Master's degree thesis

LOG950 Logistics

Measuring effects on inventory by centralization for a wholesaler in the industry sector - A case study

Axel Frost

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Molde, May 2014.
Axel Frost

Abstract

Inventory is a substantial investment in assets for most wholesalers and affects not only its profitability, but their degree of service. By correctly managing its inventory a company can achieve a competitive advantage through higher service level at a lower cost.

This case study investigates inventory allocation by virtual centralization as a way to decrease inventory among several warehouses for a wholesaler in the industry sector. Demand data from ten warehouses are analyzed, and estimates on safety stock and cycle stock are made. The status quo is compared against different degrees of centralization. The possible savings in holding cost along with ordering costs are estimated and compared against transportation cost.

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1. Introduction

Inventory for a wholesaler represents between 20 percent and 50 percent of its total assets and is the largest single investment in the company (Stock and Lambert 2001). Inventory management has a direct effect on a company's profitability (Jonsson 2008, Waters 2003, Silver, Pyke, and Peterson 1998). Too much inventory can reduce the net profit or reduce the total assets (Grant et al. 2006). Inventory can also affect the profitability indirectly with service factors as; availability, lead time, and reliability (Jonsson 2008, Waters 2003),

1.1 Company Overview

TOOLS AS is a subsidiary company of the Swedish company B&B TOOLS AB. They are a wholesaler of tools, machinery, industrial supplies, and personal protective equipment to customer within oil and gas, construction, and the public sector (TOOLS AS).

B&B TOOLS was established in 1906 and is "the largest supplier of industrial consumables and industrial components, and related services for the industrial and construction sector in the Nordic region". With their core activities located in Sweden, Finland, and Norway they employ some 2,800 persons. Their annual revenue of approximately 7,700 MSEK (TOOLS 2012). Approximately 50 percent of their total sales are from proprietary product brands from four business areas:

- Tools and Machinery
- Personal Protection Equipment
- Fastening Elements
- Workplace Equipment & Consumables (TOOLS 2014)

The largest customer segment for B&B TOOLS is the industrial sector which accounts for 67 percent of the total sales. The construction sector accounts for 20 percent, the private market have 3 percent, and other sectors are responsible for the remaining 10 percent of total sales. Sales in Norway represent 32 percent of the total group sales. With competitors on a national level like Tess, Würth, ProffPartner, and Albert E Olsen, TOOLS' competitive focus lies within the following areas:

- Reliability: The right product in the right place at the right time.
- Competence: A high level of competency ensures that the customer receives the optimal solution.
- Proximity: Both physically and in understanding the customer's needs.
- Product range: A wide product rage gives the customers more choice and the opportunity for fewer suppliers.
- Low cost: Including product price, shipping/logistics, and administrative cost.
- Sustainability: With in-house workshops they decrease the customers cost by extending the life time of each product.
- Flexibility: With close proximity to the customers and as a major player they can adapt to unexpected situations quickly (TOOLS 2012).

TOOLS AS has 60 warehouses located all over Norway from Mandal in the south and up to Hammerfest in the north. (TOOLS AS). These are divided into three districts; North, West, and East. All warehouses have a retail store as well as storage facilities to accommodate customers, mainly craftsmen, which do not want to order and wait until delivered. Their products come both from within the group from several large warehouses through a distribution center near Oslo, Norway, and from more than 300 external suppliers.

1.2 Problem Description

This thesis is concentrated around the ten company owned warehouses in the northern district. TOOLS believe that their combined inventory levels are too high and are looking at ways to reduce it. Combined, the northern district holds inventory for approximately 76.5 million NOK. This research will try to measure the effect allocating into virtual centralization has on the inventory when reducing the number of storage facilities, allowing some warehouses to supply the customers from other warehouses by designation products to each warehouse as rudimentary illustrated in Figure 1.

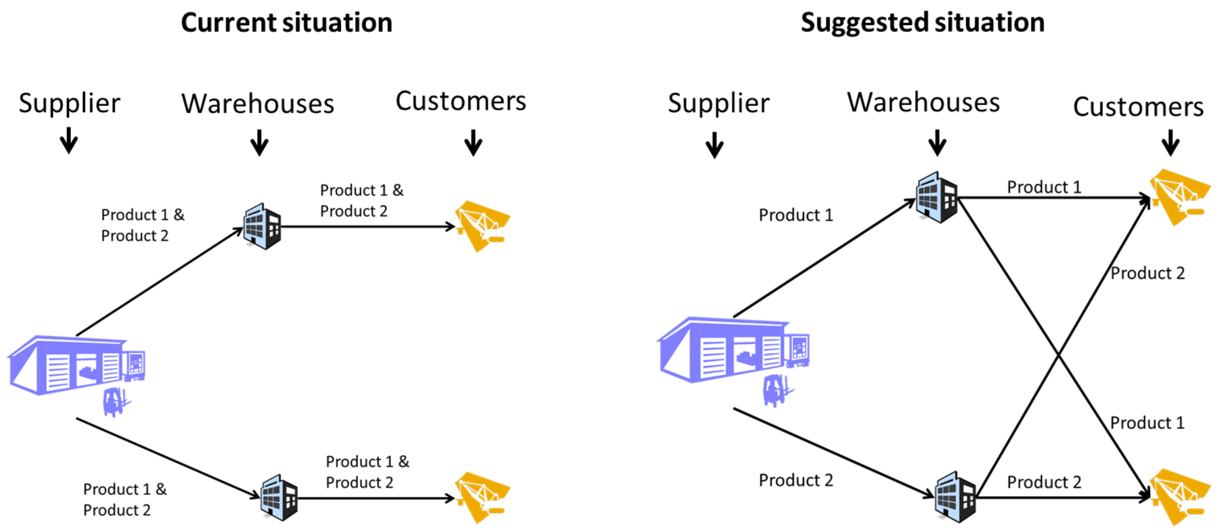

Figure 1 – Current and Suggested situation

Figure 2 shows the locations of the ten warehouses

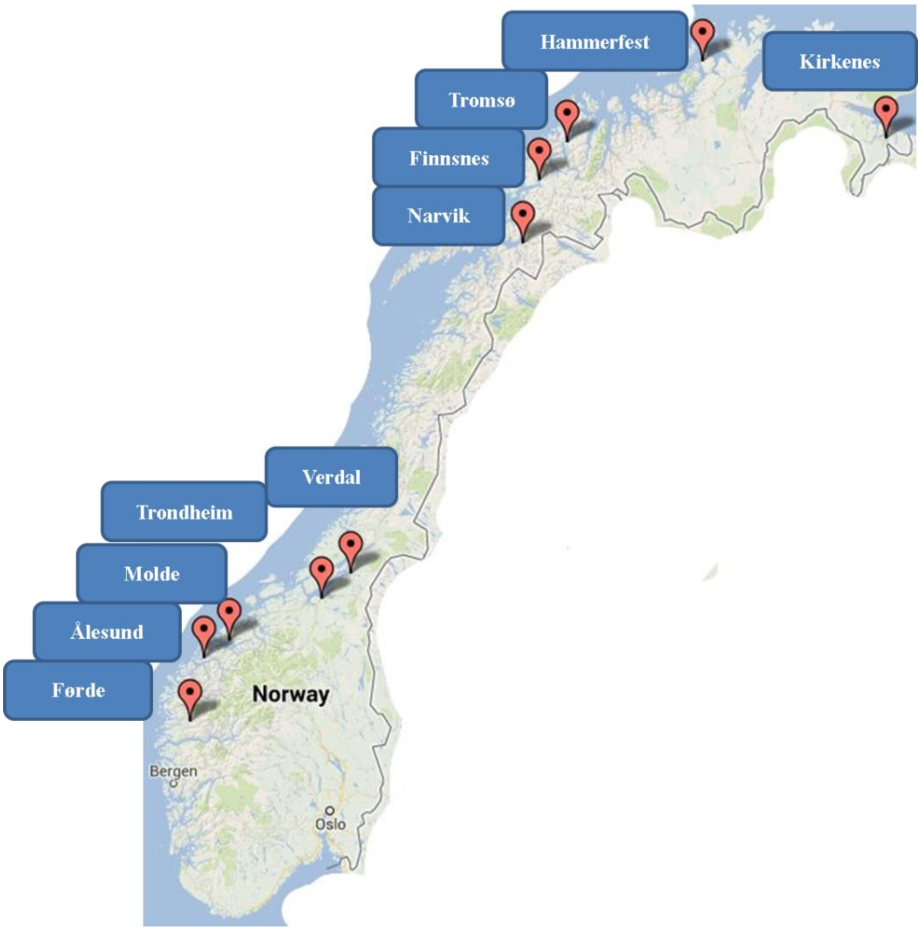

Figure 2 – Locations of the warehouses in the Northern district.

TOOLS operate with short lead times to the customers. If the customer orders in the morning one day, the customer should have it by start of business the next day. This means that full decentralization is not an option as there is no point between Førde and Kirkenes that could supply all warehouses with a lead time to customers of one day. Due to the distance between Narvik and Verdal the five most southern warehouses in the northern district; Førde, Ålesund, Molde, Trondheim, and Verdal will in this thesis be mentioned as the southern region. The rest will logically be referred to as the northern region.

1.3 Structure of the Thesis

Chapter 2 in the thesis presents the literature review that formed the basis of the research. The methodology is discussed in chapter 3 along with the research questions. The current state is discussed in chapter 4 with analyzes and discussion. Chapter 5 concludes the research listing limitations and suggestions for further research.

2. Literature Review

This chapter includes the literature on centralization that the thesis is based on. Firstly, a review of inventory theory is presented. Theory on what effect centralization has on inventory follows. The chapter is concluded with a brief review on transshipments and facility location.

2.1 Inventory

Nahmias (2009) presents 7 motivation factors for holding inventory.

1. *Economies of scale.* With large setup cost or ordering cost, higher inventories may be economical.
2. *Uncertainties.* Variations in supply and demand are both motivators for holding inventories. Other factors such as supply of labor, the price of resources, and the cost of capital also affect the inventory decision.
3. *Speculation.* With fluctuations in price, a large purchase before a large price increase has proven to improve savings.
4. *Transportation.* Higher transportation time leads to higher in-transit inventories.
5. *Smoothing.* With seasonality and other changes in demand, storing inventory before these peaks helps evening out changes in production levels and workforce stock.
6. *Logistics.* There are aspects of real life which makes it impossible to not have some sort of inventory, for instance minimum purchase quantities and continuity in a manufacturing process.
7. *Control cost.* By minimizing the inventory, there is a need to spend more time and money controlling the inventory levels and maintaining detailed records. It might be better financially to have higher levels of inventory, especially for the low cost items, where you spend less time controlling it (Nahmias 2009).

Inventory can be divided into the following six groups: - Cycle stock, in-transit inventories, safety stock, speculative stock, seasonal stock, and dead stock (Stock and Lambert 2001). Cycle stock is normal inventory resulting from a company's replenishment program. In-transit inventory is inventory on the way to a company from a producer. Safety stock is inventory held in excess of the cycle stock, this will be discussed further in 2.1.2. Speculative and seasonal stock, are describes points 3 and 5 above. Dead stock is stock that hasn't moved for a period of time and has to be dealt with accordingly (Stock and Lambert 2001).

When determining how much to order one of the most used formula is known as the *economic order quantity* (EOQ) or the Wilson formula. The EOQ finds the order quantity where the sum of holding and reorder cost is the least. It does this by taking total cost and deriving it with respect to Q and solving to zero. This is expressed in this equation:

$$Q^* = \sqrt{\frac{2DA}{iv}}$$

The economic order quantity Q^* is the square root of 2 multiplied with the yearly demand D multiple the order cost A divided by the internal interest rate i multiplied with the value of the *stock-keeping-unit* (SKU) v. The advantage with the EOQ is its robustness in term of cost, as a relative large change in order quantity, up or down, results in a small change in total cost. This means that as long as the order quantity is in the proximity of the EOQ, the corresponding costs are close to optimal. The EOQ does not take lead time into consideration, only order quantity. If the demand and lead time is known and constant, the reorder point is simply the demand in the lead time (Waters 2003). Demand is, in the real world, seldom constant. Safety stock is therefore needed as a buffer, making the inventory cycles look somewhat like Figure 3 below.

