
Average inventory on hand	69 %	84 %	100 %	113 %	116 %
T1 & T2 fill rate	53 %	65 %	78 %	87 %	90 %
T3 & T4 fill rate	52 %	64 %	76 %	85 %	88 %
T5 fill rate	34 %	45 %	53 %	59 %	60 %
Logistics center fill rate	57 %	72 %	87 %	99 %	101 %
Welding storage fill rate	48 %	65 %	79 %	91 %	95 %
Assembly storage fill rate	49 %	61 %	73 %	83 %	85 %
Floor storage fill rate	24 %	31 %	37 %	42 %	43 %

In Table 15, the first four KPIs are modeled in relation to the index value of each KPI with the given starting production value indicated as 100 per cent. Inventory fill rates, however, represent actual fill rates not tied to an index value.

From the table above it can be seen that cash flow goes hand in hand with the production rate; if production rate is increased by 17 per cent, cash flow increases by the same percentage. Similar behavior is observed with inventory value. Moreover, although not directly expressed in this thesis, as a result of practicing lean SCM, VA's calculated inventory turnover ratio resulted higher than 30, which was mentioned by Richards (2011) as the average turnover ratio of European manufacturers in Chapter 2.1.

Furthermore, results in the table indicate that the fill rate of the logistics center would exceed its maximum inventory capacity if production rate was increased by 17 per cent. Therefore, some rearrangement of storage space should be conducted should the increase of production rate be desired. According to the calculation method introduced by Simchi-Levi et al. (2008, p.90), required inventory capacity for each item should equal the maximum inventory capacity required by the item. Therefore, if this method is followed, the inventory capacity of VA is currently somewhat undersized, as inventory fill rates are already over 70 per cent, although modeled with average inventory levels. However, the likelihood that every item should have maximum inventory level at the same time is considered to be small.

7.3.2 Experimentation with different freight modes

In the presented experimentation, Figure 20 illustrates changes in SCM costs and KPIs of a certain supplier, should its freight mode be changed from normal road freight to courier freight. As this is a supplier with a small freight volume, and courier freight rates for the lane are less expensive, results indicate that change of freight mode would decrease total SCM costs and significantly increase cash flow. Cash flow is increased simply because the part numbers' cycle time is reduced when changed from road transport via terminal to express or economy courier delivery.

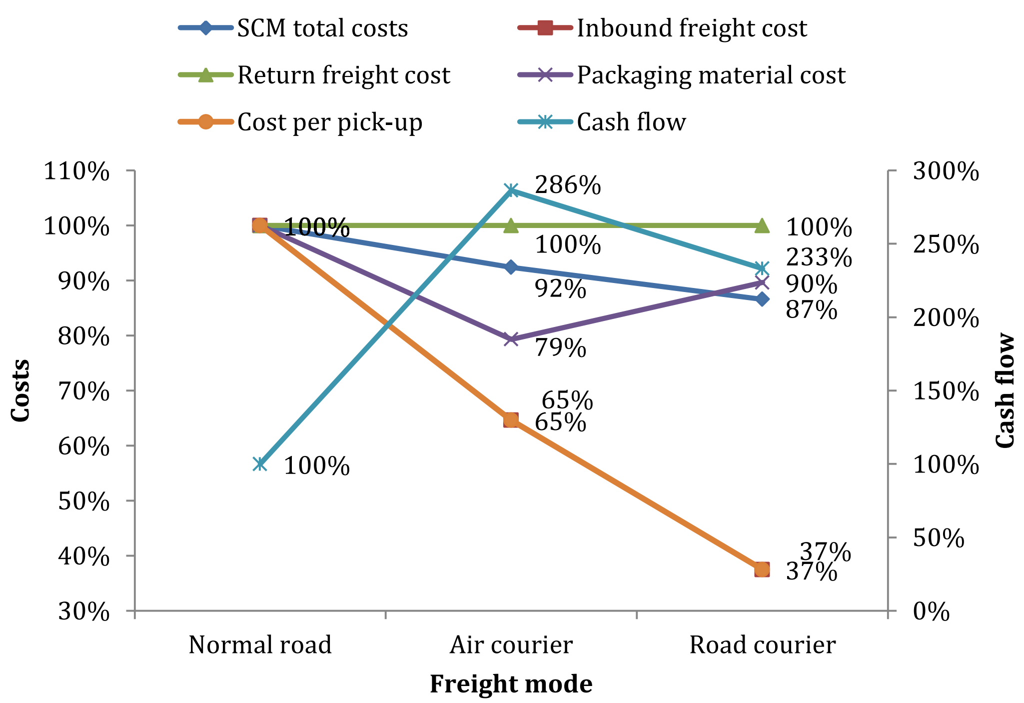


Figure 20. Modeling of different freight modes with Supplier A

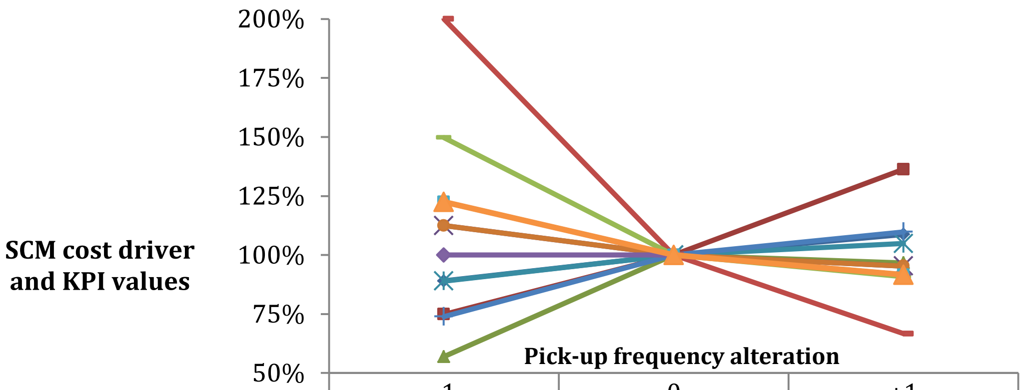
However, return freight cost remains the same as return freight is in the usual conditions of carriage by normal road freight regardless of the inbound freight mode. Although packaging material costs are higher with a road courier than with an air courier, inbound freight cost decreases more remarkably with road couriers resulting in road courier being the most cost-effective freight mode for the supplier in question. By changing freight mode from normal freight to road courier, the supplier's total SCM costs are reduced by 13 per cent.

