Master's degree thesis

LOG952 Logistics

Ordering policy and warehouse locations in Møre and Romsdal Hospital Trust

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Number of pages including this page: 64

Molde, 24 May, 2016

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Preface

Firstly, I would like to express my deepest gratitude to my supervisor Arild Hoff for the continuous support of my thesis study, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my thesis study.

I take this opportunity to express my appreciation to all of the department faculty members of Molde University College – Specialized University in Logistics, for their help. Special thanks to Ragnhild Brakstad and Buvik Arnt Sture for their guidance and support. Thanks to Anders Thorstenson for his time on grading my thesis.

I would also like to thank Helse Møre og Romsdal HF who gave me the opportunity to be part of their interesting project, especially to Emmelie Mette Brunvoll who has been an excellent contact and always responded quickly whenever I was in need of data.

Last but not least, I want to express my very profound gratitude to my ever-loving parents, Marzieh and Ramezan and my dear sister and brother-in-low Sahar and Shahriar, for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

Ali Hassani
Molde, Norway
May 2016

Abstract

The associated cost of storing goods in inventory known as Inventory Cost is a major part of costs in each organization. In this study, managing the inventories of four hospital warehouses in four cities located in Møre and Romsdal in Norway in three different situations has been challenged. The goal is to develop an ordering strategy and find the best locations and combinations of warehouses in terms of cost. The alternatives are to have one warehouse attached to the hospital in each city or reducing the number of warehouses to two or one by merging them. For this purpose, two appropriate inventory policies for ordering consumable products of four hospital warehouses in Molde, Ålesund, Kristiansund and Volda located in the middle of Norway have been determined.

Currently, the hospital in each city has its own warehouse. An analysis on the total costs of each warehouse in all three situations has been made to figure out whether it is reasonable to reduce the number of warehouses or not. For managing the inventories, finding the proper policy, classification of the goods in inventories and eventually calculating the total costs of each warehouse, some books and study papers have been reviewed. ABC-classification and major ordering policies have been discussed. The effects of each order cost and carrying charge on the Total cost in an inventory have been analyzed as well.

Analyzing the result showed that inventory cost of warehouses, regardless of some areas such as transportation and building cost, will be decreased by merging the warehouses and reducing the number of them from four to two and one.

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1.0 Introduction

All the goods which are available in the markets like shopping centers have to pass a process before reaching the destination for sale or use. In a very simple way, for example owner of a shopping center as a seller of his goods should find a supplier which could be suitable for him in terms of quality and price to supply his stuff. After concluding agreement with the supplier, goods should be transported from supplier to the owner of shopping center to store the goods for sale. The owner should hold the goods in a warehouse and transport the goods from his warehouse to the extent that he decides to put in the shopping center for sale. He should take care of the amount of goods in the inventory so that there is enough amount of all the special goods in the warehouse when it is required to be transported to the shopping center. For this purpose, the warehouses should be replenished at the right time. On the other hand, both holding the goods in the inventory and transportation have a considerable cost for the owner. Determining a favorable inventory level is one of the important parts of the business. If there is more than enough, extra capital investment would be locked; if there is not adequate, stockout can occur (King 2011). All the costs which are related to storing the goods in a certain period of time should be considered as inventory cost (Vermorel 2013). However, the number of warehouses and their locations are a challenging part of the business which varies depending on the kind of the applications.

There are different ways for optimizing the number and location of the warehouses in general. If there are some fixed locations available and the issue is to decide about which one of them could be the optimal warehouse, going through the items' details (which are going to be stored) and their specifications is unavoidable. Different items with different natures are found in the warehouses (this varies from business to business). Some of them are consumable (such as paper) and more amounts of them should be available in the inventory all the time. However, some items such as computers, furniture etc. are not required to be available in the stock in large numbers. The policy of ordering and storing will be decided depending on the items. Therefore, items in warehouses should be grouped by considering their natures. One of the most common methods used for categorizing the items in inventory is named ABC-classification which is based on Pareto analysis stating that 80% of the revenue is related to 20% of items (Dhoka and Choudary 2013). This method for classification is solely based on annual dollar usage. However, in some cases, the dollar usage of some items may not be significant but in case of stockout, the

cost of not having enough of those particular items would be high. In such cases, the annual dollar usage could be switched to another criteria such as criticality, lead time and so on (Chen et al. 2008). Different inventory policies for managing the inventory are also available such as (s, Q) system, (s, S) system, (R, S) system and (R, s, S) system which will be described in detail in chapter 4. These policies determine some important elements and procedures such as amount of demand in inventory and its frequency, plan for replenishment and the way of being aware of goods' status in the inventory. Transporting goods to destination, decision about the safety stock and finding a strategy for the case of accruing stockout are other important issues which should not be neglected.

In the current project, decreasing the number of warehouses of four hospitals in Møre and Romsdal will be studied. Particularly, reduction from four to two or one warehouse(s) is being considered. New warehouse(s) will be selected among the four current warehouses in Ålesund, Molde, Kristiansund and Volda. For this purpose, a comprehensive analysis of price and lead time will be discussed. On the way, several assumptions and conditions should be taken into account.

1.1 Hospital organization and hierarchy in Norway

The system of healthcare and hospital in Norway is based on equality and free choice of supplier. From the financial point of view, public health services are covered by the government which is part of the government budget. The healthcare centers are mostly public and the relevant costs are considered as part of the social security system. All the Norwegian citizens are insured by the national social insurance, and Norwegian Health Economic Administration (HELFO) has a control on that. Therefore, the market of private insurances for health services is not wealthy. The healthcare system in Norway is divided into three levels of national, regional and municipal. The responsibility of handling the national health politics is one of the duties of the Ministry of Health and Care Services (HOD). The Directorate of Health and the Norwegian Health Network are two departments who are playing main roles in this respect. The Directorate of Health is considered as the administrative delegation of the ministry of Health and Care Services which operates as an academic consultant who manages the rules in the health segment. The Norwegian Health Network is a governmental investment organization who has the ministry of Health and

Care Services as its owner. The goal of this organization is to develop a national information technology foundation in order to have an efficient cooperation between all components of the Healthcare Services, containing all the public and private hospitals, dentists, general doctors and specialists and so on. The specialist health service is owned by the ministry of Health and Care Services in Norway (Helse Midt-Norge 2015). This responsibility is appointed to four regional health authorities (RFH). Figure 1 shows the hierarchy of the health care system.
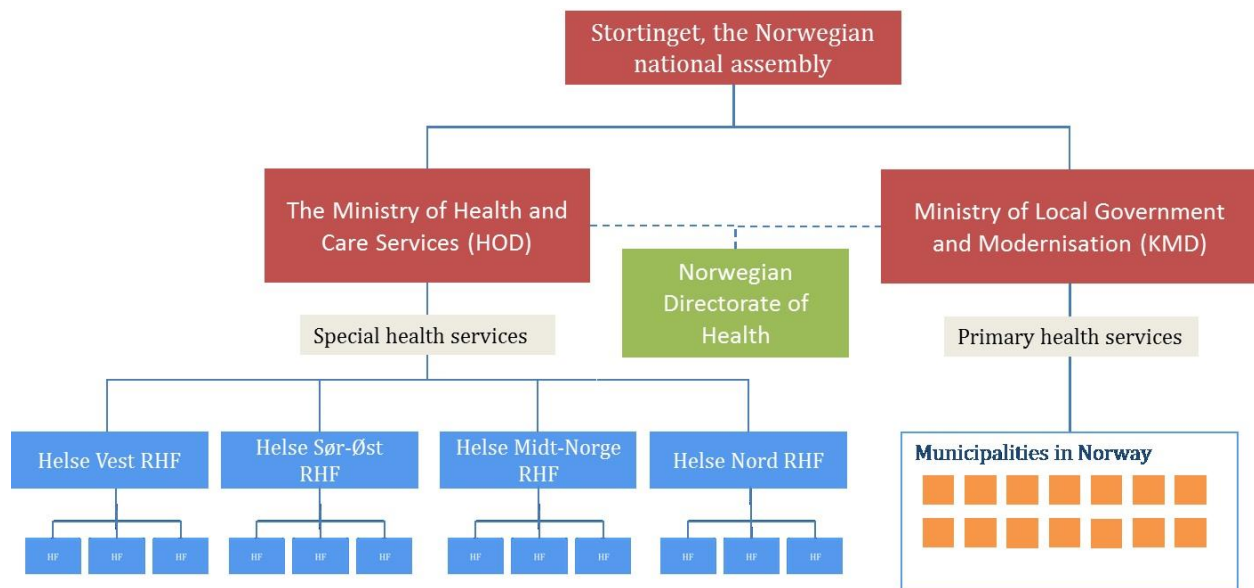
Figure 1: Hierarchy of the health care system in Norway (Helse Midt-Norge 2015)

The municipalities of Norway provide the local health services through primary health care subjecting to Ministry of Local Government and Modernization (KMD). Based on the condition of the patient and the required expertise, the relevant division for the health care system will be contacted. In this way, the required level of medical care for each patient will be found and based on that, the treatment will be applied. Primary and specialist departments in health care services attempt to provide the best services for patients monolithically.

Some local services divisions which are considered as primary health services are mentioned in the following (Helse Midt-Norge 2015):

- Health clinics
- School health services

- Local general practitioners

- Mental health services

- Home care services

- Nursing homes

Specialist health services include institutions and services such as:

- Public hospitals

- Psychiatric institutions

- Ambulance and pre hospital services

- Rehabilitation centres

- Institutions for interdisciplinary specialized treatment for substance abuse

- Pharmacies

- Laboratories

- Private specialist institutions

The health authority is divided into four major regions in Norway:

- Northern Norway Regional Health Authority

- Central Norway Health Authority

- Western Norway Health Authority

- South-Eastern Norway Health Authority

As it is shown the Figure 2 each zone is divided into some sub branches as well.
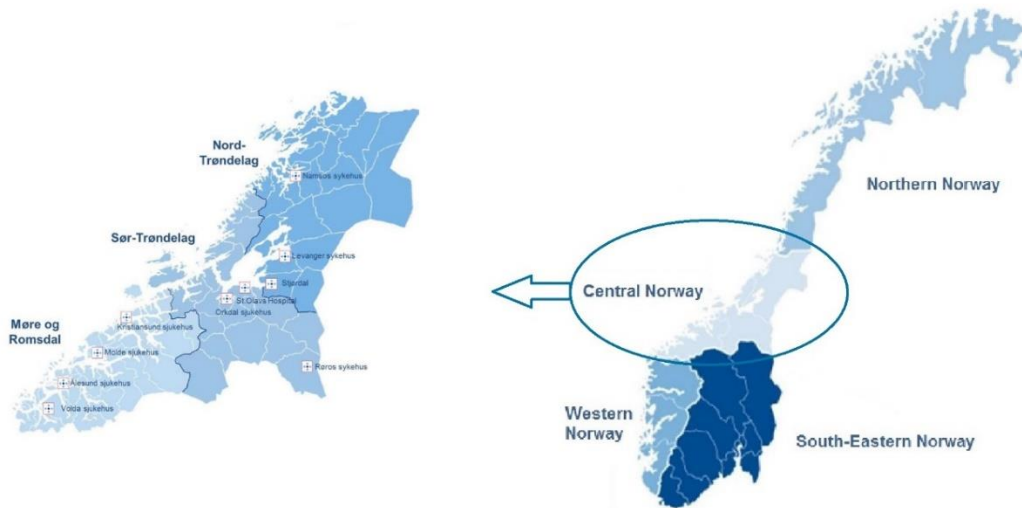
Figure 2: Four major regions of Health Authorities and their deviations in Norway (Helse Midt-Norge 2015)

1.1.1 The Health Authority of Central Norway

This region of health care is called Helse Midt-Norge (HMN, in Norwegian) and is responsible for specialist and hospital health services in the counties of Møre og Romsdal, Sør-Trøndelag and Nord-Trøndelag. This region has a population of approximately 697 000 which consists of 84 municipalities. The main goal of HMN is providing equal health services with a high quality for the inhabitants of this region at the right time and when they need it irrespective of their gender, age, nationality and social background. Security, respect and quality are three fundamental factors which are considered as the success key for reaching their purpose by HMN. There are some targets which are specified by the Central Norway Regional Health Authority's in order to reach the best result in this respect:

- Corroborated attempt for large group of patients
- Knowledge-based patient care
- A qualified organization for the care of patients
- The right services and expertise at the right time and at the right place
- Financial sustainability

HMN has had a revenue budget of around NOK 19 billion in 2015. It consists of almost 22 000 employees in average, 14 806 FTE's (The work hours by a full time based employee) in average

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and the total enterprise of nearly 700 000 sq. (Helse Midt-Norge 2015). Key figures of HMN are given in Table 1.