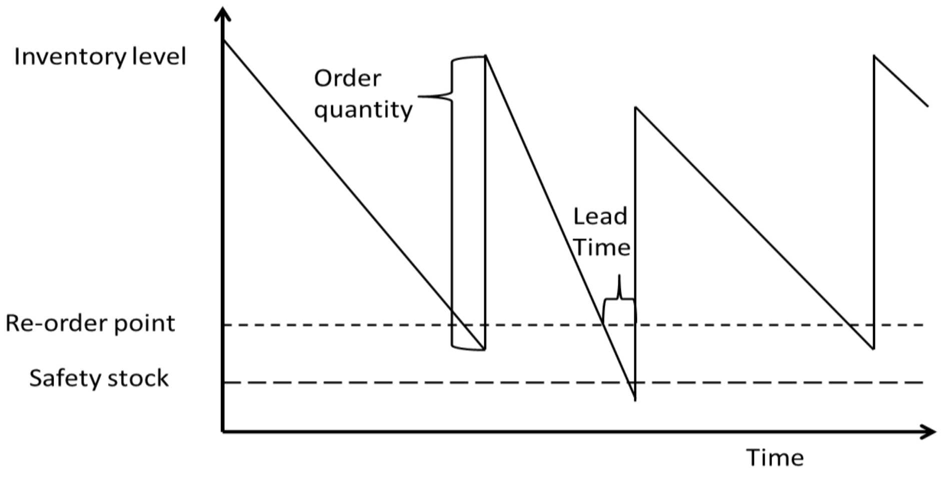

Figure 3 – Inventory cycles – adapted from (Waters 2003).

In general there are two ways of monitoring the inventory; continuous and periodic.

- Continuous monitoring triggers orders to be placed immediately when the inventory hits the re-order point. The order could then be some determined quantity, an (s,Q) system. Alternatively the order size is determined by the inventory level and an order-up-to-level, (s,S) system. If SKUs are removed from the inventory one unit at a time these are of course identically.
- Periodic monitoring differs from continuous in that the inventory level is checked at given time intervals. This can also be combined with an order-up-to-level policy ((R,s) system) without a specified reorder point. If the inventory is below the up-to-level, an order is placed to fill that cap with such a system. An (R,s,S) system is a combination of (s,S) and (R,S). The inventory is monitored periodically, but no orders are made until it reaches the reorder point. (Silver, Pyke, and Peterson 1998)

When dealing with inventory, a useful way to categorize the SKU is by an ABC analysis. This is also known as following the Pareto principle.

- Twenty percent of the SKU's produce eighty percent of the company's sales. These twenty percent is categorized as A-items and should receive the most attention when deciding service level and ordering policies (Stock and Lambert 2001).
- The next thirty percent of SKU's account for fifteen percent of sales, and are called B-items.
- C-items hold fifty percent of the SKU's and five percent of the total sales (Nahmias 2009).

These boundaries are not fixed, but are subject to judgment by the responsible. The main idea is that A items have high volume with a few SKUs, B items have medium volume with a medium number of SKUs, and C items have low volume with a high number of SKUs. There could also be more than three groups which can include properties like;

- Highly critical
- Fast moving
- Moving
- Slow moving

- Slowest
- Non moving
- Obsolete (Emmett and Granville 2007)

One could also extend the ABC analysis to include variation of demand by introducing an ABC-XYZ classification where XYZ represents for instance the variation of weekly demand (Reiner and Trcka 2004).

2.1.1 Inventory Carrying Cost

As aforementioned, inventory has a direct influence on a company's profitability. A company therefor has to consider several cost aspects of inventory other than the purchase cost. Stock and Lambert (2001) discuss four categories of these cost;

1. *Capital cost.* When a company has a large amount of inventory which they have bought, they also have a lot of money tied up in it. Money they could have spent elsewhere or put in the bank where they could earn interest. This is also called opportunity cost (Silver, Pyke, and Peterson 1998).
2. *Inventory service cost.* The inventory service cost is both the taxation cost and insurance cost of the inventory.
3. *Storage space cost.* This is the cost of maintaining a storage facility for the inventory, such as rent, electricity, and so on.
4. *Inventory risk cost.* This category can be divided into the following groups
    - *Obsolescence.* If the demand for the SKU's decreases the company might have to sell the inventory at a reduced price to get rid of it or sit on it indefinitely.
    - *Damage.* When an SKU gets damaged in the inventory and is no longer saleable, the company takes a loss.
    - *Shrinkage.* This has to do with internal theft, or security measures to minimize theft. It also occurs if the company sends the wrong quantity or SKU to a customer, or is experienced through bad record keeping (Stock and Lambert 2001).

One of the primary goals in Supply Chain Management (SCM) is to reduce inventory holding (Mangan, Lalwani, and Butcher 2008). They list several ways this can be accomplished:

- Pooling the inventory. Consequently reducing safety stock while maintain the service level.
- Reduce variation at all levels. I.e. supply and demand.
- Reduce lead time. Consequently reducing re-order points, and variation in lead time.
- Implementing *just-in-time*. Streamlining the entire supply chain (Mangan, Lalwani, and Butcher 2008).

2.1.2 Safety Stock

Safety stock, or buffer stock as some call it, is an addition of inventory the company has to counteract any variation in the demand or lead time (Stock and Lambert 2001). When a stockout that inevitable occur from time to time one of four things can result.

1. The customer could wait until the SKU is back in stock, without any cost to the supplier.
2. The customer could put the SKU on backorder. This could cost the supplier slightly more as they might need two purchase order and some follow up work.
3. The customer could buy the SKU somewhere else, causing a lost sale for the supplier.
4. The customer could change supplier. This is the worst case scenario where the supplier loses any future sales from the customer. (Coyle et al. 2009).

There are several ways of determining the safety stock. Silver, Pyke, and Peterson (1998) discuss four such methods;

1. *Safety Stocks Established Through the Use of a Simple-Minded Approach.*

   One could use an *equal safety factor k* and set the safety stock to be the safety factor multiplied with the standard deviation of demand in the lead time, σ_L, so the safety stock *SS* would be: $SS = k\sigma_L$.

   Another way is to set the *equal time supplies*, meaning that the reorder point is demand in a given time period plus the forecasted demand in the lead time.

2. *Safety Stock Based on Minimizing Cost.*

It might cost more to meet demand than the cost of stockout. This approach minimizes the total cost, but the cost of unmet demand has to be calculated. And there are several types of stockout cost;

- *Specified Fixed Cost (B_1) per Stockout Occasion.*

  This does not consider to what degree or how long the stockout occurs, just the fact that it has happened.

- *Specified Fractional Charge (B_2) per Unit Short.*

  This means the fraction of the cost of the SKU the company loses by not meeting demand for that SKU.

- *Specified Fractional Charge (B_3) per Unit Short per Unit Time.*

  This is the same as the previous charge, but including the duration of the stockout.

- *Specified Charge (B_4) per Customer Line Item Short.*

  This is a fixed cost per item the customer has to put on backorder.

3. *Safety Stock Based on Customer Service*

The company has to decide with percentile of the demand should be routinely met. There are again several types of service levels;

- *P1 – Cycle Service Level.*

  This is called the cycle service level because it is the fraction of order cycles where stockout does not appear, or in other words, the probability of no stockout per cycle.

- *P2 – Fill Rate.*

  This is the fraction of demand to be met without stockout.

- *P3 – Ready Rate.*

  This is a specified fraction of time where the inventory is positive.

- *TBS – Time Between Stockout*.

  As this is the average time between stockouts, one could use this to set an average number of times during a year were stockouts happen.

4. *Safety Stock Based on Aggregate Considerations.*

The safety factor is set by minimizing total cost of the aggregated SKUs; one could also weigh the SKUs in terms of importance (Silver, Pyke, and Peterson 1998).

2.2 The Pooling Effect, the "Square Root Law", and The Portfolio Effect

Brandimarte and Zotteri (2007, p. 57-58) present two beneficial concepts of aggregating demand:

- "A central distribution center aggregate demands and thus enables the company to enjoy economies of scale in transportation and order processing."
- "A central distribution center aggregates demand. Aggregate demand tends to be more stable, thus reducing the need for safety stocks."

They further state that as the correlation in demand between the different nodes gets closer to 1, the gain in demand smoothing reduces. If the correlation coefficient *p* between locations is equal to one, meaning full correlation, the effect is lost (Eppen 1979, Tallon 1993). If *p* is -1 on the other hand, it creates an inverse relationship where a high demand at one location is cancelled out by low demand at another, eliminating the need for safety stock all together (Tallon 1993).

By centralizing you can often reduce the overall safety stock, but it may reduce the service level as customers may have to wait for the items to be shipped from the distribution center to the demand node (Brandimarte and Zotteri 2007). By aggregating the demand from several nodes there will be a reduction in the demand variation and therefore result in a reduction in safety stock (Mangan, Lalwani, and Butcher 2008).

The standard deviation of two independent variables can be defined as the square root of the sum of variance of both variables given that the correlation between them is zero. If this is not the case the equation changes from:

$$\sigma_{1,2} = \sqrt{Var(D_1 + D_2)}$$

to $\sigma_{1,2} = \sqrt{\sigma_1^2 + \sigma_2^2 + 2\rho\sigma_1\sigma_2}$,

where ρ is the correlation coefficient (Newbold, Carlson, and Thorne 2013).

Chopra and Meindl (2013) says that if the correlation coefficient is less than 1, $\rho < 1$, the joint standard deviation of two variables are smaller than the sum of the two standard deviations.

$$\sigma_{1,2} < \sigma_1 + \sigma_2$$

They further list five variables that affect the effect of safety stock aggregation compared to holding separate safety stock;

- Increased service level causes an increase in aggregated safety stock savings. If one compares separated safety stock of two locations to an aggregated safety stock option, an increase in service level from, for instance, 95 percent to 97 percent would lead to a higher cost saving in the aggregated option.
- Increased lead time causes an increase in aggregated safety stock savings. As the lead time increases, so would the standard deviation for the lead time, resulting in higher safety stock for both separated and aggregated safety stock. The aggregated safety stock would, however, increase less than the combined value of the separated options.
- Increased holding cost causes an increase in aggregated safety stock savings. As an aggregated stock holds, in total, less safety stock than two separated one. The savings increases along with the holding cost.
- An increase in the coefficient of variation causes an increase in aggregated safety stock savings.
- An increase in the correlation coefficients causes a decrease in aggregated safety stock savings (Chopra and Meindl 2013).

Xu and Evers (2003) mentions two types of demand aggregation. First they discuss about physical aggregation. This is when the actual number of inventory locations is reduced, and you have a centralization of the inventory. Lastly, they mention virtual aggregation. This is when the management is centralized, but the inventory remains at the same place. Here the aggregation takes effect by lateral transshipments between the locations. Furthermore, they produce evidence to that complete aggregation, where all demand points are served by one supply point, is always better than partial aggregation. However, this is only true for the correlation coefficient since other factors as transportation cost and lead time may make it more beneficial for the supply chain to have partial aggregation. (Xu and Evers 2003).

2.2.1 The "Square Root Law"

The "Square Root Law" (SRL) states that in the case of centralization of *n* number of inventory location into one location, the amount of inventory as a ratio of the decentralized inventory, $\frac{decentralized\ system\ inventory}{centralized\ system\ inventory}$, is equal to $\sqrt{n}$. It also follows that the percent reduction in inventory by centralization is given by $\frac{Decentralized\ invetory - Centralizes\ inventory}{Decentralized\ inventory} = 1 - \frac{Centralized\ inventory}{Decentralized\ inventory} = 1 - \frac{1}{\sqrt{n}}$ (Maister 1976).In 1976 D.H. Maister proved the SRL correct both for cycle stock and safety stock, with the assumptions listed in Table 1.

Table 1 - Assumptions under SRL (Maister 1976)

As applied to cycle stock	As applied to safety stock
- Inventories are controlled by means of the Wilsons Lot Size Formula (EOQ). - All locations, both before and after centralization, face the same cost per order. - All locations, both before and after centralization, have the same per unit holding cost. - Total system demand, both before and after centralization, remains constant.	- All locations utilize the same safety stock multiple (the safety factor mentioned in 2.1.2). - Demands at decentralized locations are uncorrelated.

Maister furthermore introduced an adaptation SRL equation this where one consolidate *n* locations into *m* locations, *n* > *m*, as the ratio$\frac{\sqrt{m}}{\sqrt{n}}$. This is only valid under the assumption that each location have the same proportion of the total demand (Maister 1976).

2.2.2 The Portfolio Effect

The portfolio effect (PE) as defined by Zinn, Levy, and Bowersox (1989, p. 3) as – "*the percent reduction in aggregate safety stock made possible by consolidation of inventories from multiple locations into one location*". The equation for PE is as follows;

$PE = 1 - \frac{SS_a}{\sum_{i=1}^{n} SS_i}, for\ 0 \leq PE \leq 1$, where;

SS_a is the aggregate safety stock for a given product if inventory is consolidated.

SS_i is the safety stock for a given product at location *i*.

The portfolio effect goes from zero to one and at zero there is no reduction in safety stock by aggregating. While Maister assumed zero correlation between demands at different locations in the SRL, the PE accounts for both correlation and the relative values of the standard deviation which Zinn, Levy, and Bowersox (1989) called Magnitude (*M*).

$$M = \frac{\sigma_1}{\sigma_2}, for\ \sigma_1 \geq \sigma_2\ and\ \sigma_2 \neq 0$$

By inserting this into the equation for safety stock they derived that:

$$PE = 1 - \frac{\sqrt{M^2 + 1 + 2Mp_{12}}}{M + 1}$$

Consequently they proved that it is the relative values of correlation, and not the absolute value, that affects the PE (Zinn, Levy, and Bowersox 1989).