7.3.3 Altering a supplier's pick-up frequency

Figure 21 on the next page displays the results of altering a certain supplier's weekly pick-up frequency by -1 and +1. As can be seen from the figure, changing pick-up frequency has a significant impact on the total SCM costs for this particular supplier. A reduced pick-up frequency would provide the most cost-efficient solution in this case, as the supplier's inbound freight rate would change to a relatively cheaper weight class due to increased freight volume per pick-up. Moreover, altering pick-up frequency can help understand the relations between different SCM cost drivers and KPIs, as several of them are impacted by the alteration of pick-up frequency.

The change in total SCM costs is mostly due to the pick-up frequency's impact on inbound and return freight costs. On the other hand, while freight costs increase or decrease, inventory level, inventory fill rate, and inventory holding costs evolve towards the opposite direction, although cost impact of this is not as significant as that of freight costs. In other words, there was found to be a negative correlation between inventory and freight costs when pick-up frequency is altered.

In addition to decreased freight costs, reducing pick-up frequency results in lower inventory turnover ratio, reduced cash flow, and slower inventory throughput time. Moreover, when pick-up frequency is increased, logically, waiting times decrease and cycle time becomes shorter, which results in less required packages and increased cash flow. However, required packaging material is not increased in this case when pick-up frequency is reduced by one pick-up, as cycle time is dependent also on the return ratio of packaging material. When the return ratio is smaller than 1, packaging material will stay at VA and at Supplier B for the same amount of time regardless of reducing pick-up frequency.



	-1	0	+1
SCM total costs	89%	100%	109%
Inbound freight cost	75%	100%	136%
Return freight cost	57%	100%	97%
Inventory holding costs	112%	100%	95%
Inventory turnover ratio	89%	100%	105%
Inventory throughput time	112%	100%	95%
Cash flow	74%	100%	110%
m3 / pick-up	200%	100%	67%
€ / pick-up	150%	100%	91%
Required packages	100%	100%	92%
Inventory on hand	122%	100%	92%
T3 & T4 fill rate	122%	100%	92%

Figure 21. Modeling pick-up frequencies with Supplier B

7.3.4 Altering a part number's safety stock level

Experimentation by altering a random part number's safety stock level by -0,5 and +0,5 days is shown in Figure 22 on the next page. Again, the impact on total SCM costs was very minor, although a slight cost reduction would be achieved if safety stock was reduced. For instance, from Figure 22 it can be seen that all inventory and cycle time related measures improve when safety stock is shortened. Obviously, the model would always result in cost savings and improved KPIs if safety stock was reduced. However, the model does not take into account the increased risk of production disruption due to component shortage when safety stock level is lowered. Therefore, evaluation of the trade-off between cost savings and risk of production loss is left to the user.

