UNIVERSITY
OF GÄVLE

**FACULTY OF ENGINEERING
AND SUSTAINABLE DEVELOPMENT**

Lower inventory levels and costs due to reduction of transportation time

To develop a framework to understand the effects of the transportation time to inventory

Hannu Multanen

June 2011

Master's Thesis in Management of Logistics and Innovation

Supervisor: Roland Hellberg
Examiner: Robin von Haartman

Abstract

This thesis concentrates to the relation of transportation time and inventory. The overall aim of the study was to develop a framework to understand the effects of transportation time to inventory. The original need for the research came from a case company, which wanted to investigate how inventory costs would change if transportation time would be reduced. That would be done with a change to start using a faster transportation mode between a central warehouse and a distribution hub. In order to be able to reach the overall aim, a literature review and an empirical research were carried out. The literature review was done using relevant literature sources i.e. theoretical books and journal articles. It was identifying the key factors in inventory management that are affected by transportation time and also presenting relevant theory about inventory management and transportation. Also models and frameworks investigating the relation of inventory and transportation with the concentration on the effects of transportation time offered by various authors were evaluated. Further, the empirical research was carried out to find out how the reduction of transportation time would affect inventory costs in a real life company. The empirical research was done as a case study by using interviews with both closed and open-ended questions. The research was qualitative in nature and the sampling technique used was a mixture of non-probability sampling techniques: quota and convenience sampling.

It was found out that the models offered by various authors have a wide range of contexts and environments and they are aimed for differing uses. Therefore it is not possible to have a universal use with these models. What was concluded to be the most important factor altering based on the changes in transportation time is the level of average inventory. It is also one of the main factors creating the inventory carrying costs. What was proved in the empirical research, by reducing transportation time, the average inventory levels could be reduced. However, only directly changing factor of average inventory was the level of in transit inventory. Indirect effects could be seen on the safety stock through the reduction of reorder point. Average order quantities were not changed when the actual transportation time was reduced; they were dependent on the frequencies of the transportation. The reduction of transportation time was affecting the inventory carrying costs mainly through the changes in average inventory. It was proven in the empirical research that inventory carrying costs could be reduced when reducing the transportation time. It was also found out that the way the inventory carrying rate is determined is crucial. It is important to know what the inventory carrying rate is based on and how it should be determined to have the most reliable results.

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1 Introduction

1.1 Background

The research in this thesis concentrates to investigate the correlation between transportation time and inventory. What is to be solved is how reducing transportation time by changing transportation mode to a faster one, affects the levels of inventory and as result of that the costs of inventory. Also the transportation costs are considered. The problem emerges from a need of a case company to have concrete facts, how a transformation to start using faster transportation mode affects the costs of transportation and inventory and if the relation of the changed costs is economically beneficial. The major factors that are going to be considered are the specific elements of inventory management that can alter depending on the transportation time. In addition to that, models investigating the relation of inventory and transportation offered by various authors are evaluated with the main focus on the transportation time. As a result of that, the aim is to be able to provide a framework that helps to understand the effects of the transportation time to inventory.

In literature many journal articles could be found to investigate integrated transportation and inventory functions. They offer various models mainly for solving the optimized inventory management and transportation methods for minimizing the total costs. (Burns et al. 1985); (Speranza and Ukovick 1994); (Lee et al. 2008); (Strack and Pochet 2010)
However, the context and the focus of the models vary a lot. There could be found models for investigating logistics system with single- or multi-item, single or multiple origin and destination modes as well as varying demand base for the items served from the inventory, just to name a few examples. (Bertazzi and Speranza 1999); (Kang and Kim 2010); (Kiesmüller 2010); (Madadi et al. 2010)

What can be also found from the journal articles researching relation of inventory and transportation is that usually mainly the transportation frequency is taken into consideration. The actual reduction of transportation time, which is as major focus in this study, is not considered that strongly. (Bertazzi and Speranza 1999); (Kang and Kim 2010); (Zhao et al. 2010)

In addition to that, many authors having similar focus, concentrate to offer their models for different environments. E.g. some of the authors investigate manufacturing related matters with concentration on raw material or work-in-process inventory, while others aim to solve problems related to distribution centers or determining how to centralize the inventories in the most effective way. (Das and Tyagi 1997); (Wang and Cheng 2009)

Williams and Tokar (2008) introduce and review widely articles and research done in the field of inventory management within time period from year 1976 to 2008. They state that one major focus in them is in integration of transportation and warehousing with help of decisions of inventory management. They further state that these decisions are usually made using traditional inventory control models.

The models are always based on the same theories about inventory management and transportation, but it depends on the context and focus, how and where the models could be used. In addition to that, it is important to notice that most organizations have their own ways of working and their own unique processes, which is why it is difficult to find a universal model how the inventory and transportation related to that should be managed.

Therefore the overall aim of this study is to provide a framework to understand the relation between transportation time and inventory in this particular context with help of carrying out an empirical research in a case company. The structure of the thesis is as following. The next sub-section will introduce the focus of the research in more detail. Following by that, the research objectives, research questions and overall aim of the study is explained and after that a literature review follows. After literature review chapter the methodology for the research is introduced, and it leads to empirical research chapter. After the chapter about empirical research the analysis and discussion about the literature review and empirical research is introduced and lastly, the conclusions for the whole study are given.

1.2 Research focus

Logistics as a concept is extremely wide and largely researched. Even the logistical activities such as transportation and inventory management, which have the main focus in this study, have really wide theory to cover them. Transportation works as a link between various participants of a supply chain. Therefore transportation is an important linkage within logistical processes (Gattorna and Walters 1996, cited in Lysons and Gillingham 2003, p. 540). It can cover movement e.g. between supplier and manufacturer or between finished-goods warehouse and customer (Bloomberg et al. 2002). In this study the focus is on transportation between a central warehouse and a distribution hub.

In the same way, inventory management is also a really wide concept. For example Bloomberg et al. (2002) divide the activities in inventory management into six different categories: purchasing, work-in-process, finished goods, parts/service support and return goods handling. However, when looking what kind of inventories exist, Bowersox et al. (2010) and Waters (2003) offer a narrowed view stating that inventory can take place in three forms: materials, work-in-process and finished products. Heath and Danks (2003, pp. 189-191, edited by Gattorna) agree with raw materials, work-in-process and finished goods, but they also add semi-finished goods (e.g. components) and MRO items (maintenance, repair and operating supplies).
The focus of the inventory management aspect in this study is on finished goods and more accurately on spare parts.

As mentioned the need for this research came from an organization that wants to solve the effects of faster transportation mode to inventory and transportation costs. The context for the research is a single link between one origin and one destination. A central warehouse that provides spare parts to hubs in different countries works as the origin node, and a distribution hub that serves a specific country, works as the destination node. That is illustrated with a picture (Figure 1.1). The items, spare parts, in this study are considered as multiple items, each having their own demand, inventory levels etc. Also important to notice is that the focus is on reduction of transportation time from central warehouse to distribution hub and on the results that could be gained by that. The frequency of the deliveries remains the same.

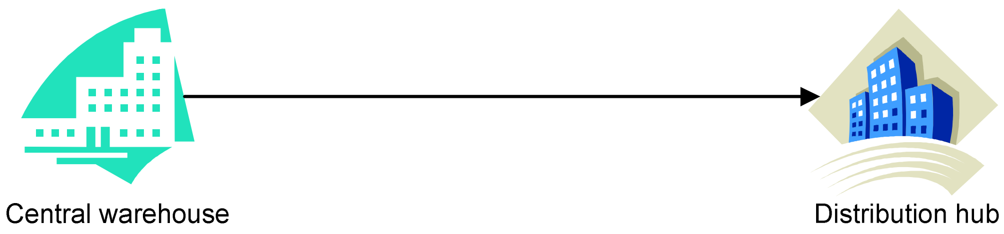

Figure 1.1 Focus of the research

2 Purpose

As introduced in the previous section, the overall aim of this research is to develop a framework to understand how transportation time affects inventory levels and that way also the costs of inventory. Also the transportation costs are considered. The main concentration of this study is on finished products in form of spare parts and the transportation of them between central warehouse and a distribution hub.

The first objective for the research is to identify the factors in inventory management that alter depending on the transportation time, with also taking the transportation frequency into consideration. Also relevant fundamental factors of transportation are identified as well as theory about transportation and inventory costs. That is done first to give better understanding about the theoretical base for the inventory management and how different functions affect each others. The second objective is to evaluate critically models and frameworks that investigate the correlation between transportation and inventory, concentrating to the relation of the transportation time and inventory. The third objective for the research is to explore how reduction of transportation time with faster transportation mode affects the inventory. In relation to this also the transportation costs are considered. That is done by doing an empirical research at a case company. Lastly, the fourth objective is to develop a framework how the transportation time affects inventory.

Therefore the research questions for this study are:

1. What are the factors in inventory management that alter depending on the transportation time and frequency?
2. What models and frameworks are available to investigate the correlation between transportation time and inventory?
3. In what ways does a faster transportation mode affect the inventory costs and what can be said about the transportation costs in this relation?
4. As a result of these a framework how the transportation time affects inventory will be developed.

In the next chapter the literature review for this study will be introduced, following by methodology for the research which finally leads to the empirical research part of the study.

3 Literature review

3.1 Introduction

Referring to the research objectives of this study, this section concentrates first to identify the factors in inventory management that are affected by transportation time and frequency. Also relevant theory about inventory management and transportation are presented. In addition to that theory about inventory and transportation costs are investigated. This is done by exploring mainly what relevant theoretical literature presents in this field.

The second section of this chapter presents the methods used for the literature review followed by a brief outline structure for the chapter. The fourth sub-chapter evaluates mainly using journal articles what kind of models and frameworks have been created studying the correlation between transportation and inventory. The main concentration is on the relation of transportation time and inventory. This will be followed by a brief summary and conclusions of the literature review chapter.

In the last sub-chapter the need for empirical research is stated and it is explained in more detail how it relates to and differs from the literature reviewed.

Sometimes it is common to confuse the terms inventory management and warehousing or warehouse management between each other. That is why it is important to make it clear what is meant by these terms in this study. This study focuses on inventory management, and the term is used to illustrate for example how the inventory levels, order quantities and inventory replenishments are managed. The terms warehousing and warehouse management refer to more physical activities to handle the actual goods warehoused. For example Frazelle (2002, p. 13) defines the objectives of inventory planning and management as:

"…to determine and maintain the lowest inventory levels possible that will meet the customer service policy requirements stipulated in the customer service policy."

In the same way he defines warehousing as:

"…to minimize the cost of labor, space, and equipment in the warehouse while meeting the cycle time and shipping accuracy requirements of the customer service policy and the storage capacity requirements of the inventory play." (Frazelle 2002, p. 14)

Similarly Gu et al. (2007) define the basic warehousing functions as receiving, storage, order picking and shipping. They also add that as major roles warehousing includes e.g. batching and consolidation of shipments and in some cases value-added processing i.e. pricing and labeling of products.

3.2 Methods for the literature review

The literature review of this study was carried out by reviewing and analyzing relevant literature sources i.e. books and journal articles. Most of the books chosen were introducing theory about supply chain management and logistics and mainly chapters about inventory management and transportation were chosen for more detailed inspection.
The articles used were found from various journals, and various databases offering them were used (i.e. Emerald, ScienceDirect, Wiley Online Library, JSTOR and SpringerLink). Key words such as “faster transportation AND inventory”; “lower inventory AND transportation”; “transportation time AND inventory”; “transportation frequency AND inventory”; “warehouse management”; “inventory management”; and “inventory management AND transportation” were used to find relevant articles researching the subject of interest. In addition to that, articles referred by articles read that were found relevant were studied.

The next sub-section will offer a brief outline structure for the literature review chapter.

3.3 Outline structure for the literature review

In order to follow the structure for the literature review of this study better, it is reasonable to provide a brief outline structure for this chapter. This will contain a brief overview of the sections for literature review.

3.4 Relevant theory for inventory and transportation management
A relevance of the logistics activities and functions of inventory and transportation are introduced as well as why both of them should be considered simultaneously and how they affect the customer service.

3.4.1 Logistics costs
Overall logistics costs and what they consist of are defined and introduced.

3.5 Inventory management
This sub-chapter consists of the following sub-sections: inventory planning and control; the key factors in inventory management; and inventory costs.

3.5.1 Inventory planning and control
The overall aim of inventory is explained and also what is meant by inventory control and planning are briefly introduced. In addition to that some strategies for inventory management are briefly illustrated.

3.5.2 The key factors in inventory management
The concept of inventory policy is introduced and closer look is done to the key factors that are needed in inventory management and which should be considered especially in this study:

Service level
Average inventory
Safety stock
Inventory in transit
Reorder point
Order quantities
Demand terms
Inventory turnover rate

3.5.3 Inventory costs
In this sub-chapter the consistency of inventory costs is defined as well as how the costs are usually calculated. Also the importance of the tied up capital created by inventory is explained.

3.6 Transportation management
The relation of transportation management and inventory is introduced and the definition for the transportation costs and what they consists of are given. These are done in two sub-sections: *Fundamental factors for transportation*; and *Transportation costs*.

3.7 Models and frameworks to investigate correlation between transportation time and inventory
Models and frameworks offered by various authors are introduced and evaluated. The concentration is on investigating mainly the relation of transportation time and inventory.

3.8 Summary and conclusions
A brief summary and conclusions of the literature review chapter are given, which leads to the need for empirical research.

3.9 Need for empirical research
Finally the need for empirical research is stated based on the literature reviewed.

Therefore, following sub-sections will take a closer look at the theory about the relation how transportation time and also transportation frequency affects inventory and what factors should be taken into consideration. Also relevant theory about inventory and transportation costs will be illustrated.

3.4 Relevant theory for inventory and transportation management

In order to understand better models and frameworks for relation of transportation and inventory management, it is reasonable to introduce what factors and activities are included in this area and how they are defined in theoretical literature. Frazelle (2002, pp. 12-15) identifies five interdependent activities that logistics is based on: customer response; inventory planning and management; supply; transportation; and warehousing. Therefore in this definition transportation and inventory management as well as warehousing are key logistics activities. Frazelle (2002, p. 91) stresses further that how inventory is managed is the center of all logistics.

In a similar way, Wood et al. (1995, pp. 215-224) define the overall activities of logistics, but they have a wider view. They also identify inventory management; traffic management; materials handling; and warehousing and distribution, but in addition to that they add scrap disposal; interplant movements; plant selection; moving people and coordination of logistics to this list. However, as it can be seen from the activities listed by Wood et al. (1995), most of them could be included into the other activities. Therefore the key activities listed by Frazelle (2002) could be seen as more relevant.

Also Bowersox et al. (2010, pp. 26-31) offer a similar view of the most important functions in logistics as Frazelle (2002). They introduce six functional areas: order processing; inventory; transportation; warehousing, materials handling and packaging; and facility network. According to the authors, these areas together create the capabilities which are needed to be able to achieve logistical value.

However, Jonsson (2008, pp. 32-33) offers a slightly different definition for the logistical functions. He also counts customer service, transportation and storage as logistics-related functions, but divides transportation into transport planning and freight transport. In addition to that, Jonsson (2008) does not separate inventory planning and warehousing into different categories as Wood et al. (1995), Frazelle (2002) and Bowersox et al. (2010) have done.

Bloomberg et al. (2002, p. 135-136) bring up the dilemma when considering inventory management. Different functions within an organization have different needs and they do not necessarily understand how their own needs affect to the activities and measurements of others. Clear example could be when a department responsible of transportation is trying to get the transportation costs down by using higher fill-rates for trucks which in turn increases inventory levels, while inventory management is aiming for reducing the average inventory at the same time. In addition to that marketing wants high inventory levels in order to satisfy the customer needs in the best possible way (Bloomberg et al. 2002).

This conflict between different functions of an organization about the inventory is typical. Also Norek (1998, p. 383, edited by Gattorna) stresses that the needs of different functions differ significantly and as a result of that they have varied views about the role of inventory. The people who are responsible for inventory management strives to keep the inventory levels as low as possible, while at the same time sales and marketing are demanding more inventory to keep the customer satisfaction at

maximum. Also transportation management is aiming for lowest cost per distance per ton, which results to higher volumes which increases the inventory in turn. (Norek 1998, p. 383, edited by Gattorna)
With these illustrations the main aim of this study is seen clearly; to identify the effects of transportation time to inventory.

Both Frazelle (2002) and Bowersox et al. (2010) stress the importance between inventory availability and customer service. Also Jonsson (2008, pp. 9-10) makes the same statement that especially within finished goods stock, the level of inventory has important effects on customer service. The aim of inventory management is to achieve the customer service level wanted, with as few inventory as possible (Bowersox et al. 2010). They emphasize that with faster deliveries, usually fewer inventory is needed. Similarly, with more frequent replacements, less safety stock is needed, which also leads to lower inventories.