Ronen (1990) argues that since a centralized stock will have more order cycles per year than any of the decentralized facilities under the assumption that they have the same ordering policies and holding cost. Consequently, by using the a safety factor based on the probability of not running out of inventory during the lead time, the results can be misleading.

2.3 Centralized Versus Decentralized

By centralizing their activities, a company can achieve significant savings due to the economy of scale (Stock and Lambert 2001). There are more benefits of a centralized inventory other than the aforementioned inventory chapter. A centralized system can work towards better solutions for the entire supply chain while the decentralized systems tend to work with a local optimum. This is especially the case, if the supply chain is owned by one company since they can use coordinated strategies to reduce total costs and improve the service level (Simchi-Levi, Kaminsky, and Simchi-Levi 2004). A centralized purchasing system can also lead to lower purchase price due to higher purchase volumes and improvement in the purchasing procedures. It can also reduce the duplication of effort (Monczka et al. 2011). The authors also discuss multiple advantages of a decentralized system like;

- Higher responsiveness to change in the customers' requirements
- Better understanding of local differences
- Higher "ownership" in the effects of their decision (Monczka et al. 2011).

2.4 Transshipments

There are, however, other possibilities to improve the supply chain other than aggregating the demand. *"Risk pooling through lateral transshipment in inventory distribution system is an effective means of improving customer service and reducing total cost*" (Tagaras 1999, p. 39). Tagaras (1999) further discuss two types of transshipment policies;

- Emergency lateral transshipments that occur when the shortage happens as a means to reduce stockouts
- Preventive lateral transshipments that happen before any stockouts and helps reduce the risk of shortage.

Wanke and Saliby (2009) came up with a decision framework for inventories based on the property of the SKU which can be seen in Table 2.

Table 2 – Decision rules for inventory (Wanke and Saliby 2009)

Major decision	Should inventories be pooled?		
	Yes		No
If yes, how should inventories be pooled?	Inventory Centralization	Regular Transshipments	Independent Systems
Adequacy in terms of product, demand, and operation characteristics for a minimal total cost	High holding costs Negative correlation High and homogeneous lead time means High and homogeneous demand std. deviations Homogeneous levels of lead time variability	Low holding costs Moderate positive correlation Possibility of balancing high/low lead time means and std. deviations of demand at different centralized locations Heterogeneous levels of lead time variability	Medium holding costs High positive correlation Low lead time means Low demand std. deviations Homogeneous levels of lead time variability
Type of pooling	Demand	Lead time demand	None
Additional benefits	One also benefits from the consolidation at the best performance facility in terms of lead time variability	None	One also benefits from the fact that undesirable or unexpected cross-effects in terms of demand peaks (or valleys) and/or lead time delays (or anticipations) are avoided

Lateral transshipments will always be outperformed by centralization of inventory in terms of holding and shortage cost, but not on accessibility and service (Tagaras 1999).

2.5 Facility Location

The decision of facility location tends to be taken at the strategic level (Brandimarte and Zotteri 2007). Their decision is costly and hard to reverse, and the parameters can vary widely in the time horizon (Snyder 2006).

Edgar M. Hoover (1963) outlined three general strategies for location theory; material-oriented, market-oriented, and intermediated stages. Production sites tend to be located closer to the supply of raw materials, while the end-products tend to be closer to the customers. The *center-of-gravity approach* is a simplistic facility location theory where the objective is minimization of the transportation cost (Grant et al. 2006). This theory says that one should place the warehouse closer to where the largest part of the transportation cost is, equalizing the transportation cost in all directions. Within the location modeling science this thesis would fall under the discrete category. Daskin (2008) divides this group into three classes; Covering-based Models, Median-based Models, and Other Models.

The Covering-based Models entail some crucial distance or time limit that has to be covered from a supply node and can be split by their objective and constraints.

- It could be desirable to minimize the number of supply nodes to cover a given area or response time. This is called the *Set Covering Model*.
- With limited resources one would want to maximize the covering given a determined number of supply nodes, the *Max Covering Model*.
- The *p-center Model* is used to find the minimum coverage distances while covering all demand nodes.

The Median Models differ from the Covering Models in that they include actual distances.

- The *p-median Model* minimizes the product of distance and demand given a determined number of supply nodes available.
- The *Fixed Charge Model* also includes any cost of establishing supply nodes.

The last category is for the models that do not fit into the other categories.

- *P-dispersion* where the objective is to maximize the minimum distance between each node. For instance in retail, if your own stores are too close together, they will fight for the same customers (Daskin 2008).

3. Methodology

When formulating a research problem, it is important to find what unit of analysis to be studied. Although there are no limitations on what the unit of analysis could be, careful selection is important as it affects not only the research design, data collection methods, and data analysis, but also the scope of the research and its level of generalization and theorizing (Frankfort-Nachmias and Nachmias 2008). In this research the unit of analysis is *the reduction of inventory levels by centralization*. Both cycle stock and safety stock will be analyzed.

3.1 Research Questions

The research questions should meet the following criteria listed by Bryman and Bell (2011).

1. *Questions should be clear.* So that both the author(s) and reader(s) alike should understand them.
2. *Questions should be searchable.* The questions should lead to a research design and enable data collection.
3. *Questions should connect with established theory and research.*
4. *Questions should be linked to each other.* Allowing for a single line of argument throughout the thesis.
5. *Questions should have potential for making a contribution to knowledge.*
6. *Questions should be neither too broad nor to narrow.*

With these criteria in mind the research question was formulated as:

How does centralization affect the inventory for a wholesaler in the industry sector?

3.2 Research Design

The main purpose with a research designs is to help the researchers with a conceptual framework that will guide them to utilize principles of scientific inquiry to answer the research questions (Edmonds and Kennedy 2013). Bryman and Bell (2011) gives five different types of research design; experimental, cross-sectional, longitudinal, comparative design, and case-study.

The experimental research design requires manipulation of the independent variables to look for changes in the dependent variable. It is often used to check differences between a treatment group and a control group. Since this thesis is based on historical data with no possibilities to manipulate the dependent variable, this was not a good fit for this thesis.

Cross-sectional design, or social survey design as it is some time called, is defined as:

"(...) the collection of data on more than one case (...) to detect patterns of association" (Bryman and Bell 2011, p. 53)

This often entails structured interviews and questionnaires to collect data so that variations between the different cases may be examined. Although this may be an appropriate design to use in order to answer the research question, it is not in this case since this work focuses on only one company.

Longitudinal design is used to look for changes over time, and requires samples from more than one time period (Bryman and Bell 2011). Time limitation presented a problem in using this kind of research method.

Comparative design "embodies the logic of comparison" (Bryman and Bell 2011, p. 63), with similar methods used on contrasting cases to be able to better understand a social phenomenon. As aforementioned, this thesis is centered on one company so the comparative design could therefore not be applied.

The case study design necessitates an intensive analysis of a single case (Bryman and Bell 2011), and can be used to gain insight in what effect different structures of logistics and purchasing organization has on the logistics role in an organization (Ellram 1996). It is an iterative process used to empirically analyze a contemporary phenomenon within its real-life context (Yin 2009). Since this research used data from an existing company, it lies within the real-life context. The subject research question should be considered contemporary as inventory is a constant factor in a company's competitive advantages, and there is continuous process to improve it. With this in mind, a case study research design was used for this thesis. With focus primarily on safety stock for the northern district of TOOLS, the thesis fell under the single-case design group (Yin 2009).

Several different cases exists within this research design there exist. This thesis was a representative case study. A representative case is one that can be used as an example for form of organization (Yin 2009, Bryman and Bell 2011). The northern part of Norway has properties that would impede the comparison to other countries or other parts of Norway. With vast distances between population centers, any results should be looked at with caution as an example for other regions. As a wholesaler TOOLS have more than 350,000 SKUs in its assortment (TOOLS AS) As long as the data foundation is wide enough it should represent the sector of wholesaler to the industry sector.

3.3 Data Classification

A normal way to categorize data in any research is by primary and secondary data. Primary data can be defined as; data that has not been collected before and therefor the researches have to collect it to answer their questions. Secondary data is data that already exist, and are faster and less costly to obtain. One could also say that primary data becomes secondary data if it is used by another researcher who did not participate in the primary data collection. Within secondary data we can distinguish between internal and external secondary data. Internal secondary data is data that comes from within the organization or company, while external secondary data can be obtained from government or industry sources, the internet, etc. (Bradley 2010).

This thesis dealt mainly with internal secondary data provided by TOOLS ERP system with regards to demand pattern and a distance matrix calculated from google maps. Since the data from TOOLS are collected through the system they use daily, they have an incentive to keep the data as accurate as possible. Consequently they can be considered to be reliable. Data from google maps were used to supplement existing distance data from TOOLS as it was easily available and should be considered adequate in the calculations done in this research.

3.4 Quality Criteria

The main goal in any research is to achieve valid results based on the relevant application of the scientific method. *Validity*, in regards to research design, is defined as: *"The extent to which the outcome accurately answers the stated research questions of the study"* (Edmonds and Kennedy 2013, p. 3). In relation to the case study design the quality criteria used are;

- *Internal validity.* This can be summed up in the known phrase: *correlation does not imply causation.* The concept is how certain we are that that the independent variable is responsible for changes in the dependent variable.
- *External validity.* This deals with the concept of whether the results can be generalized beyond the specific research question (Bryman and Bell 2011, Edmonds and Kennedy 2013, Yin 2009).
- *Reliability.* If the research is done again it should lead to the same results and conclusion (Bryman and Bell 2011, Yin 2009).

Since the company uses previous experience when determining safety stock, a theoretical safety stock for the current situation is used to measure any improvements. When determining safety stock by a predetermined service level based on customer service, the only variable is variation in demand. Hence, we can assume internal validity to be high. In terms of external validity and the possibility of generalization of a single-case, it is hard to do without further testing on similar cases (Yin 2009). So even though the situation in itself is not uncommon, it is a single-case. Consequently one should keep that in mind related to any generalization.

Reliability is the concept of documenting the research to such detail that the process can be repeated by others. To overcome any reliability deficiencies it is important to establish a case study protocol (Yin 2009). The case study protocol should include description of the steps undertaken as well as any interview guide (Ellram 1996). This research dealt primarily with secondary data, so the need for such a protocol is not that imperative. If this case study were to be research again, the data foundation would be identical.

A final issue in the quality criteria is that of *conformability*, or objectivity in other words. The concept is that the findings in the research represent the data and not the researcher's biases (Bryman and Bell 2011, Halldórsson and Aastrup 2003). Regarding this thesis, the author considers himself to have no personal gain from any results presented. Combined with a thorough literature review and a substantial amount of secondary data this should document that the results presented are that of the original inquiry, and not influenced by the researcher's potential biases.

4. Discussion

This chapter starts describing the current situation at TOOLS regarding inventory before data collection and preliminary analyzes of safety stock, cycle stock, and ton kilometers. These are followed by further analyzes in the next part before a discussion ends the chapter

4.1 Current Situation

This thesis is centered on four quantifiable costs in order to answer the research question; cycle stock cost, ordering cost, safety stock cost, and transportation cost. At the present point in time TOOLS have no rules set on neither safety stock nor order quantity. They rely instead on the experience of the purchasers in the different warehouses. This causes a problem when measuring any solution against the status quo since any theoretical solution might be distorted when measuring against the real-world data. If any warehouse holds far too much or too little inventory, any theoretical findings compared against the current situation is difficult. TOOLS do not calculate holding cost and purchasing cost. Consequently, assumptions have been made for these costs. With many large customers and competitors on a local and national level, TOOLS want to operate with a high service level. In light of this, a theoretical baseline for the safety stock and cycle stock is used to calculate any improvement by virtual centralization.

TOOLS pay no extra transportation cost for stock SKUs sent from the internal supplier whether they are sent to the warehouses or directly to the customers. However, their internal supplier will start to charge extra for direct shipments to customers. The management therefore finds it less costly to have the SKUs shipped to the warehouses and subsequently from there to the customers. By letting the warehouses stock fewer SKUs, but more of each, they will act as supply nodes for the customers of, what are now, customers of another warehouse as illustrated in Figure 1. Consequently, any added transportation cost from virtual centralization is of interest.

4.2 Data Collection and Preliminary Analysis

In order to have any benefit from virtual centralization, there has to be demand for the same SKU in more than one warehouse. Sales data containing orders delivered to customers and over the counter from each location was collected. The time period was from 01.11.2012 to 31.10.2013. These included which warehouse they were sold from, article number, description, number of items sold, cost, and revenue. Non-physical SKUs like services were removed. A comparison was made to see the relative number of equal SKUs between the different warehouses. This is shown in Table 3.

Table 3 – Relative amount of equal SKUs sold at the different locations.