Table 1: Key figures Helse Midt-Norge RHF (Helse Midt-Norge 2015)

Population	697 000
Municipalities	84
Allocated funding 2015	NOK 18.9 billion
Allocated funding 2013	NOK 18.3 billion
Employees 2013	21 835
FETs 2013	14 806
Total area	700 000 m^2
Headquarters	Stjørdal

1.1.2 Organization

The Health Authority of Central Norway is ruled by the Norwegian government and the Ministry of Health and Care Services (HOD) plays an assistant role in this organization. The government has the entire right of governance which is handed by HOD. The rules will be applied by joint regular meetings, mission documents and executive decisions. The annual budget is provided by HOD for regional health authority. From January 2015 the region has been organized with four health trusts (HF) which the Central Health Authority of Norway owns. Besides, another segment which is called Central Norway Regional Health IT (HEMIT) who provides the IT systems for the organization as an internal administrator, has been established. The duty of HEMIT is not only addressing the technical issues, but also providing the equipment for all of the health authorities in Mid-Norway. It is located in eight different places and around 300 employees are working providing operational support, computer network and some other similar operations (Helse Midt-Norge 2015). The different departments of the Helse Midt-Norge RHF are illustrated in Figure 3.
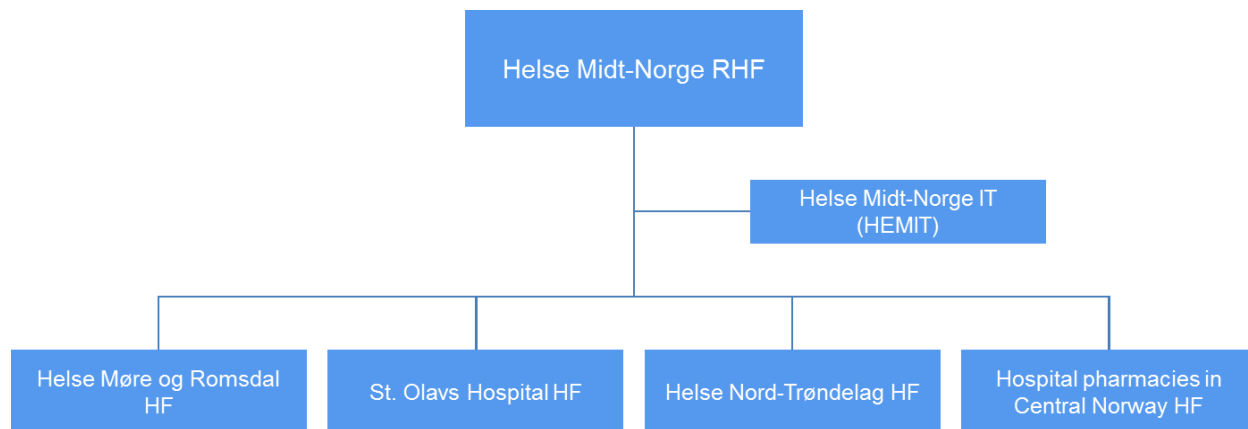
Figure 3: Chart of the departments of the Helse Midt-Norge RHF (Helse Midt-Norge 2015)

1.1.3 Hospital trusts

There are ten hospitals and three trusts in the central Norway and their headquarter is located in Stjørdal. The geographical situations of the hospitals are illustrated in Figure 4.

Figure 4: Map of the hospital trusts in the central Norway (Helse Midt-Norge 2015)

1.1.3.1 Nord-Trøndelag HF

Nord-Trøndelag is located in the north part of Helse Midt-Norge region and consists of 23 municipalities with almost 135 000 inhabitants. It had around 3 759 employees in 2014 and its budget revenue was NOK 2.8 billion in 2015. It contains three main hospitals of Namsos, Levanger and Stjørdal and some other institutions such as dialysis centers in Leksvik and Vikna (Helse Midt-Norge 2015). Some important figures of this county are given in table 2.

Table 2: Key figures Helse Nord-Trøndelag HF (Helse Midt-Norge 2015)

Population	135 000
Municipalities	25
Employees 2013	3 759
FETs 2013	2 360
Allocated funding 2015	NOK 2.8 billion
Hospitals	2
District psychiatric centres	2

1.1.3.2 Sør-Trøndelag HF

Sør-Trøndelag is located in the middle of Helse Midt-Norge region and consists of 23 municipalities with around 300 000 inhabitants. The main hospital trust in this county is St. Olavs Hospital HF which consists of St. Olavs hospital, Trondheim University Hospital and two local hospitals of Orkdal and Røros Hospital. It had approximately 10 000 employees and its revenue budget was NOK 8.8 billion in 2015 (Helse Midt-Norge 2015). Some main figures of St. Olavs Hospital HF are shown in the table 3.

Table 3: Key figures St. Olavs Hospital HF (Helse Midt-Norge 2015)

Population	300 000
Municipalities	23
Employees 2013	10 017
FETs 2013	7 258
Allocated funding 2015	NOK 8.8 billion
Hospitals	3
District psychiatric centres	3

1.1.3.3 Møre og Romsdal HF

The hospitals and warehouses which will be analyzed in terms of optimal numbers and locations in the current study, are located in Møre og Romsdal. As shown in figure 4, the four main hospitals of Kristiansund, Molde, Ålesund and Volda are located in this county. There are some small institutions, here, which are covered by this county as well. Møre og Romsdal is located in the south part of Helse Midt-Norge region and consists of 36 municipalities with around 255 000 residents. Møre og Romsdal HF has around 6 300 employees and its revenue budget was NOK 5.5 billion in 2015. The Norwegian government has decided to build a new hospital and replace it with the hospitals of Molde and Kristiansund which is planned to be ready for operation by 2021 (Helse Midt-Norge 2015). Some figures of this county's HF will be found in table 4.

Table 4: Key figures Møre og Romsdal HF (Helse Midt-Norge 2015)

Population	255 000
Municipalities	36
Employees 2011	6 300
FETs 2013	4 200
Allocated funding 2015	NOK 5.5 billion
Hospitals	4
District psychiatric centres	5

2.0 Description of the problem

As it has been mentioned before one of the challenging parts of each business is related to its inventory management. Among the issues which should be addressed in this area, finding the best location to place the inventory is one the most fundamental decisions. Especially if the items in the inventory could have a direct effect on the human life, the decision will be more sensitive. The warehouses of the hospitals are one of these kinds of inventories in which managing the inventory could not only have a large effect in the financial matters but also in some cases could be lead to some irrecoverable incidents.

The main purpose of this project is determining an appropriate ordering strategy to manage the inventory of four hospital warehouses in Møre and Romsdal in Norway. Eventually by applying

the chosen policies on the inventory of the warehouses and by calculating the relevant cost of them, the optimal number and location of these warehouses could be found. Molde, Ålesund, Volda and Kristiansund are four cities in this region in which four investigated hospitals and their warehouses are located. At the moment each city has its hospital and each hospital has its own warehouse. In this study the number and location of these warehouses will be studied in order to see whether by reducing the number of warehouses to two or one warehouse(s), the total cost of the inventory will be decreased or not. New combinations of warehouses should be selected among current buildings and no other new location will be investigated. Among three fixed situations of having four, two or one warehouse(s) decided as alternatives by the hospital trust itself, the best one in terms of cost should be determined. In fact, three main problems are being covered in this project:

- Determining an ordering strategy for the warehouses.
- Finding the optimal number of warehouses.
- Suggesting where the new warehouses should be located.

As it has been mentioned before, there are four regions of health care in Norway which are located in West, South-east, central (Mid-Norway) and North part of Norway. Møre and Romsdal, in which four mentioned cities of Molde, Ålesund, Volda and Kristiansund are placed, is located in the southernmost part of Central Norway Health Authority. In these mentioned studied areas, all the hospital warehouses contain two central and sterile warehouses in each city. The warehouse hospital in Ålesund is considered the headquarter of the warehouses. This warehouse with the capacity of 660 m^2 in the central and the capacity of 90 m^2 in the sterile part is the largest compared to the others. The warehouse of Molde hospital with the capacity of 343 m^2 in central and 90 m^2 in sterile section is the second largest one after Ålesund hospital warehouse. Then, the hospital warehouses in Kristiansund and Volda are the smallest ones with the capacity of 215 and 127 m^2 in the central warehouses and 90 and 25 m^2 in the sterile zones respectively. It should be noted that since hospital warehouse of Ålesund is headquarter and the biggest one among these four warehouses as well, it is more sensible if this warehouse would remain as one of the merged warehouses after reduction.

Some consumables stuff like plastic bags, office supplies and medical consumable products like injection needles and surgical drains are stored at these main warehouses typically. Medicines, surgical equipment and similar stuff are treated separately and are not part of the analyse in this thesis. Here are 13 categories of materials in the warehouses in general:

- Medical consumables, such as bandage and plaster.
- Laboratory supplies, such as sample cups and lens paper.
- The infusion and rinsing liquids such as sterile water and sodium chloride injection.
- Cleaners such as laundry powder and disinfection tablets.
- Workwear and protective clothing such as gloves.
- Disposables materials, such as tissue paper and baking paper.
- Fixtures and art decoration, such as cabinet and chair.
- Other consumables such as battery and coat hanger.
- Kitchenware such as mug and basket.
- Office supplies such as notepad and pen.
- Printed stuff such as receipt and journal.
- Mechanical and electrical equipment such as torch and toaster.
- Other smaller equipment and operating material such as measuring tape and cable ties.

In terms of criticality, materials and items in the warehouses are considered as three categories of high, medium and low. For example, among the above mentioned categories, the criticality of office supplies should not be as high as medical consumables. As it will be shown, this factor plays an important role in determining the safety stock.

3.0 Research Problem

As it has been mentioned previously, our main purpose is finding a convenient ordering policy for managing the inventories of hospital warehouses in three different situations. Then, based on the observed total cost of each situation, suggestion about reducing the number of hospitals' main warehouses in Møre and Romsdal from four to two or one will be proposed. In fact, final decision for merging the warehouses depends on some other aspects as well. This study will be a

part of the basis for the final decision and other aspects such as transportation cost, capacity and savings in workforce are not part of this analysis. Eventually, after estimating the cost of inventory, by adding the other mentioned costs, final decision will be made. It should be noted that we are not supposed to build any new buildings for the warehouses. In the other word, there are three situations in four fixed locations and we are supposed to make an analysis on how much reduction could be optimal in terms of inventory cost on one hand, and which of these current locations could be the best alternative instead of all, on the other hand. For this goal, all relevant costs should be considered for all of the situations. Here, determining the most appropriate inventory policy and the best location for new warehouses are two main subjects which will be covered in this study.

In order to address these issues, some other questions should be investigated as well:

- How to find the optimal number and location of warehouses?
- What are the typical products at the main warehouses and how should they be categorized?
- Which methods would be appropriate to solve the optimization problem and calculate the cost?
- How does this reduction affect the costs?

To answer the above-mentioned questions, some analysis should be done.

The general plan is to determine a similar ordering policy and calculate the total relevant logistical cost for each of the warehouses separately first. Then, for the relevant combinations of warehouses, a new ordering policy for the merged demand is determined and the costs are compared. The goods in inventory are consisting of some consumable and medical consumable items such as plastic bags, office supplies, injection needles etc. The list of items was mentioned in chapter 2 in more detail. For calculating costs and managing the inventory, there are some methods, policies and strategies which are highly dependent on the goods that should be stored in the warehouses. This issue will be discussed in more detail in chapter 5 regarding data preparation later. Suggestion for the best location for the warehouses will be proposed after calculating the Total Relevant cost by considering all the relevant elements such as order cost, inventory cost, safety stock cost and stockout cost.

4.0 Literature Review

There are loads of items in the warehouses of each hospital in Molde, Kristiansund, Ålesund and Volda. It is not convenient to treat many items separately when they are delivered by the same supplier. To address this issue, it is suitable to treat similar products as aggregated units and calculate the total demands of the products. For example, there are some plastic bags in the inventory of Ålesund in three sizes of 20 x 30 cm, 25 x 35 cm and 35 x 50 cm which have been supplied with the same supplier. For such products it is easier to estimate the demand for the main products than each variation of them. In this way, a common policy could be applied on all of the materials in one group. In this respect an ABC-classification is a common and pretty simple way to categorize the items. However, an ABC-classification is not performed in this study and all the items were treated as C-items. In fact, ABC classification is a Pareto principle based procedure for placing the priority of each group of items to manage (Ravinder and Misra 2014). This approach categorizes items based on their annual dollar usage by considering the fact that a large percentage of annual dollar use in the warehouses is related to small fraction of numbers (Cohen and Ernst 1988). A simple ABC classification is only based on one criteria such as annual dollar usage (Ng 2007). There are many cases also benefited from this approach by developing that and based on more than one criteria which usually named by the term of ABC-classification with multiple criteria.

In order to have an overview of the perspective and getting an idea for how to have more than one criteria, Ramanathan (2006) shows how the classification of items in inventory has been considered by using weighed linear organization. As it has been mentioned, ABC classification will categorize the items base on annual use of demand in two groups of A and C as large number of annual use value and low number of that respectively, and group B for the items which are not required to be put in group A and C. The model that is developed in the paper consists of N items in inventory with J criteria for classification and three A, B and C groups based on the criteria. The classification has been done by considering the average unit cost, annual dollar usage, critical factor and lead time in this research and by these criteria optimal inventory score has been calculated.

In another relevant article (Al-Qatawneh and Hafeez 2011) authors have mentioned that considering annual dollar usage as the only criteria for grouping the items is the main limitation of an ABC-classification method in healthcare inventory organization. As an explanation, it is

mentioned that there are some items in the healthcare inventory with low usage annual value which will not be placed in the right priority. In this case, one of the other criteria which should be considered as an important scale is criticality of the items. In the case study, they have used a policy with continues replenishment in which control of the system is based on order and inventory. They have applied multi-criteria classification model for the inventory. The criteria which have been considered as appropriate in the case are criticality, cost and item usage value. The three categories which have been applied for criticality are based on the following assumption:

a) High criticality for the items which are essential for fulfilling the activities and there is not any other alternative for them;

b) Medium criticality also applied for the important items but there is the possibility of using the alternatives for them – with some small differences such as theirs size – in case of stockout;

c) Low criticality for the non-vital item when out of stock.