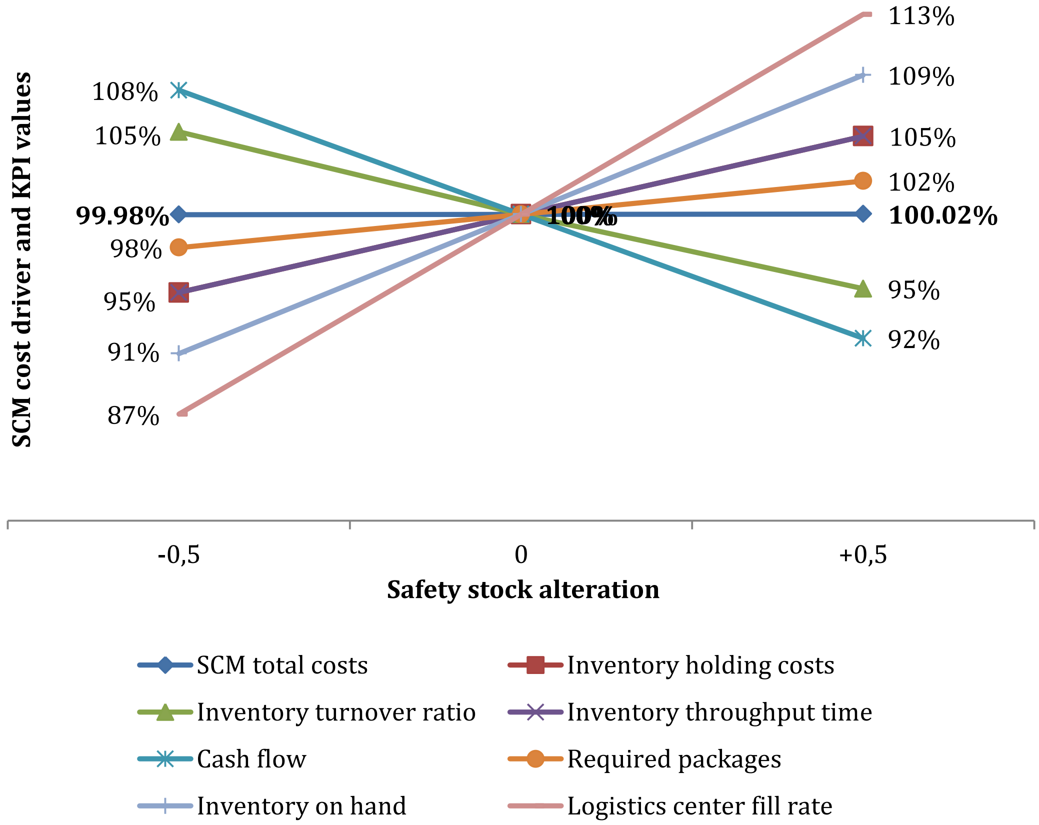


Figure 22. Modeling safety stock levels with Part A

7.3.5 Altering a part number's minimum order quantity

Lastly, alteration of the minimum order quantity was experimented with using another part number. As can be seen from Table 16, the part number's cost drivers and KPIs change considerably when minimum order quantity is altered in either direction. This particular part number has only low demand during the 10-week modeling period, and its initial MOQ is higher than demand during the modeling period. For this reason, e.g. cash flow is significantly impacted by the 50 per cent increase in MOQ, as the component's cycle time increases because a larger lot size is stored for a longer time because of the part number's low consumption. On the other hand, if MOQ was decreased by 50 per cent, the part number's cash flow and inventory turnover ratio would increase remarkably.

Moreover, total SCM costs would decrease slightly if MOQ was smaller. The saving in total costs is generated by reduced inventory holding costs and packaging material costs, which are reduced due to smaller average inventory value and faster cycle time. However, as can be seen from the table, in this case reducing MOQ does not affect freight costs as chargeable weight of this part number's freight would be within the minimum weight limit, i.e. under 100kgs, with both MOQs. Nevertheless, increasing MOQ would shift the chargeable weight class above the minimum weight limit, and thus increase freight costs.

Table 16: Modeling minimum order quantities with Part B

	Minimum order quantity alteration		
SCM cost driver and KPI	**-50 %**	**0 %**	**+50%**
SCM total costs / CAR	99,9 %	100 %	100,6 %
Inbound freight cost / CAR	100 %	100 %	103 %
Return freight cost / CAR	100 %	100 %	102 %
Packaging material costs / CAR	94 %	100 %	110 %
Inventory holding costs / CAR	81 %	100 %	119 %
Annual inventory turnover ratio	123 %	100 %	84 %
Inventory throughput time	81 %	100 %	119 %
Cash flow	193 %	100 %	7 %
Average inventory on hand	72 %	100 %	128 %
T3 & T4 fill rate	56 %	100 %	144 %

Although increasing MOQ would also increase total SCM costs, the amendment may be justified e.g. because of achieving better trailer fill rates. For example, MOQ can be set so that the material planners will always order lot sizes which fill the trailer from top to bottom. If the MOQ was not set accordingly, it may be that nothing could be loaded on top of the ordered pallet of components because goods from different suppliers in consolidated freight are not stackable with each other, which results in lower trailer fill rate. However, stacking capability is not taken into account in the model, which was not designed to conduct load planning in the first place, unlike VATG. Nevertheless, in the trade-off between increasing trailer fill rate and decreasing overall SCM costs, it ought to be kept in mind that increasing MOQ also decreases cash flow, and increases inventory holding costs, hence also the risk of obsolescence is increased.

To conclude, expected cost drivers, such as freight costs and warehousing costs, constituted the majority of VA's total SCM costs. Moreover, inbound freight cost alone was clearly the major cost driver accounting for 39 per cent, i.e. three times the cost of warehousing operations. On the other hand, inventory holding costs were surprisingly low in comparison to freight costs, albeit insurance, obsolescence, and inventory management costs were separately allocated to other SCM costs drivers. Also, packaging material costs were found to be a considerable cost driver, accounting for some 4 to 5 per cent of total SCM costs. Moreover, packing labor costs at supplier and scrapped material costs were surprisingly significant cost drivers, accounting for some 3 and 2 per cent of total SCM costs per car. Furthermore, inventory holding costs and freight costs correlated negatively with each other when pick-up frequency was altered. Lastly, the higher the daily production rate used in the model, the smaller the SCM costs per car were, except for the cost of required packaging material per car, which grows as daily consumption of components and packages is increased. However, increasing the total production volume of cars would decrease the cost of packaging material cost allocated for each car produced.

7.4 Evaluating the added business value of the model

The validated costing model has several possibilities of adding value to VA's business in terms of cost savings, SCM process streamlining, and supplier performance follow up. For instance, SCM processes can be streamlined in terms of cash flow, inventory fill rates, turnover ratios and throughput times. Also, supplier performance measures, such as quality and delivery DPMs, are included in the costing model and can be followed up together with other SCM KPIs. By providing a visualized overview of SCM, the model helps increase SCM visibility and improves overall understanding of SCM cost drivers, KPIs and their correlation.

In the main, the costing model can be used to improve cost efficiency of SCM through user-inspired optimization. In other words, the user is expected to try and compare different scenarios with different suppliers and part numbers, while the model produces results for the different scenarios. Besides using the pivot table in the model to intuitively find suppliers and part numbers that encompass a potential for cost reduction and SCM streamlining, user can experiment with suppliers and part numbers that have caused issues or significant costs in daily operations. As an example, cost savings can be achieved through optimal freight mode selection. For instance, changing freight mode as in the case in Figure 20 alone would have resulted in cost savings worth almost the development costs of the costing model itself. Other process optimization possibilities include those also used as examples in the experiments, such as safety stock, pick-up frequency, minimum order quantity, and FTL fill rate alteration.

In addition, should business or daily production rate for some other reason increase, its effects could be modeled with the costing model. For instance, it can be measured how much cost savings per car are achieved if daily production rate or total production is increased. As an example, if total production was increased by 25 per cent, cost savings in packaging material per car would be 20 per cent. On the other hand, in addition to cost savings, resource constraints such as inventory fill rates can be measured if production rate is increased, which can assist in proactive planning of inventory capacity rearrangement or inventory expansion.