As well Heath and Danks (2003, p. 189, edited by Gattorna) state that the customer expectations have to be satisfied, but they also stress that both the operational and financial performance of the company has to be optimized at the same time. Lutz et al. (2003) agree with that by stating that customer satisfaction is not only dependent highly on traditional factors i.e. cost and function but as well on logistical success factors i.e. lead time and service level. Tyworth and Zeng (1998) stress also the importance of transportation and inventory in supply chain management. They further identify these elements to be significant in contributing the customer service quality and that they usually create the most of the costs in a distribution network. That leads to investigate what is included in the logistics costs while concentration is on costs that come from transportation and inventory.

According to Frazelle (2002, p. 91) inventory carrying costs are typically the most expensive costs of logistics. However, Bowersox et al. (2010, pp. 35) as well as Bloomberg et al. (2002, p. 118) state that instead of inventory carrying costs, the transportation costs are one of the most significant logistics costs, while Jonsson (2008, p. 102) defines transportation costs as “normally a small proportion of the total logistics costs… [Excluding a business with very valuable goods transported]”. Also Lysons and Gillingham (2003, p. 540) and Martin (1995, p. 219) state that transportation is the most expensive aspect in logistics. Martin (1995) further defines that transportation costs usually form more than a half of total logistics costs in companies. Wilson (2006, cited in Williams and Tokar 2008) defines as an example that in United States approximately 33 percent of logistics costs are formed by inventory holding costs.

Therefore it can be seen that the opinions between different authors varies about which one is more expensive for a company, inventory or transportation costs. Surely reasons for this are at least that different authors have differing focuses and context. This matter is discusses in more detail at the later sections of this study.

Accordingly it is relevant here to emphasize the importance of relation between transportation and inventory. All of these activities, inventory management, transportation and customer service level, has to be in balance in order to gain the best performance and those are also critical factors in creating of the logistics costs. With properly managed inventory the customer service can be kept in a desired level. However, that usually leads to higher inventory costs. Therefore with the help of transportation functions the inventory levels and that way the costs could be reduced. The following sub-section takes a closer look how the logistics costs are defined.

3.4.1 Logistics costs

Before taking a closer look at the inventory and transportation management and the key factors related to them, the overall logistics costs are introduced first. Consequently, in this sub-section a brief introduction to logistics costs is given, and then in connection to the following sub-sections about inventory and transportation management, the costs related directly for them are illustrated.

Jonsson (2008, pp. 101-106) defines logistics costs as costs that can be attributed to logistics activities. He further states that they include both indirect and direct costs. Direct costs can be e.g. costs from transportation or storage of goods (and the tied-up capital used by them); and indirect costs can be capacity or shortage costs influenced by logistical system. He categorizes total logistics costs into following cost types:

“

- *Transportation and handling costs*
- *Packaging costs*
- *Inventory-carrying costs*
- *Administrative costs*
- *Ordering costs*
- *Capacity-related costs*
- *Shortage and delay costs*
- *Environmental costs”*

(Jonsson 2008, pp. 101-102)

However, he also writes that there are different types of categorizations for the total logistics costs, but the most important thing is not to include any of the costs twice into more than one different category.

Bentz (2003, pp. 156-158, edited by Gattorna) offers a narrower view of total logistics costs which is also more relevant to this particular study where the main concentration is only on transportation and inventory. She defines the total logistics costs relevant to transportation and inventory to be as:

Total logistics costs = Transportation + Warehousing + Administration + Inventory carrying costs.

When looking at the logistics costs, the main interest in this study is on the transportation and inventory costs created by the relation of transportation time and inventory. In this study, the total logistics costs consist of transportation costs and inventory carrying costs. Warehousing costs are included into the inventory carrying costs. The cost structures used in this study are defined in more detail in later sections, in *4.3 Framework for data analysis* and *5 Findings*.

As an example, Jonsson (2008, pp. 105-106) offers an illustration that total logistics costs have to be considered rather than just minimizing costs of every individual logistics activity when monitoring the effects of logistics decisions. In his example when decreasing inventory carrying costs, the transportation costs are increasing most likely due to the need for more frequent and faster transportation. In order to save in costs, the reduced inventory carrying costs need to be greater than the increased transportation costs. This relation is under the main concentration in this study.

There are also different ways to represent the logistics costs. Harrison and van Hoek (2002, pp. 56-63) offer three different ways to represent logistics costs: fixed/variable, direct/indirect and engineered/discretionary. Fixed costs mean that the costs stay the same when the volume of activity is changing while variable costs are changing when the volume of activity is changing. Direct costs mean costs that can be tied for specific products while indirect costs are the costs that are left after direct costs and have to be allocated. The engineered and discretionary costs are more related to manufacturing. Engineered costs can be seen and calculated to have clear output benefit, while the output of discretionary costs are not easily quantifiable. (Harrison and van Hoek 2002, pp. 56-63)

When concentrating to the costs of transportation and inventory in this study, the way fixed and variable costs are constituted is important to be noticed. As an example of this, if majority of the total costs are defined as fixed costs, then increasing of volume for units decreases the cost per unit. On the other hand, if the majority of total costs are consisting of variable costs, then increasing of volume of units does not have the same influence on the cost per unit.

3.5 Inventory management

3.5.1 Inventory planning and control

As mentioned before, inventory aims to provide enough products to meet the customer demand levels. Another main goal of inventory is commonly to achieve maximum inventory turn. While meeting both of these aims, the inventory management has to make sure to keep the service commitments for customers at a wanted level. (Bowersox et al. 2010, p. 27)

Frazelle (2002) agrees with Bowersox et al. (2010) about the goals of inventory management by stating that the inventory management tries to increase the financial return on inventory, while increasing the customer service levels at the same time. He even states that: “Inventory availability is the most important aspect of customer service” (Frazelle 2010, p. 91).

However, Bloomberg et al. (2002, p. 136-137) offers a slightly different point of view for the primary reason for holding an inventory. They state that it is to cover the uncertainties in demand. That is close and very much related to the goals stated by Frazelle (2002) and Bowersox et al. (2010), but has more concentration on the demand uncertainty.

Similarly, Lysons and Gillingham (2003, pp. 267-268) state that one aim of inventory is to provide the required service level to customers in terms of quantity and order rate fill (inventory availability). They also define two other aims for inventory as to keep the costs of inventory as minimum and to ascertain present and future requirements for production. However, the latter aim can be included into the service level, because the requirements for production can be also seen as the service level that the inventory needs to be able to provide.

As a conclusion of the different perspectives of the aim for inventory management, it is commonly always the same; to meet the demand of customers by providing required service level, while keeping the inventory levels and costs as minimum at the same time.

When planning inventory, the main things to consider are when and how much to order. The inventory control is done to define these and it is the procedure for management to implement inventory policy (driving elements of inventory performance). The reorder point (when to order) is determined by average and variation in demand and replenishment and how much to order depends on the order quantity. (Bowersox et al. 2010, p. 163-179)

There are different basic strategies to manage inventory. One strategy is to make sure that customer service level is as high as possible by increasing inventory, while another way is to use faster or more reliable transportation to reduce transportation time and uncertainty. (Bowersox et al. 2010, p. 159) As mentioned, the concentration of this study is on using faster transportation to reduce transportation time and as a result of that investigate how it affects the levels and costs of inventory. However, important to notice is that the focus of this study is the transportation between supplier (central warehouse) and receiver (distribution hub) rather than the transportation between the distribution hub and the final customer.

Frazelle (2002, pp. 92-93) has strong opinions about the initiatives that lead to increased return on inventory and simultaneously also to increased inventory availability. He stresses that five initiatives are needed: improved forecast accuracy; reduced cycle times; lower purchase order/setup costs; improved inventory visibility; and lower inventory carrying costs. However as mentioned before in this study, in order to meet the best performance of inventory, many different aspects have to be managed in a best way, which is not always that simple. It is quite clear that the initiatives defined by Frazelle (2002) are needed to have the best performance of inventory, but the way they affect to other functions and the way other functions affect to them are also extremely important to have in mind. After all, few of these initiatives are under major concentration in this study when exploring the relation of transportation time to inventory: reduced cycle times and lower inventory carrying costs.

Sometimes in order to be profitable, a company needs to divide their products into low-profit and –volume products and high-profit products and to concentrate offering the highest availability to the most profitable products. However, this is not always possible, because sometimes it is needed to offer also high level of service for less profitable items, if the question is about core customers. (Bowersox et al. 2010, p. 28) Important to be noticed is that when concentration is on spare parts, it can be inferred that usually it is important to be able to provide the parts needed at a given time, no matter how profitable they are. (Schatteman and Wright 2003, pp. 207-209, edited by Gattorna) However, Cohen et al. (1989) offer an inventory management model which takes into consideration two different priority classes; low and high. They further state that it is common also in environment of spare parts to consider one customer group as more important than other. Kutanoglu and Lohiya (2008) stress further that fast supply for service parts is essential especially in a case of critical downtime.
Otherwise the customer service suffers, which can affect the performance of the whole company or a certain unit of a company.

On the other hand, when categorizing products in inventory under different categories by volume and sales, it might be a useful way to help to select inventory policies. A widely used understanding is that a small percentage of the entities form a large percentage of the volume. That is called Pareto's law or 80/20 rule. Using this kind of categorization, ABC analysis can be performed. In ABC analysis products can be labeled as A, B and C, products. A-items are often high-volume and fast moving products; B-items are moderate-volume products; and low-volume or slow moving products are categorized as C-items. (Bowersox et al. 2010, pp. 188-190)

Jonsson (2008, p. 94-96) states that with ABC analysis it is easier for inventory management to decide which products or product categories should be given the highest inventory service level (inventory availability). Therefore it can also be a great help when determining the safety stock levels for these product categories. Jonsson (2008) also emphasizes that it is important to remember that items with high volume and value are tying up more capital, when relating to items with lower volume and value, which leads to more costly storing.

When looking at the item sales activities, Frazelle (2002, pp. 74-75) gives a more precise illustration. He states that products in category A comprise typically 5 percent of items but they cover 80 percent of sales. In a similar way, category B covers 15 percent of items and 15 percent of sales; and category C 80 of items and 5 percent of sales.

Bloomberg et al. (2002, pp. 146-148) offer a theory that ABC analysis could also be used in a different bases (as seen from the examples by Bowersox et al. (2010) and Frazelle (2002)). The importance which the categorizations are based could be changed to come from e.g. cash flows, lead time, stockouts, stockout costs, sales volume or profitability. According to them the ranking factor could be chosen, and then the ABC analysis could be done on that basis.

The next sub-sections look closer on the key factors and costs that are usually important to take into consideration when managing inventory. Those are then followed by sub-sections investigating relevant theory of transportation and its costs.

3.5.2 The key factors in inventory management

The main element that drives inventory performance is inventory policy and the two key indicators to be considered are service level and average inventory. The inventory policy is used to control the main actions and decisions in inventory management. It offers the guidelines for the main decisions, when to take action and in what quantity. (Bowersox et al. 2010)

Christopher (2005, pp. 86-87) agrees with that stating that the inventory policy determines the inventory levels of a company, but also in addition to that it defines the locations for inventories.

Frazelle (2002, pp. 127-136) states further that the inventory control policy is really important for the operation of inventory system. What kind of control system and policy to choose is dependent on the complexity of the scenario, number of items, numbers of locations and the availability of timely information. He defines inventory availability, typically referred also to as fill rate, as one of the two most important inventory management quality indicators alongside of forecast accuracy (Frazelle 2002, pp. 58-59).

Service level

According to Lysons and Gillingham (2003, p. 306) service level is: "the ability to meet the demands of customers from stock". They also offer an expression for it as:

$$\frac{\text{Number of times an item is provided on demand}}{\text{Number of times an item is demanded}}$$

Bowersox et al. (2010, p. 159) define service level as a performance target which is specified by the management. It states the objectives for the inventory performance. The authors offer a wider definition to measure service level. According to Bowersox et al. (2010) means to measure service level are often used as: performance cycle (the time that it takes after releasing an order by buyer to receive the actual shipment) (usually expressed as lead time (Bloomberg et al. 2002); (Lysons and Gillingham 2003); (Frazelle 2002)); case fill rate (percentage of units shipped as requested from available stock); the line fill rate (percentage of completely filled order lines) and order fill (percentage of completely filled customer orders). (Bowersox et al. 2010, p. 159)

Frazelle (2002, pp. 58-59) uses a term fill rate or inventory availability, to illustrate what Bowersox et al. (2010) states as case fill rate. Similarly he is using a term order fill rate, for term order fill used by Bowersox et al. (2010). Therefore it is easy to notice, that the terms used by different authors are very similar, but small differences on the names of the exact terms could be identified.

Jonsson (2008, p. 85) refers to the terms mentioned before, inventory availability and fill rate, as inventory service level. However, he also states that it is called either inventory service level or fill rate. Therefore, as a conclusion offered by these authors, the percentage of units shipped as requested from available stock has many terms with the same meaning, e.g.: fill rate, inventory availability, inventory service level or case fill rate, but how it is illustrated remains the same.

Average inventory

Average inventory refers to the typical amount of inventory across time. Normally average inventory is of one-half of order quantity plus safety stock and in-transit stock (the inventory that is in transit but not received yet). Important to notice is that average inventory is a function of the reorder quantity. Lower order quantities lead to lower average inventory. But the uncertainty of performance cycle, purchasing discounts and transportation economies are also important to take into consideration when determining order quantity. (Bowersox et al. 2010, pp. 159-160)

However, different opinions how the average inventory consist could be found. Ballou (1992, p. 330) states that average inventory consists only of regular stock and safety stock. However, he does not clearly identify, if the in transit stock is included into regular stock or not. After all he further stresses the importance to take the in transit stock into consideration by stating that the cost for holding the in transit stock is usually surprisingly high (Ballou 1992, pp. 349-350).

Therefore the average inventory can be illustrated as following:

$$Average\ inventory = \frac{Order\ quantity}{2} + Safety\ stock + in\ transit\ stock$$

This formula will be used in the empirical research part of the study when calculating the average inventory levels. More detailed definition for the formulas and values used in empirical research are introduced in later sub-section *4.3 Framework for data analysis* and in chapter *5 Findings.*

Safety stock

Bowersox et al. (2010, p. 160) and Lysons and Gillingham (2003, p. 306) define safety stock as an inventory kept to protect against uncertainties in demand and lead time. It is usually needed close before receiving the replenishment to inventory in cases where demand has been higher than expected or the transportation has taken longer time to arrive than expected. According to other authors (Bloomberg et al. 2002) and (Frazelle 2002) the aim of safety stock is the same. Also Jonsson (2008, p. 285) acquiesces the same definition while stating that safety stock is used against uncertainties in quantity and in time. Also in some literature, instead of the term safety stock, term buffer stock is used for the same meaning (Bloomberg 2002, p. 139); (Norek 1998, pp. 383-384, edited by Gattorna).

According to Bowersox et al. (2010, p. 169), the planning of safety stock is done in three steps. First step is to measure the likelihood of stockout; second is to estimate demand during a stockout period and third step is to make the policy decision determining the wanted level of protection for stockout. The demand uncertainty is usually done using statistical application, standard deviation. (Bowersox et al. 2010, pp. 171-172)

However, it is also important to remember that the demand uncertainty is not the only constraint to be considered when planning inventory. In most cases both demand uncertainty and performance cycle (lead time) uncertainty exist. When setting safety stock, the impact of the probability for both has to be determined. Bowersox et al. (2010, p. 177) stress further that by increasing order sizes, decrease of safety stock levels could be compensated, and also another way around

Jonsson (2008, p. 286) defines that the economically optimal safety stock occurs while minimizing the shortage costs and inventory carrying costs. He also identifies many different safety stock methods to exist: e.g. manually estimated safety stock; safety stock as percentage of lead time demand; and safety stock calculated by desired service level.

Lysons and Gillingham (2003, pp. 306-307) emphasize the relation of safety stock and service levels. They state that by increasing the investments on inventory and keeping higher safety stock, increased service levels can be maintained.

Inventory in transit

As this study concentrates on the effects of transportation time to inventory and as inventory in transit is considered as a part of the average inventory, it is reasonable to illustrate more precisely what is meant by the term inventory in transit. Sürie and Wagner (2002, pp. 39-40, edited by Stadtler and Kilger) give a definition that inventory in transit is the lot-sizing stock that is currently transported between the inventories. They further state it as to be dependent only on the transportation time and demand during that time. In addition to that the inventory in transit is independent on the transportation frequency and also independent on the lot-size transported. While reducing the transportation time using faster transportation mode, the inventory in transit can be reduced. To calculate the average inventory in transit average transportation time is multiplied by the average demand. (Sürie and Wagner 2002, pp. 39-40, edited by Stadtler and Kilger)

To illustrate the consistency of in transit inventory, it is showed as following:

$$In\,transit\ inventory = Transportation\ time\ (days) \times Demand\ (days)$$

Reorder point

Reorder point is a specified amount of inventory that defines when to place a new replenishment order. It can be specified either in terms of units or days' supply. If the demand and transportation time are known and certain, the reorder point is calculated as:

$$R = D \times T \text{ , where}$$

R = reorder point in units;
D = average daily demand in units; and
T = average performance cycle length in days

However, in normal cases, there is usually uncertainty either in demand or in the performance cycle (lead time). As mentioned before, therefore safety stock is usually needed. In that kind of situation, the safety stock could be added to the formula given:

$$R = D \times T + SS \text{ , where}$$

SS = safety stock in units.
(Bowersox et al. 2010, pp. 161-163)

Also Frazelle (2002, pp. 104-105) and Jonsson (2008, p. 273) illustrate the formula to calculate reorder point similarly, but instead of using term average performance cycle length, they use term lead time. The formula to determine the reorder point remains always the same, but different authors might be using different terms.