	Kirkenes	Hammerfest	Tromsø	Finnsnes	Narvik	Verdal	Trondheim	Molde	Ålesund	Førde
Kirkenes	100.00 %	34.78 %	44.75 %	42.25 %	39.51 %	26.33 %	41.94 %	36.58 %	46.23 %	41.16 %
Hammerfest	31.46 %	100.00 %	51.49 %	40.97 %	36.98 %	23.95 %	39.73 %	33.11 %	45.19 %	39.22 %
Tromsø	24.11 %	30.67 %	100.00 %	34.81 %	32.86 %	19.11 %	34.43 %	28.64 %	38.47 %	33.69 %
Finnsnes	22.45 %	24.06 %	34.32 %	100.00 %	33.14 %	18.60 %	34.07 %	27.15 %	37.14 %	33.44 %
Narvik	27.33 %	28.27 %	42.18 %	43.15 %	100.00 %	22.35 %	37.08 %	31.28 %	40.41 %	37.98 %
Verdal	20.18 %	20.29 %	27.17 %	26.84 %	24.77 %	100.00 %	30.56 %	28.54 %	35.50 %	30.11 %
Trondheim	19.92 %	20.86 %	30.35 %	30.47 %	25.46 %	18.94 %	100.00 %	29.39 %	39.55 %	34.37 %
Molde	16.80 %	16.80 %	24.41 %	23.47 %	20.77 %	17.10 %	28.41 %	100.00 %	35.63 %	32.73 %
Ålesund	15.77 %	17.04 %	24.35 %	23.85 %	19.93 %	15.80 %	28.40 %	26.47 %	100.00 %	31.80 %
Førde	13.87 %	14.61 %	21.06 %	21.21 %	18.50 %	13.24 %	24.38 %	24.02 %	31.40 %	100.00 %

Table 3 should be read like (Hammerfest, Kirkenes), where the first name is found along the rows and the second name is found along the columns, is the number of SKUs sold in Kirkenes as a percent of the total of the SKUs sold in Hammerfest which is 31.46 percent. And (Kirkenes, Hammerfest) we see that 34.78 percent of SKUs sold at Kirkenes was also sold in Hammerfest. By disregarding the ten values representing the same warehouses, (Kirkenes, Kirkenes), (Hammerfest, Hammerfest), and so on, the average is 29.35 percent and the two warehouses with the highest percent of equal SKUs is (Hammerfest, Tromsø) at 51.49 percent. This means that over half of the items sold in Tromsø were also sold in Hammerfest. The two warehouses with the least amount of equal SKUs are (Førde, Verdal) with 13.24 percent. However, Førde has more than twice the number of SKUs sold than Verdal. Førde also has the least average percent at 20.25 against the overall percent which is 29.35. Kirkenes has the most equal SKUs with the other warehouses with 39.28 percent on average. This might be because Kirkenes has the least amount of different SKUs sold in the time period with 6662 unique SKUs. This might mean that the demand is closer to the core assortment, but this is pure speculation. The ten warehouses have, on average, sold 12508 different SKUs each.

4.2.1 Safety Stock

To check for correlation between the warehouses a small amount of data containing a hundred SKUs where collected; these were the top ten SKUs in respect of revenue for each of the ten locations. Several SKUs were in the top ten for more than one location. When that happened, the next item in respect to revenue from either of the locations was also selected. There were also SKUs that had been replaced with another SKU. The new SKU was then included in the set and the article number for the replaced SKU was changed to that of the new one. This data set contained order date, the customers unique ID-number, customer name, order number, amount of each SKU ordered, their description, delivery date, and amount. Another data set containing the purchase price of the SKUs was also collected. By summing the product of the SKUs and their price, an estimate for correlation was made as shown in Table 4.

Table 4 - Correlation

	Kirkenes	Hammerfest	Tromsø	Finnsnes	Narvik	Verdal	Trondheim	Molde	Ålesund	Førde
Kirkenes	0.000	0.051	-0.020	-0.003	-0.003	0.029	0.001	0.013	0.010	0.020
Hammerfest		0.000	-0.019	-0.021	-0.042	-0.008	0.037	0.058	0.010	0.042
Tromsø			0.000	-0.028	-0.085	0.019	0.011	0.000	-0.051	0.062
Finnsnes				0.000	0.096	0.193	0.152	0.122	0.064	0.021
Narvik					0.000	0.171	0.029	0.059	0.071	0.128
Verdal						0.000	0.137	-0.004	0.091	-0.052
Trondheim							0.000	-0.016	0.145	0.161
Molde								0.000	0.042	0.023
Ålesund									0.000	0.034
Førde										0.000

Table 4 shows that the correlation is very small. The highest correlation coefficient is 0.193 and the lowest is -0.085. The average correlation between them is 0.039. As this is very close to zero, zero correlation between the warehouses is assumed.

When a large amount of independent variables are combined, their probability distribution tend to approach normal distribution, this is called the Central Limit Theorem. (Mattsson 2007). If there are more than thirty observations, normal distribution can be used as an approximation (Johnson and Bhattacharyya 2011). In this thesis, weekly demand over one year was used so the assumption of normal distribution has therefore been applied.

A second test to check the assumption of zero correlation between the different warehouses was carried out with five SKUs. The five SKUs were picked out of the highest A-items where the demand was high. By using the *Customer Service* approach from chapter 2.1.2; where safety stock is the product of a safety factor for a service level P1 of 95 percent and the standard deviation of demand for the lead time, $SS = k\sigma_L$. The middle case lead time from the internal suppliers were used. The description, price, and weekly standard deviation of the five SKUs can be found in Appendix A along with the lead time for the different warehouses from their internal supplier. The warehouse that should act as a supply node was selected by these criteria;

- When an odd number of warehouses were combined, the warehouse in the middle was chosen.
- When an even number of warehouses were combined, the warehouse with the highest demand in term of value of the two in the middle was chosen.
- The case of the three warehouses furthest to the north, (Tromsø, Finnsnes, and Kirkenes) presents a special case when looking at distances and lead times. In the case of all three combined Tromsø was selected as the supply node. When Kirkenes and Hammerfest were combined Kirkenes was selected as the supply node.

As it can be seen from Table 5 the safety stock was approximately NOK 143,000 in total for all ten locations.

Table 5 – Safety stock, 5 SKUs.

Kirkenes	kr	3 104.92
Hammerfest	kr	-
Tromsø	kr	673.04
Finnsnes	kr	13 397.44
Narvik	kr	3 231.30
Verdal	kr	16 345.97
Trondheim	kr	509.20
Molde	kr	33 265.34
Ålesund	kr	59 494.16
Førde	kr	13 149.61
Sum	kr	143 170.98

This result was then analyzed by both manually aggregating the demand of each SKU over two scenarios; using two warehouses and four warehouses. The two scenarios were also analyzed by and adding the variation with zero correlation. Table 6 is showing potential benefit of centralization and the comparison of the two methods. A maximum reduction of up to 29 percent could be achieved. The differential between the two methods was 4.1 percent at the most.

Table 6 – Difference of safety stock value between aggregating demand method versus sum of variation under zero correlation.

Aggregating Demand			$\sigma_{1,2}=\sqrt{\sigma_1^2 + \sigma_2^2}$	
Two Warehouses			**Two Warehouses**	
South	kr 93 219		South	kr 90 414
North	kr 13 982		North	kr 10 965
Sum	kr 107 201		Sum	kr 101 379
Percent reduction	**25.1 %**		**Percent reduction**	**29.2 %**
Four Warehouses			**Four Warehouses**	
Trondheim & Verdal	kr 16 319		Trondheim & Verdal	kr 16 373
Molde, Ålesund, & Førde	kr 82 535		Molde, Ålesund, & Førde	kr 80 508
Narvik, Finnsnes, & Tromsø	kr 13 727		Narvik, Finnsnes, & Tromsø	kr 13 741
Hammerfest & Kirkenes	kr 2 443		Hammerfest & Kirkenes	kr 2 443
Sum	kr 115 024		Sum	kr 113 064
Percent reduction	**19.7 %**		**Percent reduction**	**21.0 %**

In light of these results the decision to assume zero correlation was made. New data sampling for 150 SKUs from each warehouse, 50 in each Pareto group. All were randomly selected with a random number generator[1] for a total of 1500 SKUs. No attempt to remove duplicates was made. The large amount of SKUs was chosen to make the number of SKUs without duplicates substantial. The same procedure, with replaced SKUs, was done as before, making a total of 1457 SKUs to be evaluated further. Eight scenarios were chosen and calculated with all three possibilities of lead time and a service level of 90 percent, 95 percent, and 99.9 percent respectively. Scenario 1 represents zero centralization and scenario 2 is full possible aggregation, meaning that there is one supply node in the northern region and one supply node in the southern region. The others are combinations that are defined in Appendix C. Table 7 shows the monetary value as well as percent reduction of the safety stock in the eight scenarios.

[1] http://www.random.org/integers/

Table 7 – Comparison between different service levels and lead times.

NOK				Reduction percent			
Scenario 1				**Scenario 1**			
P1=	**Best**	**Middle**	**Worst**	**P1=**	**Best**	**Middle**	**Worst**
90.0 %	kr 3 150 278	kr 3 265 976	kr 3 369 754	**90.0 %**	0 %	0 %	0 %
95.0 %	kr 3 314 233	kr 3 496 990	kr 3 646 739	**95.0 %**	0 %	0 %	0 %
99.9 %	kr 4 183 143	kr 4 628 896	kr 4 984 407	**99.9 %**	0 %	0 %	0 %
Scenario 2	Metric tonne-kilometers		351 995 tkm	**Scenario 2**			
P1=	**Best**	**Middle**	**Worst**	**P1=**	**Best**	**Middle**	**Worst**
90.0 %	kr 1 574 045	kr 1 683 923	kr 1 766 126	**90.0 %**	50 %	48 %	48 %
95.0 %	kr 1 728 458	kr 1 868 936	kr 1 977 455	**95.0 %**	48 %	47 %	46 %
99.9 %	kr 2 429 472	kr 2 703 490	kr 2 956 905	**99.9 %**	42 %	42 %	41 %
Scenario 3				**Scenario 3**			
P1=	**Best**	**Middle**	**Worst**	**P1=**	**Best**	**Middle**	**Worst**
90.0 %	kr 1 840 055	kr 1 960 616	kr 2 051 098	**90.0 %**	42 %	40 %	39 %
95.0 %	kr 2 006 524	kr 2 150 297	kr 2 279 931	**95.0 %**	39 %	39 %	37 %
99.9 %	kr 2 713 703	kr 3 046 526	kr 3 325 494	**99.9 %**	35 %	34 %	33 %
Scenario 4				**Scenario 4**			
P1=	**Best**	**Middle**	**Worst**	**P1=**	**Best**	**Middle**	**Worst**
90.0 %	kr 2 102 785	kr 2 234 454	kr 2 321 570	**90.0 %**	33 %	32 %	31 %
95.0 %	kr 2 268 108	kr 2 433 913	kr 2 560 022	**95.0 %**	32 %	30 %	30 %
99.9 %	kr 2 989 551	kr 3 394 548	kr 3 660 919	**99.9 %**	29 %	27 %	27 %
Scenario 5				**Scenario 5**			
P1=	**Best**	**Middle**	**Worst**	**P1=**	**Best**	**Middle**	**Worst**
90.0 %	kr 1 740 400	kr 1 858 039	kr 1 938 004	**90.0 %**	45 %	43 %	42 %
95.0 %	kr 1 904 572	kr 2 045 320	kr 2 157 740	**95.0 %**	43 %	42 %	41 %
99.9 %	kr 2 673 030	kr 2 950 250	kr 3 219 175	**99.9 %**	36 %	36 %	35 %
Scenario 6				**Scenario 6**			
P1=	**Best**	**Middle**	**Worst**	**P1=**	**Best**	**Middle**	**Worst**
90.0 %	kr 2 056 645	kr 2 162 820	kr 2 244 616	**90.0 %**	35 %	34 %	33 %
95.0 %	kr 2 231 114	kr 2 357 052	kr 2 475 067	**95.0 %**	33 %	33 %	32 %
99.9 %	kr 2 956 088	kr 3 243 877	kr 3 479 085	**99.9 %**	29 %	30 %	30 %
Scenario 7				**Scenario 7**			
P1=	**Best**	**Middle**	**Worst**	**P1=**	**Best**	**Middle**	**Worst**
90.0 %	kr 2 637 487	kr 2 751 605	kr 2 843 486	**90.0 %**	16 %	16 %	16 %
95.0 %	kr 2 801 779	kr 2 965 609	kr 3 100 083	**95.0 %**	15 %	15 %	15 %
99.9 %	kr 3 620 876	kr 4 066 381	kr 4 343 263	**99.9 %**	13 %	12 %	13 %
Scenario 8				**Scenario 8**			
P1=	**Best**	**Middle**	**Worst**	**P1=**	**Best**	**Middle**	**Worst**
90.0 %	kr 2 344 337	kr 2 468 828	kr 2 568 586	**90.0 %**	26 %	24 %	24 %
95.0 %	kr 2 518 687	kr 2 681 556	kr 2 823 622	**95.0 %**	24 %	23 %	23 %
99.9 %	kr 3 288 044	kr 3 652 293	kr 3 959 751	**99.9 %**	21 %	21 %	21 %

It can be seen from Table 7 that the second scenario gives a reduction of safety stock between 50 percent with service level at 90 percent and best case in lead time, to 41 percent with 99.9 percent service level and worst case lead time. This is a nine percent difference between the best case and the worst case. This difference gets smaller as the scenario gets closer to decentralized. Scenario 7 is the least centralized scenario with seven warehouses instead of ten: the difference is only three percent.