Furthermore, should suppliers or contract terms change, they can also be modeled to some extent. For instance, if a supplier from Germany is switched to a supplier in Spain, the cost and KPI effects of this can be simply modeled by adjusting transit time, and changing the postcode and payment term of the supplier. After changing the parameters, impacted measures such as freight costs, cycle times, packaging material, and cash flow calculations are updated.

Also, the packaging calculation method and tool developed by the researcher have already been used successfully in procurement of packaging material, which resulted in notable cost savings as excessive orders could be canceled and further avoided with the knowledge of actual demand. Should production rate increase or another manufacturing contract take place, packaging material requirements can be calculated with the tool as long as suppliers' delivery times, pick-up frequencies, part numbers' forecasted daily consumption rates, and packaging holding capacities are known.

Moreover, the costing model and/or packaging material calculation tool can be used to calculate the cost savings of converting JIT supplied components to sequenced JIS supplied components by removing the safety stock values of the component variants, and setting the part number's MOQ to 1 and pick-up frequency to 5, if the components are used daily. Possible cost savings of this alteration should then be compared to increased supplier costs for adjusting to this amendment, if it is logistically and productively possible in the first place.

As a rough guideline, Wagner and Silveira-Camargos (2011) state that if a component has more than three variants, it should be delivered as JIS; because using JIT supply with several variants will increase handling costs and stock levels excessively. Furthermore, Hall and Braithwaite (2001, p. 90) add that parameters of the component, such as size, price, and usage affect the decision, and components at the upper end of the scale of these parameters should be supplied in a JIS manner. Besides, if several part numbers are converted from JIT to JIS and pick-up frequency is increased for numerous suppliers, it should also be ensured that carriers have enough available trailers for the amendment. However, consideration of these kinds of practical implications will be left to the user of the costing model.

Nevertheless, in regard to the added business value of the model, as mentioned earlier by D'este (2001, p. 533), quality models and quality decisions come from quality inputs. The limitations of the model must be acknowledged. All modeling involves compromise, and a model should not be given credit for more accuracy than it has. This SCM costing model is a management tool whose results need to be considered along with other inputs to the decision making process. Indeed, the model should be seen as an extension to the supply chain manager's capability. It is not an alternative to it.

8. Discussion and conclusions

The author begins the final chapter of this thesis with a brief summary of the conducted research. A research summary is followed by a short description of some main research limitations and a discussion of the key findings of this study. In addition, the research's implications for managers are discussed in Chapter 8.4. Lastly, the thesis is completed with suggestions for future research.

8.1 Research summary

This study was commissioned by a Finnish automotive contract manufacturer, Valmet Automotive Inc. The main objectives of the study were to increase understanding and provide the means to improve the case company's supply chain management by developing a supportive tool for management decision making. Furthermore, the thesis consisted of three research questions, which were:

(1) *How to create a tool for calculating and modeling supply chain costs?*

(2) *What are Valmet Automotive's key supply chain cost drivers, and how are they correlated?*

(3) *How can the costing model be used to add value to Valmet Automotive's business*?

The nature of this study was empirical and innovative, as similar research on process streamlining and modeling SCM costs of a single company in the automotive manufacturing industry did not appear. The literature of supply chain management and cost management was used to develop understanding of SCM cost drivers and key performance indicators to be measured. In addition, the simulation and modeling literature formed a basis for building, verifying and validating the costing model.

Eventually, a mechanical spreadsheet costing model was developed. The tool is based on mathematical methods, deterministic modeling techniques and *what-if* scenarios. The costing model was successfully verified and validated for the most part together with VA's SCM personnel. Apart from being able to simultaneously model with multiple selected suppliers and part numbers, the model satisfies the requirements of the conceptual model. However, a downside of the spreadsheet costing model is that it requires rather much computational capacity and time; modeling a selected supplier or part number's costs takes about 20 seconds. Still, other calculations are usually completed within five seconds.

A validated costing model was developed and taken into use at the case company. Although the model proved to be valid, it is a theoretical model and its results should not be considered alone, but along with other inputs to the decision making process, such as supply chain managers' experience and implicit knowledge, risks of conducting the amendments, and the stochastic nature of events in reality. The model should always be seen as an extension to a supply chain manager's capability. It is not an alternative to it.

Lastly, besides adding value to the case company's business, this research has contributed to filling the research gap regarding SCM costs in the automotive manufacturing industry. Moreover, this research has provided a case study of extensive modeling of SCM cost drivers and KPIs, and thus contributed towards the academic research in the discipline of supply chain modeling.

8.2 Main limitations of the study

This research was limited to calculating SC costs within the case company only, and thus did not consider total costs of the whole supply chain or any influences regarding the performance of inter-firm value chain partners. The calculations were limited only to concern supply chain costs in regard to VA's automotive manufacturing contract with its current client, Daimler. Moreover, manufacturing costs and the cost or risk of production disruptions were excluded from the scope of the research.

Furthermore, the developed tool is based on deterministic modeling methods and average values, and thus does not take into account the stochastic nature of lead times, demand, or quality of deliveries. Besides, the operation of the model is purely mechanical and based on mathematical methods to model supply chain costs and key performance indicators in different scenarios. Therefore, the model is not designed to dynamically simulate scenarios or optimize SCM costs and KPIs by itself.

As a contract manufacturer, the case company can only influence its own operations and contracted freight carriers, and thus the research was focused on the case company's supply chain process optimization only. In other words, no research into changing or reducing the number of suppliers could be conducted. Neither could part numbers or their prices be influenced. However, material costs were still included in the costing model as a reference to other SCM costs.