Also the service level of safety stock for items with high, medium and low level of criticality of 100%, 90% and 80% has been determined respectively. As a conclusion, the result showed that the service level factor does not have any effect on the number of orders. It was clarified that selecting different service levels with respect to items by considering the criteria of criticality, usage and value could be effective in reducing the cost in the inventory. Besides, it will secure the warehouses in terms of having enough inventory of items which are critical for the human life saving. In fact, the service level will only affect the size of the safety stock, while the cyclic inventory will remain the same.

Another important matter which should be considered, here, is whether the concept of the merging warehouses is profitable or not at all. In this respect, Lim, Ou, and Teo (2003) have a study in which the benefit of consolidation on inventory replenishment cost has been discussed. They showed that consolidation system is very close to optimal inventory replenishment cost. They proved that by having two selected warehouses, replenishment cost even in the worst case is very close to optimal. They considered the transportation cost as an important element in saving cost.

Finding an optimal location for the warehouses after reduction is also another important issue which should be figured out. In this study, the optimal location should be selected among some fixed warehouses. Özcan, Çelebi, and Esnaf (2011) have written an article in which they use a

model for choosing the best location between some alternatives. Based on the article five fundamental criteria should be considered in order to make the decision: Unit cost, stock holding capacity, average distance to shop, average distance to main supplier and movement flexibility have been mentioned as the most important criteria in this research. Based on the volume of the criteria and some calculation, the best alternative could be found as the selected one that is closer to the optimized warehouse.

Ho and Perl (1995) have also written an article in which they have defined the service-sensitive warehouse location problem as the problem of determining the number and location of warehouses. In a chapter of the article, fraction of unsatisfied demand and cycle time have been considered and found that as sensitivity of demand increases, the error in warehouse will be increased as well. Some highlights of the conclusion are given below:

- The number of warehouses will be increased by having the sensitive demand.
- Increasing the replenishment size could decrease the number of warehouses.
- Increasing the safety stock levels can lead to increasing the number of warehouses.
- Strategy for selecting the optimal location for warehouses is sensitive to the unite price.

Apart from what has been discussed about the warehouse optimal location and classification of the materials in the inventory, ordering strategy of the goods should be considered as a fundamental issue. There are a lot of strategies for managing the inventory, among them Just in Time (JIT) and Economic Order Quantity (EOQ) could be mentioned as two common ones. Fazel, Fischer, and Gilbert (1998) have made an analysis on comparing these two strategies in terms of cost advantages in a manufacturing company. By developing a mathematical model, they found that a more appropriate strategy to choose is dependent on many factors. Altogether the results show that in the low level of demand, Just in Time is more proper while Economic Order Quantity has more cost advantages for the items with high demand.

There is also a case study by Soshko, Vjakse, and Merkuryev (2010) in which the inventory management system of a distribution coffee company has been analyzed. In the inventory of that, lead time of goods is one day and the replenishment is placed in a continuous review with the period of one day and delivery of the supplier is monthly by a periodic review. Based on ABC Analysis, an appropriate strategy has been investigated. Product have been divided into three

main categories: Group A, with a high level of safety stock and continues strategy for review, group B with average safety stock and periodic review, and group C safety stock is not made at all with very rarely control of inventory level. (S, s) and (s, Q) have been used and demands have been calculated in three ways and found that results in (S, s) system are very close to empirical results. Silver, Pyke, and Peterson (1998) describe two common service levels: P_1 which is defined as probability of not having a stockout and P_2 defined as the fraction of satisfied routinely demand. Returning back to the Soshko and Vjakse study, a simulation model has also been developed and P_1 and P_2 with the 95% and 100% service level have been used. In the main conclusion of the case study, it has been found that the most reasonable strategy is strategy (s, Q) system with the service level of 95%.

Another article which is about the inventory of different items written by Mohammaditabar, Ghodsypour, and O'Brien (2012) could be very relevant and helpful in this research. Two main problems of categorization of different items in one group and finding optimal policy for each category have been considered in this paper. For these purposes a model has been developed to cover both issues. In the model based on the similarity, categorization of the items has been done and minimization of the costs has not been neglected either. In this research the group has been divided to groups A and B with continuous review and group C with periodic review. An ABC classification has been used in the model for classification of the items which tries to put items with high annual value in the same group and items with low annual value in another group.

Transportation cost is another part of the cost which is very relevant when deciding whether the warehouses should be merged or not. In fact, for the final decision, this cost and some other costs should be added to what will be estimated for inventory cost in this study in order to make final decision. Litman (2009) has done a research about transportation cost and benefits and impacts of that in terms of economical aspect. In this article, 11 kinds of traveling transportations such as electric car, compact car and diesel bus, based on mile for both vehicle and passenger have been analyzed. Optimal pricing has been mentioned as one of the impact of cost analyzing in this study. Transportation cost on the one aspect has been divided into three part of external, internal and social cost and from another aspect has been divided into variable and fixed cost. There are also some other kinds of cost division such as market or non-market costs, perceived or actual cost and direct or indirect cost from the writer's perspective. In the following, table 5 has been

taken from this paper in which some different aspects of transportation cost have been mentioned.

Table 5: Vehicle cost distribution

	Variable Cost	Fixed Cost
Internal	Fuel Short term parking Maintenance of vehicle Time of user Risk of crash for user	Vehicle purchase Vehicle registration Insurance payments Parking for long time Maintenance of vehicle
External	Maintenance of road Services of traffic Insurance Delay of Congestion Impact of environment Uncompensated risk of crash	Construction of road Subsidized parking Planning of traffic Lighting for street Impacts of land use Social inequity

One of the most fundamental issues which should be considered in this study could be related to different policies for managing an inventory and associated costs of that. Silver, Pyke, and Peterson (1998) have written a comprehensive book in this respect. As it has been mentioned before, the main purpose of our study is analyzing different situations of warehouses and finding the optimal one by using different policies for managing and ordering goods in these warehouses. In order to make such analysis, Total Relevant Cost (TRC) of warehouses in different conditions, as the most important criterion, should be analyzed. TRC-formula should be defined for a specific time period which is usually one year and the other associated parameters such demand and interest rate must be annual as well. Total Relevant Cost contains four major parts:

- Ordering Cost or Setup Cost
- Inventory Cost or Holding Cost
- Safety Stock Cost
- Stockout Cost or Shortage Cost

Each of these components in the perspective of Silver, Pyke, and Peterson (1998) are briefly described below:

Ordering Cost

Ordering Cost should be defined as a fixed cost related to each replenishment, regardless of the ordering size. This may comprise cost when physically receiving the order, telephone cost, cost of order forms, unexpected conditions related to an order and so on. After calculating this factor, by using the formula given below, the ordering cost for the whole specific materials in the inventory will be calculated:

$$Ordering\ cost = \frac{D\ A}{Q}$$

D: Estimated demand for the items during time horizon
A: Cost of placing one order
Q: Order quantity

Inventory cost

The associated cost of holding goods in the inventory is known as inventory cost which consists of cost of physical space, insurance, taxes, capital cost and so on. Inventory cost is calculated by multiplying an average size of stock by cost of holding one item in inventory according to the formula given below:

$$Inventory\ cost = \frac{Q\ v\ r}{2}$$

Q: Order quantity
v: Unit value
r: Carrying charge

Safety Stock Cost

Safety stock could be defined as the average level of the stock when a new order arrives. Associated cost for keeping such items in the stock will be considered as Safety Stock Cost. The

determined safety stock is not supposed to remove all stockouts, but the majority of them (Peter L. King 2011). For example, for a 95% service level, for 50% of the cycles, the safety stock will not be touched. For 45% of cycles safety stock is adequate. 5% of the cycles anticipate a stockout. Figure 5 illustrates this situation. The figure represents a production situation since the line is not vertical when increasing inventory.
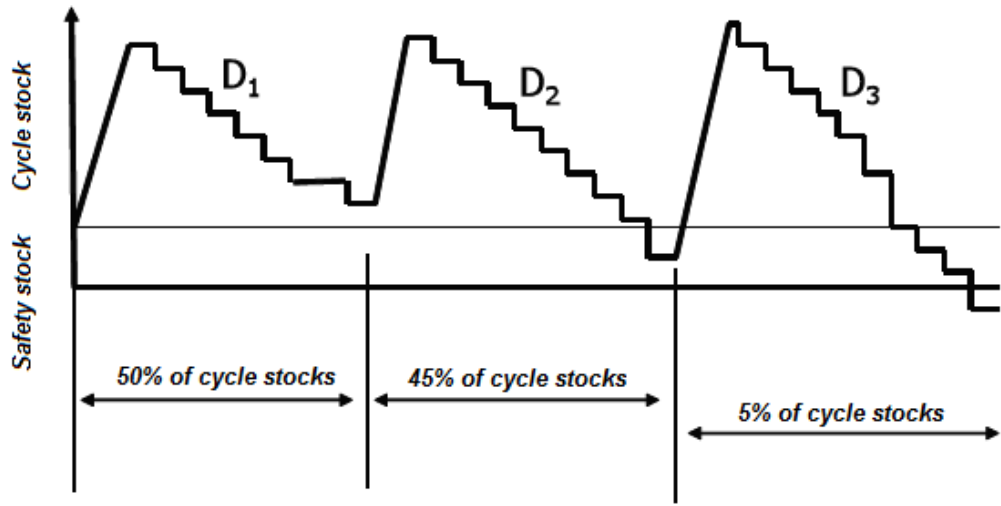
Figure 5: Inventory designed for a 95 percent service level (Peter L. King 2011)

Safety Stock Cost will be calculated by the following formula (Silver, Pyke, and Peterson 1998):

$$Safety\ stock\ cost\ =\ SS\ vr$$
$$SS\ =\ k\ \sigma_L$$

SS: Safety stock
v: Unit value
r: Carrying charge
k: Service factor
σ_L: Standard deviation in lead time assuming that the demand is normally distributed

Safety stock from one perspective is defined based on minimizing cost. From another perspective, service level also will be effective in the safety stock. In fact, the service level defines the safety factor (k), which is what decides the size of the safety stock. Here, safety stock

will be determined based on customer services. In this respect, P_1 is defined as the probability of not having stockout in each replenishment. P_2 is defined as fractional demand to be satisfied routinely. P_3 is defined as the fraction of time in which the net stock is positive. TBS which stands for Time Between stockout could be used to define the acceptable time between stockout situations.

Stockout Cost

The cost associated with not having enough stock in the inventory is called Stockout Cost which consists of internal costs such as delays and external costs such as loose of profit because of lost sales. Here, there are for major kinds of penalties for the stockout situation which will be described briefly. Among them B_1 and B_2 are the most common ones. B_1 penalty is a fixed amount of cost which should be considered in the case of stockout. B_2 penalty is a fractional charge which will be considered per each unit short. Third one is a B_3 penalty which is the fractional charge for each unit cost per unit time. This penalty will be chosen in the situation in which for example the relevant items are part of spare and when it is required and there is not in the stock, the whole process will be stopped and there is some idle time as well. B_4 is the last kind of penalty which is a penalty per customer line of item short. This kind of penalty will be appropriate for the situations in which there are several different kinds of items for one specific customer and some of them are not available in the stock. Mostly large manufacturers ask for this kind of penalty from their suppliers. With a B_2 penalty (which has been used in this case study), this cost could be calculated by the formula given in below:

$$Stockout\ cost = \frac{D\ B_2 v\ ES}{Q}$$
$$ES = G(k)\ \sigma_L$$

D: Estimated demand for the items during time horizon
B_2: Fractional charge per unit short
v: Unit value
ES: Expected number of unit short
Q: Order quantity
G(k): Standardized loss function for a given k-value in the normal distribution
σ_L: Standard deviation in lead time assuming that the demand is normally distributed

For calculating these costs, first the strategy for managing the inventory and ordering the goods should be determined. There are two major policies for checking the status of the inventory in general: continuous review and periodic review. In a continuous review, the status of inventory should be known all the time. With the computer systems, this will not be any issue to check the situation of the inventory continuously. In a periodic review, the status of inventory should be checked only at a certain time period. There are two common types of inventory control systems with a continuous review and two common types of that with a periodic review as well which will be described separately in the following. (Silver, Pyke, and Peterson 1998)

(s, Q) System, a continuous review policy

In this system, s and Q are the symbol of order point and order quantity. In this continuous system review of inventory, the status of the inventory and goods in stock should be checked continuously and once the level of inventory fall to the reorder point of s down or lower than that, a new order with a fixed quantity of Q will be placed. The simplicity of this system should be considered as the main advantage. Since this controlling system of inventory is quite simple, the managing errors will be less likely to occur. The problematic situation happens when the individual transactions are large. Figure 6, illustrates the behaviour of inventory level in this system.

Figure 6: Behavior of Inventory Level with Time, (s, Q) system (The figure is adopted and modified from Inventory Management and Production Planning and Scheduling (Silver, Pyke, and Peterson 1998))

(s, S) System, a continuous review policy

In this system with a continuous inventory review, a new replenishment will be made when the inventory level of goods reaches to the level of s or lower than that. In this system, the quantity of each order is variable and in each order, the inventory level will be replenished up to the level of S. The total relevant cost in this system in the best situation is not larger than the total relevant cost in the best situation of (s, Q) system. Figure 7, shows the behaviour of inventory level in this system.