Under the assumption that warehouses can only be joined together if they are adjacent and that the five in the northern region cannot be joined with the five in the southern region, there are 256 possible ways of centralizing the warehouses. However, by looking at the northern and southern region as two different cases the number of possibilities decreases to two cases of 16 possibilities each. A list over these all scenarios is found in Appendix D along with what will for the rest of this thesis be called degree of centralization. The degree of centralization is how many virtual warehouses the estimates are based on.

Calculation of all 32 scenarios with a P1 service level of 95 percent, middle lead time from internal supplier, and selecting warehouse by the aforementioned criteria was done and is summarized in Table 8. The monetary value can be found in Appendix E and Appendix F along with estimates on the value for all SKUs sold during one year.

Table 8 – Reduction in safety stock value.

South		North	
Scenario	Reduction in percent of decentralized value	Scenario	Reduction in percent of decentralized value
S01	43.44 %	S01	50.14 %
S02	34.76 %	S02	40.16 %
S03	30.44 %	S03	35.85 %
S04	24.80 %	S04	31.13 %
S05	28.40 %	S05	32.70 %
S06	23.24 %	S06	27.09 %
S07	21.96 %	S07	26.54 %
S08	15.55 %	S08	19.79 %
S09	17.99 %	S09	22.81 %
S10	14.41 %	S10	16.94 %
S11	16.41 %	S11	19.41 %
S12	9.25 %	S12	11.33 %
S13	11.25 %	S13	13.80 %
S14	8.73 %	S14	11.47 %
S15	5.16 %	S15	5.61 %
S16	0.00 %	S16	0.00 %

From the estimates in Appendix E and Appendix F when adjusting to all SKUs sold, the ten warehouses hold a combined theoretical safety stock of NOK 83 million. This is higher than the combined total inventory of the current state of NOK 76.5 million mentioned in chapter 1.2. There are a number of reasons why this theoretical number is artificially high;

- When using *Customer Service* to determine safety stock, the answer is generally a fractioned number. To ensure that the safety stock help to achieve a P1 service level of at least 95 percent, this number has been rounded up to the closest integer. By doing this there are SKUs with low demand that should mean that the SKUs should not be held in stock, would in this case have one in stock.
- There are a number of SKUs that in today situation is not in stock. Especially slow moving A-items which are ordered when there is a demand for them. This means that the numbers of items sold are not equal to the number of items in stock leading to this high value of the theoretical safety stock.

Consequently, the percent decreasing safety stock would be a more accurate picture of the possibilities. When averaging these percentiles for scenarios with the same degree of centralization for North and South it is clear that a higher degree of centralization leads to lower safety stock. This is shown in Table 9.

Table 9 – Degree of centralization on safety stock

Reduction in percent of decentralized value			
Number of warehouses	**South**	**North**	**Square Root Law**
1	43.44 %	50.14 %	55.28 %
2	29.60 %	34.96 %	36.75 %
3	18.26 %	22.10 %	22.54 %
4	8.60 %	10.55 %	10.56 %
5	0.00 %	0.00 %	0.00 %

The northern region follows Maister (1976) square root law on consolidating *n* location into *m* location rather close, while the southern region shows a slighter potential reduction in safety stock.

4.2.2 Cycle Stock and Ordering Cost

No basic data foundation for ordering cost and holding cost exist at TOOLS. Hence, the EOQ have been calculated with several values for both. For the ordering cost the values NOK 250, 500, 1000, and 1500 have been used. For the holding cost 10, 20, and 30 percent have been used. To calculate the EOQ it is assumed that there is one order per SKU. The values and percent reduction for all alternatives can be found in Appendix G to J. The percent reduction in both ordering cost and inventory value are close to identical for all values of ordering cost and holding cost. The average is shown in Table 10

Table 10 – Comparison of reduction in ordering cost and cycle inventory reduction

Ordering cost			Inventory		
Scenario	South	North	Scenario	South	North
S01	36 %	38 %	S01	36 %	38 %
S02	29 %	28 %	S02	29 %	28 %
S03	24 %	26 %	S03	24 %	26 %
S04	20 %	22 %	S04	20 %	22 %
S05	23 %	23 %	S05	23 %	24 %
S06	19 %	19 %	S06	19 %	19 %
S07	17 %	17 %	S07	17 %	17 %
S08	12 %	15 %	S08	12 %	15 %
S09	15 %	14 %	S09	14 %	14 %
S10	13 %	12 %	S10	12 %	12 %
S11	13 %	13 %	S11	13 %	13 %
S12	8 %	7 %	S12	8 %	7 %
S13	8 %	8 %	S13	8 %	9 %
S14	6 %	7 %	S14	6 %	7 %
S15	4 %	5 %	S15	4 %	5 %
S16	0 %	0 %	S16	0 %	0 %

Since the EOQ is located in the intersection between ordering cost and holding cost, it is naturally that these two tables are close to identical. The ordering value was rounded to its closest integer. This explains why the values are not completely identical. When comparing South and North, there are a lot of similarities. They are only separated by a maximum of three percent. By averaging the same degree of centralization the results are presented in Table 11.

Table 11 – Degree of centralization on cycle stock.

Reduction in percent of decentralized value		
Inventory Value		
Number of warehouses	**South**	**North**
1	36.35 %	37.85 %
2	24.08 %	24.90 %
3	14.58 %	14.93 %
4	6.75 %	6.79 %
5	0.00 %	0.00 %
Ordering Cost		
Number of warehouses	**South**	**North**
1	36.38 %	37.67 %
2	24.14 %	24.70 %
3	14.64 %	14.79 %
4	6.79 %	6.71 %
5	0.00 %	0.00 %

The reduction in cycle stock is less than that of the safety stock, but with 37.85 percent reduction at most, it still represent a major possibility to decrease their inventory value.

4.2.3 Ton Kilometers

TOOLS do not operate with transportation cost into the warehouses. With centralization it is expected to be an increase in transportation cost out from the warehouses. There is no data foundation for what the transportation cost is, but ton kilometers were used as an indication of cost. If we assume that all the customers are located equally around the warehouses, a reasonable approximation would be to say that ton kilometers from one warehouse to the customers of another warehouse is the same as from one warehouse to another. TOOLS do not monitor the weight of the SKUs. Data for all SKUs were therefore not obtained. Knowing the weight of 1046 SKUs, the average was used for the rest. Calculations were made for all scenarios by letting the warehouse with the highest demand, of each SKU in each collaboration group, store it. The added transportation was then product of the demand from the other warehouses in that group, the weight, and the distance from the supply node to the demand node. A table over the distances used is listed in Appendix K. Table 12 shows the added ton kilometers for each centralization scenario.

Table 12 – Added ton kilometer by centralization

North		South	
S01	99 445 tkm	S01	150 462 tkm
S02	43 705 tkm	S02	123 457 tkm
S03	80 569 tkm	S03	68 328 tkm
S04	57 841 tkm	S04	75 142 tkm
S05	30 165 tkm	S05	72 743 tkm
S06	16 007 tkm	S06	68 749 tkm
S07	31 201 tkm	S07	24 613 tkm
S08	53 012 tkm	S08	31 948 tkm
S09	25 255 tkm	S09	50 760 tkm
S10	18 987 tkm	S10	47 189 tkm
S11	19 981 tkm	S11	15 340 tkm
S12	4 829 tkm	S12	43 195 tkm
S13	5 823 tkm	S13	11 346 tkm
S14	20 426 tkm	S14	7 565 tkm
S15	14 159 tkm	S15	3 994 tkm
S16	0 tkm	S16	0 tkm

When looking at ton kilometer for the northern region Scenario 12 and 13 stand out. These scenarios represent the combination that only Narvik and Finnsnes, and Finnsnes and Tromsø collaborating respectively. These two scenarios are also the ones with the shortest distance between them; Narvik and Finnsnes are only 159 kilometers apart, while Finnsnes and Tromsø are 160 kilometers apart.

For the southern region it is Scenarios 14 and 15 that stand out. This is Molde and Trondheim, and Trondheim and Verdal collaborating respectively. Interestingly the two with the least distance between them are Ålesund and Molde at 74 kilometers, while scenarios 14 and 15 have 216 and 88 kilometers respectively between them. It is naturally that the scenarios which give the least amount of added ton kilometers are the ones with the lowest degree of centralization, but these are also the ones that give the least benefit in terms of lower inventory and ordering cost.

Average cost per ton kilometers can be calculated with data from Norway's Institute of Transport Economics (Transportøkonomisk institutt). Costs are depended on what kind of transport it is by sea, land, or rail. Since land transportation is the type used mostly by TOOLS now, these are the cost issues of interest. The relevant statistical cost data are listed in Table 13.

Table 13 – Cost per ton kilometer (Grønland 2011)

Transport Type	Capacity (ton)	Per ton kilometer	
Semi-trailer, closed unit	33	kr	3.55
Semi-trailer, container	33	kr	3.77
Heavy distribution, containers	12	kr	10.18
Light distribution	5.7	kr	11.77
Heavy distribution, Panel Van	9	kr	12.26
Van	2.2	kr	28.22

The numbers listed in Table 13 have been calculated with an assumption of speed at 60 kilometers per hour and represent the actual cost of land transportation. The cost through a third party logistics operator would most likely be higher.

4.3 Analysis

To compare annual savings associated with potential centralization between ordering cost, cycle stock, safety stock, and ton kilometers it was decided to use ordering cost of NOK 500 and holding cost of 20 percent. These were assumed to be closest to real-life cost. The annual savings can be calculated by using these parameters for each scenario. A graph compering potential savings and added ton kilometers for the different scenarios for the northern region is shown in Figure 4.

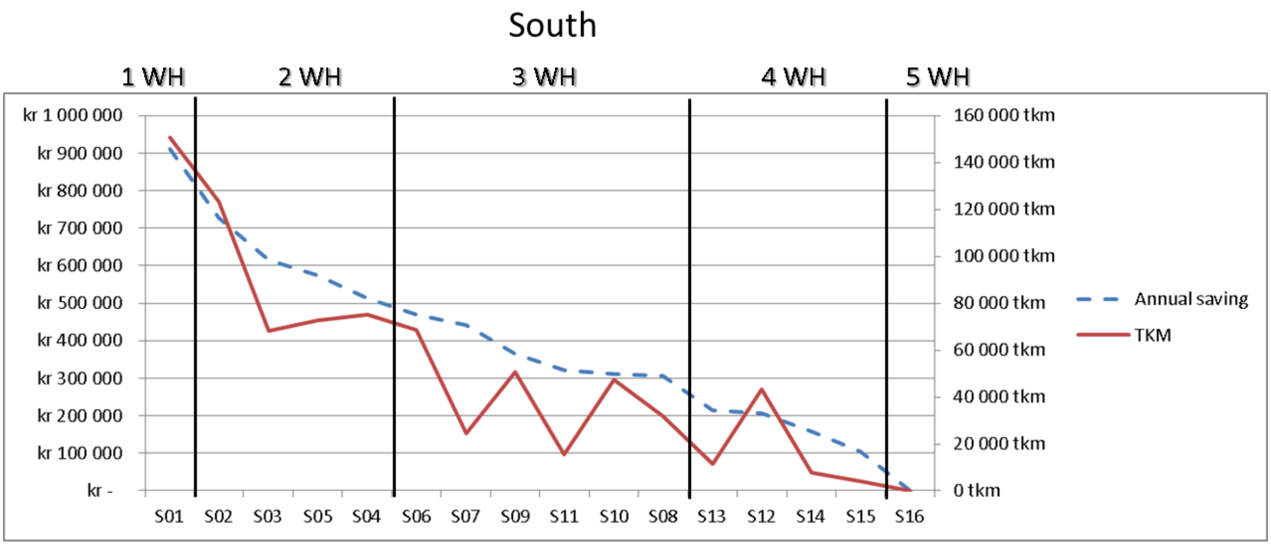

Figure 4 – Annual savings versus added ton kilometers. Southern region

Scenario 15 is the best in term of annual savings compared to added ton kilometers; this is when Trondheim and Verdal collaborate. This gives an annual saving of NOK 26.42 per ton kilometer (TKM). For three virtual warehouses Scenario 11 is best; this is the collaboration of Trondheim and Verdal, and a separate group of Molde and Ålesund whereas Førde operates on its own. Here the savings are 20.9 NOK/TKM. When all warehouses except Førde collaborates, Scenario 3, the savings are 8.9 NOK/TKM. This is the best option for two warehouses. Full collaboration gives an annual savings of 6 NOK/TKM. A graph comparing annual savings versus added ton kilometers for the different northern scenarios is shown in Figure 5.