Order quantities

Usually the simplest way to determine the quantity to order is done using the basic EOQ (Economic Order Quantity) formula. The EOQ aims to identify the quantity to order that can minimize the total inventory carrying costs and costs of ordering. However Bowersox et al. (2010, pp. 164-168) define that to be able to use this formula properly, demand and costs should be relatively stable throughout the whole year. In more detail they state eight assumptions that are required for optimal use of EOQ:

"

1. *all demand is satisfied;*
2. *rate of demand is continuous, constant and known;*
3. *replenishment performance cycle time is constant and known;*
4. *there is a constant price of product that is independent of order quantity or time;*
5. *there is an infinite planning horizon;*
6. *there is no interaction between multiple items of inventory;*
7. *no inventory is in transit;*
8. *no limit is placed on capital availability"*

Also Bloomberg et al. (2002, pp. 149-150) defines these same assumptions, except they add one more to that list: "Transportation costs are constant no matter the amount moved or distance travelled."
Chase et al. (2006, p. 597) agree with most of the assumptions stated in the list and add also few assumptions stating that no back orders are allowed and that the inventory holding cost is based on average inventory.
Jonsson (2008, p. 281) agrees also that there are some common assumptions when using the basic EOQ formula. He is defining to be only four common assumptions, which all are included into the list by Bowersox et al. (2010).

However, there are various adjustments of the formula and some of the assumptions illustrated can be avoided using computational extensions. The basic formula for EOQ is:

$$EOQ = \sqrt{\frac{2C_0 D}{C_i U}} \text{ , where}$$

EOQ = Economic order quantity;
C_0 = cost per order;
C_i = annual inventory carrying cost;
D = annual sales volume in units; and
U = cost per unit
(Bowersox et al. 2010, pp. 164-168)

Bowersox et al. (2010, pp. 166-168) state that a general rule is that the larger the shipment the lower the transportation costs. Here the dilemma of transportation and inventory costs can be seen again; to use larger shipments the transportation costs can be reduced, but at the same time, the order quantity is increasing which leads to higher average inventory and higher inventory carrying costs. In order to analyze how the transportation costs are affecting, two calculations should be done; total cost with transportation savings and total cost without them (ibid.).

Jonsson (2008, pp. 119-122) offers a simplified way for order quantities. He introduces a way to calculate the average order quantity as:

$$\frac{\textit{Total annual demand}}{\textit{Total annual times of departures}}$$

Demand terms

Frazelle (2002, pp. 101-102) states that for every item, there is a unique set of demand characteristics. Important characteristics include:

- Annual demand (number of units for an item requested during a year);
- Forecast annual demand (forecasted annual demand);
- Lead time (time from the placement of order until receiving the item);
- Lead time demand (demand for item during lead time);
- Forecast lead time demand (forecasted demand during the lead time); and
- Standard deviation of lead time demand (measure of the variability of the demand during a lead time).

Lysons and Gillingham (2003, pp. 268-270) divide demand into two: independent and dependent. They define further that independent demand is for items that are influenced by market conditions and that are not related for any other item held in stock to production decisions. In other words, if an item is e.g. a component for another item in manufacturing, its demand is dependent, because it derives from the product decisions of other items. Therefore only independent demand can be estimated (ibid.).

Inventory turnover rate

As have mentioned before, the aim of inventory is to have lowest level possible, while still satisfying customer needs. Inventory turnover rate measures the productivity of inventory (Frazelle 2002, p. 110). The inventory turnover rate is expressed as the ratio of annual sales to the average inventory value (ibid.). In other words by Jonsson (2008, pp. 107-108) it refers how many times in a year the average inventories are turned over.

However, Bowersox et al. (2010, p. 387) emphasize that depending on the type of a company, three specific metrics exist for inventory turnover:

$$Inventory\,turnover = \frac{Cost\ of\ \ goods\ sold\ during\ a\,time\ period}{Average\ \ inventory\,valued\ at\ \ Cost\ during\ the\,time\ period}$$

$$Inventory\,turnover = \frac{Sales\ revenue\,during\ a\,time\ period}{Average\ \ inventory\,valued\ at\,selling\ \ price\,during\ time\ period}$$

$$Inventory\,turnover = \frac{Units\ sold\ during\ a\,time\ period}{Average\ \ unit\,inventory\,during\ the\,time\ period}$$

They state further that to calculate the turnover rate, the majority of companies use the first formula to do it. Waters (2003, p. 203) also agrees to that by illustrating the formula for stock turnover similarly.

3.5.3 Inventory costs

Importance of tied up capital

When concentrating to the inventory costs, tied-up capital is important factor to keep in mind. Jonsson (2008, p. 10) stresses that tied-up capital is affecting to cash flow and solvency of a company. He states further that it also affects to the potential returns that could be received from invested capital, if a company would have used it in another way. Therefore, if there is too much tied-up capital in inventory, it hinders the capacity of a company to make other investments with that capital.

Related to the invested capital, Jonsson (2008, pp. 13-14) emphasizes that as a long-term goal for all companies, they aim for as high return on invested capital as possible. Therefore it is important to illustrate how the employed capital affects the profitability. Jonsson (2008, p. 13) illustrates that the profitability is also indicated as return on capital employed (ROCE):

$$ROCE = \frac{profit}{Total\ capital\ employed} = \frac{revenues - Costs}{Total\ capital\ employed}$$

Consequently, by decreasing the tied-up capital in inventory and transportation, it could affect directly as an improvement to the rate of capital employed (ibid.).

Often the return on capital employed (ROCE) is expressed as return on investment (ROI). The formula to calculate it remains the same, but it could be expanded as:

$$ROI = \frac{profit}{sales} \times \frac{sales}{capital\ employed}\text{, and}$$

also be illustrated as the percentage of capital employed:

$$ROI\ \% = 100 \times \frac{profit\ €}{capital\ employed\ €}$$

(Harrison and van Hoek 2002, pp. 52-54); (Christopher 2005, pp. 83-85)

Total inventory costs

Total inventory costs consists of inventory carrying cost and the cost of personnel, space used for offices and systems that are employed to manage inventory (Frazelle 2002, pp. 44-45). Christopher (2005, p. 86) states that it could be even more than 50 percent of the current assets of a company that are tied up in inventory.

However it is important to notice that many authors refer to inventory carrying costs while illustrating total inventory costs. It can be seen that most authors include all the costs related to inventory i.e. costs of personnel to inventory carrying costs, while e.g. Bowersox et al. (2010) and Frazelle (2002) are excluding those costs from inventory carrying costs. The difference is that when all the costs related to inventory are included to inventory carrying costs, the percentage of them from the total inventory is higher than if they are excluded. This is explained in more detail in the following inventory carrying costs section.

Inventory carrying costs

Bowersox et al. (2010, pp. 162-163) explain inventory carrying cost as the expense cost of maintaining inventory. Further, they define inventory expense as annual inventory carrying cost percentage multiplied by average inventory value. Usually inventory is valued at the purchase or manufacturing cost, not the price of selling the inventory. Bloomberg et al. (2002, pp. 142-144) state that usually the total inventory cost for a product is between 14 to more than 50 percent of the value of the product.

Jonsson (2008, p. 102) has also the same definition for inventory carrying costs when defining them to be “the costs for keeping goods in stock… ”. He also agrees that the inventory carrying costs are the annual incremental inventory carrying costs as percentage of the average inventory value. However, he uses a different term when writing about inventory carrying cost percentage by using the term incremental inventory carrying costs or inventory carrying interest rate and he includes the costs of storage and labor into the inventory carrying costs.

Determining carrying costs percentage requires calculations of inventory-related costs. Relevant financial accounts to inventory carrying costs percentage are: capital, insurance, obsolescence, storage (facility expense related to product holding, not handling.) (Also allocation is usually needed, because the expenses for specific product is unlikely to be specified) and taxes. The final carrying cost percentage used in a company depends on the management and the policy of the organization. (Bowersox et al. 2010, pp. 162-163)

Jonsson (2008, pp. 430) offers a way to calculate the inventory carrying percentage (inventory carrying interest), if a company has not determined it for themselves. He presents the formula to calculate the average inventory carrying interest as following:

$$Inventory\,carrying\ Interest = \frac{\sum IC\ Cost + \sum IS\ Cost + \sum IU\ Cost}{average\,stock\ value}\text{, where}$$

IC = incremental capital;
IS = incremental storage; and
IU = incremental uncertainty.

Also Frazelle (2002, p. 45) states the inventory carrying costs as same than Bowersox et al. (2010), but he uses a different term for annual inventory carrying cost percentage, as inventory carrying rate (ICR). Frazelle (2002) agrees with Bowersox et al. (2010) that ICR consists of capital, insurance, obsolescence and taxes, but he also adds losses there and explains that storage and warehousing costs can be either included there or as a part of total logistics costs. He defines further that without including storage and warehousing costs, ICR is typically between 10 and 30 percent per year. If storage and warehousing costs are also included, he defines the percentage normally being between 15 and 40 percent. To compare this with the statement from Norek (1998, p. 381, edited by Gattorna), according to him the inventory carrying costs are usually between 25 to 40 percent of the value of the inventory. Also Christopher (2005, p. 102) agrees it to be around 25 percent of the value of the inventory.

When estimating correctly the inventory carrying costs, Jonsson (2008, pp. 102-103) agrees with Frazelle (2002) and Bowersox et al. (2010) by offering a definition that three components have to be estimated: capital costs, storage costs and uncertainty costs. These components include the same factors than offered by Frazelle (2002) and Bowersox et al. (2010).

Lysons and Gillingham (2003, p. 271) use a different term for the inventory carrying costs; they express it as holding costs of inventory. However, the constitution they offer for these costs are the same. They divide the costs into two types, proportional for the value of the inventory and to the physical characteristics of inventory. With the former type they refer to the factors mentioned before such as capital, insurance and losses; and with the latter one they mean the costs of storage and labor.

Bloomberg et al. (2002, pp. 144-145) refer to capital costs by stating that it compares inventory investment to earnings that could be received from other investments of that capital. They state further that it is usually the largest part of many companies' carrying costs. Also Jonsson (2008, pp. 102-103) agrees to that statement by writing that the inventory carrying costs are usually the largest single cost items that are logistics-related.

To illustrate this clearer, the inventory carrying costs are illustrated here as a formula:

$$ICC = AIV \times ICR \text{, where}$$

ICC = inventory carrying costs;
AIV = average inventory value; and
ICR = inventory carrying rate.

It is also relevant to illustrate the consistency of average inventory value for an item in a formula form:

$$AIV_i = AIL_i \times UIV_i \text{, where}$$

AIV_i = average inventory value for an item
AIL_i = average inventory level in units for an item
UIV_i = unit inventory value for an item
(Frazelle 2002, p. 45)

Waters (2003) offers also the same approach for calculating the average value for a single product. As the way to determine the average total inventory value for all products the result of the former calculation is just summed for all the items (Waters 2003, p. 203):

$$Average\,total\,inventory\,value = \sum (Average\,number\,of\,units\,held \times Unit\,value)$$

The formulas used in the empirical research of this study are introduced in more detail in later sub-section *4.3 Framework for data analysis* and in chapter *5 Findings*.

3.6 Transportation management

3.6.1 Fundamental factors for transportation

When concentrating to transportation and how it should be arranged, Bowersox et al. (2010, pp. 28-29) emphasize three factors that have the main importance: cost, speed and reliability. The cost should be considered in a way that usually faster transportation, have higher costs and vice versa. Therefore it is important to keep in mind that when aiming for lowest total logistical costs possible, not always is the cheapest transportation option the best. The balance of the time and cost for transportation is crucial. This is one of the main questions in this study, which leads to the overall aim to find out how faster transportation affects to the levels and costs in inventory held. Bowersox et al. (2010, pp. 28-29) stress also that in addition to help to reduce the inventory, shorter delivery time makes also the time interval shorter, when the inventory is in transportation and as a result of that unavailable to be used. However, Bloomberg et al. (2002, p. 120) have an interesting point of view, stating that some companies may prefer slower transportation and due to that longer transportation times. That way they are using the transportation vehicle as a moving warehouse.

Bowersox et al. (2010, pp. 28-29) highlight the importance of reliability of transportation. It is not profitable for a company, if they can reduce their transportation and inventory costs, but still the transportation used is not reliable enough. As a result the company most likely does not meet the customer service levels anymore. The combination of reliability and speed of transportation creates together the quality aspect for transportation (ibid.).

Typically there are five transportation modes in use: road, rail, air, waters and pipeline (Lysons and Gillingham 2003, p. 542); (Ballou 1992, pp. 141-146); (Bloomberg et al. 2002). In the case of this study, the only transportation mode used is road transportation with trucks. However, the concentration of this study is on the relation of transportation and inventory and therefore these transportation modes are not illustrated in more depth.

In the next sub-section the costs of transportation are dealt in more detail to get better understanding of their relation to inventory.

3.6.2 Transportation costs

As stated before, some authors disagree with the amount of transportation costs related to the total logistics costs. E.g. Frazelle (2002) and Jonsson (2008) keep the transportation costs as less significant, while Bowersox et al. (2010); Bloomberg et al. (2002); and Lysons and Gillingham (2003) define them as the most costly expenses in logistics. Also e.g. Swenseth and Godfrey (2002), Zhao et al. (2004) and Madadi et al. (2010) all state that the transportation costs are the highest costs in logistics. What is important to notice here is that also the type of products handled can make difference to the relation of inventory and transportation costs. If the goods in case are e.g. sensitive to cold, then the transportation costs and inventory costs both increases due to the need for a specific temperature monitored during transportation and storage. Also if the products in case are extremely valuable, then the holding costs for them will increase radically. It also depends on the way the inventory carrying costs are defined; e.g. if the storage and labor costs are included into inventory carrying costs or not. However, in this study, as the main interest is on the relation of transportation and inventory, it is critical to focus on both, inventory and transportation costs.

When looking at the costs of transportation, Frazelle (2002, p. 45) defines total transportation costs as sum of inbound and outbound transportation costs. Further he states that the transportation costs are different, depending on if a company is using their own fleet or if the transportation is outsourced to be done by carriers. In case when a company uses their own fleet, much more factors have to be taken into consideration i.e. cost of fueling; maintaining the fleet; acquiring and staffing. However, if the transportation functions are outsourced, usually the whole transportation costs can be calculated from freight bills. (Frazelle 2002, p. 45)
Similarly, for the price of transport service, Ballou (1992, p.138) defines only the price of the line-haul rate for transporting the shipment and any additional or terminal charges if there are used some additional services. This applies when there are used services of a transportation company to handle the transport and any other needed additional services. In a case of using an own transportation system Ballou (1992) states that allocation of the costs is needed. In that case cost i.e. fuel, labor, maintenance, depreciation of equipment and administrative costs are taken into account.

Skjoett-Larsen et al. (2007, p. 268) refer to third-party logistics providers when writing about reduced costs in logistics. They further state that using this “broader, long-term, and customized, cooperative arrangement” called third-party logistics provider, has been a way to reduce costs in logistics and to release tied up capital to another purposes. This kind of usage of outsourced logistics partners can be a way to reduce costs in transportation and also as Frazelle (2002) states, it can make it simpler to calculate and track the transportation costs for a company. Bedeman and Gattorna (2003, pp. 472-473, edited by Gattorna) define third-party logistics (3PL) providers to have at least following relevant attributes; owns or leases and operates a vehicle fleet and warehouses; and provides wide range of value-added services.

Jonsson (2008, p. 102) emphasizes that during the time the goods are transported, they represent tied-up capital. Therefore the tied-up capital costs for the transported goods are part of transportation costs. The concept of inventory in transit is explained earlier in this study in sub-chapter 3*.5.2 The key factors in inventory management*, and in this study, the in transit inventory is included to the average inventory and inventory carrying costs rather than to transportation costs.

3.7 Models and frameworks to investigate correlation between transportation time and inventory

As illustrated in the earlier sub-sections of this study, transportation and inventory management are in the center of logistics activities. In addition to that, customer service level has a critical role alongside of transportation and inventory management. In the literature reviewed so far, authors disagree about the most expensive costs in logistics; some of them say the most critical costs are the inventory carrying costs, while others state that transportation costs are the most crucial costs in logistics. This also depends on the type of goods transported and stored as well as how the inventory and transportation costs are determined. As a conclusion of this, both of these costs, inventory and transportation costs, should have high interest when concentrating to total logistics costs. The aim of all companies is to minimize the total costs, hence minimizing transportation and inventory costs are critical when aiming for that. As have been illustrated in the earlier sub-sections, there are many factors that are affecting the costs that come from inventory and transportation, and that in most cases it is not possible to reach the minimum for both of these simultaneously; instead the right kind of optimization between these two costs should be the aim. This relation of transportation and inventory leads again to the overall aim of this study: to investigate how transportation time affects inventory in the means of levels and costs.
Referring to the second research question of this study, "What models and frameworks are available to investigate the correlation between transportation time and inventory?", this sub-chapter takes a deeper investigation to evaluate critically models and frameworks that investigate the correlation between transportation and inventory, concentrating on the relation of inventory and transportation time.