Figure 7: Behavior of Inventory Level with Time, (s, S) system (The figure is adopted and modified from Inventory Management and Production Planning and Scheduling (Silver, Pyke, and Peterson 1998))

(R, S) System, a periodic review policy

This system with a periodic review of inventory will be mostly used in the companies who lack computer system controller. However, there are some other reasons for using periodic review as well, for example, if purchaser can only receive or if the supplier only can deliver at specific days of the week. In this system, each replenishment will be made every R unit time and the inventory level will be refilled up to the level of S in each order. However, the carrying charge, here, is higher than in the continuous review system, but the order up to level S will be adjusted every R unit of time (Silver, Pyke, and Peterson 1998). Figure 8, shows a typical behaviour of this system.
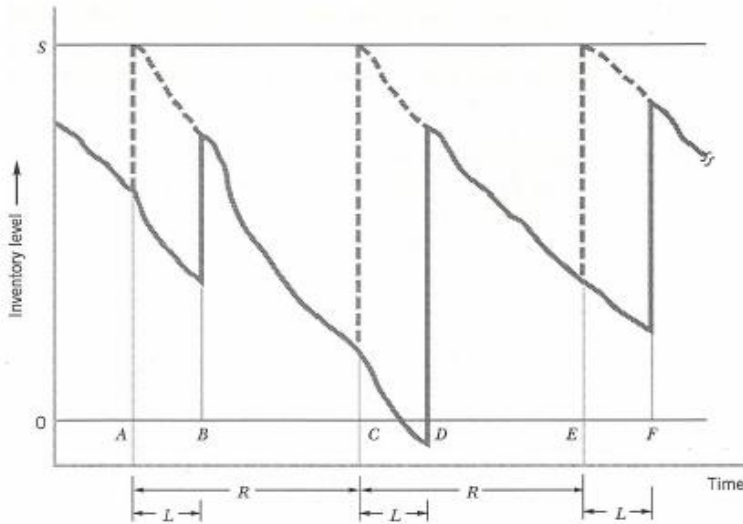
Figure 8: Behavior of Inventory Level with Time, (R, S) System (Silver, Pyke, and Peterson 1998)

(R, s, S) System, a periodic review policy

This periodic review policy is in fact a mixture of (s, S) and (R, S) system. In this system the inventory will be checked every R time unit. If the level of stock reaches s or smaller, the replenishment will be done up to the level of S. If not, without any operation, the inventory will be left until the next R time unit. It has been shown that under the same situation, total of replenishment, stockout and carrying cost of this system is less than others (Silver, Pyke, and Peterson 1998). Figure 9, illustrates the behavior of inventory level in a (R, s, S) system.
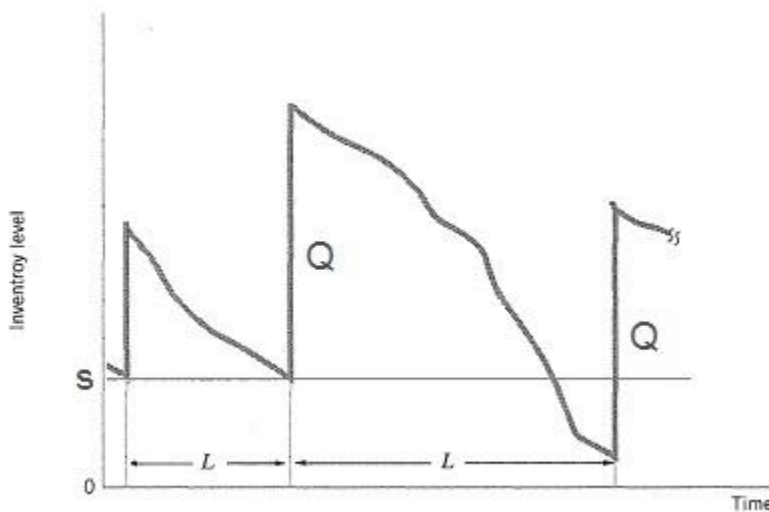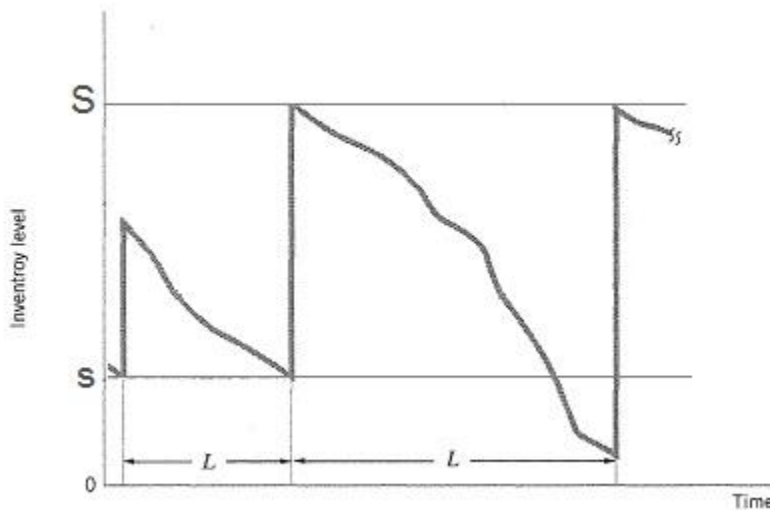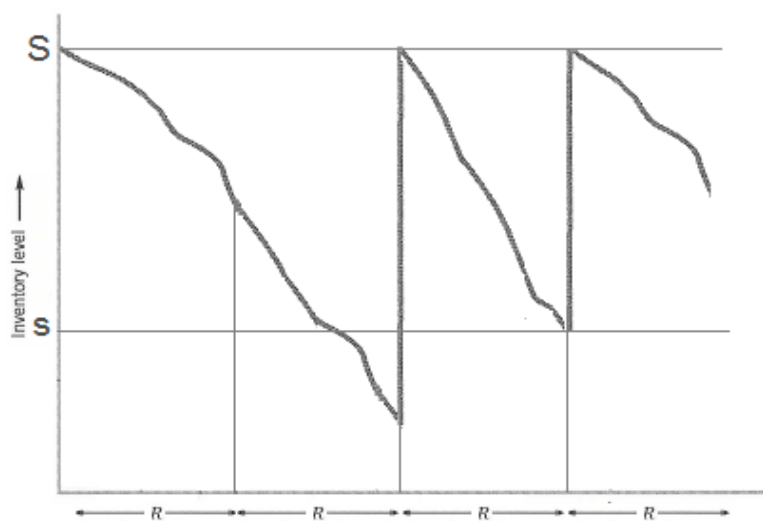

Figure 9: Behavior of Inventory Level with Time, (R, s, S) system (The figure is adopted and modified from Inventory Management and Production Planning and Scheduling (Silver, Pyke, and Peterson 1998))

As it has been mentioned before, items in inventory are categorized in three different groups of A, B and C-items. The policy that will be applied on each group should be selected by considering the items. By considering the criteria for classification of the items, it would be clear that the efficiency of selected policy for A-items is more critical than C-items. Above mentioned policies are more practical for A and B-items and a simple procedure could be applied for C-items. Table 6 shows the classification of items with their appropriate methods based on Silver, Pyke, and Peterson's point of view (1998).

Table 6: Different policies for different items groups

Type of inventory review	Continuous	Periodic
A-items	(s, S)	(R, s ,S)
B-items	(s, Q)	(R, S)
C-items	Simple method	

5.0 Material and method

5.1 Methodology

As it has been mentioned before, one of the most critical issues for each organization is related to the inventory part of that special business. In general, there are two important points in the inventory department of each business which are always considered as important elements in a warehouse:

- Having sufficient inventory level of materials
- Optimizing the inventory costs

In fact, the main goal of managing an inventory is having the right amount of goods at the right time with the lowest cost. For reaching this prominent purpose the main strategy for managing the inventory should be determined. As there are many items in each inventory system of each business, depending on the goods, different strategies maybe used as ordering policy. Since the selected strategies are very dependent on the items and almost always there are some items in

inventory which are quite similar to each other, first of all materials should be categorized in some different groups. Then, the proper strategy could be applied for each group of them. ABC classification could be considered as one the simplest and most common methods for grouping the goods, in which items will be divided into three categories: A-items, B-items and C-items. In general, this categorization is based on annual dollar usage. To put it simply, demand and cost are two fundamental criteria in this kind of classification. ABC classification is based on Pareto principle (Dhoka and Choudary 2013). In this respect, the rule implies that 20% of the goods in the inventory have the value of 80% in terms of annual dollar usage. These items should be considered as A-items and because of their importance, the strategy for ordering and having enough inventory of them would be more crucial. The items with lowest level of criticality in terms of cost should be grouped as C-items which are usually encompassed about 50% of the items in the inventory. The policy for managing these items could be simpler that the other groups. Rest of the goods, which are around 30% of the inventory, are those which could neither be considered as A or C-items. This group are B-items for which the inventory policy could not be considered as very critical one and should not be considered as the simplest one either. After specifying the items as the A, B and C-items, strategy for ordering should be decided. As items are more critical in group A, than B and C, the policies for these items are more important as well.

In the hospital trust cases, by considering the historical data in the inventory list, it was found that the stored items in the warehouses are consumables which suits to the definition of C-items. Therefore, an ABC classification has not been applied in this analysis. In the initial model which had been developed at the first steps, all the items had been considered as C-items. Then by calculating the frequency of the items in each order, it was found that there are some items which are small in amount. Some of them should be ordered only once a year. So, in the second step, after detecting such items, they were brought out from these groups. It should be noted that however most of the items were similar and placed in the same groups, but because of having different criticality for the items (depending on the items and defined by the hospital trust) the service level and the corresponding stock level would be different. The applied strategies for each group of the items will be explained after having a look at some different kinds of inventory policies in general.

In this respect, there are some different strategies to review the inventory status whether there are enough items or the new order should be placed. In general, these strategies could be divided into two major methods: continuous and periodic review. As it could be found from the names, in a continuous review, the status of the inventory should be known all the time. So, it could be more suitable for items with higher level of importance. In a periodic review, status of the inventory will be inspected after each specified period of time. This kind of reviewing the status of inventory is more suitable for items which are not important as much as the others.

5.2 General idea

As it has been mentioned before, the purpose, here, is making an analysis of the number of warehouses for the hospitals in the four cities of Molde, Ålesund, Volda and Kristiansund by determining appropriate policy for their inventories. Two main questions to be answered are: a) Which policy is proper for each inventory? b) How much savings can be achieved by merging the warehouses? Currently each hospital in each city has its own warehouse close to the hospital. But if the number of warehouses is supposed to be reduced to two or one, some of them should be merged with each other. For this purpose, the general idea is first to calculate the Total Relevant Cost (TRC) with an appropriate policy for each warehouse in the current situation. For finding the TRC for each warehouse, an estimation of the cost factors should be computed. At the next stage, the TRC for the combination of warehouses after merging should be calculated. Since the warehouses of Molde and Ålesund are larger than the others in terms of capacity, the reduction should be done by merging the warehouses in Volda with Ålesund and merging Kristiansund with Molde. Besides, the hospital warehouses of Volda and Kristiansund do not have enough space to be viable to hold and supply the required items. Therefore, based on the confirmation from the hospital trust, only three feasible combinations should be analyzed:

1. The current situation, four hospitals with their own warehouses in the cities which they are located in;
2. Molde and Kristiansund warehouses would be combined with each other located in Molde, while Ålesund and Volda warehouses would be merged and located in Ålesund;
3. All the warehouses of Molde, Ålesund, Kristiansund and Volda would be incorporated and located in Ålesund.

It should be noted that the combinations of the Molde and Volda in Molde, and Ålesund and Kristiansund in Ålesund are not geographically justified. By having a look at the situation of the cities in the map one could see that Molde and Kristiansund are close to each other similar to Ålesund and Volda.

Eventually, by comparing the cost of all considered situations, the best combination – in terms of feasibility and cost – could be selected.

5.2.1 Overview

As it has been mentioned before, this thesis is a real case study in which a research for finding a proper inventory strategy of four hospital warehouses and analyzing a potential reduction of the number of warehouses in county of Møre and Romsdal in the middle of Norway has been studied. In the current situation there are four hospitals in this area and each hospital has its own main warehouse. The goal here, is managing the inventories with the befitting policies for the purpose of decreasing the number of warehouses from four to two or one considering reducing the costs and delivery time. In other world, the main focus is to compare the logistical costs for different alternatives of warehouse locations. One of the means for doing this is to obtain an appropriate inventory policy. Hence, associated costs of other area such as potential reduction of workforce, buildings, internal and external transportation etc. has not been considered. Then, among these four main warehouses, two or one will be suggested as the best located warehouses after reduction at the end of this research. For having a general overview, the process of what should be done has been mentioned very briefly below.

For this purpose, some information and data for the items in the inventory of the hospitals should be obtained. Based on the information such as unit cost, criticality, cost of each item, cost of placing each order for the items and the historical data in general, some estimation for the future and after decreasing the number of warehouses could be calculated. One of the initial activities which should be done at the first stages could be grouping the items with same characteristics together and categorize them, then different inventory policies could be applied on each group. After categorizing the items, the most appropriate policy for each group should be selected. Simply put, the amount of inventory, stockout and reorder point, based on the demand distribution, ordering cost and the penalty for stockout will be determined (Arrow, Harris, and Marschak 1951). Criticality of the items in the warehouses, as the most and solely element

should be noted for determining the safety stock and stockout costs. The quantity of orders for each item group and its frequency would be decided and based on all these findings, the total relevant cost for each warehouse could be calculated. By making a comparison and analysis on the results, the optimal number and fixed locations for the warehouses can be chosen.

For such analysis, we have gone through the items in each warehouse in the current situation to obtain some estimation mostly about the costs and items description in order to categorize them. Based on the historical data from 2010 to 2015, which has been received from the hospital trust, a reasonable estimation for the future costs has been forecasted. A model for calculating the relevant parts, and eventually Total Relevant Cost (TRC), has been developed by using Excel spreadsheets.