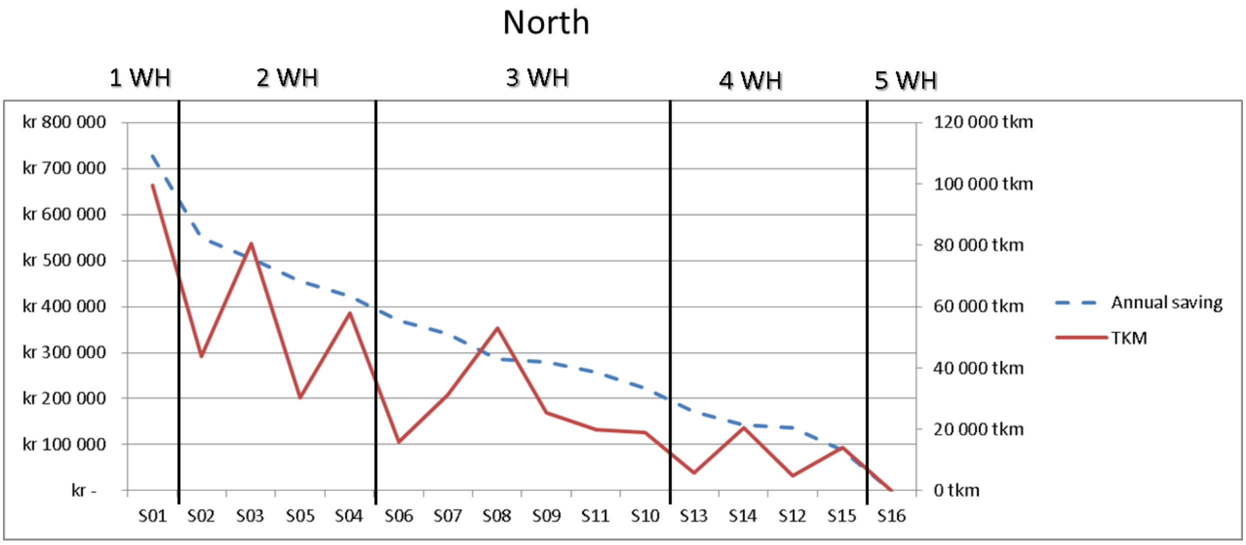

Figure 5 – Annual savings versus added ton kilometers. Northern region

Scenario 13 is the best option for the northern region. This gives a saving of 29.3 NOK/TKM and is the collaboration of Finnsnes and Tromsø. Scenario 12, which is where Narvik and Finnsnes collaborate, is very close to the best with 28.3 NOK/TKM. Scenario 6 yields the best results with 23 NOK/TKM when looking at the scenarios with 3 warehouses is. Here the three southernmost, Narvik, Finnsnes, and Tromsø collaborate. Scenario 5 is the best of the alternatives within 2 warehouses at 15.1 NOK/TKM. This is the same as Scenario 6, but with the collaboration of the two northernmost warehouses, Hammerfest and Kirkenes. With full virtual centralization the savings are 7.3 NOK/TKM.

4.4 Discussion

There are qualitative and quantitative advantages and disadvantages of centralization that is not covered in this thesis. By splitting the product range or groups between different warehouses, the purchasers get more time to focus on the SKUs (s)he are responsible for, leading to better service for the customers and more accurate orders. Furthermore, by having less number of SKUs to order, while ordering more of each can lead to lower unit purchasing cost (Monczka et al. 2011). Since the total amount of each SKU should be lower after any centralization. Any dead stock, should also decreased if the product becomes obsolete and the purchaser could response to it quicker when they have to focus on fewer SKUs.

When one warehouse deal with half of the SKUs both in ordering and stocking, and the collaborating warehouse deal with the rest, the purchasers are moved away from the demand in half of the cases. This could lead to poorer understanding of local differences and lower ownership of their decisions (Monczka et al. 2011).

When comparing annual savings to added ton kilometer, the possibilities of profitable centralization under the estimates presented in this thesis are limited. When comparing with heavy distribution (containers) from Table 13, full collaboration are not favorably for neither region as both have less than 10 NOK/TKM. With two warehouses there exist two possibilities above 10 NOK/TKM. This is Scenario 2 and 5, both from the northern region. When the degree of centralization decreases there are more favorable possibilities with seven out of twelve scenarios within the three warehouses group, although only two are from the southern region. The last group has five scenarios where centralization is favorable, three from the southern region and two from the northern. There appear to be a higher profitability of centralization the lower the grade of centralization is. Four warehouses give on average 17.73 NOK/TKM, three give 12 NOK/TKM, two give 8.86 NOK/TKM, and one warehouse give 6.68 NOK/TKM. There are factor that would improve these results that are not taken into account, like the aforementioned economy of scale and order precision. But these are hard to estimate.

5. Conclusion, Limitations, and Further Research

Effects on inventory by centralization have been presented. Both the literature and the estimates support that the total inventory decreases as the degree of centralization increases. Choosing the degree of centralization is a decision that needs to be taken on a strategic level. The decision has consequences beyond economic of scale, demand aggregation, and transportation cost. There are pros and cons on for choosing centralization that have to be taken into consideration. In terms of saving cost, it is transportation cost that could counteract any benefits gained by this virtual centralization. The distances between the warehouses suggest that having all five warehouses in each region collaborate is not as beneficial since this causes a lot of added ton kilometer and with it; transportation cost.

The author recommends TOOLS to start with collaboration the warehouses closest together in light of these results. The collaboration of Narvik and Finnsnes is the scenario in the northern region that offers the highest savings per added ton kilometer at NOK 29 per ton kilometer. For the southern region it is the collaboration of Trondheim and Verdal which gives an annual saving of NOK 26 per ton kilometer. Decision on further centralization could be based on the results theses give.

As the numbers presented in this research are measured against a theoretical inventory and the lead time from the internal suppliers have been used for all SKUs, there are no guaranties that the effect will be the same if TOOLS implement centralization. The locations where the SKUs should be stored for estimating the added ton kilometers were decided by where the demand is the highest. However, distances are also important parameters. It might be optimal to store the SKUs elsewhere dependent on the demand of other locations.

Further investigation should be put into the holding, ordering, and transportation cost in order to evaluate any annual savings by centralization accurate. Further research on inventory locations should also be carried out, by optimizing the product of demand and distances in order to minimize the added ton kilometers with a *p-median Model* mentioned in chapter 2.5. There are other factors as well that should be considered in order to view the whole situation from a strategic, and not only cost reduction, side. Customer satisfaction and ability to respond to changes in the demand pattern are some factors that need consideration.

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7. Appendix

A Description and variation of 5 articles.

Article	Price	Description	Førde	Ålesund	Molde	Trondheim	Verdal	Narvik	Finnsnes	Trømsø	Hammerfest	Kirkenes
1	kr 18.41	LAMELLSKIVE K40 125X22,2	0.00	1201.33	813.48	0.00	64.89	0.00	0.00	0.00	0.00	0.00
2	kr 13.40	GLASSFIBERDUK M/ALU 620 GR/MTR	164.78	1479.55	22.58	34.57	296.04	8.86	15.59	5.35	0.00	30.47
3	kr 28.00	NAVRONDELL 178 X 4,0 X 22,2	0.00	0.00	0.00	0.00	312.70	0.00	0.00	0.00	0.00	0.00
4	kr 32.18	HALVMASKE FILT 3M 9332+ FFP3V	250.84	31.80	0.00	0.00	8.16	67.81	327.76	13.96	0.00	41.61
5	kr 7.83	KAPPESKIVE 41F 125X1X22,2	241.66	1563.66	1992.10	0.00	125.12	0.00	0.00	0.00	0.00	0.00
		Lead Time	3	3	3	3	3	5	4	4	8	5

B Lead time from internal suppliers.

Warehouse	Number of days lead time from supplier. Best case/Middle/Worst case
Førde	2/3/4
Ålesund	2/3/4
Molde	2/3/4
Trondheim	2/3/4
Verdal	2/3/4
Narvik	3/5/6
Finnsnes	3/4/5
Tromsø	3/4/5
Hammerfest	7/8/10
Kirkenes	3/5/6

C List of 8 scenarios

Scenario 1:	Status Quo
Scenario 2:	Full Aggregating:
Group 1	Førde, Ålesund, Molde, Trondheim, Verdal
Group 2	Narvik, Finnsnes, Tromsø, Hammerfest, Kirkenes
Scenario 3	
Group 1	Trondheim, Verdal
Group 2	Molde, Ålesund, Førde
Group 3	Narvik, Finnsnes, Tromsø, Hammerfest, Kirkenes
Scenario 4:	
Group 1	Trondheim, Verdal
Group 2	Molde, Ålesund, Førde
Group 3	Narvik, Finnsnes, Tromsø
Group 4	Hammerfest, Kirkenes
Scenario 5:	
Group 1	Førde, Ålesund, Molde, Trondheim, Verdal
Group 2	Narvik, Finnsnes, Tromsø, Hammerfest
Group 3	Kirkenes
Scenario 6:	
Group 1	Trondheim, Verdal
Group 2	Molde, Ålesund
Group 3	Førde
Group 4	Narvik, Finnsnes, Tromsø, Hammerfest, Kirkenes
Scenario 7:	
Group 1	Trondheim, Verdal
Group 2	Molde, Ålesund
Group 3	Førde
Group 4	Finnsnes, Tromsø
Group 5	Narvik
Group 6	Kirkenes
Group 7	Hammerfest
Scenario 8:	
Group 1	Trondheim
Group 2	Verdal
Group 3	Molde
Group 4	Ålesund
Group 5	Førde
Group 6	Finnsnes, Narvik, Kirkenes, Tromsø, Hammerfest

D List of scenarios.

						Scenario
1 WH	1	2	3	4	5	1
2 WH	1	2	3	4	5	2
	1	2	3	4	5	3
	1	2	3	4	5	4
	1	2	3	4	5	5
3 WH	1	2	3	4	5	6
	1	2	3	4	5	7
	1	2	3	4	5	8
	1	2	3	4	5	9
	1	2	3	4	5	10
	1	2	3	4	5	11
4 WH	1	2	3	4	5	12
	1	2	3	4	5	13
	1	2	3	4	5	14
	1	2	3	4	5	15
5 WH	1	2	3	4	5	16

South		North	
1=	Førde	1=	Narvik
2=	Ålesund	2=	Finnsnes
3=	Molde	3=	Tromsø
4=	Trondheim	4=	Hammefest
5=	Verdal	5=	Kirkenes

E Comparison between sample and population. Safety stock. North

From 1457 SKUs

Scenario	Combined Independent Value	Combined Centralized Value	Total Savings	Savings in percent of decentralized value
S1	kr 1 626 274	kr 810 841	kr 815 433	50.14 %
S2	kr 1 406 743	kr 753 559	kr 653 183	40.16 %
S3	kr 1 304 949	kr 721 962	kr 582 987	35.85 %
S4	kr 1 626 274	kr 1 120 041	kr 506 233	31.13 %
S5	kr 1 626 274	kr 1 094 456	kr 531 818	32.70 %
S6	kr 1 117 286	kr 676 692	kr 440 594	27.09 %
S7	kr 1 085 418	kr 653 844	kr 431 574	26.54 %
S8	kr 930 819	kr 608 908	kr 321 911	19.79 %
S9	kr 1 406 743	kr 1 035 848	kr 370 894	22.81 %
S10	kr 1 204 442	kr 928 897	kr 275 546	16.94 %
S11	kr 1 304 949	kr 989 314	kr 315 636	19.41 %
S12	kr 695 455	kr 511 133	kr 184 322	11.33 %
S13	kr 795 961	kr 571 550	kr 224 412	13.80 %
S14	kr 711 288	kr 524 716	kr 186 573	11.47 %
S15	kr 508 988	kr 417 764	kr 91 224	5.61 %

Warehouse	Safety stock sample	Number of SKUS from sample	Number of SKUs from all SKUs	Safety stock all SKUs
Narvik	kr 321 325	531	9632	kr 5 828 623
Finnsens	kr 374 130	568	12541	kr 8 260 500
Tromsø	kr 421 831	625	12364	kr 8 344 838
Hammerfest	kr 289 457	464	7365	kr 4 594 501
Kirkenes	kr 219 531	448	6663	kr 3 265 035

All SKUs

Scenario	Combined decentralized value	Combined centralized value	Total savings	Savings in percent of decentralized value
S1	kr 30 293 497	kr 15 103 976	kr 15 189 521	50.14 %
S2	kr 27 028 462	kr 14 861 254	kr 12 167 208	40.16 %
S3	kr 24 464 874	kr 13 605 256	kr 10 859 618	35.85 %
S4	kr 30 293 497	kr 20 863 620	kr 9 429 877	31.13 %
S5	kr 30 293 497	kr 20 387 037	kr 9 906 460	32.70 %
S6	kr 22 433 961	kr 14 226 778	kr 8 207 183	27.09 %
S7	kr 21 199 839	kr 13 160 671	kr 8 039 168	26.54 %
S8	kr 16 204 374	kr 10 207 960	kr 5 996 414	19.79 %
S9	kr 27 028 462	kr 20 119 611	kr 6 908 851	22.81 %
S10	kr 21 948 659	kr 16 815 920	kr 5 132 740	16.94 %
S11	kr 24 464 874	kr 18 585 356	kr 5 879 519	19.41 %
S12	kr 14 089 123	kr 10 655 661	kr 3 433 463	11.33 %
S13	kr 16 605 338	kr 12 425 097	kr 4 180 241	13.80 %
S14	kr 12 939 339	kr 9 463 950	kr 3 475 389	11.47 %
S15	kr 7 859 536	kr 6 160 259	kr 1 699 277	5.61 %