As have been mentioned before, the subjects of inventory management and transportation have been widely researched in literature. In addition to that, the relation of transportation and inventory has had the interest of many authors. In a research from the 80's, Burns et al. (1985) develop a method that aims to minimize transportation and inventory costs by optimizing the trade-off between these costs. The focus is on the situations under known demand.

Burns et al. (1985) consider two kinds of transportation strategies and their relation to costs in inventory and transportation; direct shipping (one-to-one deliveries) and peddling (one-to-many deliveries). Interesting to notice is that they state their models not to be dependent on the type of supplier. It could be e.g. manufacturer, warehouse or distribution center. However, one of the main constraints used is the time from production to shipping. Therefore it refers that the usability of this model is mainly meant for manufacturing environments. Especially the direct shipping strategy is interesting in this study, because in that Burns et al. (1985) consider among other factors, also transportation time as one important factor. However, even in this case the model by Burns et al. (1985) considers also that there are multiple customers to serve. When considering the peddling strategy, the authors emphasize the dependence of the number of customers and the density of them.

Burns et al. (1985) compare the results of the peddling and direct shipping with each other. They find that in the case of direct shipping, the optimal size of shipment is less than a full truck, while in case of peddling the trucks should always be full to attain the minimum costs. They also take into consideration the value of the items, stating especially in a case of valuable items, peddling is less expensive. Even thought Burns et al. (1985) concentrate mainly to the peddling strategy and the context is single-supplier and many customers with main focus on minimizing the distribution costs of freight trucks, the relation of inventory and transportation is considered.

In a relatively early research, Speranza and Ukovich (1994) investigate the relation of transportation and inventory costs. The context in their research is a multi-product production system which is based on the fact that with more frequent deliveries, average inventory levels can be reduced, while the transportation costs increases simultaneously. Therefore the main concentration is on transportation frequencies; what quantity of products to ship at each frequency to minimize the total transportation and inventory costs? In addition to that it is assumed that the products are produced in a single location and they are transported to a single destination but further required in different locations. The demand of the products is constant and known and the cost for each truck delivery is constant with finite capacity of vehicles to use.

Speranza and Ukovich (1994) consider four different types of scenarios with two different types of shipping policies (total loading or partial loading) and consolidation rules (time consolidation or frequency consolidation). They further state that when using mostly full loading practice, but allowing also partial loading with the shipments traveling at the lowest frequencies, the overall costs can be reduced. However, in this case the products that need to travel at different frequencies, cannot share same trucks. In this model as stated before, the main focus in on the transportation frequencies. It assumes that the transportation time in all situations is the same. Even though, the frequency of transportation is also an aspect to consider, this model does not take into account how the actual reduction of the transportation time affects the inventory and how it could be reduced.

Bertazzi et al. (1997) use the model introduced by Speranza and Ukovich (1994) as a base, when they investigate a logistics system with one origin and several destinations for several products, while Speranza and Ukovich (1994) focused only on a single link with single origin and single destination. The authors further state that their model could also be used from several destinations to a single origin respectively. Bertazzi et al. (1997) aim to minimize the transportation and inventory costs by optimizing the transportation frequencies used in shipments. They argue that usually models that use continuous frequencies cannot be used in practice, and therefore the frequencies used in their model are following given sets. The constraints used are that there is limited capacity for a truck and that the customer demand for each product for each destination has to be fulfilled. According to their model, it is possible to ship different products with different frequencies, which the authors emphasize to be important in order to maintain the utilization of the trucks. However, as well as the model introduced by Speranza and Ukovich (1994), Bertazzi et al. (1997) has the main focus on transportation frequencies. They do not consider transportation time reduction and its effects on the inventory levels and costs resulted.

Tyworth and Zeng (1998) introduce a model to estimate the effects of carrier transit-time performance on logistics costs and service. They focus on the demand and lead time uncertainty, stating that typically transportation-inventory models cannot perform well under such circumstances. The authors assume that the inventory is controlled by continuous review inventory system (based on reorder point and quantity) with independent demand. Tyworth and Zeng (1998) also assume that transportation costs are not linear function of order quantity and that the transportation is between single origin and destination. This model could also be used in different contexts, e.g. from vendor to replenish repair-part, from production to supply or from distribution center to a field warehouse.

The model illustrated by Tyworth and Zeng (1998) is highly related to the focus of this study. They investigate transportation between single origin and destination and the concentration is on how logistic costs respond to changes in the transit time.

Kutanoglu and Lohiya (2008) present a model for minimizing inventory and transportation costs, while having the wanted service level at place simultaneously. In other words, this model is aiming to optimize the costs coming from inventory and transportation functions, while taking care at the same time that the constraint of the needed service level is met. The products investigated in this case are service parts with stochastic demand. The model is used in single-echelon environment with many facilities meaning that there are multiple distribution warehouses serving multiple customer locations. The possible transportation speeds that could be used are low, medium and fast. In addition to that Kutanoglu and Lohiya (2008) have included penalty level as one of the main concentrations for the model and base-stock inventory model is used, which means one-to-one replenishment policy.

After simulating and analyzing four different networks with the model, Kutanoglu and Lohiya (2008) conclude that in some cases it is preferable not to stock all items in all locations. They further emphasize that in case of certain items, using faster transportation from central warehouse, inventory and warehousing costs can be saved, while still satisfying the customer demand. However, the context this model is created for differs slightly from the main focus of this study. The model introduced by Kutanoglu and Lohiya (2008) has concentration on multiple distribution warehouses and the transportation from these to multiple customer locations, while the mainly investigated interval in this study is between central warehouse and a distribution hub.

Another model to consider simultaneously inventory and transportation decisions is presented by Kang and Kim (2010). This model has a relatively wide area to cover; it investigates a two-level supply chain by taking into consideration both inventory levels of many retailers and demand of many final customers of these retailers. However, the model uses only single type of products. The model aims for setting optimal replenishment quantities and timings for the retailers. In addition to that it takes into consideration how much products should be delivered to retailers in each vehicle to minimize the total costs for fixed vehicles.

As mentioned, the model focuses on a single regional distribution center and multiple retailers dedicated to that. The consideration is on reducing the overall costs of inventory and transportation in the whole supply chain. Therefore the area to cover for this model is relatively wide. The vehicles are assumed to be homogeneous with finite capacity. In addition to that the model takes into consideration the material handling costs at the retailer locations in part of the transportation costs, which differ depending on the retailer in question. Kang and Kim (2010) state that this results to a situation, where the amount of vehicles and the frequency for sending them should be reduced in order to reduce transportation costs. However, this further leads to increased inventory holding costs for the retailers. Therefore the aim is to consider a coordinated planning problem which reduces the overall costs.

Kang and Kim (2010) further conclude that when using smaller replenishment quantities the decreasing of the inventory holding costs are greater than the increased transportation costs resulted from more frequent deliveries.
This model investigates the relation of transportation costs and inventory costs, but to be absolutely usable in this study, it lacks the consideration of the transportation time, which is under the main inspection in this study. Instead of considering differing transportation speed or time, it has the main interest on the transportation frequency and also the handling costs at retailers' locations have huge effects on the transportation costs. In addition to that the study of Kang and Kim (2010) questions only a single product type in this model.

Qu et al. (1999) offer a model to investigate integrated inventory and transportation system. The focus for their model is to minimize the total average costs that consist of inventory and transportation costs. The authors consider multiple-item replenishment problem with a stochastic demand under a periodic-review inventory policy. Qu et al. (1999) emphasize that in order to minimize the total costs of transportation and inventory, these functions have to be closely coordinated. However, in their model, Qu et al. (1999) consider a system with several suppliers which are providing replenishments for a central warehouse and they further state that their model is formulated to be used from a point of view of manufacturer. In addition to that the model has high concentration on the routing of the vehicles rather than the actual transportation time of the vehicles. Also Mason et al. (2003) emphasize the importance of integration of inventory and transportation functions. They stress further that because of today's increasing influence of internet and e-commerce, the need for integrated systems for managing inventory and transportation is crucial. Main reason for that is the use of even smaller and more frequent shipments in order to keep the inventory costs as minimum. With a highly integrated management of these logistical functions, the variability of lead time could be reduced to increase reliability.

Zhao et al. (2010) introduce a model based on vendor managed inventory which considers different transportation modes and costs with the relation of inventory issues. The authors state that typical models that use integrated transportation and inventory functions are either too simplified or not suitable to a situations investigated in real life.

According to them, the gap between theory and practice investigating integrated transportation and inventory models is still wide. The model presented by Zhao et al. (2010) is used in two-echelon logistics system with single origin and multiple destinations under stochastic demand. They take into consideration different transportation modes with different capacities and costs. In addition to that constraints i.e. lead time and penalty costs are considered fully.

While emphasizing the high uncertainty in demand, Zhao et al. (2010) introduce a Markov decision process (MDP) which they further state to be useful e.g. when determining inventory levels under uncertainties and it results in lower average inventory levels. The inventory levels are reviewed periodically in the context for the model of Zhao et al. (2010). The model aims for the optimal delivery quantity while meeting the demand with using the just-in-time (JIT) practice. In addition to investigating only the transportation between the central warehouse and its delivery destinations, subsidiaries, the authors take the order decisions of the central warehouse into account as well. The model offered by Zhao et al. (2010) is comprehensive and it could be used in different contexts. It aims to take as many factors as possible into consideration and to provide a model that would not only work in theory, but also in real life situations.

Mattsson (2007) claims that traditional inventory control methods cannot be used properly with short lead times. He states that in cases with short lead times, the desired customer service levels cannot be ensured. He also declares that most of the theoretical models introduced in literature cannot be used properly in real life situations. As reasons for that he gives e.g. too complicated to be understood or used, based on too restrictive assumptions or requires input data that is not available in normal situations. Mattsson (2007) introduces enhanced versions of basic inventory control models and illustrates their advances using simulations. The concentration of the model presented by Mattsson (2007) is on modified reorder formulas with the focus on safety stocks and service levels in an environment with short lead time. The model could be useful in real life situations, but when investigating the effects of transportation time to inventory, it does not fully take into consideration the transportation time as a requirement.

Bertazzi and Speranza (1999) formulate a model for multi-product logistics network with a constant and known demand rate. Their problem is for system with one origin, one or more intermediate nodes in between and one destination node and it aims to minimize the total costs of inventory and transportation of the network by determining each link a periodic shipping strategy. Their assumptions and constraints are that there are set of possible shipping frequencies, transportation capacity is finite, demand has to be met during a set time horizon and no stock-outs of the destination are allowed.

The authors state that typical EOQ based models are not necessarily suitable in practical real life situations, mainly because they usually give non-integer solutions. In addition to that they construct formulations for the inventory cost to help to reduce number of constraints and decision variable to make it easier to use in practice. To conclude the main focus of this model, is that it concentrates to the transportation frequencies and therefore there is not investigated the actual effect of transportation time. Accordingly

Bertazzi and Speranza (1999) assume in their model that transportation time is constant, whatever mode is used.

Lutz et al. (2003) offer an interesting method for evaluating performance of inventory and consequently setting suitable targets for service levels and reducing inventory levels. Their investigation focuses mainly on manufacturing environment. However, the items under consideration are finished products from the production processes. The authors introduce operating curves which are helpful for evaluating limit values of logistical objectives for single items in inventory. Therefore these curves can be used to display relations between logistics performance measures. The main types of curves illustrated are service level operating curve and delivery delay operating curve. These curves show the dependency between delivery capability, which is specified by mean delivery delay, service level and mean inventory level. For the transportation point of view it is interesting to notice that the importance of delivery quantity, reliability and delivery date are under main inspection of the delivery delay operating curve.

Madadi et al. (2010) introduce an extension for the basic EOQ model in their model when aiming for minimizing total inventory and transportation costs. The authors consider transportation costs to be part of the inventory costs. They exclude transportation costs from ordering costs in their formulated EOQ model and consider it as a discrete cost arguing that most inventory management strategies do not take transportation costs into consideration carefully enough. They stress that usually the transportation cost is neglected or included into another cost e.g. into setup cost. In addition to that Madadi et al. (2010) introduce two other models; for decentralized and centralized ordering policies, stating that centralized orders where many receivers send a collective order to one supplier have not been investigated widely in literature. The environment for the models is multi-level meaning that it consists of single supplier, single warehouse and several retailers used with single-item inventory under normally distributed stochastic demand.

In addition to that Madadi et al. (2010) take both inventory policies, at the warehouse and at retailers into consideration. Another aim they have is to solve if the centralized ordering method can lead to savings in transportation and inventory costs. Even though they consider the distance between transports as a factor in the transportation costs as well as fixed and variable costs of transportation, the actual relation of the transportation time and inventory levels is not easy to be seen.

Rieksts and Ventura (2008) investigate the relation of inventory models and transportation modes. The aim is to optimize the inventory policies and transportation functions by determining optimal order quantity and the best transportation mode for that. The authors argue that in many inventory models, the cost per load does not change with the number of truckloads. They further state that cost improvements can be achieved by allowing the combination of different transportation modes to be used simultaneously. Therefore they assume that two different kinds of modes can be used or the combination of both; truckload and less than truckload. The main constraint is that the constant demand rate has to be met without shortages and the context for the system is one-stage model with infinite horizon.

As conclusions Rieksts and Ventura (2008) state that in order to meet the optimal order quantity for inventory, in some cases it is recommendable to use mixed transportation methods, because the normal models for optimal order quantity does not take the capacities for trucks into consideration. The way how the relation of the inventory models and transportation modes is investigated by these authors is interesting, but the actual effects of transportation time has lower interest, while the main focus is on what kind of transportation mode to use in order to use the capacity in the best way.

Vernimmen et al. (2008) emphasize how the safety stock forms a crucial component in total logistics costs under stochastic demand. They also judge that usually in inventory management models with stochastic demand the demand during lead time is normally distributed, but that gives invalid results in real life situations. Consequently they suggest that lead time demand should follow gamma distribution. Therefore Vernimmen et al. (2008) emphasize the importance to concentrate on lead time and the demand during that time. As a result of that the authors state that transportation speed and transit time reliability should be under major interest when determining inventory management model for safety stock. They further state that the higher the service level wanted, the higher the safety stock. That results from their assumption that depending on the transportation mode used, the lead time is not usually constant.

Zhao et al. (2004) introduce a model for inventory management which is based on the EOQ formula. The model works in supplier-retailer system with a constant demand. In a similar way than Madadi et al. (2010), the authors emphasize that the traditional EOQ models does not take transportation costs into consideration clearly enough. It is either included into the production or ordering cost. They further identify transportation costs to consist of fixed and variable costs where variable costs are directly dependent on the transportation distance. Zhao et al. (2004) offer an enhanced model of EOQ where both fixed and variable transportation costs are considered. Therefore this model aims for minimizing transportation and inventory costs as well production costs at the same time. Interesting to notice in that model is that unlikely many similar models introduced, it takes also the time for transportation into consideration.

3.8 Summary and conclusions

It is relevant to summarize what has been written in the literature review chapter and to conclude how this information will be used in the empirical research. Therefore in this sub-section the literature review will be summarized and concluded and the usage of these conclusions in the empirical research will be stated.

Both inventory management and transportation are main functions in logistics. The main aim of inventory is to provide the customer service level needed while keeping the inventory levels and that way the inventory costs as minimum. Transportation is important activity that has to be managed in a correct way to make this possible. It is stated in theory that both inventory and transportation costs are major parts of creating total logistics costs. Therefore in order to minimize the total costs, the right relation of transportation and inventory costs should be found. However, this might create tension between different departments, because of their varying aims.

Many authors in journal articles offer varying models for optimizing the functions of inventory management and transportation to attain the minimum total costs. Most of the models evaluated in this study are expanding standard models and formulas introduced in theory to achieve this. Some of them have a major focus in inventory while others concentrate more to the transportation aspect. The context they work and the environment they are suitable differs also a lot. Some authors investigate mainly the manufacturing environment while others have the focus on distribution network for serving the customers or how to supply the retailers in between, or even both. Therefore the context and focus varies a lot also between the amounts of levels of inventories. In addition to that, some authors concentrate to offer models for single item system, while others use several or multi-item systems. In this particular study maybe the most important thing to notice is that most research about offered models concentrate to the frequencies of transportation rather than the actual transportation time. Transportation frequency is, of course highly related to the transportation time and has major effects in the total costs optimization, but from the point of view of this particular study, the main interest is to see how the actual transportation time reduction or change affects inventory.