5.3 Data preparation

In this case study, at the first stages, we have received some data files from hospital trust in some Excel spreadsheets containing two kinds of data in general: information about the items in inventory and information about the items which had been ordered from 2010 to 2015 as external order from some different suppliers. For simplicity, the terms of "inventory file" and "external order file" will be used instead. Since there were so many items in the inventory file and the items which came from the same supplier were mostly similar to each other and in many cases only differed in their dimensions, an aggregate cost for each group of items which have been supplied by the same vendors has been created. Therefore, all the items supplied by the same supplier will be considered as a single artificial item (aggregate product) and an aggregate unit value should be determined for this item group (Nahmias 2009). In this way, the amount of items from a very large number was reduced to 150 items. However, the main reason for making such aggregated items could be related to their distribution. Since these items are delivered from the suppliers to warehouses directly, it is more convenient to deliver several items in each delivery simultaneously. Therefore, the aggregate cost as a representation for all the goods from the same supplier could be a good option giving us a pretty reasonable estimation for the cost of each unit. In this way it has been assumed that each supplier represents one item with a typical unit value. In determining such aggregate unit value, it has been tried to create a unit value typical for all products of the supplier by taking both price and sales volume into consideration.

Simultaneously, the amount of demands has been used from the external order file in which the standard deviation has been extracted from the demand by inspecting all these six years as well. Annual demand has been found through demands in the historical data of six years and by calculating a simple average demand from them. The products stored in the hospital warehouses are consumables which suits to the definition of C-items. A-items at hospitals are not part of this study, as they are typically more expensive and important products to be treated separately. By considering the items in "inventory file" and "external order file", it was found that there are some items which have been ordered but are not available in the inventory and vice versa, there are a few items in inventory which has not been ordered at all. By asking about these items from the hospital trust, it was decided to ignore those items which are not available in inventory and have not been ordered in 2015 (meaning that these items may be outdated and they would not be ordered anymore). Hence, some adjustments had to be done due to replacement of products or suppliers. Moreover, the information of those items which had been ordered but had not been available in inventory was extracted from "external order" files. So, the process was started by preparing the data. First of all, all the supplier numbers which represented a group of items were put in separate Excel sheets for each year. Then all of them were collected in a single sheet together with the aggregated unit cost. The duplications of the supplier numbers were deleted. The supplier numbers from the "inventory file" were placed as well. Then, all supplier numbers from "external order file" and "inventory file" was gathered and a unit costs relevant to each unique supplier number was found. As it could be observed from the table 7, the supplier numbers with their unit costs are prepared now (supplier numbers have been changed in this thesis for the sake of confidentiality). Similar process for preparing the data was done for all four hospitals.

Table 7: Data preparation, Unit Cost

Inventory file, Supplier No	Unit cost	External order file, Supplier No.	Inventory + External order file Supplier No.	Unit cost
~~082~~	~~NOK 14.67~~	_	_	_
106	NOK 147.18	106	106	NOK 147.18
108	NOK 636.04	108	108	NOK 636.04
110	NOK 481.38	110	110	NOK 481.38
132	NOK 17.44	132	132	NOK 17.44
160	NOK 148.75	160	160	NOK 148.75
161	NOK 18.10	161	161	NOK 18.10
162	NOK 21.28	162	162	NOK 21.28

Our goal is calculating Total Relevant Cost (TRC) for each hospital at the current situation. Historical data show that the lead time is approximately one week for all suppliers. As earlier mentioned, for calculating TRC at the first stage, it was decided to consider all the items as C-items and calculate TRC by a simple policy with periodic review. For this purpose, some values and variables are required. Preparing and calculating each of these required values will be explained separately in the following.

5.4 Weekly standard deviation

Standard deviation of demand is one of the parameters which should be considered for calculating the TRC. For calculating this effective parameter, demands from the historical data should be investigated. The estimated standard deviation would be more accurate by observing more historical data. We have received the data for 6 years from 2010 to 2015. Some items may not have been ordered every year, so, demands for some of the years may be zero. The years with zero demand should not be considered in the calculation. In an Excel sheet, first the prepared supplier numbers (considered as items) and the value of the annual demand (Dv) for the six years were placed. Afterward, by dividing each Dv over the relevant unit cost (v) the demands of each year were calculated. The summations of Dvs for the total of six years were also prepared. By dividing these summations over the number of non-zero years, the average demands over the active past years were calculated. Then by diving these average demands of the active years by the unit cost for each supplier number, the average amount of those aggregate items during the active past years were calculated. Eventually, standard deviation of active years for each supplier number during the six years (only by considering the active years) was calculated. Now, we have calculated annual standard deviation. By using the formula below, it could be change to weekly standard deviation in the next and last column:

$$\sigma_{New} = \sigma_{Old} \sqrt{\frac{New\ time}{Old\ time}}$$

Where σ_{Old} is annual standard deviation, By considering a year as 52 weeks, weekly standard deviation will be calculated according to:

$$\sigma_{New} = \sigma_{Old} \sqrt{\frac{1}{52}}$$

It should be noted that the gained values, here, are weekly standard deviation in a year. Weekly standard deviation in the lead time is what is required in our calculation. How to find the lead time for each item will be explained later in the chapter of Frequency. Here, by using the above equation, based on the lead time of each item, the new values for the standard deviation of each item were determined.

Table 8 shows calculation of weekly standard deviation for some items in the inventory of Ålesund (supplier numbers have been changed here for the sake of confidentiality).

Table 8: Calculation of Weekly standard deviation

Supplier No.	Demand (2010)	Demand (2011)	Demand (2012)	Demand (2013)	Demand (2014)	Demand (2015)	Standard Deviation	Weekly standard deviation
110	_	6	_	30	34	10	14.04	1.94
214	_	_	_	_	7	2	3.53	0.49
222	_	_	48	50	300	99	119.51	16.57
238	286	209	268	303	360	228	54.29	7.53
244	_	59	37	61	13	73	23.76	3.29
248	131	139	154	155	159	128	13.38	1.86
251	5 988	6 301	17 398	8 544	14 055	1 6843	5 215.53	723.26

5.5 Criticality

One of the other parameters required for estimating the TRC is criticality. In the data sheet received from the hospital trust, each item has a number determining the criticality of the item. Since all of the items which were supplied from the same vendors have been considered as one item, the criticality of each item group should be investigated. All of the supplier numbers before and after aggregation were put in a single Excel sheet. A table for the criticality was also provided by the hospital trust based on which the criticality of each item and item group should

be determined. By considering the table and the amount of items with different criticality, the final criticality for each supplier number (considered as an item or item group) was determined. In most cases the products from the same supplier were of the same criticality. For example, the suppliers of some medical consumables such as bandages had high criticality, while suppliers of office equipment e.g. pens had low criticality. For example, bandages of three sizes where found in the inventory all had been considered as high level of criticality, or pens of different colours had similar criticality of low. So, for the items group of bandages and pens, the criticality of high and low were considered respectively. In the few examples where the products of one supplier had different criticalities, the highest criticality was chosen.

5.6 Ordering cost (A) and Carrying cost (r)

Ordering cost is a fixed cost regardless of the size of order in each replenishment and could consist of cost of order forms, phone calls, work hours when receiving goods, unanticipated situations and so on. The carrying cost of inventory or interest rate refers to all the costs of holding items in inventory such as opportunity cost of investment, insurance, warehouse rent etc. Definitions given by Silver, Pyke and Peterson (1998) are "Ordering cost is a fixed cost component independent of the magnitude of the replenishment quantity – The carrying charge is the cost of having one dollar of the items tied up in inventory for a unit time interval (normally one year)".

As it could be understood from the definition, these two parameters are constant in each warehouse and the values of them could be effective in our calculations. The exact values for these two parameters were not provided at the moment of the analysis, so we have used two typical and pretty realistic values of 20% and NOK 800 (which were approved by the hospital trust) for interest rate and ordering cost, respectively, in our calculations. We have also made some analysis on if these values would be increased or decreased by some amount in different warehouses and situations.

5.7 Penalty cost for Stockout

For determining the cost where the stockout accrued, penalty cost for stockouts should be considered as one of the most important elements. This coefficient number could be assigned as a fixed number (B_1), a fractional charge per unit (B_2) or per time (B_3) and a specified charge per line item short (B_4). Two first ones are most common kinds of penalties. In fact, the penalty can be seen as the inconvenience of not having the product when needed. Since in the hospitals' warehouses, there are a variety kind of materials with a wide range of price, a B_2 has been decided to use as a penalty per item short. The number which will be determined for this variable has a direct effect on the stockout cost. Since here are the items in the warehouses which should be supplied for the hospitals and the items should be available at the right time, a 100% penalty was decided to use for all the items in the inventory.

5.8 Service level

Service level is one of the most important factors which has a direct effect on safety stock. It affects the probability of getting a stockout as well. Based on this value safety stock will be determined. There are some different kinds of service levels which among them P_1, P_2 and P_3 are the most common ones. As a very short description, P_1 is defined as probability of not having stock out per replenishment cycle, P_2 is defined as a fraction of demand to be satisfied routinely and P_3 as the fraction of time during which net stock is positive. Since this factor has a fundamental effect on safety stock cost, the importance of the specific items should be considered. Importance of the items could be found from the criticality of them. So, by the rule of thumb, the items with higher levels of the criticality should have the higher service levels. In calculation of this study a P_2 service level has been used. As criticalities had been found for each items some steps before and by a confirmation from the hospital trust as well, the P_2 of 99.9% for those items with high level of criticality and 98% and 96% for the items with the medium and low level of criticalities were allocated as the service levels, respectively. In order to calculate safety stock and stockout cost, two other values called k-value and G-value are required which should be found from the Normal Distribution table. The relevant calculations are given in below:

$$SS = k\,\sigma_L$$

$$ES = G(k)\,\sigma_L$$

$$Safety\ stock\ cost = SS\ v\ r$$

$$Stockout\ cost = \frac{D\ B_2 v\ ES}{Q}$$

SS: Safety stock
k: Service factor
σ_L: Standard deviation in lead time assuming that the demand is normally distributed
ES: Expected number of unit short
G(k): Standardized loss function for a given k-value in the normal distribution
v: Unit value
r: Carrying charge
D: Estimated demand for the items during time horizon
B_2: Fractional charge per unit short
Q: Order quantity

Table 9 and 10 show different service levels based on the criticality of items and calculation of safety stock costs and stockout cost for some items in the inventory of Ålesund (supplier numbers have been changed here for the sake of confidentiality).

Table 9: Allocated service levels based on criticality

Supplier No.	Demand	Unit Price	Criticality	B_2	P Value	K Value	G value
110	20	NOK 481.37	High	100%	99.9%	3.09	0.0002771
214	5	NOK 13 510.35	Low	100%	96.0%	1.75	0.01617
222	125	NOK 204.85	High	100%	99.9%	3.09	0.0002771
238	276	NOK 116.34	High	100%	99.9%	3.09	0.0002771
244	48	NOK 191.25	High	100%	99.9%	3.09	0.0002771
248	145	NOK 909.74	High	100%	99.9%	3.09	0.0002771
251	11522	NOK 3.52	High	100%	99.9%	3.09	0.0002771

Table 10: Calculations of Safety Stock Cost and Stockout Cost

Supplier No	Standard deviation in lead time	Safety Stock	Expected number of unit short	Safety Stock Cost	Stockout Cost
110	13.76	42.51	0.004	NOK 4 092.56	NOK 2.03
214	1.95	3.42	0.032	NOK 9 241.50	NOK 1233.43
222	89.18	275.56	0.025	NOK 11 289.69	NOK 9.08
238	38.37	118.56	0.011	NOK 2 758.86	NOK 2.47
244	22.86	70.63	0.006	NOK 2 701.69	NOK 1.31
248	6.82	21.09	0.002	NOK 3 836.85	NOK 6.88
251	3 468.63	10 718.07	0.961	NOK 7 542.67	NOK 7.65

5.9 Frequency

For items considered as C-items and in a simple policy, the frequency of ordering could be calculated mainly based on the two parameters of demand and unit value of each item. By setting the ordering cost and cyclic inventory cost for two ordering intervals (T_1 and T_2) given in weeks, a proper frequency in which total cost for both alternatives are the same, will be found. Different steps for finding value of annual demand with indifference between ordering every T_1 or every T_2 weeks are as following:

$$\frac{D\,A}{Q_2} + 0.5\,Q_1\,v\,r = \frac{D\,A}{Q_2} + 0.5\,Q_2\,v\,r$$

By considering a year as 52 weeks, each order quantity will be calculated using the following formula:

$$Q = \frac{D\,T}{52}$$

Then, by replacing the order quantity in the first equation, we will have:

$$\frac{52\,A}{T_1} + \frac{D\,T_1\,v\,r}{104} = \frac{52\,A}{T_2} + \frac{D\,T_2\,v\,r}{104}$$

After simplifying this equation, a formula for the value of the annual demand will be derived:

$$Dv = \frac{5408\,A}{T_1 T_2\,r}$$

D: Estimated demand for the items during time horizon
A: Cost of placing one order
Q: Order quantity
v: Unit value
r: Carrying charge
T_1, T_2: Alternative ordering frequencies in weeks

This formula gives the value of the annual demand with indifference between ordering every T_1 or every T_2 weeks. Thus, the total cost will be the same for the two alternatives and the gained alternatives could be appropriate time for ordering in between.