F Comparison between sample and population. Safety stock. South

From 1457 SKUs				
Scenario	Combined Independent Value	Combined Centralized Value	Total Savings	Savings in percent of decentralized value
S1	kr 1 870 716	kr 1 058 095	kr 812 621	43.44 %
S2	kr 1 600 150	kr 949 924	kr 650 226	34.76 %
S3	kr 1 475 025	kr 905 567	kr 569 458	30.44 %
S4	kr 1 870 716	kr 1 406 757	kr 463 958	24.80 %
S5	kr 1 870 716	kr 1 339 457	kr 531 259	28.40 %
S6	kr 1 269 420	kr 834 711	kr 434 709	23.24 %
S7	kr 1 204 459	kr 793 561	kr 410 898	21.96 %
S8	kr 1 023 912	kr 733 045	kr 290 867	15.55 %
S9	kr 1 600 150	kr 1 263 678	kr 336 472	17.99 %
S10	kr 1 448 099	kr 1 178 458	kr 269 641	14.41 %
S11	kr 1 475 025	kr 1 168 056	kr 306 969	16.41 %
S12	kr 846 804	kr 673 713	kr 173 091	9.25 %
S13	kr 873 730	kr 663 311	kr 210 419	11.25 %
S14	kr 753 346	kr 589 965	kr 163 381	8.73 %
S15	kr 601 295	kr 504 745	kr 96 550	5.16 %

Warehouse	Safety stock sample	Number of SKUS from sample	Number of SKUs from all SKUs	Safety stock all SKUs
Førde	kr 395 691	618	19773	kr 12 660 178
Ålesund	kr 451 113	666	19528	kr 13 227 240
Molde	kr 422 616	576	14508	kr 10 644 648
Trondheim	kr 330 729	597	14024	kr 7 769 091
Verdal	kr 270 566	409	13909	kr 9 201 234

All SKUs				
Scenario	Combined decentralized value	Combined centralized value	Total savings	Savings in percent of decentralized value
S1	kr 53 502 391	kr 30 261 467	kr 23 240 924	43.44 %
S2	kr 44 301 157	kr 25 704 728	kr 18 596 429	34.76 %
S3	kr 40 842 214	kr 24 555 746	kr 16 286 468	30.44 %
S4	kr 53 502 391	kr 40 233 202	kr 13 269 189	24.80 %
S5	kr 53 502 391	kr 38 308 403	kr 15 193 988	28.40 %
S6	kr 36 532 066	kr 24 099 407	kr 12 432 659	23.24 %
S7	kr 31 640 979	kr 19 889 305	kr 11 751 675	21.96 %
S8	kr 27 614 973	kr 19 296 187	kr 8 318 786	15.55 %
S9	kr 44 301 157	kr 34 678 075	kr 9 623 082	17.99 %
S10	kr 42 857 743	kr 35 146 010	kr 7 711 733	14.41 %
S11	kr 40 842 214	kr 32 062 915	kr 8 779 299	16.41 %
S12	kr 25 887 418	kr 20 937 015	kr 4 950 403	9.25 %
S13	kr 23 871 889	kr 17 853 919	kr 6 017 969	11.25 %
S14	kr 18 413 739	kr 13 741 061	kr 4 672 678	8.73 %
S15	kr 16 970 325	kr 14 208 996	kr 2 761 330	5.16 %

G Cycle inventory and ordering cost. South

Order Cost

	10 %						20 %						30 %			
Scenario\ Order cost	kr 250	kr 500	kr 1 000	kr 1 500			kr 250	kr 500	kr 1 000	kr 1 500			kr 250	kr 500	kr 1 000	kr 1 500
S01	kr 328 600	kr 464 869	kr 657 399	kr 807 402		S01	kr 461 249	kr 657 199	kr 929 737	kr 1 139 125		S01	kr 562 101	kr 800 404	kr 1 134 834	kr 1 394 606
S02	kr 367 159	kr 518 679	kr 732 977	kr 899 977		S02	kr 515 368	kr 734 319	kr 1 037 359	kr 1 271 425		S02	kr 625 802	kr 891 499	kr 1 263 467	kr 1 556 038
S03	kr 389 791	kr 554 206	kr 782 777	kr 960 692		S03	kr 550 299	kr 779 583	kr 1 108 412	kr 1 352 638		S03	kr 668 326	kr 951 135	kr 1 355 051	kr 1 662 618
S04	kr 410 593	kr 583 182	kr 822 254	kr 1 009 562		S04	kr 576 134	kr 821 186	kr 1 166 363	kr 1 422 658		S04	kr 701 639	kr 1 001 103	kr 1 420 994	kr 1 749 545
S05	kr 398 026	kr 563 898	kr 797 744	kr 977 550		S05	kr 561 269	kr 796 051	kr 1 127 796	kr 1 382 474		S05	kr 680 173	kr 967 730	kr 1 380 164	kr 1 691 694
S06	kr 420 163	kr 594 985	kr 840 301	kr 1 030 619		S06	kr 592 032	kr 840 326	kr 1 189 971	kr 1 457 427		S06	kr 716 939	kr 1 021 302	kr 1 453 463	kr 1 784 956
S07	kr 425 836	kr 604 665	kr 852 693	kr 1 046 793		S07	kr 599 201	kr 851 672	kr 1 209 330	kr 1 476 713		S07	kr 726 870	kr 1 037 358	kr 1 475 389	kr 1 813 995
S08	kr 453 116	kr 644 447	kr 908 692	kr 1 115 400		S08	kr 636 873	kr 906 232	kr 1 288 895	kr 1 570 558		S08	kr 776 151	kr 1 108 063	kr 1 570 543	kr 1 933 342
S09	kr 441 341	kr 625 958	kr 882 490	kr 1 082 967		S09	kr 618 614	kr 882 683	kr 1 251 917	kr 1 527 631		S09	kr 752 184	kr 1 074 454	kr 1 527 316	kr 1 877 875
S10	kr 450 661	kr 640 737	kr 904 271	kr 1 108 532		S10	kr 631 677	kr 901 322	kr 1 281 473	kr 1 565 959		S10	kr 771 150	kr 1 097 655	kr 1 560 835	kr 1 922 210
S11	kr 449 976	kr 640 331	kr 904 048	kr 1 107 916		S11	kr 633 031	kr 899 952	kr 1 280 662	kr 1 564 643		S11	kr 770 517	kr 1 097 278	kr 1 562 326	kr 1 920 993
S12	kr 472 799	kr 671 824	kr 946 828	kr 1 161 600		S12	kr 662 439	kr 945 597	kr 1 343 647	kr 1 640 912		S12	kr 807 917	kr 1 151 227	kr 1 634 135	kr 2 015 471
S13	kr 472 113	kr 671 418	kr 946 606	kr 1 160 984		S13	kr 663 793	kr 944 227	kr 1 342 836	kr 1 639 596		S13	kr 807 284	kr 1 150 850	kr 1 635 626	kr 2 014 255
S14	kr 483 864	kr 687 224	kr 968 928	kr 1 188 805		S14	kr 679 353	kr 967 729	kr 1 374 448	kr 1 675 531		S14	kr 826 696	kr 1 181 414	kr 1 676 865	kr 2 061 673
S15	kr 493 184	kr 702 002	kr 990 708	kr 1 214 370		S15	kr 692 416	kr 986 368	kr 1 404 005	kr 1 713 859		S15	kr 845 661	kr 1 204 615	kr 1 710 384	kr 2 106 007
S16	kr 515 322	kr 733 090	kr 1 033 266	kr 1 267 438		S16	kr 723 178	kr 1 030 643	kr 1 466 179	kr 1 788 812		S16	kr 882 428	kr 1 258 187	kr 1 783 683	kr 2 199 269

Inventory

	10 %						20 %						30 %			
Scenario\ Order cost	kr 250	kr 500	kr 1 000	kr 1 500			kr 250	kr 500	kr 1 000	kr 1 500			kr 250	kr 500	kr 1 000	kr 1 500
S01	kr 3 288 319	kr 4 652 226	kr 6 575 672	kr 8 028 091		S01	kr 2 329 499	kr 3 288 319	kr 4 652 226	kr 5 693 118		S01	kr 1 887 424	kr 2 678 379	kr 3 817 963	kr 4 652 226
S02	kr 3 661 546	kr 5 184 275	kr 7 332 300	kr 8 953 979		S02	kr 2 591 481	kr 3 661 546	kr 5 184 275	kr 6 342 923		S02	kr 2 106 850	kr 2 995 049	kr 4 263 729	kr 5 184 275
S03	kr 3 919 900	kr 5 521 792	kr 7 807 780	kr 9 540 797		S03	kr 2 769 852	kr 3 919 900	kr 5 521 792	kr 6 780 550		S03	kr 2 260 833	kr 3 195 405	kr 4 520 066	kr 5 521 792
S04	kr 4 118 062	kr 5 823 346	kr 8 241 319	kr 10 070 686		S04	kr 2 901 716	kr 4 118 062	kr 5 823 346	kr 7 151 884		S04	kr 2 384 981	kr 3 357 564	kr 4 764 331	kr 5 823 346
S05	kr 3 995 314	kr 5 644 041	kr 7 971 499	kr 9 753 327		S05	kr 2 826 875	kr 3 995 314	kr 5 644 041	kr 6 903 179		S05	kr 2 294 697	kr 3 267 597	kr 4 617 623	kr 5 644 041
S06	kr 4 205 168	kr 5 941 289	kr 8 404 710	kr 10 274 611		S06	kr 2 973 245	kr 4 205 168	kr 5 941 289	kr 7 272 588		S06	kr 2 417 525	kr 3 442 474	kr 4 869 166	kr 5 941 289
S07	kr 4 266 019	kr 6 013 325	kr 8 516 219	kr 10 403 227		S07	kr 3 020 008	kr 4 266 019	kr 6 013 325	kr 7 380 996		S07	kr 2 467 480	kr 3 485 536	kr 4 932 639	kr 6 013 325
S08	kr 4 552 838	kr 6 426 388	kr 9 094 148	kr 11 114 863		S08	kr 3 207 968	kr 4 552 838	kr 6 426 388	kr 7 900 019		S08	kr 2 636 352	kr 3 704 065	kr 5 258 806	kr 6 426 388
S09	kr 4 413 014	kr 6 246 919	kr 8 842 632	kr 10 808 705		S09	kr 3 112 537	kr 4 413 014	kr 6 246 919	kr 7 669 522		S09	kr 2 558 684	kr 3 607 291	kr 5 106 199	kr 6 246 919
S10	kr 4 521 610	kr 6 401 306	kr 9 051 758	kr 11 073 933		S10	kr 3 190 862	kr 4 521 610	kr 6 401 306	kr 7 846 966		S10	kr 2 598 873	kr 3 694 851	kr 5 243 624	kr 6 401 306
S11	kr 4 523 031	kr 6 379 014	kr 9 022 043	kr 11 038 083		S11	kr 3 209 376	kr 4 523 031	kr 6 379 014	kr 7 823 836		S11	kr 2 602 387	kr 3 692 190	kr 5 234 826	kr 6 379 014
S12	kr 4 731 464	kr 6 698 554	kr 9 484 968	kr 11 595 216		S12	kr 3 337 232	kr 4 731 464	kr 6 698 554	kr 8 216 375		S12	kr 2 721 701	kr 3 869 727	kr 5 495 166	kr 6 698 554
S13	kr 4 732 885	kr 6 676 261	kr 9 455 253	kr 11 559 366		S13	kr 3 355 746	kr 4 732 885	kr 6 676 261	kr 8 193 245		S13	kr 2 725 215	kr 3 867 067	kr 5 486 368	kr 6 676 261
S14	kr 4 847 790	kr 6 849 962	kr 9 695 461	kr 11 852 883		S14	kr 3 418 789	kr 4 847 790	kr 6 849 962	kr 8 417 657		S14	kr 2 810 055	kr 3 953 792	kr 5 600 675	kr 6 849 962
S15	kr 4 956 386	kr 7 004 349	kr 9 904 587	kr 12 118 110		S15	kr 3 497 114	kr 4 956 386	kr 7 004 349	kr 8 595 100		S15	kr 2 850 243	kr 4 041 351	kr 5 738 099	kr 7 004 349
S16	kr 5 166 240	kr 7 301 596	kr 10 337 798	kr 12 639 393		S16	kr 3 643 484	kr 5 166 240	kr 7 301 596	kr 8 964 509		S16	kr 2 973 071	kr 4 216 228	kr 5 989 642	kr 7 301 596