Also from the perspective of this particular study, what could be concluded to be most relevant from the theory to be used in the empirical research, many of the key factors introduced before are needed to be used in order to carry out the empirical research. To start with, the average inventory levels are under main concentration. As a result of that, the way average inventory is defined and the factors connected to that i.e. order quantities, safety stock and in transit stock should have high level of consideration. In addition to that, as the aim is to solve also how the inventory costs change depending on the transportation time, the definition and consistency of inventory carrying costs are needed. The exact factors and formulas used in the empirical research are introduced in more detail in the upcoming sub-chapter *4.3 Framework for data analysis* and in chapter *5 Findings.*

The summary and conclusions given from the literature review, lead to the following sub-section, where the exact need for empirical research is stated in more detail.

3.9 Need for empirical research

To remind about the third research question, “In what ways does a faster transportation mode affect the inventory costs and what can be said about the transportation costs in this relation?”, this section identifies and states the need for empirical research of this study. As mentioned in the very beginning, the problem investigated in this study emerges from the need of an organization to solve, what effects a change for using faster transportation mode would have in costs in inventory and transportation. Thus far, relevant theory and models offered by various authors in journal articles have been examined and evaluated.

It is clear what is stated in theory about the effects of shorter transportation time to inventory and what factors have to be taken into consideration. With reduction of transportation time, the inventory levels should be reduced and as a result of that the inventory costs should decrease. By carrying out an empirical research it should be possible to see clearer which particular factors affect to which parts of the costs and how. As stated before, important factors to consider are e.g. average inventory and consistency of inventory costs. As a result of that it is recommendable to test with an empirical study in an environment of a real life company how this relation could be seen in practice and how much the actual reduction of the inventory costs will be. It is also interesting to look at the transportation costs in this relation.

In a similar way, many different kinds of models are offered in the literature, i.e. journal articles. As concluded in the former sub-chapter the context and focus for the models differ a lot. Most research about offered models concentrate to the frequencies of transportation rather than the actual transportation time. In addition to that, some authors argue that usually these models offered, cannot be used in practice in a similar way.

Therefore it is important to carry out an empirical research to get results from a primary source in a practical way. It is reasonable to explore how this exact relation of transportation time and inventory work out in a real life company and in this particular context they act in by investigating the reduction of transportation time and its effects on inventory in levels and costs. In addition to that it is interesting to see how the transportation costs act in this relation.

4 Methodology

4.1 Introduction

When looking at the research objectives and the research questions that have set for this study, they can be divided into three categories:

1. Research questions 1 and 2

   1: *"What are the factors in inventory management that alter depending on the transportation time and frequency?"*
   2: *"What models and frameworks are available to investigate the correlation between transportation time and inventory?"*

   These research questions were carried out in this study by reviewing and analyzing relevant literature sources i.e. books and journal articles. That was explained in more detail in the earlier section of this study in methods for the literature review, *3.2 Methods for the literature review.*

2. In a similar way, research question 3

   3: *"In what ways does a faster transportation mode affect the inventory costs and what can be said about the transportation costs in this relation?"*

   This research question was solved out by carrying out an empirical research, because there was seen a need to investigate how a real life company is dealing with such processes. Consequently, data was collected in order to be able to perform the analysis. The need for the empirical research was discussed in more detail in the previous sub-chapter 3.*9 Need for Empirical research.*

3. The last category consists of the research objective 4

   4: *"As a result of these a framework how the transportation time affects inventory will be developed."*

   To solve this, combination of both the first and second categories with first three research questions were used. Accordingly, all the three research objectives and questions were needed to be done, in order to complete the fourth research objective.

The concentration of this chapter is on the research question 3, which was done by carrying out an empirical research in a case company.

In the later sub-sections of this chapter, the research strategy and data collection methods are introduced in more detail. That is done to offer enough validity for the research. Respectively, the exact information how the research was constructed and the questions what were included into the interviews are introduced to gain reliability for the research. In addition to that, framework for data analysis will be introduced as well as the limitations the research methods of this study have brought up.

4.2 Research strategy and data collection

As mentioned in the former sub-section, in order to answer the first two research questions, relevant literature were analyzed. This part of the study was carried out by completing a literature review to first identify and introduce a relevant theory of the relation of inventory management and transportation and then to evaluate models offered by various authors about investigating the relation of inventory management and transportation concentrating to the effects of transportation time to inventory. The literature review was done by using a number of relevant literature sources i.e. books and journal articles.

There was risen the need for empirical research that was completed to answer to the third research question. As mentioned, the need for empirical research was discussed in more detail in a former sub-chapter 3.*9 Need for empirical research.*

The empirical research was done by using a case study research strategy. Case study was chosen for this research, because the focus was on one part of a particular organization and by using case study the data and information needed for the empirical analysis were possible to gain. As Yin (2009, pp. 4-5) states, the case study is a suitable strategy when a real life event e.g. processes or performance of particular organization should be investigated. He further states that it allows maintaining the important characteristics of the event investigated. Blaxter et al. (1996, pp. 66-67) state also that case study is suitable for researching a part of an organization with a focus on only one or few examples. Therefore the research strategy chosen for this study appears to be appropriate and to give enough validity for the research. In a similar way, also the data collection techniques described below are appropriate for the research strategy used, which ensures validity for the research.

The data collection was performed using structured interviews with both closed and open-ended questions. Using structured interviews the exact answers needed could be gained. The combination of both closed and open-ended questions was used to make sure to get specific answers and also to offer the possibility for the interviewed to express their ideas further. As Blaxter et al. (1996, pp. 153-154) state, interviews can be very useful in situations when it is unlikely to get access to certain information by using observation or questionnaire techniques. Also Yin (2009, pp. 106-107) states that usually in case studies, the one of the most important sources to gain information is using of interviews. However, as result of the interviews, not all the questions could be answered straightforward. Therefore, based on the interviews, also data from the activities of the case company, i.e. performance data and values were received and analyzed in order to gain the information needed for the empirical research.

The empirical research was qualitative in nature, because the data was gathered by carrying out interviews, even though some of the answers were found out by analyzing data. As defined by Blaxter et al. (1996, pp. 60-61), qualitative research aims for focusing as detailed information as possible, while quantitative research aims for wider breadth. Therefore, even most of the data needed for empirical research in this study is numerical data, the way it was collected and handled was still qualitative rather than quantitative. According to Silverman (2000, p. 2) qualitative research could be understood as more flexible to carry out than quantitative research. He further states that with using qualitative methods, it encourages researcher to be more innovative. That could also be seen in this particular research, because being flexible and innovative was important when executing this research.

The sampling technique used was a mixture of non-probability sampling techniques: quota and convenience sampling. The mixture of these sampling techniques were chosen, because the aim was only to use one particular contact person for the interviews and also because the contact person used were the only one to get accessed at the case company and to provide the information needed in the organization. As defined by Biggam (2008, pp. 89-90), in quota sampling the number and type of members included into data collection are defined beforehand and in convenience sampling, the particular interviewed is selected because it is convenient for the researcher, e.g. target that could be accessed at a organization researched. Cohen et al. (2007, pp. 113-114) also state that in convenience sampling, the target with easy access is chosen. Therefore, the data collection was done by interviewing a particular manager in the case company at the premises of the company. The interviews took place twice. For the sake of non-disclosure agreement, no names of persons or the case company are revealed in this study. To offer reliability for the research, the questions used in the interviews can be found from the *Appendix A*.

4.3 Framework for data analysis

Two kinds of data were gathered by performing interviews; direct answers for questions asked, and performance data charts of the case company. Most of the direct answers could be used in the analysis of empirical research without further processing of the data. The performance data received for the study had to be analyzed further in order to reach the information needed. In this sub-section the framework for data analysis will be introduced to explain how the data collected was planned to be utilized in the analysis of empirical research.

It seems relevant to remind about the third research question at this point once again:

"In what ways does a faster transportation mode affect the inventory costs and what can be said about the transportation costs in this relation?"

In order to find out how the reduction of transportation time by using faster transportation mode affects the inventory costs, it was helpful to first investigate the effects on inventory levels.

Therefore the analysis of the data was first done to explore the current situation, which is called *Situation 1* in this study (See Figure 4.1). In the *Situation 1* the average inventory levels resulted from the current transportation time were calculated. Then the transportation and inventory carrying costs for this situation were calculated.

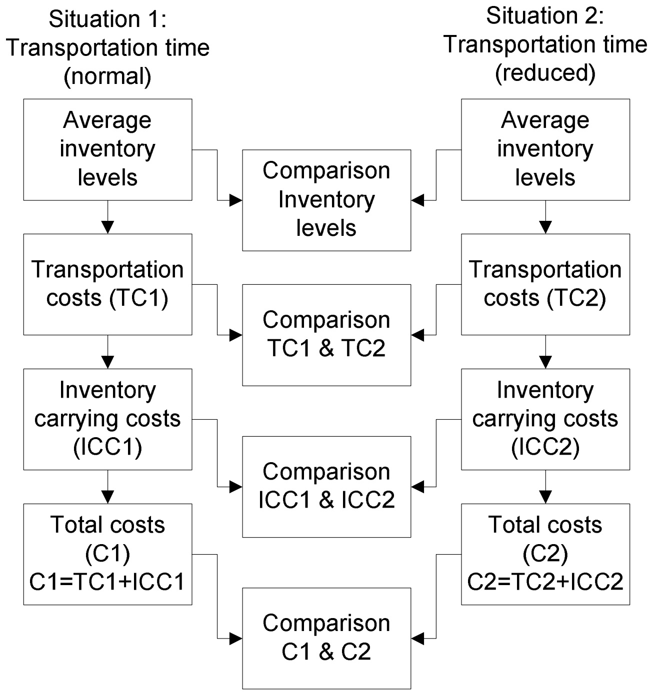

Figure 4.1 Framework for data analysis

After that in the *Situation 2,* transportation time using the reduced time resulted from the faster transportation mode was used to introduce the average inventory levels. Then the same procedure than for *Situation 1* was done to *Situation 2* to calculate transportation and inventory costs resulted from this new transportation mode.
After completing the actions mentioned for both of the situations, the relation between the inventory levels were compared. Then the total costs resulted from the *Situation 1* and *Situation 2* were calculated and compared. Also the relation between inventory costs alone in both situations was illustrated and the same was done for the transportation costs.

Average inventory

The formula for calculating the average inventory levels was used as:

$$Average\ inventory = \frac{Order\ quantity}{2} + Safety\ stock + in\ transit\ stock$$

First the factors included into average inventory (order quantity, safety stock and in transit stock) were calculated for all the items separately and then the results were summed together to be able to calculate the average inventory levels for all the items together:

$$\sum_{i=1}^{n} AI_i = \left(\frac{\sum_{i=1}^{n} Q_i}{2}\right) + \left(\sum_{i=1}^{n} SS_i\right) + \left(\sum_{i=1}^{n} IT_i\right)$$, where

AI = Average inventory;
Q = Average order quantity;
SS = Safety stock;
IT = In transit stock; and
n = amount of item numbers.

The factors needed in the average inventory formula were achieved in a following way:

- Safety stock values for items were received based on the interviews.

- Average order quantities were calculated with the data received by analyzing the data from the performance charts by using following formula:

$$Average\ order\ size = \frac{Total\ annual\ demand}{total\ annual\ times\ of\ departures}$$

  The value for total annual times of departures was used as 260, because departures were taking place once every day. (Assuming that departures were taking place only on weekdays (52 weeks *x* 5 days a week)).

- In transit stock was calculated by:

$$In\ transit\ inventory = Transportation\ time\ (days) \times Daily\ demand$$

Transportation costs

For transportations an outsourced transportation company was used. The total annual transportation costs were calculated based on the annual number of units transported. The transportation cost per unit for each item was found out to be the same and constant. Therefore the costs for transportation in this case are dependent only on the annual number of units and they are independent which particular items are being transported. The values for cost per unit were received based on the interviews. The annual transportation costs were calculated as following:

$$TC = Annual\ demand \times Transportation\ Cost\ per\ unit$$, where

TC = total transportation cost

It is important to mention here that for calculating the transportation costs in this particular case, the formula introduced above could be used. That is because the transportation costs were given as cost per unit and the cost is constant. However, if the transportation costs would have been given as cost per kilo or volume, the ratio of units of different items would have had more influence and the weight and volume of each item would have needed to be taken into consideration. Also important to notice is that the consideration is on total annual transportation costs, rather than transportation cost per each delivery.

Inventory carrying costs

In this study, the term inventory carrying cost is used to illustrate the total inventory costs. Inventory carrying costs were calculated using the following formulas:

$$ICC = AIV \times ICR \text{, where}$$

ICC = inventory carrying costs;
AIV = average inventory value; and
ICR = inventory carrying rate

Average inventory value was first calculated for each item separately, and then summed together to have the average value for all the items together which was then used in the formula:

$$\sum_{i=1}^{n} ICC_i = \sum_{i=1}^{n} AIV_i \times ICR$$

The values for units of items which were needed in these calculations were received from the performance chart of the case company. The average inventory value for items was calculated using following formula:

$$AIV \ = AI \ \times UIV \text{ , where}$$

AIV = average inventory value for an item;
AI = average inventory level in units for an item; and
UIV = unit value for an item

To receive the summed results for the total average inventory value, following formula was used:

$$\sum_{i=1}^{n} AIV_i = \sum_{i=1}^{n} (AI \times UIV)$$

However in the literature reviewed, the inventory carrying rate was mentioned to be commonly determined by the company and to take into consideration the costs of tied-up capital, insurance, obsolescence, losses, taxes, storage and labor. In this particular case of the case company, only costs of storage and handling were considered to specify the inventory carrying costs. This is explained in more detail in following chapter, *5 Findings.* Therefore there was a need to calculate inventory carrying rate for the case company that could be used to calculate the inventory carrying costs. The inventory carrying rate for case company was calculated with following formula:

$$ICR = \frac{\sum Storage\,and\,handling\,Costs}{\sum Average\,inventory\,value} \times 100\%$$

However, in order to have a wider view how the inventory carrying costs in most cases are dependent on the transportation time taking especially the tied-up capital into consideration, also alternatively exemplary calculations were done for the inventory carrying costs by using an inventory carrying rate of 25% of the value of the item. That percentage was used based on the common values introduced in the literature, and considering it to include also the tied-up capital, insurance, obsolescence, losses, taxes as well as the storage and labor costs all together.

Total costs

For calculating the total costs, the inventory carrying costs and the transportation costs were summed:

$C = ICC + TC$, where

C = Total costs;
ICC = Inventory carrying costs; and
TC = Transportation costs.

The more precise calculations used are introduced in the next chapter *5 Findings.* Before presenting the actual findings of the empirical research, the limitations of using the research methods for this study are stated.

4.4 Limitations

Maybe the most visible limitation raised by the research strategy used in this study is the using of quota and convenient sampling technique with choosing only one person to be the interviewed. That could lead to biased data. On the other hand, most of the questions used in the interviews were closed questions that could not be possible to answer in a different way. Most of the answers needed were exact performance figures and values. Therefore the data collected cannot be too biased to lose the reliability of the research.

To concentrate on the possible limitations of case study research method, Yin (2009) stresses that all research methods have their limitations. A common claim against case study method is that it makes it more difficult to follow systematic procedures in the research. In addition to that he claims that case studies could have easier biased views that could have effects on the final conclusions. Another typical complaint against case studies is that by using a single case, the results cannot be generalized.

As stated by Yin (2009), a limitation in this study could also be that the results cannot be generalized, because only one case company was used. However, the results for the case company were calculated using two different scenarios. The transportation between the central warehouse and the distribution hub was done similarly for cases of two distribution hubs in different countries. This gave a wider view, because the results were gathered and calculated for two cases in different countries. However, both cases were similar and not so many differing values were used. This will be explained in more detail in the following chapter, *5 Findings.*

Also another limitation was that in the inventory carrying rate used for the case of case company, only the storage and handling costs were considered, leaving the effects of especially tied-up capital aside. However, therefore the alternative example for the inventory carrying costs using the percentage of 25 were introduced to an alternative approach and illustration for the inventory carrying costs.

As mentioned about the flexibility offered by quantitative research method, Silverman (2000, p. 2) also emphasizes that on the other hand, too much flexibility could be criticized to lead to lack of structure for the research. Therefore it is critical to have a high concentration on the structure of the study, to avoid the limitation raised by the flexibility issue.

5 Findings

5.1 Background

In this chapter of findings, the actual results of the empirical research are revealed. The chapter starts with a sub-section explaining the background for the empirical research in more detail including the description of the case studied. That will be followed by introducing the results of first the situation with the transportation time today and then the results of the situation for the reduced transportation time. The results for both of these cases are explained with necessary calculations and lastly, a comparison for these results will be shown. The actual analysis and discussion about these findings will be presented in the following chapter *6 Analysis and discussion.*

As have been mentioned before in this study, the original need for the empirical research was raised by a case company that wanted to find out how a change for using a faster transportation mode with reduced transportation time would affect their inventory levels and the costs of inventory and transportation. Before presenting the actual findings of the empirical research, a more detailed case description is reasonable to be illustrated. That will be done in the following sub-section.