For determining an appropriate ordering frequency, first, we prepared a table in which one column was allocated to the multiplication of the number of Demand in Unite cost of each item. Next two columns were devoted to different alternatives of frequency for a whole year (based on week) and the last and determinative column was created by the formula for the value of the annual demand. Then, Dv (multiplying of Demand and Unit value) for all the item groups was calculated. Here, by comparing the gained number from each item with the calculated number from above formula for 52 weeks, the frequency of each item was determined. Table 11 illustrates how the frequency of order for one item in the warehouse of Ålesund has been determined. In this table, the Dv of 106 170.48 for the item with supplier number of 292 has been placed between two numbers of 103 009.52 and 118 857.14 which shows an order frequency of 14 could be suitable for this item (supplier number has been changed here for the sake of confidentiality). A similar process was applied for all of the aggregated items in all of the warehouses.

Table 11: Frequency of orders for one item in Ålesund warehouses

Supplier No.	Demand	Unite Value	Dv	Ordering frequency in week (T1)	Ordering frequency in week (T2)	Indifference: $\dfrac{5408 * 800}{T_1 T_2\ 0.2}$
292	1026	103.48	106 170.48	1	2	10 816 000.00
				2	3	3 605 333.33
				3	4	1 802 666.67
				4	5	1 081 600.00
				5	6	721 066.67
				6	7	515 047.62
				7	8	386 285.71
				8	9	300 444.44
				9	10	240 355.56
				10	11	196 654.55
				11	12	163 878.79
				12	13	138 666.67
				13	14	118 857.14
				14	15	103 009.52
				15	16	90 133.33

These frequency values also have been used as the lead time. Since there is a simple policy with periodic review, all the reviewing and ordering time would be determined in advance. So, if we place the orders and expect to receive the items exactly during the period of the frequency, the ordered items would be available in the inventory at the right time. So using this frequency value as the lead time could give us a reasonable estimation for the lead time.

5.10 Order quantity

The last required parameter, here, for our calculation is order quantity. By extracting the annual demand from the historical data and having the frequency which was calculated some steps before, calculating the order size in each replenishment is not a big issue. Here, safety stock will consist of a given number of each product, and thus the exact order might differ from time to time based on the actual usage in the previous period. Over time, however, the orders will be levelled out. The formula below could give us the order quantity for each group items:

$$Q = \frac{D\,T}{52}$$

Q: Order quantity
D: Estimated demand for the items during time horizon
T: Frequency in weeks

5.11 Total Relevant Cost

Total Relevant Cost (TRC) consists of four major parts: order cost, inventory cost, safety stock cost and stockout cost. Two last ones – safety stock cost and stockout cost – were described before (in chapter 5.8 Service level). Order cost and inventory cost also will be calculated by the two formulas. The complete formula for calculating Total relevant cost is given below:

$$TRC = \frac{D\,A}{Q} + 0.5\,Q\,v\,r + SS\,v\,r + \frac{D\,B_2\,v\,ES}{Q}$$

TRC: Total relevant cost
D: Estimated demand for the items during time horizon
A: Cost of placing one order
Q: Order quantity
v: Unit cost
r: Carrying charge
SS: Safety stock
B_2: Fractional charge per unit short
ES: Expected number of unit short

Here, it should be noted that since a periodic review has been applied, order quantity will be decided by the frequency and can be replaced by the mentioned formula in the chapter of Order quantity.

Table 12 shows calculations for different parts of Total Relevant Cost and eventually Total Relevant Cost itself, for some items from the inventory of hospital warehouse in Ålesund. (Supplier number have been changed here for the sake of confidentiality)

Table 12: Calculation of Total Relevant Cost

Supplier No.	Order Cost: $\frac{800\ D}{Q}$	Inventory Cost: $0.5\ Q\ v\ 0.2$	Safety Stock Cost: $0.2\ SS\ v$	Stockout Cost: $\frac{D\ B2\ v\ ES}{Q}$	Total Relevant Cost
110	NOK 885.11	NOK 888.25	NOK 4 092.56	NOK 2.03	NOK 5 867.95
214	NOK 2 311.11	NOK 2 251.87	NOK 9 241.50	NOK 1 233.43	NOK 15 037.91
222	NOK 1 434.483	NOK 1 423.87	NOK 11 289.70	NOK 9.08	NOK 14 157.13
238	NOK 1 600	NOK 1 606.10	NOK 2 758.86	NOK 2.74	NOK 5 967.70
244	NOK 866.67	NOK 857.07	NOK 2 701.69	NOK 1.31	NOK 4 426.74
248	NOK 3200	NOK 3 293.68	NOK 3 836.85	NOK 6.88	NOK 10 337.41
251	NOK 1 808.70	NOK 1 793.22	NOK 7 542.67	NOK 7.65	NOK 11 152.24

Here, Total Relevant Cost for all of the items in the inventory has been calculated. Result shows that some products ended up with a very high safety stock by the current strategy. By going through the items with a high safety stock, it has been found that there are some highly important products with a low order frequency. For example, there are some products which calculations show that should be delivered only once per year and the lead time would then be 52 weeks for them. Thus, to maintain the necessary service level, the safety stock of the product needs to be very high. For such items, an individual ordering policy could be more reasonable than a periodic review as for C-items.

5.12 (s, Q) Model

A proper strategy for those products with a high safety stock (highly important products with a low order frequency) could be an ordering policy in which a new order will be placed when the stock level reaches the reorder point. As it has been explained before, there are four major policies for controlling the amount of available items in inventory. Among these policies, two of them are based on a continuous review and two of them are periodic review based. In this study, it has been decided to use a (s, Q) policy in which the inventory level will be replenished by the quantity of Q, when the stock level falls to the level of s. In the new policy, we have considered the average of one week as the lead time for all the group items by having a look at the historical data of six years. The safety stock will be decided by the service factor (k-value) and the standard deviation will be considered for the lead time of one week. Another difference between

this policy and primary policy is that, here, the order quantity will be calculated by Wilson formula at first. Then it will be updated based on the given service level due to its criticality. Thirty-six items groups out of 201 items groups in Ålesund, 53 out of 143 in Molde, 46 out of 172 in Kristiansund and 36 out of 153 in Volda have been detected and new policy have been applied on them. Table 13 shows the changes in TRCs for some items in the warehouse of Ålesund by applying the new ordering policy (Supplier numbers have been changed here for the sake of confidentiality).

Table 13: Total Relevant Cost for some items in the warehouse of Ålesund with two different ordering policies

Supplier No.	Total cost with simple policy	Total cost with the new policy	Saving in the Total cost
222	NOK 14 157.12	NOK 4 956.45	NOK 9 200.67
261	NOK 92 368.07	NOK 39 481.48	NOK 52 886.59
277	NOK 32 665.90	NOK 15 965.13	NOK 16 700.77
285	NOK 38 979.59	NOK 14 241.63	NOK 24 737.96
287	NOK 26 888.87	NOK 17 700.92	NOK 9 187.95
292	NOK 22 590.54	NOK 10 308.97	NOK 12 281.57
310	NOK 28 274.16	NOK 11 019.33	NOK 17 254.83

The applied formula for determining the order quantity is given below. This formula will give us the optimal order size when using a given service level defined by the k-value. For a simultaneous decision for ordering size and service factor, both ordering size and service factor will be updated until they stabilize on the optimal combination. Here, the service factor has been given as three fixed values, based on three values for a P_2 service level. Therefore, ordering size will be updated only one time for this adaption.

$$Q_{Wilson} = \sqrt{\frac{2\,A\,D}{v\,r}}$$

$$Q_{Updated} = Q_{Wilson}\sqrt{\frac{1 + (B_2\,v\,\sigma_L\,G(k))}{A}}$$

A: Cost of placing one order
D: Estimated demand for the items during time horizon
v: Unit value
r: Carrying charge
B_2: Fractional charge per unit short
σ_L: Standard deviation in lead time assuming that the demand is normally distributed
G(k): Standardized loss function for a given k-value in the normal distribution

After calculating the new order quantity, order cost, inventory cost, safety stock cost and stockout cost were calculated. The formulas and their explanations were demonstrated before. Table 14 shows the calculation of Total Relevant Cost for some items with new policy in Ålesund warehouse (Supplier numbers have been changed here for the sake of confidentiality).

Table 14: Total Relevant Cost, new policy

Supplier No.	Order quantity (Wilson Formula)	Updated order quantity	Order Cost (NOK)	Inventory Cost (NOK)	Safety Stock Cost (NOK)	Stockout Cost (NOK)	Total Relevant Cost (NOK)
277	10	10	4 112.07	4 129.83	7 705.47	17.75	15 965.12
285	298	356	2 396.64	3 420.84	7 399.95	1 024.20	14 241.63
287	116	116	6 050.04	6 068.90	5 563.12	18.86	17 700.92
292	360	360	2 911.33	2 918.63	4 471.72	7.30	10 308.98
310	87	87	2 629.63	2 638.10	5 743.13	8.46	11 019.32
313	841	844	2 434.31	2 444.22	7 262.90	9.91	12 151.34
317	62	62	4 037.78	4 046.53	3 868.25	8.75	11 961.31

Now, by the summation of gained values as the Total relevant cost in both policies, the final TRC of each warehouse at the current situation (each hospital has its own warehouse in the city that they are located) will be calculated. In the next step, these processes will be repeated for the warehouses after merging by applying some required adaptations in the new warehouses after combination.

5.13 Combined warehouses

By now, the TRCs for the current situation of the warehouses – four warehouses separately – could be found. In the next step, TRC should be calculated for combination of the warehouses. As it was mentioned previously, among all of the circumstances, three of them are the relevant options given by the hospital trust. First one is the same with the current situation which already has been calculated. For the two others, all the items have to be put in one or two warehouses, based on the condition. In the combination of Molde and Kristiansund warehouses, all the items in both Molde and Kristiansund warehouses have been placed in the warehouse of Molde, for Ålesund and Volda warehouses have been placed in Ålesund, and in the third feasible combination, all the items in the warehouses of Molde, Ålesund, Volda and Kristiansund have been placed in the warehouse of Ålesund as well. In an Excel sheet, the supplier numbers – considered as aggregated items – regarding to the combinations, were put in a single sheet. Items with the same supplier numbers were detected and combined with each other. For the other items, since all warehouses' materials are consuming in the hospitals, the items should be similar. For example, hospital warehouses of Molde and Kristiansund are supposed to be combined. If the same types of consumables are purchased from local vendors in Molde and Kristiansund, the Molde vendor will be used for the combined warehouse. As an example, disposable container is one of the items which is required to be stored in both warehouses. Before combining and in the current situation, the disposable container is supplied by a specific supplier for each warehouse. However, after merging, since the combined warehouses will be located in Molde, it should be supplied by the supplier which has supplied the disposable container for the hospital warehouse of Molde. Therefore, by inspecting through all of the materials, item by item, materials by the similar descriptions and natures were detected and merged with each other based on the supplier numbers of the selected hospital warehouse (which should be remained as the supplier after incorporation). For this purpose, in an excel sheet, Dvs and the amount of annual demands for the items with similar descriptions were summed. Then, by dividing the gained Dvs over the calculated annual demands, unit values for the aggregated items were found (the values were pretty close to the unit value of every constitutive item). Afterwards, by comparing calculated Dvs with the table which were explained in the chapter of Frequency, the frequency of the order for each items were found. Apart from demand, unit value and standard deviation, all the other calculations and values were similar as in the case of

warehouses before merging. Standard deviation for each items group were calculated according to the following formula:

$$\sigma_{COM} = \sqrt{\sigma_A^2 + \sigma_B^2 + \sigma_C^2}$$

σ_{COM}: Combined standard deviation
$\sigma_A, \sigma_B, \sigma_C$: Standard deviation of the each component

Mutual criticality of each aggregated item was also selected. The procedure of calculating the different components of Total relevant cost are similar to what was explained for each warehouse previously. Then the items which have a costly safety stock (highly important products with a low order frequency) were detected and taken out from the simple policy which has been explained. Another ordering policy will be applied for these suppliers individually similar to the process that was done for the items in the warehouses before merging. Then by adding the calculated TRC in both policies, the Total Relevant Cost for each combined warehouses will be gained. Now, by making a comparison table, the relative cost difference will be found.

6.0 Discussion

6.1 Analysis of costs for alternative number of warehouses

Table 15, shows the gained values of Total Relevant Cost of warehouses for the three alternatives by considering the values of NOK 800 and 20% for cost of placing an order and carrying charge respectively.

Table 15: Total Relevant Cost for three alternatives

	Cost of each order	Carrying charge	Total Relevant Cost
4 Hospital Warehouses	NOK 800	20%	NOK 6 918 705
2 Hospital Warehouses	NOK 800	20%	NOK 5 379 393
1 Hospital Warehouse	NOK 800	20%	NOK 4 685 561

Results demonstrate that Total Relevant Cost of the warehouses has its lowest level when all four warehouses are merged into a single one in Ålesund. The logistical costs are estimated to NOK 4 685 561. The second best option is to have two warehouses. One as a combination of Molde and Kristiansund in Molde and another as a combination of Ålesund and Volda in Ålesund where the costs will be nearly NOK 5 379 393. Finally, regarding to the observed TRCs, that current situation of having four separate warehouses in these four cities of Molde, Kristiansund, Ålesund and Volda is the worst case in terms of logistical costs with around NOK 6 918 705. However, it should be noted again, here, transportation cost is not part of the result and it should be added to the calculated TRCs for making final decision.

Table 16 illustrates the Total Relevant Costs and different parts of that for three different situations.