8.3 Key findings

Key findings of this thesis derive from answers to the three posed research questions. First of all, the essential steps in developing a costing model were to understand the case company's supply chain operations and process flow. After initial understanding of operations and the stakeholders involved, it was necessary to understand what kind of data and in which format it was extractable from the database. Furthermore, to understand what kind of data was required, the desired capabilities and qualities of the model to be developed needed to be known. This necessitated the construction of a conceptual model. After the purpose of the costing model was understood and the conceptual model was approved, development of the executable model could begin. However, before starting to construct the model, suitable modeling techniques and software platforms were to be determined. Considering the intended uses of the model and available resources for the task, a mechanical mathematical spreadsheet model proved to be the most suitable resolution for the project.

The next steps in the development process were to verify and validate the executable model, which also involved data validation. The costing model was successfully verified, except that the feature of simultaneously modeling with several suppliers could not be implemented as in the conceptual model. However, this feature was not primary, and thus did not invalidate the model. As soon as the model was validated, experimentation of different scenarios could be conducted and results analyzed. In this phase, it was found that the model is valid, although not completely so, as there were some flaws in the basic data, and certain parameters could not be validated either because of their stochastic nature, or due to the lack of actual data records. For instance, the utility of modeling packaging requirements is dependent on the quality of input packaging data, which was discovered to contain some errors. However, in the separate packaging calculation tool data was manipulated, and thus validated. Nevertheless, although overall basic data was of good quality, the case company's SCM data was found to be somewhat fragmented and accessing especially up to date financial and procurement related data could have been more straightforward.

However, items that could not be fully validated in the costing model consisted of part number and packages' cycle times, which affect cash flow and packaging material requirement calculations. These cost drivers and KPIs can therefore be considered as suggestive information. However, the main intended uses of the model, such as calculating freight costs and volumes, and inventory values and fill rates, proved to be valid. The model proved to be especially accurate when modeled results where compared to actual long time averages. For instance, with a study period of 25 weeks, modeled freight costs represented actual freight costs by 101 per cent, which indicates only a minor error margin of 1 per cent.

Moreover, during the validation process incorrect assumptions were revealed, and the significance of error derived from these assumptions was discovered. First of all, average inbound trailer fill rate turned out to be less than the assumed $90m^3$, which contributed to an error margin of some 20 per cent in calculating overall inbound freight cost. Secondly, terminal freight rate calculation was assumed to be based on minimum chargeable weight, but after examining actual invoices, terminal freight costing turned out to be based on maximum chargeable weight instead, which had an impact of some 10 per cent on the overall inbound freight cost. Therefore, calculation methods should be carefully designed and validated in order to achieve accurate and reliable results.

Secondly, freight was found to be undisputedly the major cost driver of VA's SCM, accounting for 70 per cent of total SCM costs, of which inbound freight cost alone formed 39 percentage units. Freight cost's share of VA's total SCM costs was 70 per cent, and thus considerably more than the average of 30 to 50 per cent found in a study of Finnish manufacturing companies conducted by Solakivi et al. (2012). This finding may indicate that VA has been able to minimize all other SCM costs. On the other hand, the difference can also be explained by the fact that companies commonly do not have return freight costs, whereas VA operates a closed-loop logistics system, in which empty packaging material is returned to suppliers daily.

Warehousing costs were clearly the other major cost driver accounting for some 13 per cent of total SCM costs, which is also closer to the average share of 20 per cent discovered by Solakivi et al. (2012). SCM labor costs and packaging material costs both accounted for some 4 to 5 per cent of total SCM costs. However, and rather surprisingly, including packing costs at suppliers, total packaging related costs accounted for as much as 8 per cent of total SCM costs. Yet another surprisingly significant cost driver was the cost of surplus material, which accounted for some 2 per cent of total SCM costs per car.

On the other hand, inventory holding costs, which are generally one of the three biggest SCM costs, accounting for some 20 to 30 per cent (Solakivi et al. 2012), accounted only for some 3 per cent of VA's SCM costs, which is an indication of lean supply chain management on VA's behalf. However, the difference is also partly explained by the fact that insurance, obsolescence, SCM IT and labor costs of inventory management were calculated separately from the inventory holding costs. Nevertheless, even the combined share of these inventory related costs would still not result in more than 10 per cent of total SCM costs.

Overall findings of SCM cost driver and KPI correlations were for instance that freight costs and cash flow correlate negatively with inventory holding costs and packaging material costs when pick-up frequency is altered. All cost drivers and KPIs were found to improve or remain the same when either MOQ or safety stock level was decreased. Moreover, all KPIs improved and costs decreased or remained the same, except for packaging material costs per car, when daily production rate was increased.

Thirdly, the costing model can be used in several ways to add value to business. For instance, during the development of the costing model, a new calculation method and a separate calculation tool were developed by the researcher to support the procurement of packaging material. These same calculation principles were applied in the costing model as well. Validity of the packaging calculation tool was evaluated together with VA's packaging engineers and packaging purchasers. The calculation method was commonly approved with the condition that particular suppliers' special arrangements regarding cycle times were taken into account. After approval, the packaging calculation tool was taken into use and successfully utilized in procurement of packaging material. Cost savings were achieved, as unnecessary packaging material orders could be cancelled and further orders were computationally better-justified investments.

Moreover, the user-inspired optimization of supplier freight mode selection, pick-up frequencies, and safety stock levels are proved in the model to bring in cost savings to the case company. Besides using the pivot table in the model to find potential suppliers and part numbers for reducing SCM costs and streamlining processes, users can experiment with suppliers and part numbers that are highlighted in daily operations. Furthermore, the model can be used to model the effects of different scenarios, such as changing supplier location, supplier payment term, or sequenced supply of components. Still, the costing model enables the follow up of supplier performance and streamlining of different SCM KPIs, such as DPMs, cash flow, inventory fill rates, turnover ratio and throughput time. Also, the model provides supportive calculations for packaging procurement, and the model can work as a proactive planning tool e.g. for inventory managers, should production rate or total production be increased.