5.1.1 Case description

What was mentioned in the earlier sections of this study, for the sake of non-disclosure agreement no name of organization will be revealed. Therefore the name for the company used in the empirical research, is presented as *the case company.* The case company investigated in the research is a provider of mainly computer appliances and equipment. The part of the organization which is under investigation in this research is concentrated for providing spare parts for their products for a particular region. For serving the customers in the region, several distribution centers are used with one of them acting as a main country hub. The items stored in country hub (called in this study only as distribution hub) are resupplied from the central warehouse. The central warehouse is located in another country than the distribution hub, and the transportations are done by road using trucks of an outsourced transportation company. The focus in this research is on the transportation between the central warehouse and the distribution hub while concentrating to the inventory levels in distribution hub. A simplified picture of the environment is illustrated in Figure 5.1.

In this research, two similar cases with distribution hubs in two different countries are considered. The distribution hubs in the two countries are independent on each other. The countries in question are illustrated as *country A* and *country B.*

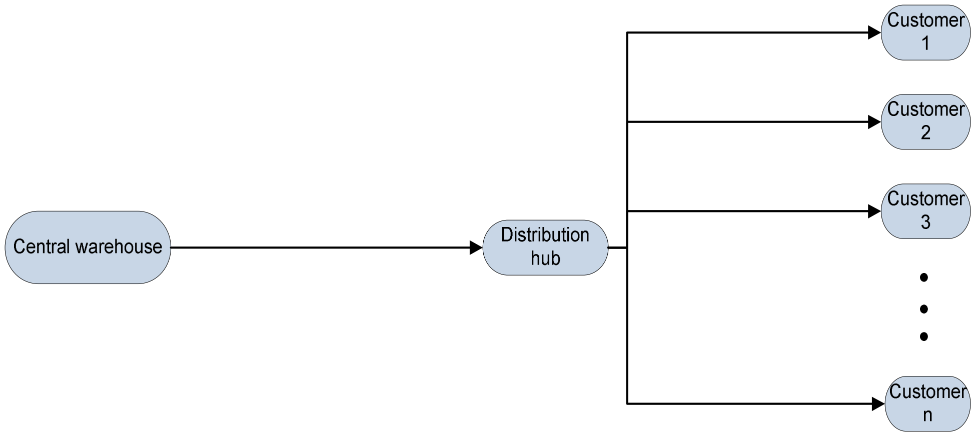

Figure 5.1 Case environment

Therefore the case under investigation is a single link between one origin (central warehouse) and one destination node (distribution hub). The case consists of multiple items and the inventory at the central warehouse is assumed to be infinite. Therefore the inventory levels are considered only at the destination node. The demand for the items is known. Transportation time between the origin and destination is constant as well as the transportation frequency (one delivery each day). In addition to that the transportation time is considered to be the same as the lead time. From the moment for placing the order from distribution hub, the delivery leaves the next day from the central warehouse. In other words, there is no additional setting time for the deliveries leaving from the central warehouse to the distribution hub. The transportation time (= lead time) today is four days from central warehouse to the distribution hub. In the possible situation with the faster transportation mode, the transportation time (= lead time) is reduced to one day. Therefore the effects of that reduction of the transportation time to the inventory at distribution hub are under main investigation in this research.

The amount of total item numbers handled are around 10 000. However, because there are many items having really low demand, based on the 80/20 –rule only around 20 percentage of item numbers are considered in the study.

Also to be noticed is that as introduced in the earlier sub-section, *4.3 Framework for data analysis,* the case company does not consider the tied-up capital to be included into the inventory carrying costs from the point of view of the distribution hub. The inventory carrying costs considered in this case are consisting only on the storage and handling costs. In addition to that, based on the interviews, the inventory carrying costs for the actual situation, Situation 1, with transportation time (lead time) of 4 days was received (237 000 SEK, same for both countries in question). Therefore the inventory carrying costs for situation 1 was used to calculate the inventory carrying rate, which was further used to calculate the inventory carrying costs for situation 2. Because the inventory carrying rate calculated for the case company takes into consideration only the storage and handling costs, also another exemplary scenario with higher inventory carrying rate of 25 percent is introduced alongside the results of the actual case company to illustrate better the effects of tied-up capital to the inventory costs.

Because values received from the case company were in different currencies (e.g. unit values in US dollars, transportation costs in Euros and inventory carrying costs in Swedish Kronas), it was necessary to change the currency for some of the results in order to have all the costs under same currency. As this study was carried out in Sweden, Swedish Kronas were used. The following currency rates offered by XE (2011) were used to convert the results in Euros and US dollars into Swedish Kronas (currency rates used in the study were dated on 2011-05-02):

1 USD = 6,01 SEK
1 EUR = 8,93 SEK

In the next sub-sections the actual findings from the empirical research will be presented. Also the necessary calculations for gaining these results are shown.

5.2 Situation 1

The situation 1 considers the transportation mode which is used today (transportation time is 4 days). First the average inventory levels for this transportation time are calculated. After that the average inventory levels are used to calculate the inventory carrying costs and transportation costs for this situation. Also as mentioned, the results from two similar cases in distribution hubs in different countries are introduced simultaneously.

Average inventory for Situation 1: Country A

The formula used for calculating average inventory levels was following:

$$\sum_{i=1}^{n} AI_i = \left(\frac{\sum_{i=1}^{n} Q_i}{2}\right) + \left(\sum_{i=1}^{n} SS_i\right) + \left(\sum_{i=1}^{n} IT_i\right)$$, where

AI = Average inventory;
Q = Average order quantity;
SS = Safety stock;
IT = In transit stock; and
n = Amount of item numbers.

Following values for this situation were used:

$$\sum_{i=1}^{n} Q_i = \frac{Total\ annual\ demand}{total\ annual\ times\ of\ departures} = \frac{86929}{260}$$

$$\sum_{i=1}^{n} SS_i = 3570$$

$$\sum_{i=1}^{n} IT_i = Daily\ demand \times Transportation\, time\ (lead\ time) = \frac{86929}{365} \times 4$$

Transportation time (lead time) = 4 days

n = 1435

Using the formula illustrated before, following results were achieved for the average inventory levels:

$$\sum_{i=1}^{1435} AI_i = \left(\frac{\frac{86929}{260}}{2}\right) + (3570) + \left(\frac{86929}{365} \times 4\right) \approx 4690\, units$$

Result:

Average inventory for situation 1 for country A ($AI1_A$) = 4690 units

Average inventory for Situation 1: Country B

In a same way, the same formulas were used for this situation, but with following values:

$$\sum_{i=1}^{n} Q_i = \frac{Total\ annual\ demand}{total\ annual\ times\, of\ departures} = \frac{89851}{260}$$

$$\sum_{i=1}^{n} SS_i = 3267$$

$$\sum_{i=1}^{n} IT_i = Daily\ demand \times Transportation\, time\ (lead\ time) = \frac{89851}{365} \times 4$$

Transportation time (lead time) = 4 days

n = 1236

The calculations for the average inventory levels:

$$\sum_{i=1}^{1236} AI_i = (\frac{\frac{89851}{260}}{2}) + (3267) + (\frac{89851}{365} \times 4) \approx 4424\,units$$

Result:

Average inventory for situation 1 for country B ($AI1_B$) = 4424 units

Inventory carrying costs for Situation 1: Country A

As mentioned in the sub-chapter, *4.3 Framework for data analysis,* the inventory carrying costs were calculated in two different ways. First the way for the actual case company will be introduced here, and that will be followed by the alternative example.

The calculations for inventory carrying costs were done using the following formula:

$$\sum_{i=1}^{n} ICC_i = \sum_{i=1}^{n} AIV_i \times ICR \text{, where}$$

ICC = inventory carrying costs;
AIV = average inventory value; and
ICR = inventory carrying rate

$$\sum_{i=1}^{n} AIV_i = \sum_{i=1}^{n} (AI_i \times UIV_i) \text{, where}$$

AIV = average inventory value for an item;
AI = average inventory level in units for an item; and
UIV = unit value for an item

First the average inventory value was calculated:

$$\sum_{i=1}^{1435} AIV_i = \sum_{i=1}^{1435} (AI_i \times UIV_i) = 634308\,USD$$

Because the unit values were received as US dollars, they were needed to be changed to Swedish Kronas:

$$\sum_{i=1}^{1435} AIV_i = 634308 \times 6{,}01 \approx 3812191\,SEK$$

The inventory carrying rate for Country A was calculated:

$$ICR_A = \frac{\sum Storage\, and\, handling\, Costs}{\sum AIV} \times 100\% == \frac{237000 SEK}{3812191 SEK} \times 100\% \approx 6{,}22\%$$

What can be seen here is that because inventory carrying costs on this case consist only on storage and handling costs, the sum of storage and handling costs are the same as inventory carrying cost for this situation (237 000 SEK).

To illustrate this, the inventory carrying costs were also calculated using the formula:

$$\sum_{i=1}^{n} ICC_i = \sum_{i=1}^{n} AIV_i \times ICR$$

, where

n = 1435;

$$\sum_{i=1}^{n} AIV_i = 3812191 SEK$$

;

$ICR = 6{,}22\ \%$

Therefore:

$$\sum_{i=1}^{1435} ICC_i = \sum_{i=1}^{1435} AIV_i \times ICR = 3812191 \times 0{,}0622 \approx 237118 SEK$$

As mentioned the result, 237 118 SEK, should be the same than sum of storage and handling costs, which are 237 000 SEK. The difference of 118 SEK comes only because the sums calculated were rounded up.

Result:

Inventory carrying costs for situation 1 for country A ($ICC1_A$) = 237 000 SEK

Alternative example for inventory carrying costs for Situation 1: Country A

The alternative example for calculating the inventory carrying costs is introduced in order to have a wider view how also other factors especially tied-up capital affects the inventory carrying costs. In these calculations inventory carrying rate of 25% of the value of the item was used. That percentage was used based on the common values introduced in the literature.

The calculations were done using the same formulas than above, only the inventory carrying rate were changed to 25 percent:

ICR = 25 %
n = 1435

$$\sum_{i=1}^{1435} ICC_i = \sum_{i=1}^{1435} AIV_i \times ICR = 3812191 \times 0{,}25 \approx 953048\, SEK$$

Result:

Inventory carrying costs for situation 1 for country A with alternative example ($ICC1X_A$) = 953 048 SEK

Inventory carrying costs for Situation 1: Country B

In a similar way than for country A, first the inventory carrying rate was calculated for country B.

The average inventory value was calculated:

n = 1236

$$\sum_{i=1}^{1236} AIV_i = \sum_{i=1}^{1236} (AI_i \times UIV_i) = 439650\, USD$$

Because the unit values were received as US dollars, the result needs to be changed to Swedish Kronas:

$$\sum_{i=1}^{1236} AIV_i = 439650 \times 6{,}01 \approx 2642297\, SEK$$

Then the inventory carrying rate for Country B was calculated:

$$ICR_B = \frac{\sum Storage\, and\, handling\, Costs}{\sum AIV} \times 100\,\% == \frac{237000\, SEK}{2642297\, SEK} \times 100\,\% \approx 8{,}97\,\%$$

Also in a same way, the sum of storage and handling costs in this case were the same, 237 000 SEK, which in a similar way is also the same as the inventory carrying cost.

To illustrate this, the inventory carrying costs were also calculated using the formula:

$$\sum_{i=1}^{n} ICC_i = \sum_{i=1}^{n} AIV_i \times ICR$$
, where

n = 1236;

$$\sum_{i=1}^{n} AIV_i = 2642297\,SEK$$
;

ICR = 8,97 %

Therefore:

$$\sum_{i=1}^{1236} ICC_i = \sum_{i=1}^{1236} AIV_i \times ICR = 2642297 \times 0{,}0897 \approx 237014\,SEK$$

As mentioned the result, 237 014 SEK, should be the same than sum of storage and handling costs, which are 237 000 SEK. The difference of 14 SEK comes only because the sums calculated were rounded up.

Result:

Inventory carrying costs for situation 1 for country B ($ICC1_B$) = 237 000 SEK

Alternative example for inventory carrying costs for situation 1: Country B

In a similar way than for country A, the calculations were done using the same formulas than above, only the inventory carrying rate were changed to 25 percent:

ICR = 25 %
n = 1236

$$\sum_{i=1}^{1236} ICC_i = \sum_{i=1}^{1236} AIV_i \times ICR = 2642297 \times 0{,}25 \approx 660574\,SEK$$

Result:

Inventory carrying cost for situation 1 for country B with alternative example ($ICC1X_B$) = 660 574 SEK

Transportation costs for Situation 1: Country A

The transportation costs for all items in this case are based on the number of units transported. Therefore the total annual transportation costs will be:

$$TC = Annual\ demand \times Transportation\ Cost\ per\ unit$$, where

TC = total transportation cost;
Annual demand = 86929 units;
Transportation cost per unit = 1 EUR

Therefore:

$$TC1_A = 86929 \times 1 = 86929\ EUR$$

Because the transportation costs per unit were received as Euros, the result needs to be changed to Swedish Kronas:

$$TC1_A = 86929 \times 8{,}93 \approx 776276\ SEK$$

Result:
Transportation costs for situation 1 for country A ($TC1_A$) = 776 276 SEK

Transportation costs for Situation 1: Country B

In a similar way, the transportation costs in this case are:

Annual demand = 89851 units
Transportation cost per unit = 1 EUR

$$TC1_B = 89851 \times 1 = 89851\ EUR$$

And in Swedish Kronas:

$$TC1_B = 89851 \times 8{,}93 \approx 802369\ SEK$$

Result:
Transportation costs for situation 1 for country B ($TC1_B$) = 802 369 SEK

Total costs

Total costs for Situation 1: Country A

$$C1_A = ICC1_A + TC1_A = 237000\ SEK + 776276\ SEK = 1013276\ SEK$$

Result:

Total costs for situation 1 for country A ($C1_A$) = 1 013 276 SEK

Total costs with alternative way for inventory carrying costs for Situation 1: Country A

$$C1X_A = ICC1X_A + TC_A = 953048 SEK + 776276 SEK = 1729324 SEK$$

Result:

Total costs for situation 1 for country A with alternative example ($C1X_A$) = 1 729 324 SEK

Total costs for Situation 1: Country B

$$C1_B = ICC1_B + TC1_B = 237000\ SEK + 802369\ SEK = 1039369\ SEK$$

Result:

Total costs for situation 1 for country B ($C1_B$) = 1 039 369 SEK

Total costs with alternative way for inventory carrying costs for Situation 1: Country B

$$C1X_B = ICC1X_B + TC1_B = 660574 SEK + 802369 SEK = 1462943 SEK$$

Result:

Total cost for situation 1 for country B with alternative example ($C1X_B$) = 1 462 943 SEK

5.3 Situation 2

In the situation 2 the reduced transportation time was considered when using the possible faster transportation mode. In the same way as for the situation 1, first the average inventory levels were calculated, and then the inventory, transportation and total costs were presented for this situation.

Therefore exactly same formulas and values were used for this situation than for situation 1, except the transportation time was reduced to be 1 day instead of 4 days.