Table 16: Total Relevant Cost and its different components for three situations

	Order Cost	Cyclic Inventory Cost	Safety Stock Cost	Stockout Cost	Total Relevant Cost
4 Hospital Warehouses	NOK 1 510 100	NOK 1 498 926	NOK 3 817 818	NOK 91 861	NOK6 918 705
2 Hospital Warehouses	NOK 1 152 864	NOK 1 193 579	NOK 2 944 234	NOK 88 716	NOK 5 379 393
1 Hospital Warehouse	NOK 856 177	NOK 1 036 782	NOK 2 582 169	NOK 210 433	NOK 4 685 561

It shows that all three parts of order cost, inventory cost and safety stock cost will be decreased by merging the warehouses. Stockout cost is the only cost which has not been decreased by combining the warehouses which may due to increasing the standard deviation of products after incorporating. However, the aggregated products were similar to each other, since the suppliers and the delivery schedule is not the same after and before merging, standard deviation by considering the current data will be increased and it could be the source of raising the stockout cost. This much increasing in the stockout cost in comparison of saving in the other costs is as low as could be neglected. Figure 10 shows the Total cost with its components for three alternatives in a chart.
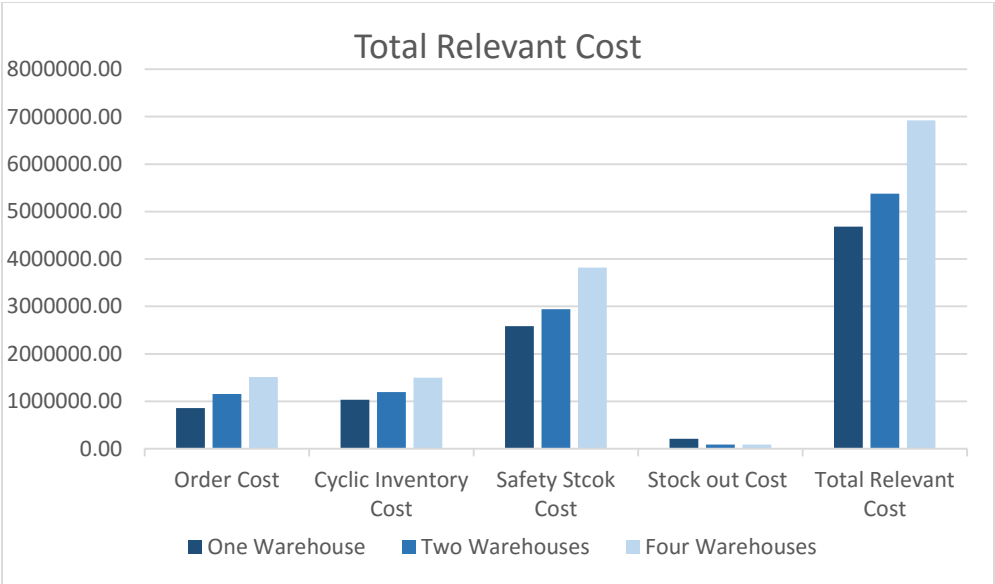
Figure 10: Total Relevant Cost and its different components for three situations

Table 17 shows the percentages of different parts of Total Relevant cost in three different combinations.

Table 17: Different parts of TRC for three alternatives

	Order Cost	Cyclic Inventory Cost	Safety Stock Cost	Stockout Cost
4 Hospital Warehouses	21.83%	21.66%	55.18%	1.33%
2 Hospital Warehouses	21.43%	22.19%	54.73%	1.65%
1 Hospital Warehouse	18.27%	22.13%	55.11%	4.49%

Results demonstrate that there is not a sensible different between these percentages in comparison with each other in each warehouse. It means the proportions and distributions of the different components of TRCs are pretty similar in different situations. The only part will be changed and increased by a rather big margin and allocated some percentages more than the other situations to itself in combination of one warehouses is stockout cost which may be related to increasing the standard deviations in merged warehouses caused by changing the delivery plan and supplier. It should be emphasised that table 15 analyses the percentages of the different part of TRCs in each warehouses and the comparison has been made between these parts as the percentages in each single situation and does not show the cost variation of TRCs in each situation in comparison of TRCs in other three situations.

6.2   Transportation cost

Another important cost element which should be taken into account in any business or organization is related to its affiliated transportation cost. Transportation cost has been defined as all the associated expenses for moving and carrying materials or products from a specific place to another different place. In some trades in which physical productions are not part of the business, this cost may be neglected. By considering some data from different businesses it could be found that transportation cost usually should be considered as an important part of cost in each business. Here, there is a transportation cost from supplier to warehouses of the hospitals which has been counted in the ordering cost for each of the warehouses before merging. The point which should not be neglected, here, is the transportation cost after merging the warehouses. In the current situation in where each hospital has its own warehouse and each warehouse is close to the hospital, the internal transportation cost (the cost of transporting the goods after receiving of the suppliers, from the warehouses to the hospitals) could be neglected. But after combining the warehouses, the transportation status from transporting inside a city will be switched to transporting between cities. The transportation cost after merging the warehouses will be definitely growing higher. So for a more certain decision, cost of transportation after merging the warehouses should be added to the calculations. According to our discussion with the hospital trust, it should be assumed that there will be a daily transportation between hospitals and warehouses after combining the warehouses and its cost will depend on the negotiations with

an external transportation corporation. Therefore, since there is not adequate information about the decision and kind of transportation in this stage it was decided to omit this part of cost and the definite decision will depend on the actual data in this respect.

6.3 Uncertainty of the Lead time, Ordering cost and Carrying charge

6.3.1 Lead time

In a periodic review which has been used as the simple policy, the founded order frequency was chosen as the lead time. However, in this way since the suppliers know exactly when to deliver, this will probably be close to zero. In a periodic review, since the order time is determined beforehand, it could be a reasonable estimation.
For those items with an individual ordering policy, it might have some effect, but due to the data files, the deviation from one week is not very much.

6.3.2 Ordering Cost

All the calculations for the Total Relevant Costs were based on two estimated values of ordering cost and Carrying cost. Since the exact values of these two parameters were not available during this project, by a confirmation from hospital trust, it was decided to use two typical values of NOK 800 and 20% for ordering cost and carrying cost respectively. Then it was decided to make an analysis on the different TRCs in different situations with ±10 % and ±20% changes in cost of placing an order. Table 18 shows the different results for TRCs with five different values for ordering cost and the percentages of changes in comparison to an ordering cost of NOK 800.

Table 18: Total Relevant Cost in different combinations with different values of Ordering cost

Ordering Cost	NOK 640 (800 – 20%)	NOK 720 (800 – 10%)	NOK 800 800	NOK 880 (800 + 10%)	NOK 960 (800 + 20%)
Carrying charge	20%	20%	20%	20%	20%
4 Hospital Warehouses	NOK 6 607 513	NOK 6 765 524	NOK 6 918 705	NOK 7 067 745	NOK 7 213 183
2 Hospital Warehouses	NOK 5 14 0371	NOK 5 262 107	NOK 5 379 393	NOK 5 492 866	NOK 5 603 020
1 Hospital Warehouse	NOK 4 507 949	NOK 4 598 433	NOK 4 685 561	NOK 4 769 808	NOK 4 851 545
Value change (4 warehouses)	-4.709669%	-2.26414%	_	+2.154160%	+4.256259%
Value change (2 warehouses)	-4.649898%	-2.22888%	_	+2.109402%	+4.157105%
Value change (1 warehouse)	-3.939974%	-1.89473%	_	+1.798013%	+3.542457%

The gained results from table 16 show that by increasing the ordering cost by 10% and 20%, Total Relevant Costs for all situations of four, two and one warehouse(s) will be increased by the averages of around 2% and 4%, respectively. These changes in the TRCs values have also been applied negatively for decreasing the ordering cost by some pretty similar percentages. It looks there is a linear dependency between the cost of each order and total cost. Figure 11, shows these changes for the situation of four separate warehouses in a chart.
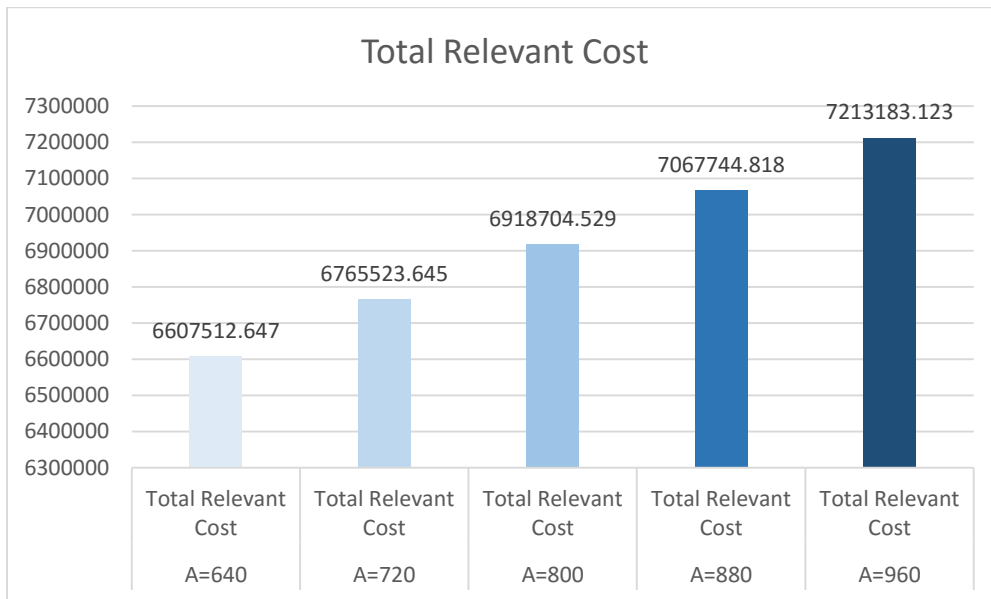
Figure 11: Different Total Relevant Cost with different costs of one order

Increasing Total Relevant Cost by increasing the cost of each order and decreasing that with decreasing this value was not unexpected. The question that appears here is which parts of the TRCs could be more affected by the changes of ordering cost?

Figures 12 – 15 show the effects of changes in ordering cost on the different components of Total Relevant Cost separately for four separate warehouses.
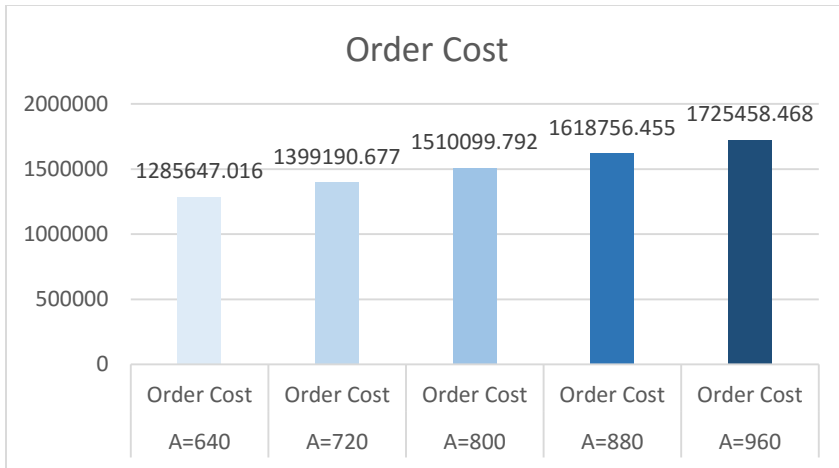
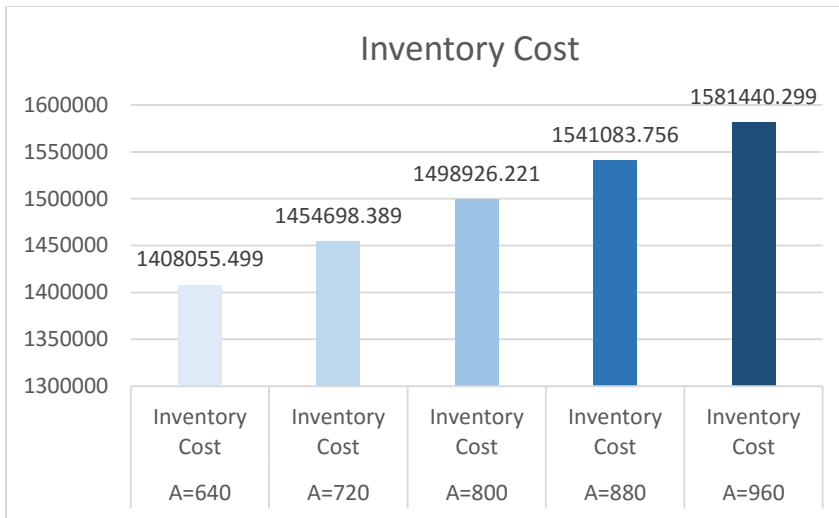*Figure 12: Ordering Cost for different costs of placing one order*

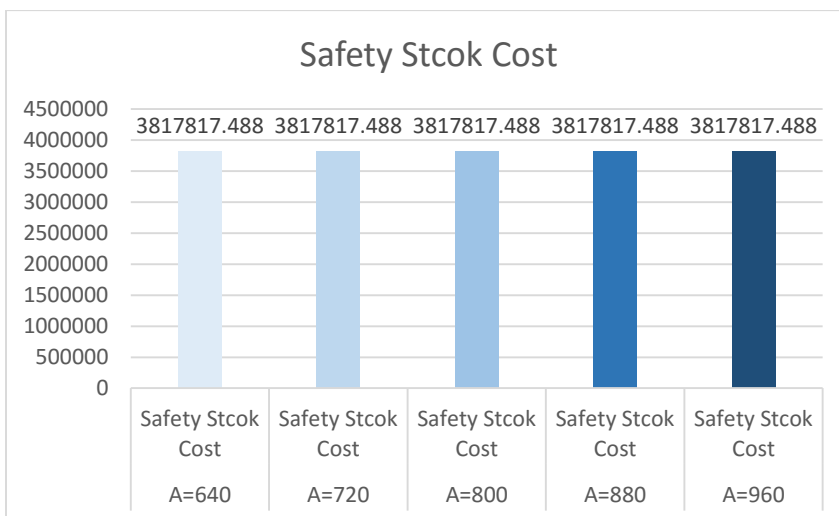*Figure 13: Inventory Cost for different costs of placing one order*