8.4 Managerial implications

The research findings discussed in the previous section indicate that the developed costing model has potential for adding value to business if used as a supportive tool in SCM decision making. Besides discussing the model's potential for adding value to business, the following two parts of this chapter shall also present possible areas for development that the researcher discovered during this study.

8.4.1 Developed model can provide support for SCM decision making

First and foremost, the results of the model proved to be consistent and reliable, which is a key precondition in starting to use a model. The validation process indicated a general error margin of a few percentage points, and the error margin decreased as the modeling period extended. Therefore, the model can be a useful tool especially in long term strategic planning, as modeling of long term costs is of high accuracy.

As a supportive tool for SCM decision making, the tool provides possibilities to model and follow up SCM KPIs, such as cash flow, average inventory value, inventory fill rates, inventory turnover ratio, inventory throughput time, as well as quality and delivery DPMs. This information can be utilized both in daily operations as well as in strategic long term SCM planning, e.g. the model can indicate if proactive procurement of packaging materials, inventory capacity rearrangement or inventory expansion is needed. Furthermore, the model enables the user to observe potential cost savings in different scenarios modeled by adjusting several SCM decision variables, such as freight mode, pick-up frequency and daily production rate.

Moreover, should VA's client propose a change of supplier, the impacts of changing supplier location can be modeled, which helps evaluate the influence of such an amendment. Results of different scenarios are visualized as savings on overall, supplier number and part number level for each supply chain cost driver and key performance indicator. Besides, the amendment's overall impact on total SCM costs is projected until the end of the manufacturing contract in order to put the impact into a larger perspective.

Lastly, in regard to possible future contracts, the developed packaging calculation tool can be used to model the cost of required packaging material. The exact same calculation methods are included in the costing model as well, but because of necessary data manipulation, results of the packaging calculation tool are more accurate than those produced by the costing model.

8.4.2 Researcher's suggestions for management

The researcher also made some operational findings during the study. For example, it became evident to the researcher that the average trailer fill rate has a considerable impact on total freight costs. During validation of the model, it was observed that a 20 per cent adjustment in average trailer fill rate would impact freight costs with approximately the same ratio. Thus, this finding highlights the importance of transport management and load planning, and also enables another possibility for SCM scenario modeling, in which the cost impact of trailer fill rates can be studied.

Furthermore, the rather significant value lost (2 per cent of total SCM costs) in scrapping of components was considered worth mentioning. Real time communication with the client, short lead times and lean inventory management practices can help reduce the risk of added obsolescence. Moreover, if VA's client could confirm orders further in advance, VA would be able to make more call-offs to its first tier suppliers based on actual demand instead of forecast demand. In addition, increased demand accuracy would improve supply chain visibility, which could result in cost savings e.g. through increased average trailer fill rates, and reduced special freight costs and safety stock levels, which would both reduce obsolescence as well as inventory holding costs.

Furthermore, management of packaging material proved to create occasional bottlenecks in the supply chain. Compared to transportation costs (70 per cent) or warehousing costs (13 per cent), packaging material costs (5 per cent) are relatively low. However, the lack of packages may cause serious bottlenecks and additional SCM costs in forms of special inbound and return freight, lower trailer fill rates, extra labor costs in managing the special arrangements in the flow of packaging materials and, in the worst case, lack of packages may cause production disruption if required components cannot be delivered in time. For instance, a possible investment for acquiring a greater amount of packaging material could be gained from savings achieved through better trailer fill rates or selecting more optimal freight modes for suppliers, as explained earlier. The increased amount of packaging material would help in managing the material flow should disturbances in the supply chain appear.

In regard to packaging material, correcting erroneous data of packages' holding capacity, part numbers' outer and inner package codes, volume data of packages, suppliers' payment term data, and other pieces of erroneous data would increase the accuracy and utility of the costing model. Moreover, integration of fragmented financial and logistics data into one data source would help updating basic data in the costing model. Indeed, easy access to and straightforward extraction of SCM data ought to be also considered in the case company's possible future ERP development projects.

Lastly, intended users for the costing model are initially the case company's SCM managers. However, should the model be used daily or e.g. also by material planners, who would each be able to follow up and improve their designated suppliers' performance, the researcher suggests to seek possibilities to improve the usability of the model. For instance, implementation of the model could be outsourced to an external server that would encompass the required computational power to run the model effortlessly, as has been done with VATG. Currently the issue with the model is that its execution is somewhat slow, especially when switching between suppliers and part numbers. Outsourcing the development and upkeep of a customized costing model to an IT company with professional programmers would not be inexpensive, but should be much more straightforward and affordable now when the blueprint of the model already exists, i.e. SCM cost drivers and KPIs, as well as functionalities and other requirements of the costing model are known, the desired outcome can be visualized, hence only a more capable implementation is desired.

8.5 Suggestions for future research

The conducted study also raised interesting topics for future research. For instance, the current costing model could still be developed further to include the option of modeling simultaneously with multiple suppliers and part numbers. As discussed earlier, a possible working solution for this amendment could be to re-engineer the modeling process with VBA code instead of spreadsheet formulas. Besides, should the current spreadsheet version of the model be used, some means of reducing the required computational capacity should be investigated. Lastly, it would make an interesting study trying to develop the current calculation model into an optimization tool using an appropriate solver program, which would be able to find the SCM improvements itself instead of the user-inspired optimization where the user manually experiments with different scenarios one supplier at a time.

In addition, the created costing model could be further developed to assist at the commencement of new manufacturing projects and especially in tendering for new contracts. If SCM costs and required packaging investments as well as possible rearrangement of inventory capacity in regard to new projects could be modeled, decisions on tenders would be more fact-based and computationally justified. However, the functioning of the costing model is dependent on basic part number data, which would still be scarce at the tendering stage. Nevertheless, even if cost modeling was based only on assumptions and dummy values, it could still increase the credibility of VA's tenders and lead to better business decisions.