Average inventory for situation 2: Country A

Transportation time (lead time) = 1 day

$$\sum_{i=1}^{1435} AI_i = (\frac{\frac{86929}{260}}{2}) + (3570) + (\frac{86929}{365} \times 1) \approx 3975 units$$

Result:

Average inventory for situation 2 for country A ($AI2_A$) = 3975 units

Average inventory for situation 2: Country B

Transportation time (lead time) = 1 day

$$\sum_{i=1}^{1236} AI_i = (\frac{\frac{89851}{260}}{2}) + (3267) + (\frac{89851}{365} \times 1) \approx 3686 units$$

Results:

Average inventory for situation 2 for country B ($AI2_B$) = 3686 units

Inventory carrying costs for Situation 2: Country A

For inventory carrying costs, the reduced average inventory levels lead to lower average inventory value:

$$\sum_{i=1}^{n} AIV_i = \sum_{i=1}^{n} (AI_i \times UIV_i) = 547491\, USD$$

The average inventory value in Swedish Kronas:

$$\sum_{i=1}^{n} AIV_i = 547491 \times 6{,}01 \approx 3290420 SEK$$

ICR = 6,22 %

n = 1435

Therefore the costs were calculated with the same formula than before as following:

$$\sum_{i=1}^{1435} ICC_i = \sum_{i=1}^{1435} AIV_i \times ICR = 3290420 \times 0{,}0622 \approx 204664\, SEK$$

Result:

Inventory carrying costs for situation 2 for country A ($ICC2_A$) = 204 664 SEK

Alterative example for inventory carrying costs for Situation 2: Country A

In the case of the inventory carrying costs for the example with using the inventory carrying rate of 25 percent, the inventory carrying costs were calculated in a same way than above:

$$\sum_{i=1}^{n} AIV_i = \sum_{i=1}^{n} (AI_i \times UIV_i) = 547491\, USD$$

The average inventory value in Swedish Kronas:

$$\sum_{i=1}^{n} AIV_i = 547491 \times 6{,}01 \approx 3290420\, SEK$$

ICR = 25 %

n = 1435

Therefore:

$$\sum_{i=1}^{1435} ICC_i = \sum_{i=1}^{1435} AIV_i \times ICR = 3290420 \times 0{,}25 \approx 822605\, SEK$$

Result:

Inventory carrying costs for situation 2 for country A with alternative example ($ICC2X_A$) = 822 605 SEK

Inventory carrying costs for Situation 2: Country B

Similarly:

$$\sum_{i=1}^{n} AIV_i = \sum_{i=1}^{n} (AI_i \times UIV_i) = 379815\ USD$$

The average inventory value in Swedish Kronas:

$$\sum_{i=1}^{n} AIV_i = 379815 \times 6{,}01 \approx 2282688\, SEK$$

ICR = 8,97 %

n = 1236

Therefore the costs were calculated with the same formula than before as following:

$$\sum_{i=1}^{1236} ICC_i = \sum_{i=1}^{1236} AIV_i \times ICR = 2282688 \times 0{,}0897 \approx 204757\, SEK$$

Result:

Inventory carrying costs for situation 2 for country B ($ICC2_B$) =
204 757 SEK

Alternative example for inventory carrying costs for Situation 2: Country B

In the case of the inventory carrying costs for the example with using the inventory carrying rate of 25 percent, the inventory carrying costs were calculated in a same way than above:

$$\sum_{i=1}^{n} AIV_i = \sum_{i=1}^{n} (AI_i \times UIV_i) = 379815\ USD$$

The average inventory value in Swedish Kronas:

$$\sum_{i=1}^{n} AIV_i = 379815 \times 6{,}01 \approx 2282688\, SEK$$

ICR = 25 %

n = 1236

Therefore:

$$\sum_{i=1}^{1236} ICC_i = \sum_{i=1}^{1236} AIV_i \times ICR = 2282688 \times 0{,}25 \approx 570672\, SEK$$

Result:

Inventory carrying costs for situation 2 for country B with alternative example ($ICC2X_B$) = 570 672 SEK

Transportation costs for Situation 2: Country A

The costs for transportation in the situation 2, were not changed comparing to situation 1, because the transportation cost per unit for the possible faster mode was the same and the demand for the units is still the same in this case. Therefore:

$$TC2_A = 86929 \times 1 = 86929\ EUR$$

Because the transportation costs per unit were received as Euros, the result needs to be changed to Swedish Kronas:

$$TC2_A = 86929 \times 8{,}93 \approx 776276\ SEK$$

Result:

Transportation costs for situation 2 for country A ($TC2_A$) = 776 276 SEK

Transportation costs for Situation 2: Country B

The same is considering also this case, therefore the transportation costs were:

$$TC2_B = 89851 \times 1 = 89851\, EUR$$

And in Swedish Kronas:

$$TC2_B = 89851 \times 8{,}93 \approx 802369\ SEK$$

Result:

Transportation costs for situation 2 for country B ($TC2_B$) = 802 369 SEK

Total costs

Total costs for Situation 2: Country A

$$C2_A = ICC2_A + TC2_A = 204664\,SEK + 776276\,SEK = 980940\,SEK$$

Result:

Total costs for situation 2 for country A ($C2_A$) = 980 940 SEK

Total costs with alternative way for inventory carrying costs for Situation 2: Country A

$$C2X_A = ICC2X_A + TC2_A = 822605 SEK + 776276 SEK = 1598881 SEK$$

Result:

Total costs for situation 2 for country A with alternative example ($C2X_A$) = 1 598 881 SEK

Total costs for Situation 2: Country B

$$C2_B = ICC2_B + TC2_B = 204757\,SEK + 802369\,SEK = 1007126\,SEK$$

Result:

Total costs for situation 2 for country B ($C2_B$) = 1 007 126 SEK

Total costs with alternative way for inventory carrying costs for Situation 2: Country B

$$C2X_B = ICC2X_B + TC2_B = 570672 SEK + 802369 SEK = 1373041 SEK$$

Result:

Total cost for situation 2 for country B with alternative example ($C2X_B$) = 1 373 041 SEK

5.4 Summary of results and comparison of situation 1 and situation 2

In this sub-section the results for all the cases calculated above, will be summarized and a comparison between the results will be introduced.

As was illustrated in the earlier section, the results were following:

Average inventory (*AI*):

	Situation 1	Situation 2	Alteration (%)
Country A:	4690 units	3975 units	-15,25 %
Country B:	4424 units	3686 units	-16,68 %

Inventory carrying costs (*ICC*) (in thousands):

	Situation 1	Situation 2	Alteration (%)
Country A:	237 tSEK	205 tSEK	-13,50 %
Country B:	237 tSEK	205 tSEK	-13,50 %

Inventory carrying costs calculated in the alternative way (*ICCX*) (in thousands):

	Situation 1	Situation 2	Alteration (%)
Country A:	953 tSEK	823 tSEK	-13,64 %
Country B:	661 tSEK	571 tSEK	-13,62 %

Transportation costs (*TC*) (in thousands):

	Situation 1	Situation 2	Alteration (%)
Country A:	776 tSEK	776 tSEK	0 %
Country B:	802 tSEK	802 tSEK	0 %

Total costs (*C*) (in thousands):

	Situation 1	Situation 2	Alteration (%)
Country A:	1 013 tSEK	981 tSEK	-3,16 %
Country B:	1 039 tSEK	1 007 tSEK	-3,08 %

Total costs with alternative way of inventory carrying costs (*CX*) (in thousands):

	Situation 1	Situation 2	Alteration (%)
Country A:	1 729 tSEK	1 599 tSEK	-7,52 %
Country B:	1 463 tSEK	1 373 tSEK	-6,15 %

Since the transportation costs are the same in both situations, it is interesting to see especially from the case company's point of view, how much transportation costs could be higher in order to still retain the same total costs. Consequently, what to be illustrated here is how much more could be paid for the transportation when achieving the reduction for lead time from four days to only one day without increasing the total costs. That will be illustrated with the following calculations:

$$
\begin{aligned}
&C1_A = C2_A \\
&ICC1_A + TC1_A = ICC2_A + TC2_A \\
&TC2_A = ICC1_A + TC1_A - ICC2_A \\
&TC2_A = 237000 + 776276 - 204664 = 808612\,SEK
\end{aligned}
$$

Therefore possible transportation cost to pay per unit is:

$$TCU = \frac{TC2_A}{annual\,demand} = \frac{808612}{86929} \approx 9{,}3\,SEK \text{ , when}$$

the transportation cost per unit with the transportation mode today was:

$$1\,EUR \times 8{,}93 = 8{,}93\,SEK$$

Therefore it would be possible to pay 4,14 percent more for the transportation not to increase the total costs.

The same calculations illustrated for the country B are following:

$$
\begin{aligned}
&C1_B = C2_B \\
&ICC1_B + TC1_B = ICC2_B + TC2_B \\
&TC2_B = ICC1_B + TC1_B - ICC2_B \\
&TC2_B = 237000 + 802369 - 204757 = 834612\,SEK
\end{aligned}
$$

Therefore possible transportation cost to pay per unit is:

$$TCU = \frac{TC2_B}{annual\,demand} = \frac{834612}{89851} \approx 9{,}29\,SEK \text{ , when}$$

the transportation cost per unit with the transportation mode today was:

$$1\,EUR \times 8{,}93 = 8{,}93\,SEK$$

Therefore it would be possible to pay 4,03 percent more for transportation not to increase the total costs.

Based on the findings introduced in this chapter and on the literature reviewed earlier, more detailed analysis and discussion will be followed in the next chapter of *6 Analysis and discussion*.

6 Analysis and discussion

In this chapter of analysis and discussion, the results presented in the previous chapter of findings will be analyzed and discussed in relation to the theory and literature review presented in this study. Also the research questions and overall aim of the study are revised. Therefore this chapter will be structured according to the research questions and matters related to them are discussed and analyzed. The actual final conclusions for this study will be revealed in the following chapter or conclusions.

To first remind about the overall aim of the study and the research questions set, the overall aim for this study is "to develop a framework to understand how transportation time affects inventory." Accordingly the research questions for this study are:

1. What are the factors in inventory management that alter depending on the transportation time and frequency?
2. What models and frameworks are available to investigate the correlation between transportation time and inventory?
3. In what ways does a faster transportation mode affect the inventory costs and what can be said about the transportation costs in this relation?
4. As a result of these a framework how the transportation time affects inventory will be developed.

First the matters related to the first two research questions are discussed briefly mainly by revising the findings found out from literature and after that, the concentration will be turned to the third research question which was done by carrying out an empirical research. The findings will be analyzed and discussed in relation to the literature review and this is the main focus of this chapter of analysis and discussion. That will lead to the chapter of conclusions, where the final conclusions for the study will be given.

6.1 Literary view of inventory management and its dependence on transportation

In the first research question the aim was to solve what factors are most important in inventory management when considering the changes in transportation time and also in transportation frequency. Respectively, the second research question was aiming for illustrating and evaluation models offered by different authors concentrating to the inventory management with the relation of transportation. What is reasonable to mention first, is that commonly the aim for inventory is the same; to be able to provide enough products to meet the service level requirements and at the same time keep the inventory levels and that way the costs of inventory as low as possible. The transportation function is needed to be added, in order to be able to take care of the actual movement of the products and to maintain the replenishment for the inventory in an effective way.

However, in many cases, there are differing views and aims between different functions and departments in companies. Inventory management aims for keeping the inventory turn high and the levels and costs low, while transportation management aims for reducing the costs of transportation. At the same time customer service is requiring higher inventory levels to keep the customer service level and satisfaction high. Therefore numerous journal articles can be found researching inventory management and aiming to solve how the inventory levels and costs could be reduced. But as mentioned, also other functions are relevant to take into consideration while aiming for reducing the inventory. Therefore the system is needed to be looked as a whole, including also such functions as transportation and customer service. Only reducing the costs of the inventory in most cases is not enough; the concentration should be on the total costs and that is why many authors in journal articles reviewed are trying to optimize all the functions together, to achieve the minimum total costs.

In theoretical literature as well as in journal articles, inventory management is widely researched area. In theory various formulas are introduced to evaluate inventory performance and to determine functions needed to operate inventory in the best way. As this study is concentrating to the relation of inventory and transportation time, some specific factors were introduced in more detail to see how the transportation time can affect the levels and costs of inventory. In addition to that also the effects of transportation frequency were important to be considered; even the main concentration was on the particular effects of transportation time.

Most important factors offered by theoretical literature for this particular study are clearly the inventory costs and their consistency as well as the definition of average inventory and all the parts that should be taken into consideration when investigating these. Important to notice here is that varying opinions about the consistency of average inventory can be found from literature. Some authors emphasize that it is important to include in transit inventory to the average inventory, while also e.g. an opinion to count in transit inventory into transportation costs were offered. Especially for the sake of this particular study, it seems important to consider in transit inventory as part of average inventory, because it is the only factor in average inventory where the actual transportation time, or lead time, is considered directly. More detailed analysis will be given in the next sub-sections, where the actual findings of the empirical research will be discussed.

When considering the inventory costs, differing opinions of the consistency can also be found. However, the importance to use average inventory to determine the inventory costs is emphasized by most of the authors. What is the main difference in theoretical literature about the inventory costs, is that part of the authors are separating inventory costs and inventory carrying costs by stating that inventory carrying costs are including mainly the costs from tied-up capital, insurance, taxes, obsolescence and losses; and to have the actual inventory costs, warehousing and handling costs should be added to these inventory carrying costs. Differing opinions can be found to state that the actual inventory costs are called as inventory carrying costs and that they should include all the costs from tied-up capital to warehousing and handling. In addition to that, arguments about the ratio of inventory and transportation costs are varying a lot in theoretical literature as well as in journal articles. The reason for that seems to be mainly that it depends strongly on the type and value of goods that are handled, as well as how the inventory carrying rate is determined.

In the journal articles reviewed, varying models could be found. Most of the models are aiming for optimizing inventory and transportation functions in order to gain maximum reduction of the total costs. However, wide range of contexts and environments considered can be found and it is difficult to find a model which could be used like that to solve a particular case in question. One of the most important findings is that in many of these models the main concentration is commonly on transportation frequency rather than the actual transportation time. When concentrating to models that consider the relation of inventory and transportation, rarely the actual transportation time is seen as a constraint or main factor to be included into the function of the model. In many cases the transportation time is not even considered at all or no changes for it are assumed. As the models introduced were also already evaluated in the literature review chapter and as the main focus of this analysis and discussion chapter is on the actual findings of the empirical research and to relate those into literature review, more detailed analysis will be introduced in the following sub-chapters. Therefore in the next sub-chapters the actual analysis and discussion of the findings will take place in more detail in relation to what was found from literature review.

6.2 The effects of reduced transportation time in a real life company

The empirical research was carried out investigating how a reduction of transportation time affects the average inventory levels and that way how the inventory carrying costs as well as total costs will change. In this sub-chapter the results gained from the empirical research are analyzed and discussed in more detail related them to the findings from literature review.

6.2.1 Average inventory

As mentioned for determining the average inventory, differing opinions can be found from literature. In this case it was seen important to include the inventory in transit into the calculations of the average inventory due to the fact that the only factor considering directly the transportation time is the inventory in transit. As the results state, when reducing the transportation time from four days into only one day, the average inventory could be reduced by 15,25 percent in the case of country A, and 16,68 percent in the case of country B. To be noticed here is that the main cause for the reduction of the average inventory is because of the in transit inventory is reduced due to the shorter transportation time. As can been seen from the formula used to calculate average inventory, the only factor that is directly taking the transportation time into consideration is the inventory in transit. The other factors, average order quantity and safety stock do not take transportation or lead time directly into consideration. However, if the transportation frequency is under consideration, then the average order quantity could be changed due to changed transportation frequency. But in the case of investigating only the actual transportation time, it does not have any change to the average order quantities. In addition to that, when considering the third factor which was used for calculating the average inventory, safety stock, it does not have either a direct impact on the average inventory in this case when the change of transportation time is under consideration. However, it can have indirect effects on the average inventory from the reducing of lead time, which in this case, is the same as transportation time. That can be seen when looking at the formula introduced before to determine the reorder point:

$R = D \times T + SS$, where

R = Reorder point;
D = demand (days);
T = lead time (days); and
SS = safety stock.

In this formula the safety stock as well as the lead time are considered both simultaneously. Therefore when modifying the formula as following:

$SS = R - (D \times T)$, the effects of lead time to safety stock can be seen better.

From the former formula; by reducing lead time, the reorder point could be reduced. Consequently by reducing the reorder point, the safety stock can be reduced, which in turn leads to even lower average inventory due to the fact that safety stock is one factor for creating the average inventory. Therefore, as was mentioned, when altering the transportation frequency, the average order quantities could be altered, and when reducing the lead time and transportation time (which are the same in this case), direct effects in average inventory can be seen in the inventory in transit and indirect effects could be gained in safety stock. Also to be noticed here is that the overall demand is known and it is remaining the same, because it is assumed that the service level for customer still remains the same after reducing the transportation time. On the other hand, when reducing the transportation time, improvements for the service level could be possibly gained. But this would be more visible in a case when the transportation time between the distribution hub and customer is reduced, rather than the transportation time between the central warehouse and the distribution hub.

However, in a case where transportation time is not the same than lead time, e.g. when additional time i.e. setting time, collecting and packing will be added to transportation time to have the total lead time, then the effects of reduced transportation time are not as strong when considering the indirect effects of reorder point and safety stock. That is because the formula introduced above, takes lead time into consideration, and in such cases, transportation time is only a part of lead time. To be also noticed is that the reliability of transportation time should be really high, especially in a case when lead time is the same than transportation time, because if the transportation time is not as expected, then more safety stock will be needed.

6.2.2 Inventory carrying costs

The changes in inventory carrying costs are most likely the most interesting part from the point of view of companies. Changes in average inventory can illustrate how much the average level of inventory could be reduced with shorter transportation time, but the actual costs savings are considered when looking at the inventory carrying costs.

Interesting to notice especially in the case of the case company used in this study, is that they have not determined an inventory carrying rate that could be directly used to calculate the inventory carrying costs based on the average inventory. According to literature reviewed, in common cases companies have determined an inventory carrying rate for them that takes all the important factors into consideration i.e. tied-up capital, insurance, taxes, obsolescence, losses, storage and handling. The main reason in this case why case company has not determined an inventory carrying rate, might be that they consider the inventory from the point of view of the central warehouse, and therefore the impact of tied-up capital and such costs are not considered from the point of view of the country hub. However, as the tied-up capital is said to be the largest factor in inventory carrying costs, it was seemed reasonable to calculate the inventory carrying costs in two different ways: one with using an inventory carrying rate based on the actual inventory carrying costs of the case company, and one with an alternative inventory carrying rate of 25 percent considering it to include all the relevant factors, i.e. tied-up capital and also the storage and handling costs.