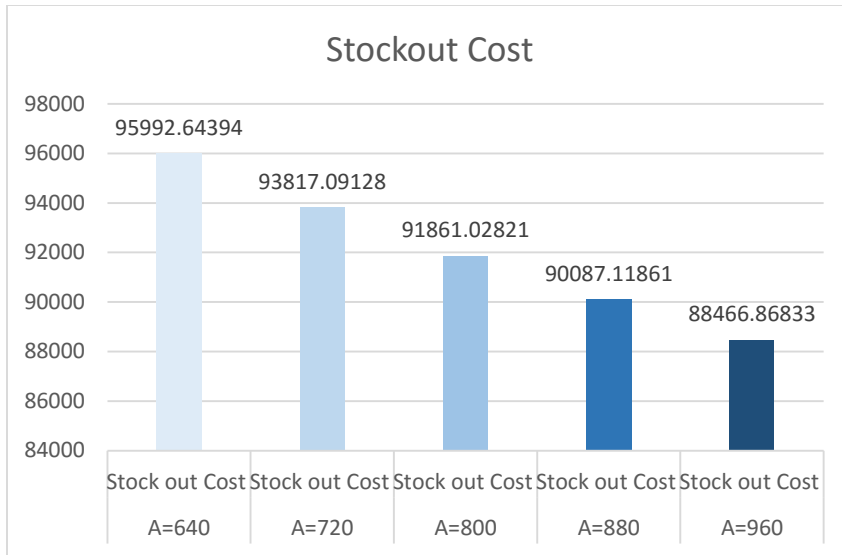*Figure 14: Safety Stock Cost for different costs of placing one order*

Figure 15: Stockout Cost for different costs of placing one order

Figures show that the cost of placing an order for each item is positively correlated with order cost and Inventory cost and negatively correlated with stockout cost. To put it simply, if the cost of placing an order increases, it will be favourable to order less frequently. Then each order will be larger and the inventory cost will be increased as well. With larger orders, the probability of getting a stockout will decrease even if the safety stock remains the same, since there will be less cycles in a full year. Figure 14 shows that there is not any correlation between the cost of placing an order and safety stock cost.

6.3.3 Carrying charge

As it has been mentioned before, used values for two parameters of carrying charge and the cost of placing an order in our calculations were two estimated values. Some analysis for Total relevant cost and its components with five different values of ordering cost was studied in previous chapter. The same analysis for three different values of carrying charge has been run in this chapter. Since the level of the national base rate is very low in these days, the effect of carrying charge on Total relevant cost and it components with two lower values of 10% and 15% was studied. Table 19 shows the different Total costs for the ordering cost of NOK 800 and three different values for carrying charge in three different combinations of warehouses.

Carrying Charge	10%	15%	20%
Ordering Cost	NOK 800	NOK 800	NOK 800
4 Hospital Warehouses	NOK 4 180 976	NOK 5 572 914	NOK 6 918 705
2 Hospital Warehouses	NOK 3 236 326	NOK 4 329 423	NOK 5 379 393
1 Hospital Warehouse	NOK 2 806 207	NOK 3 766 202	NOK 4 685 561
Value change (4 warehouses)	-65.480620%	-24.148785%	_
Value change (2 warehouses)	-66.219132%	-24.251962%	_
Value change (1 warehouse)	-66.971325%	-24.410772%	_

Results demonstrate that by decreasing the Carrying charge from 20% to 15% and 10%, Total relevant cost will be reduced (on average) by nearly 24% and 66%, respectively, for all three alternatives. This much reduction in the total cost, affected by carrying charge, shows the importance of this factor. Figure 16 illustrates the effect of different carrying charge on the Total relevant cost for the situation of having four separate warehouses in a chart.
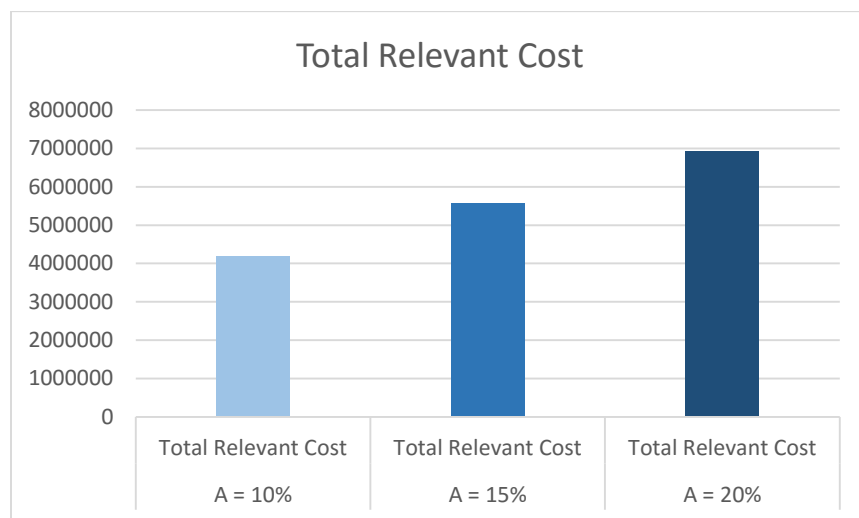

Figure 16: Different Total Relevant Costs with three different value of Carrying Charges

Figure 16 indicates the increase on the Total relevant cost by increasing the carrying charge. Figure 17 – 20 show the effect of carrying charge on different components of Total cost.
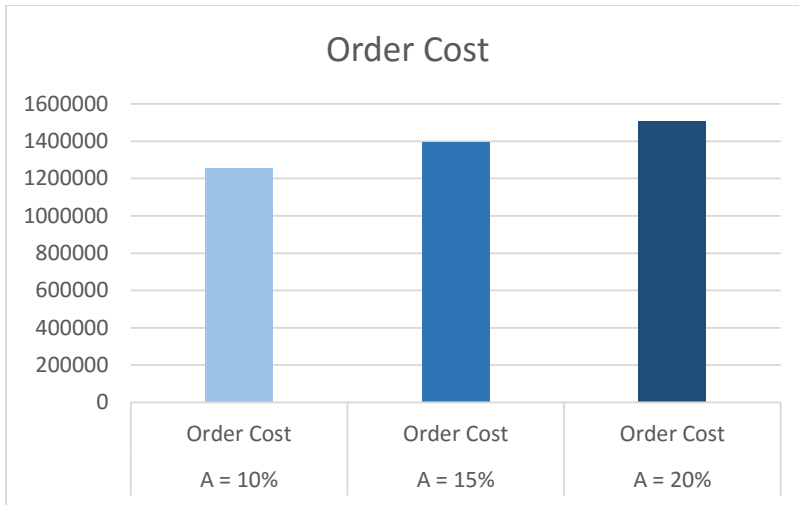
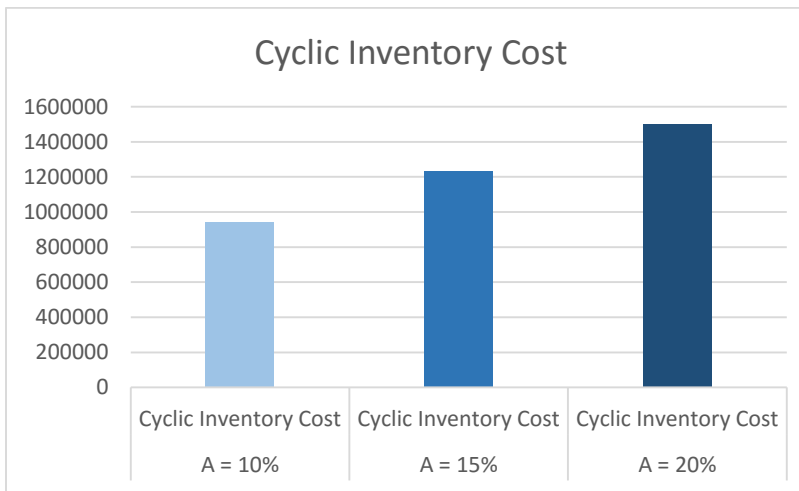*Figure 17: Order Cost with three different values for Carrying Charges*

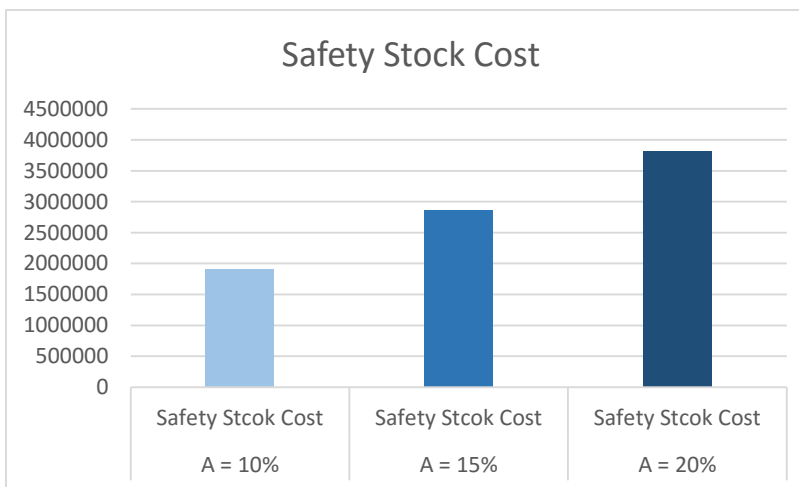*Figure 18: Cyclic Inventory Cost with three different values for Carrying Charges*

Figure 19: Safety Stock Cost with three different values for Carrying Charges
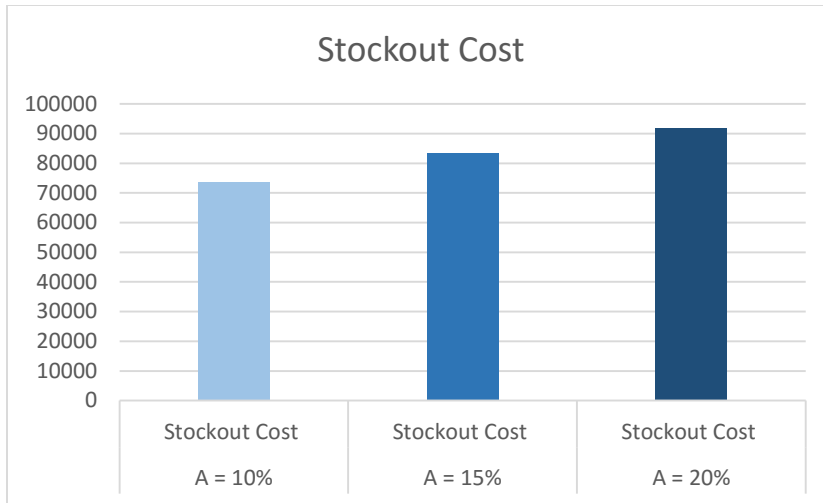
Figure 20: Stockout Cost with three different values for Carrying Charges

Results demonstrate that there is a positive correlation between Carrying charge and all different parts of order cost, inventory cost, safety stock cost and stockout cost. However, the most effected part of the cost, by Carrying charge, is safety stock cost

7.0 Conclusion

Finding an ordering policy for a warehouse requires some classification of the stored products in each warehouse which very much depends on the items and goods in the inventory. The inventory policy has a fundamental effect on the total cost of inventory for the warehouses. This could be obviously seen in the calculated TRCs in this study for some important products with low frequency which had a high Stockout Cost before changing the policy. Results showed a big saving in inventory cost after applying new policy for such items.

The analysis on the cost of placing an order demonstrated that this factor has a positive correlation with Order Cost and Inventory Cost and a negative correlation with Stockout Cost. It is also shown that it does not have any effect on Safety Stock Cost.

Apart from transportation cost which was not taken into account in this study, gained results of Total Relevant Cost for each inventory, before and after merging, showed that there is considerable savings by combining the warehouses. The saved money after reducing of the warehouses from four to two is around NOK 1 540 000 which could be increased to nearly NOK 2 230 000 saving by having one warehouse instead. It means that there is about 22% and 32% saving by combining the warehouses and reducing the number of that from four to two or one, respectively. It should be noted that this much saving depends on the chosen parameter values and it could be changed by different values. For example, result shows that by increasing the cost of placing an order by 20%, the saved money could be increased to around NOK 1 610 000 and NOK 2 360 000 by having two or one warehouse(s), respectively. Similarly, it could be decreased to approximately NOK 1 470 000 and NOK 2 100 000 for two or one warehouses, respectively, by decreasing the cost of placing an order by 20%. The percentages in saved money, however, are pretty similar. Results demonstrate that Carrying charge has also a fundamental effect on the different parts of cost. Moreover, although some other costs such as potential reduction of workforce, cost related to buildings, internal and external transportation etc have not been taken into consideration, but the percentage of saving in the inventory cost itself is as much substantial as the general idea of combining the warehouses should be considered. Then, by including the cost for elements like the transportation between warehouses and hospitals and adding those amounts to the calculated total cost of the inventories, the basis for taking a final decision could be made.

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