As this research has provided the case company with information about SCM cost drivers, their correlation, and methods for calculating and modeling these objects, an essential basis for developing a simulation or optimization tool in the future has been established. Research of SCM modeling could be carried on by developing separate dynamic models that could be used to simulate different supply chain processes, such as inbound freight, taking into account the probabilities of different time delays, and the probabilistic impact on inventory development by early and late deliveries. Furthermore, a simulation tool for risk management could also add value to business. A risk management tool should be able to simulate e.g. the probability and cost impact of production disruption after certain SCM alterations. This simulation could further impact also the development of insurance costs.

As the research was closely connected to the management of packaging materials, it was found that the topic of packaging materials management would contain interesting research questions for further studies as well. For instance, more efficient design of packaging material could increase average trailer fill rates, and thus generate cost savings. Additional SCM costs could also be reduced if suppliers and carriers would pay more attention to packing of components and securing of packages during transportation. However, packaging engineering should consider quality issues as well, as poor design of packages may result in components being unusable because of damage due to e.g. collapsed packaging material. It should be emphasized that components need to be properly placed inside packages, and that packages should be correctly assembled by component suppliers and also appropriately secured by carriers to avoid quality issues. These are issues that should be scrutinized together with VA's packaging engineers, packaging suppliers, component suppliers and carriers in order to ensure efficient space utilization in trailers and protection of components.

Moreover, VA should consider evaluating whether it would be profitable to integrate some kind of track and trace system to the purchased packaging material, which has been a considerable investment in the first place. If not to all packages, radio-frequency identification (RFID) tags could be attached at least to the most critical and expensive packages. Besides, RFID readers should be installed at the factory gate to keep track of the inbound and outbound movement of packages. By doing this, manual labor of counting packages would be reduced, and data of asset loss, i.e. lost or broken packages, could be accessed in order to know the number of existing packages still in the logistics cycle. Furthermore, records of actual cycle times of packaging material could be kept, which would help calculate packaging material investments even more accurately. Moreover, unless current packaging material is widely usable, it could also be studied whether outsourcing management and ownership of packaging materials to a 3PL would be a cost-effective solution regarding possible future manufacturing contracts.

Finally, the last suggestion for future research would be to find out whether the developed costing model could be applied to other companies as well. As became evident while going through previous modeling studies, each case is a unique setting with its own requirements and constraints, and no common costing models exist. Nevertheless, it would be interesting to study whether the developed costing model would work for another car factory or in a totally different field of business, such as the garment industry. Obviously, basic data and the whole ETL process would need to be re-engineered according to the case company, as the model would probably not work as such in another setting. However, a similar kind of model could be constructed applying the same mathematical methods and logic used in this research. If a working solution could be achieved in another environment, it would be interesting to study what kind of differences in SCM cost drivers and KPIs could be found among various companies and industries, and how would the differences influence business performance.

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Lectures

Kuula, M. 2014a. Lecture on *Product and Inventory Management* on the 12th of January 2014 in Aalto University School of Business, Helsinki.

Kuula, M. 2014b. Lecture on *Product and Inventory Management* on the 22nd of January 2014 in Aalto University School of Business, Helsinki.

Nyberg, P. 2011. Lecture on *Introduction to Finance* on the 2nd of May 2011 in Aalto University School of Business, Helsinki.

Vepsäläinen, A. 2014. Lecture on *Quality Leadership* on the 11th of March 2014 in Aalto University School of Business, Helsinki.

Interviews

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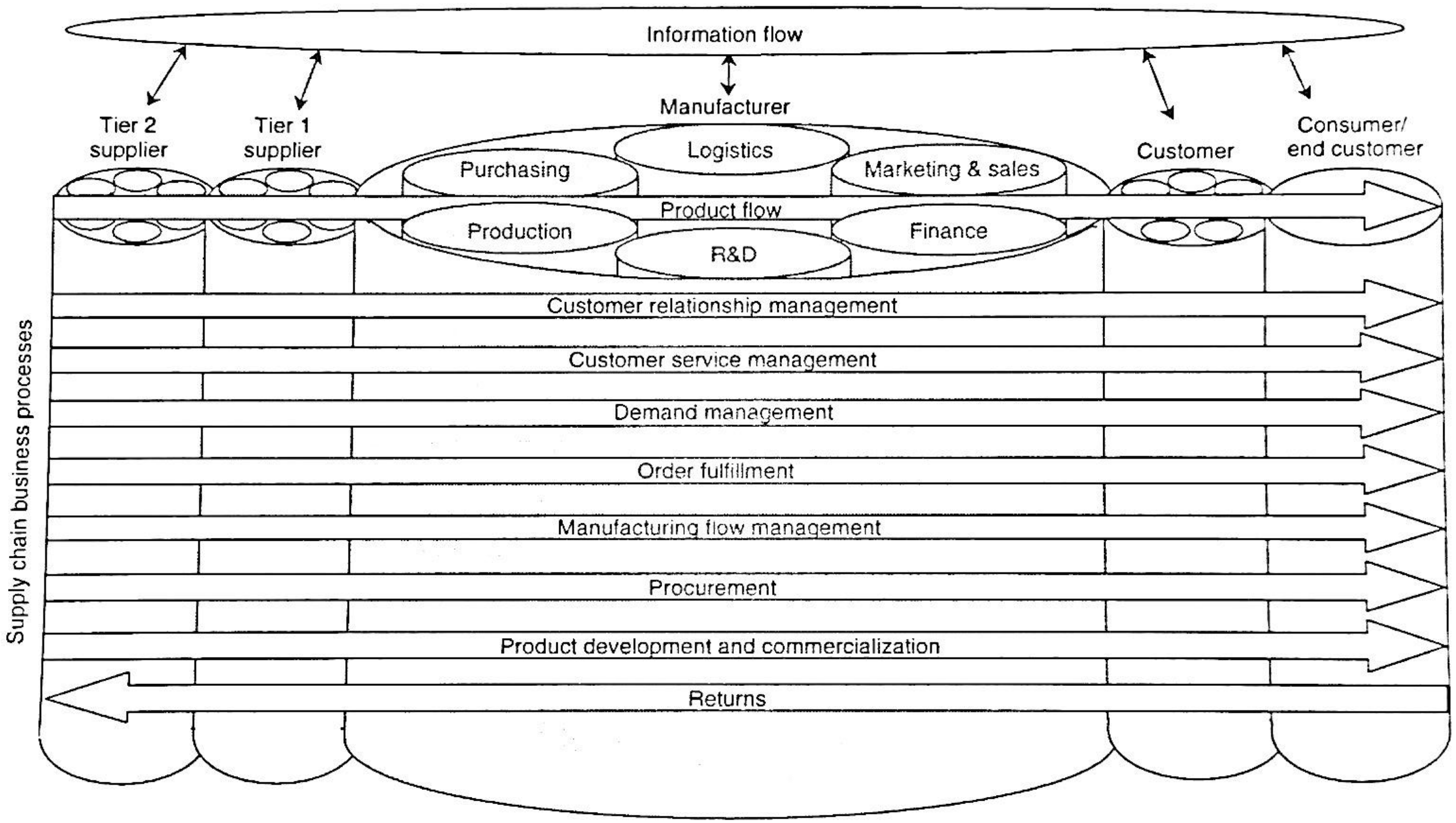
Appendices