As can be seen from the results, the reduction of inventory carrying costs in percentages are almost the same in both cases; when using the inventory carrying rate based on the actual inventory carrying costs of the case company, and when using the alternative inventory carrying rate of 25 percent:

Inventory carrying costs (*ICC*) (in thousands):

	Situation 1	Situation 2	Alteration (%)
Country A:	237 tSEK	205 tSEK	-13,50 %
Country B:	237 tSEK	205 tSEK	-13,50 %

Inventory carrying costs calculated in the alternative way (*ICCX*) (in thousands):

	Situation 1	Situation 2	Alteration (%)
Country A:	953 tSEK	823 tSEK	-13,64 %
Country B:	661 tSEK	571 tSEK	-13,62 %

In the case of country A the alterations when comparing these two ways of calculating the inventory carrying costs are 13,50 % and 13,64 %, and in the case of country B 13,50 % and 13,62 %. However, when looking at the total sum of inventory carrying costs in money, naturally the ones with tied-up capital included are much higher. For example in the case of country A, the saved costs due to reduction of transportation time when tied-up capital is considered is around 130 tSEK, which is more than 50 % of the inventory carrying costs (237 tSEK) in the case of the case company. Similarly in the case of country B, the percentage is 38%. Therefore the saved costs in percentages are almost the same with these two ways of calculating, but the actual amount in money, is much higher when the tied-up capital is included. Also important to be noticed is that the inventory carrying costs are not only dependent on the average inventory, also the value of the items and ratio of how many units of particular items are stored is affecting the inventory carrying costs. For example if the most valuable items are also having the most units stored in the inventory, then the inventory carrying costs will be higher.

In this case when the unit values was received as in different currencies than the inventory carrying costs (storage and handling costs), also to be important to notice is that the currency rates change constantly. Therefore there might be changes in the costs based in that.

What is also mentioned by some of the authors offering models for inventory management is that the models commonly require data that is not available or might not be in the right form when trying to use them in real life situations. This was also noticed when carrying out the empirical research that for example when considering the inventory carrying rate, the case company did not have determined a rate which could have been used directly. Most of the literature reviewed, both theoretical and journal articles, were assuming that especially the inventory carrying rate was always at hand when using the formulas or models. Also generally most of these models and formulas expect that the input data would be available in only one particular form to be able to be used with these models. In some real life cases the companies might not even be able to provide the data needed for such models or they are not available in normal situations. Therefore, what was noticed is that with real life situations all the data required is not necessarily available or it might not be in the form needed.

6.2.3 Transportation costs

In literature, some authors are stating that when reducing the transportation time, usually the transportation costs are increasing respectively. That is true especially if considering the faster transportation to be e.g. a change from truck or ship transportation to use of flights. But in a case of considering only truck transportation, that is not necessarily needed to be so. For example some different transportation service providers could offer the same price than others, with being able to execute the same transportation during a shorter time. The price of transportation does not necessarily need to increase, and of course it could be also possible that the transportation costs could even decrease.

In the case investigated in the empirical research, the transportation costs for the transportation mode today as well for the possible faster transportation were the same. However, it could be assumed that when reducing the transportation time thus radically, from four to one day, there might be some amount of raise in the transportation prices needed. Therefore in the end of the findings chapter, a possible increase for the transportation costs was considered to see how much more the transportation costs would be, not to increase the total costs coming from inventory carrying costs and transportation costs. It was found out that the transportation costs per unit could be increased in the case of country A by 4,14 % and in country B by 4,03 % not to increase the total costs. Therefore if the transportation time would be possible to be reduced from four to one day, then it would be possible to pay up to 4,14 % / 4,03 % more for the transportation.

Some of the models reviewed are focusing to the transportation aspect, e.g. in means of finding the optimal filling rate for trucks and if also full or partly-full trucks would be most economical to be used. In this case the fill rate or amount of truck were not considered at all, because the case company is using outsourced carriers to handle the transportation and the transportation costs are not dependent on the amount of trucks or how full they are, only on the amount of units transported.

Also the way the transportation costs are charged should be considered. In a case when using an outsourced transportation company, the transportation costs can be charged e.g. based on the weight or volume of the goods or the amount of trucks used. Or as was used in the case of the case company in this study, the costs can only be considered to be based on the amount of units transported. In addition to that, it is important to notice that there is a difference when considering the transportation costs as annual total costs of transportation or cost for each delivery.

Similarly than what was mentioned about the unit values received as in different currencies, the same is true also for the transportation costs. Therefore it is important to notice, that when considering all the resulted values including the transportation costs as Swedish Kronas, changes for the currency rates between Euros and Swedish Kronas might affect some changes for the results.

6.2.4 Closing words

Because the transportation costs for both situations were considered to be the same, the results of total costs when summing together the inventory carrying costs and transportation costs are not that interesting to look at. Consequently it is more interesting to look only at the alteration of the costs of inventory instead of the total costs.

Total costs (*C*) (in thousands):

	Situation 1	Situation 2	Alteration (%)
Country A:	1 013 tSEK	981 tSEK	-3,16 %
Country B:	1 039 tSEK	1 007 tSEK	-3,08 %

Total costs with alternative way of inventory carrying costs (*CX*) (in thousands):

	Situation 1	Situation 2	Alteration (%)
Country A:	1 729 tSEK	1 599 tSEK	-7,52 %
Country B:	1 463 tSEK	1 373 tSEK	-6,15 %

What can be seen from the total costs calculated is that the alteration of them in percentages is not that that high than in the cases of inventory carrying costs. The main reason for that especially in the case of using the inventory carrying rate with only the storage and handling costs (the case for case company) is that the transportation costs are a major part of the total costs. The inventory carrying costs are only around one third of the transportation costs in this case. When looking at the total costs which were calculated using the alternative example, it can be seen that the alteration in percentages is much higher. That is due to the fact that the inventory carrying costs were higher. In the case of country A the inventory carrying costs were even higher than the transportation costs and in the case of country B the inventory carrying costs were just below the transportation costs.

In the next chapter of conclusions, the final conclusions for the study will be presented and the framework to understand how transportation time affects inventory will be introduced.

7 Conclusions

7.1 Introduction

The purpose of this chapter is to state the final conclusions for the complete study. This will be done by first stating the conclusions and findings for the first three research questions and as a result of those, the final conclusion for the overall aim of the study will be presented. To remind once again, the overall aim is "to develop a framework to understand the effects of transportation time to inventory". Accordingly the research questions are:

1. What are the factors in inventory management that alter depending on the transportation time and frequency?
2. What models and frameworks are available to investigate the correlation between transportation time and inventory?
3. In what ways does a faster transportation mode affect the inventory costs and what can be said about transportation costs in this relation?
4. As a result of these a framework how the transportation time affects inventory will be developed.

In addition to that, based on the conclusions given, recommendations and suggestions for further research will be presented.

Therefore the following sub-chapters will introduce first the conclusions for the individual research questions, and based on those, the final conclusion for the overall aim will be given.

7.2 Research questions: Findings and conclusions

7.2.1 The key factors in inventory management to consider transportation time

For managing inventory in the best way by providing the required customer service level and simultaneously keeping the levels and costs of inventory as minimum, transportation is an important function to make it possible. The most visible key factor that was found to be relevant for inventory management when considering the transportation time, can be said to be the average level of inventory. Therefore also the factors included into the average inventory are important to be considered, i.e. average order quantities, safety stock and in transit inventory. When cutting these factors even into smaller pieces; it was found that actually average order quantities are dependent on the transportation frequencies, rather than the actual transportation time. In transit inventory is the most visible factor to affect the average inventory levels when transportation time is under consideration. In addition to that, safety stock levels affect indirectly the average inventory through the changes in reorder point and lead time.

When stating the average inventory to be a key factor resulted from the changes in transportation time, also the costs of inventory should be considered. Average inventory is directly affecting the inventory carrying costs. Therefore the factors for inventory carrying costs can also be said to be key factors that are affected by the changes in transportation time. When concentrating to the inventory carrying costs, the factors affecting directly to them are average inventory levels and inventory carrying rate. However, despite to the fact that differing opinions can be found about the consistency of inventory carrying rate, it should be determined based on the tied-up capital, insurance, obsolescence, taxes, losses, storage and handling costs to make sure to take all relevant factors into consideration for it. Therefore the alternative inventory carrying rate of 25 percent was seen relevant to be used in additional calculations to have better understanding especially about the effects of tied-up capital in the inventory carrying costs.

7.2.2 Models and frameworks investigating inventory management and transportation

Differing models were found to investigate the relation of inventory management and transportation. Most of the models are aiming for minimizing the total costs resulted from inventory and transportation by optimizing the operation for these functions. Differing focuses could be found; some focusing more to the actual inventory management while others trying to solve how the transportation should be done in order to gain the best results. In addition to that it was found out that these models are meant to be used in various contexts and environments, and the assumptions based e.g. on demand terms, type of products or levels and types of inventories are varying a lot. Therefore a universal use for the models investigating inventory management and transportation is not possible to find, and when trying to solve a particular problem in question, a suitable model from amongst the models offered by literature is hard to find.

Especially for this particular study, one of the most important findings was that usually the transportation frequency and changes to that were investigated rather than the actual transportation time. The actual transportation time was rarely considered to be changed or to be even included into the model as a variable. Also critique about the usability of models offered in literature in real life situations was found. It is claimed by some authors that the models offered cannot be used in a real life situation e.g. because of the high complexity of the model or the input data required is not available in normal situations.

It is relevant to mention here how this study contributes to the existing literature about the relation of inventory management and transportation. As mentioned, most of the models evaluated, are concentrating strongly on changes in the transportation frequency rather than the changes in the actual transportation time. Through this study the effects of reducing the actual transportation time can be seen, while keeping the frequencies of the transportation the same.

7.2.3 The effects of faster transportation to inventory in a real life case

To be concluded based on the empirical research carried out; it was found out that it could be difficult or not possible to attain the input data required by formulas in a particular form needed. Also a real life company might not consider certain factors introduced in theoretical literature as relevant in the same way the literature is suggesting. That was seen especially in the case of inventory carrying rate. Literature is strongly defining that inventory carrying rate should be determined by the company and that it contains at least the tied-up capital among other factors. However in the case of the case company, such value for inventory carrying rate was not available and the inventory carrying costs were considered to contain only the costs of storage and handling.

However, from the empirical research it was found out that the average inventory levels are decreasing as the results of reduction of transportation time. The direct factor affecting to the reduction of average inventory is in transit inventory. Safety stock is affecting to the average inventory levels as an indirect factor through the reorder point and lead time. However, if the transportation time and lead time are not considered to be the same, then the changes that could be achieved from the reduction of safety stock are not as high. Also the reliability of the transportation time is important to be considered when focusing on safety stock. The factor of average order quantity, is not dependent on the actual transportation time, it depends on the frequency of the transportations.

Respectively, also the inventory carrying costs were reduced. The actual amount of inventory carrying costs is strongly dependent on what is included into the inventory carrying rate. If only the storage and handling costs are considered to be the inventory carrying costs, the total sum is much lower than in a case when tied-up capital and other such costs as insurance, taxes, obsolescence and losses are also included into the inventory carrying rate. Also the total costs of holding inventory are dependent on the value of the items stored in inventory and the ratio of the units of the items with different unit values.

When considering the effect of reduced transportation time to transportation costs, it is not necessarily true that the transportation costs increase while the transportation time reduces. Especially in a case when the transportation function is outsourced (what is the situation in this study), it depends only on the transportation rates which are offered by the transportation company.

7.2.4 The framework to understand the effects of transportation time to inventory

In this sub-section, the actual framework that is the overall aim of the study, will be introduced based on the findings and conclusions presented about the individual research questions above.

First it is important to remind that usually the models and frameworks offered in literature cannot be universally used. The usability is dependent on many elements and it also depends on the context and environment they are aimed for. Therefore this framework introduced here is particularly applicable in the certain context illustrated in this study. However, many of the factors could be also used in cases with different focus and context, but when looking the framework as a whole, it is mainly aimed for the particular context that is handled in this study. Therefore it can be seen that the framework built in this study contributes to the existing knowledge by offering a way to solve this kind of a problem in this kind of a context that is introduced in this particular study. Also as was mentioned before, this study offers a stronger concentration on the changes of the actual transportation time, rather than to the transportation frequencies, which is usually under the main investigation.

To start with, integrated management of inventory and transportation is important. By integrating the management of inventory and transportation, especially the costs could be followed and managed simultaneously while also the visibility of the whole system increases. That way the possible conflicts between these functions could be reduced and their differing aims could be understood better.

The most important factor that alters depending on the transportation time, is average inventory. Further it is also the base for the total inventory costs, inventory carrying costs. Therefore the effects of transportation time on average inventory levels are the most important factor to consider in this case. Average inventory level is based on three factors: average order quantity, safety stock and in transit inventory. What was also proved in the empirical research part of this study, by reducing transportation time, the average inventory levels will be reduced. Important to be noticed is that the only absolutely direct change as an effect of the reduced transportation time in average inventory is that the in transit inventory is reduced. Indirect effects can be seen on the possibility to reduce also the safety stock through reducing the reorder point. However, the closer the transportation time is to the lead time, the more radically the reorder point could be reduced and that way also the safety stock. The factor of average order quantity is only dependent on the transportation frequency. Therefore it will not alter when the actual transportation time is reduced.

Beside the average inventory, also the effects to inventory costs are relevant to consider when looking at the effects of transportation time to inventory. Inventory carrying costs consists of factors of average inventory value and inventory carrying rate. Further the average inventory value is consisting of average inventory level and the unit values of items. Therefore, all of these factors are important in creation of the inventory carrying costs. The level of average inventory is affecting directly to the inventory carrying costs. From the empirical research it was also found out that inventory carrying costs are reducing when the transportation time is reduced. Therefore, by reducing the transportation time, the average inventory levels are reduced and that further reduces the average inventory value and as results of that the inventory carrying costs are reduced. However, the way the inventory carrying rate is determined is also crucial, especially when considering the savings in amount of money rather than the in percentages. If the inventory carrying rate is considered to include all the possible costs from tied-up capital to storage and handling costs, the saved amount of money is much more than when considering only the storage and handling costs into the inventory carrying rate. In addition to that what should be mentioned is that also the value of the goods stored are affecting to the inventory carrying costs and the ratio of the units of items in inventory. However, when considering the absolute effects of transportation time, the value of the goods are not changing anything, despite that fact that they are forming the average inventory value based on the average inventory levels.

The costs of transportation are not necessarily dependent on the changes of transportation time. Especially in a case with outsourced transportation, the transportation costs are only depending on the transportation rates offered by the carrier. Therefore with the change of transportation time, no direct effects on the transportation costs can be necessarily seen. That is also a reason why total costs consisting of transportation and inventory carrying costs are not necessarily interesting to be looked at. In this particular case, the only factor that is altering the total costs is the inventory carrying costs. However, in some cases it might be interesting to see how much the transportation costs could be increased due to the reduced transportation time. What was illustrated based on the empirical research, is that by increasing the transportation costs while reducing transportation time, the total costs would not necessarily increase, due to the fact that savings in inventory carrying costs will be gained simultaneously. In addition to that, the reliability of the transportation is also important to be considered.

7.3 Recommendations and suggestions for further research

As the context for the research was considering a single-level inventory and the inventory levels were considered at the distribution hub, a further research could be made to add also another level of inventory into the consideration as the central warehouse. Alternatively the system as a whole could be investigated, including the central warehouse, distribution hub and the final customers in more detailed investigation. Many of the models offered in journal articles are focusing on the transportation frequency, and in this study the concentration was on the transportation time. Therefore it would be recommendable to consider these both factors in more detail simultaneously.

Also, as the reduction of transportation time was only considered between the central warehouse and the country hub it is providing, it would be interesting to see the effects of the reduced transportation time between the actual inventory (country hub) and the customers. It might have even more radical effects to the average inventory and inventory carrying costs, as well to the service level.

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Appendixes

Appendix A: Questions used in the interviews

Interviews performed at the premises of the case company on 2011-03-08 and 2011-04-11.

Inventory:

- How many items (item numbers) are concerned in this case from central warehouse to distribution hub?

- What inventory management model is used and how the inventory control is done? (What to order, when to take action and in what quantity?)

- How often inventory levels are reviewed to determine the order sizes?

- Average inventory levels for items / average stock?

- Order sizes / quantities?

- Safety stock levels (how many units are in safety stock for items)?

- What is the total lead time (from placing an order to receiving the shipment in distribution hub)?

- Average demand for the items? (E.g. units / day or annual demand for items)

- Fixed ordering costs (SEK / order)?

- Inventory carrying/holding costs?

- How the inventory carrying costs are determined?

- Average item value (SEK / unit)?

- Reorder point?

- Target level of inventory for items (units)?

- What is the capacity for the distribution hub to receive parts (units / day)?

Transportation:

- Is own fleet used or is the transportation outsourced?
- What transportation mode is used for the transportation?
- How often shipments are loaded from central warehouse to distribution hub?
- Transportation time from central warehouse to distribution hub today?
- Transportation time from central warehouse to distribution hub for the possible faster transportation mode?
- Freight transport costs?
    - In what bases are they charged? (E.g. per ton, per unit, per truck)
- Transport costs for the new possible faster transportation mode?
    - In what bases are they charged?
- What is the maximum capacity per truck and is the amount of trucks finite or infinite?
- What is usually the level of filling the trucks? (How full are they?)