Appendix 1. Framework for supply chain management, modified by Lambert (2001), based on Cooper et al. (1997)



Appendix 2. Draft version of the costing model based on dummy values

Material Planner	Supplier Country Code	Supplier Name	Part Number	Part Name
Example MAP 1	XXX	Example Supplier 1	Example Part 1	Example Part 1
Example MAP 1		Example Supplier 2	Example Part 2	Example Part 2
Example MAP 2		Example Supplier 3	Example Part 3	Example Part 3

Cars per Day	Cars per Simulation	Simulation weeks
xxxxx	xxxxx	1

Supplier 1 variables	Current	New
Pick-up frequency	1	2

Supplier 2 variables	Current	New
Pick-up frequency	1	2

Supplier 3 variables	Current	New
Pick-up frequency	1	2

Part 1 variables	Current	New
Safety Stock	x	
Package size, cbm	x	
Quantity / package	x	
Throughput time	x	

Part 2 variables	Current	New
Safety Stock	x	
Package size, cbm	x	
Quantity / package	x	
Throughput time	x	

Part 3 variables	Current	New
Safety Stock	x	
Package size, cbm	x	
Quantity / package	x	
Throughput time	x	

Current (for simulation period)				
SCM TCO	Total	Car	Supplier(s)	Part(s)
Packing at supplier	25000	22,52	1250	187,5
Transportation (in & out)	185000	166,67	9250	1387,5
Package	44000	39,64	2200	330
Inspection	5500	4,95	275	41,25
Receiving, handling & storage	165000	148,65	12210	1831,5
Obsolete material	1200	1,08	60	9
Delay and quality	2000	1,80	100	15
Cost of capital	60000	54,05	10440	1566
Insurance	11000	9,91	550	82,5
Administration	5000	4,50	250	37,5
Total	503 700,00 €	453,78 €	36 585,00 €	5 487,75 €
Inventory value	10000000	9009,01	500000	75000
Inventory usage	65,00 %	6 %	3 %	0 %

New (for simulation period)				
SCM TCO	Total	Car	Supplier(s)	Part(s)
Packing at supplier	25000	22,52	1250	187,5
Transportation	193991	174,77	15000	2250
Package	44000	39,64	2200	330
Inspection	5500	4,95	275	41,25
Receiving, handling & storage	158895	143,15	6105	915,75
Obsolete material	1200	1,08	60	9
Delay and quality	2000	1,80	100	15
Cost of capital	54780	49,35	5220	783
Insurance	11000	9,91	550	82,5
Administration	5000	4,50	250	37,5
Total	501 366,00 €	451,68 €	31 010,00 €	4 651,50 €
Inventory value	9245000	8328,83	462250	69337,5
Inventory usage	61,00 %	5,50 %	3 %	0 %

Difference in €				
SCM TCO	Total	Car	Supplier(s)	Part(s)
Packing at supplier	0	0,00	0	0
Transportation	8991	8,10	5750	862,5
Package	0	0,00	0	0
Inspection	0	0,00	0	0
Receiving, handling & storage	-6105	-5,50	-6105	-915,75
Obsolete material	0	0,00	0	0
Delay and quality	0	0,00	0	0
Cost of capital	-5220	-4,70	-5220	-783
Insurance	0	0,00	0	0
Administration	0	0,00	0	0
Total	-2 334,00 €	-2,10 €	-5 575,00 €	-836,25 €
Inventory value	-755000	-680,18	-37750	-5662,5
Inventory usage	-4,0 %	-0,36 %	0 %	0 %

Difference in %				
SCM TCO	Total	Car	Supplier(s)	Part(s)
Packing at supplier	0 %	0 %	0 %	0 %
Transportation	5 %	5 %	62 %	62 %
Package	0 %	0 %	0 %	0 %
Inspection	0 %	0 %	0 %	0 %
Receiving, handling & storage	-4 %	-4 %	-50 %	-50 %
Obsolete material	0 %	0 %	0 %	0 %
Delay and quality	0 %	0 %	0 %	0 %
Cost of capital	-9 %	-9 %	-50 %	-50 %
Insurance	0 %	0 %	0 %	0 %
Administration	0 %	0 %	0 %	0 %
Total	-8 %	-8 %	-38 %	-38 %
Inventory value	-8 %	-8 %	-8 %	-8 %
Inventory usage	-7 %	-7 %	-7 %	-7 %