H Cycle inventory and ordering cost. North

Order Cost

	10 %			
Scenario\ Order cost	kr 250	kr 500	kr 1 000	kr 1 500
S01	kr 233 702	kr 329 779	kr 468 082	kr 569 706
S02	kr 270 505	kr 381 565	kr 540 370	kr 658 409
S03	kr 277 669	kr 392 553	kr 557 637	kr 679 630
S04	kr 294 265	kr 415 148	kr 589 323	kr 719 403
S05	kr 287 302	kr 405 850	kr 577 413	kr 702 822
S06	kr 304 591	kr 430 066	kr 611 590	kr 744 551
S07	kr 311 354	kr 439 911	kr 624 608	kr 761 769
S08	kr 319 052	kr 452 450	kr 642 783	kr 785 682
S09	kr 322 862	kr 455 693	kr 648 285	kr 789 773
S10	kr 331 188	kr 469 614	kr 667 928	kr 813 126
S11	kr 325 677	kr 462 533	kr 657 628	kr 799 988
S12	kr 348 477	kr 493 831	kr 702 105	kr 854 856
S13	kr 342 966	kr 486 749	kr 691 805	kr 841 717
S14	kr 347 649	kr 492 995	kr 701 745	kr 856 053
S15	kr 355 974	kr 506 917	kr 721 387	kr 879 406
S16	kr 373 263	kr 531 133	kr 755 564	kr 921 135

	20 %			
	kr 250	kr 500	kr 1 000	kr 1 500
S01	kr 329 586	kr 467 405	kr 659 559	kr 808 398
S02	kr 379 602	kr 541 011	kr 763 130	kr 934 281
S03	kr 389 468	kr 555 339	kr 785 105	kr 965 369
S04	kr 411 238	kr 588 531	kr 830 296	kr 1 021 695
S05	kr 403 378	kr 574 604	kr 811 699	kr 996 343
S06	kr 426 766	kr 609 182	kr 860 131	kr 1 056 920
S07	kr 435 894	kr 622 707	kr 879 821	kr 1 082 107
S08	kr 447 078	kr 638 105	kr 904 900	kr 1 110 937
S09	kr 450 350	kr 645 724	kr 911 387	kr 1 123 344
S10	kr 462 238	kr 662 375	kr 939 229	kr 1 153 194
S11	kr 455 975	kr 651 353	kr 925 066	kr 1 132 845
S12	kr 485 626	kr 696 953	kr 987 661	kr 1 213 771
S13	kr 479 364	kr 685 931	kr 973 499	kr 1 193 422
S14	kr 486 191	kr 695 298	kr 985 991	kr 1 212 586
S15	kr 498 078	kr 711 949	kr 1 013 833	kr 1 242 436
S16	kr 521 466	kr 746 527	kr 1 062 265	kr 1 303 013

	30 %			
	kr 250	kr 500	kr 1 000	kr 1 500
S01	kr 401 576	kr 570 776	kr 810 320	kr 989 338
S02	kr 464 581	kr 661 280	kr 935 260	kr 1 144 695
S03	kr 474 079	kr 678 921	kr 967 099	kr 1 177 658
S04	kr 500 528	kr 714 711	kr 1 019 261	kr 1 245 444
S05	kr 489 815	kr 704 415	kr 997 017	kr 1 217 549
S06	kr 522 030	kr 746 922	kr 1 055 735	kr 1 290 197
S07	kr 533 859	kr 760 874	kr 1 081 466	kr 1 319 732
S08	kr 544 776	kr 776 861	kr 1 113 584	kr 1 357 350
S09	kr 551 626	kr 784 425	kr 1 119 739	kr 1 367 080
S10	kr 563 355	kr 808 595	kr 1 151 069	kr 1 408 843
S11	kr 556 478	kr 797 995	kr 1 137 503	kr 1 387 599
S12	kr 595 571	kr 851 102	kr 1 209 787	kr 1 481 492
S13	kr 588 694	kr 840 502	kr 1 196 222	kr 1 460 248
S14	kr 595 873	kr 846 575	kr 1 214 062	kr 1 478 986
S15	kr 607 603	kr 870 745	kr 1 245 392	kr 1 520 750
S16	kr 639 818	kr 913 252	kr 1 304 111	kr 1 593 398

Inventory

	10 %			
Scenario\ Order cost	kr 250	kr 500	kr 1 000	kr 1 500
S01	kr 2 332 388	kr 3 296 869	kr 4 645 054	kr 5 718 818
S02	kr 2 689 263	kr 3 801 461	kr 5 367 059	kr 6 601 311
S03	kr 2 774 564	kr 3 935 004	kr 5 535 237	kr 6 804 997
S04	kr 2 944 744	kr 4 155 996	kr 5 851 844	kr 7 186 293
S05	kr 2 867 986	kr 4 064 498	kr 5 710 708	kr 7 029 502
S06	kr 3 037 593	kr 4 305 236	kr 6 050 983	kr 7 447 531
S07	kr 3 108 008	kr 4 407 738	kr 6 203 053	kr 7 621 826
S08	kr 3 195 531	kr 4 545 780	kr 6 384 612	kr 7 831 932
S09	kr 3 238 538	kr 4 567 302	kr 6 419 764	kr 7 897 780
S10	kr 3 336 400	kr 4 699 905	kr 6 605 197	kr 8 131 151
S11	kr 3 262 534	kr 4 619 349	kr 6 489 385	kr 7 992 753
S12	kr 3 506 007	kr 4 940 643	kr 6 945 471	kr 8 549 180
S13	kr 3 432 141	kr 4 860 087	kr 6 829 660	kr 8 410 782
S14	kr 3 489 324	kr 4 957 086	kr 6 952 532	kr 8 543 420
S15	kr 3 587 187	kr 5 089 689	kr 7 137 964	kr 8 776 790
S16	kr 3 756 793	kr 5 330 427	kr 7 478 239	kr 9 194 819

	20 %			
	kr 250	kr 500	kr 1 000	kr 1 500
S01	kr 1 652 932	kr 2 332 388	kr 3 296 869	kr 4 033 697
S02	kr 1 910 323	kr 2 689 263	kr 3 801 461	kr 4 656 283
S03	kr 1 968 463	kr 2 774 564	kr 3 935 004	kr 4 793 692
S04	kr 2 065 547	kr 2 944 744	kr 4 155 996	kr 5 061 584
S05	kr 2 024 151	kr 2 867 986	kr 4 064 498	kr 4 961 788
S06	kr 2 149 034	kr 3 037 593	kr 4 305 236	kr 5 250 287
S07	kr 2 206 049	kr 3 108 008	kr 4 407 738	kr 5 368 899
S08	kr 2 242 054	kr 3 195 531	kr 4 545 780	kr 5 540 306
S09	kr 2 270 367	kr 3 238 538	kr 4 567 302	kr 5 554 827
S10	kr 2 328 065	kr 3 336 400	kr 4 699 905	kr 5 736 772
S11	kr 2 304 385	kr 3 262 534	kr 4 619 349	kr 5 646 989
S12	kr 2 452 948	kr 3 506 007	kr 4 940 643	kr 6 025 271
S13	kr 2 429 268	kr 3 432 141	kr 4 860 087	kr 5 935 487
S14	kr 2 446 875	kr 3 489 324	kr 4 957 086	kr 6 033 549
S15	kr 2 504 572	kr 3 587 187	kr 5 089 689	kr 6 215 495
S16	kr 2 629 456	kr 3 756 793	kr 5 330 427	kr 6 503 993

	30 %			
	kr 250	kr 500	kr 1 000	kr 1 500
S01	kr 1 345 318	kr 1 912 610	kr 2 687 660	kr 3 296 869
S02	kr 1 551 792	kr 2 203 630	kr 3 106 136	kr 3 801 461
S03	kr 1 607 841	kr 2 276 396	kr 3 201 554	kr 3 935 004
S04	kr 1 686 352	kr 2 403 531	kr 3 395 042	kr 4 155 996
S05	kr 1 659 165	kr 2 344 032	kr 3 316 404	kr 4 064 498
S06	kr 1 751 749	kr 2 481 411	kr 3 514 901	kr 4 305 236
S07	kr 1 794 249	kr 2 551 264	kr 3 593 296	kr 4 407 738
S08	kr 1 843 385	kr 2 605 492	kr 3 706 805	kr 4 545 780
S09	kr 1 843 044	kr 2 645 422	kr 3 728 894	kr 4 567 302
S10	kr 1 901 287	kr 2 715 362	kr 3 846 812	kr 4 699 905
S11	kr 1 883 062	kr 2 672 377	kr 3 766 080	kr 4 619 349
S12	kr 1 993 872	kr 2 852 740	kr 4 045 310	kr 4 940 643
S13	kr 1 975 647	kr 2 809 755	kr 3 964 578	kr 4 860 087
S14	kr 2 000 076	kr 2 847 383	kr 4 040 657	kr 4 957 086
S15	kr 2 058 320	kr 2 917 323	kr 4 158 575	kr 5 089 689
S16	kr 2 150 904	kr 3 054 702	kr 4 357 073	kr 5 330 427

I Percent reduction. Cycle inventory and ordering cost. South

Percent reduction

Order Cost

	10 %				20 %				30 %			
Scenario\ Order cost	kr 250	kr 500	kr 1 000	kr 1 500	kr 250	kr 500	kr 1 000	kr 1 500	kr 250	kr 500	kr 1 000	kr 1 500
S01	36 %	37 %	36 %	36 %	36 %	36 %	37 %	36 %	36 %	36 %	36 %	37 %
S02	29 %	29 %	29 %	29 %	29 %	29 %	29 %	29 %	29 %	29 %	29 %	29 %
S03	24 %	24 %	24 %	24 %	24 %	24 %	24 %	24 %	24 %	24 %	24 %	24 %
S04	20 %	20 %	20 %	20 %	20 %	20 %	20 %	20 %	20 %	20 %	20 %	20 %
S05	23 %	23 %	23 %	23 %	22 %	23 %	23 %	23 %	23 %	23 %	23 %	23 %
S06	18 %	19 %	19 %	19 %	18 %	18 %	19 %	19 %	19 %	19 %	19 %	19 %
S07	17 %	18 %	17 %	17 %	17 %	17 %	18 %	17 %	18 %	18 %	17 %	18 %
S08	12 %	12 %	12 %	12 %	12 %	12 %	12 %	12 %	12 %	12 %	12 %	12 %
S09	14 %	15 %	15 %	15 %	14 %	14 %	15 %	15 %	15 %	15 %	14 %	15 %
S10	13 %	13 %	12 %	13 %	13 %	13 %	13 %	12 %	13 %	13 %	12 %	13 %
S11	13 %	13 %	13 %	13 %	12 %	13 %	13 %	13 %	13 %	13 %	12 %	13 %
S12	8 %	8 %	8 %	8 %	8 %	8 %	8 %	8 %	8 %	9 %	8 %	8 %
S13	8 %	8 %	8 %	8 %	8 %	8 %	8 %	8 %	9 %	9 %	8 %	8 %
S14	6 %	6 %	6 %	6 %	6 %	6 %	6 %	6 %	6 %	6 %	6 %	6 %
S15	4 %	4 %	4 %	4 %	4 %	4 %	4 %	4 %	4 %	4 %	4 %	4 %
S16	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %

Inventory

	10 %				20 %				30 %			
Scenario\ Order cost	kr 250	kr 500	kr 1 000	kr 1 500	kr 250	kr 500	kr 1 000	kr 1 500	kr 250	kr 500	kr 1 000	kr 1 500
S01	36 %	36 %	36 %	36 %	36 %	36 %	36 %	36 %	37 %	36 %	36 %	36 %
S02	29 %	29 %	29 %	29 %	29 %	29 %	29 %	29 %	29 %	29 %	29 %	29 %
S03	24 %	24 %	24 %	25 %	24 %	24 %	24 %	24 %	24 %	24 %	25 %	24 %
S04	20 %	20 %	20 %	20 %	20 %	20 %	20 %	20 %	20 %	20 %	20 %	20 %
S05	23 %	23 %	23 %	23 %	22 %	23 %	23 %	23 %	23 %	22 %	23 %	23 %
S06	19 %	19 %	19 %	19 %	18 %	19 %	19 %	19 %	19 %	18 %	19 %	19 %
S07	17 %	18 %	18 %	18 %	17 %	17 %	18 %	18 %	17 %	17 %	18 %	18 %
S08	12 %	12 %	12 %	12 %	12 %	12 %	12 %	12 %	11 %	12 %	12 %	12 %
S09	15 %	14 %	14 %	14 %	15 %	15 %	14 %	14 %	14 %	14 %	15 %	14 %
S10	12 %	12 %	12 %	12 %	12 %	12 %	12 %	12 %	13 %	12 %	12 %	12 %
S11	12 %	13 %	13 %	13 %	12 %	12 %	13 %	13 %	12 %	12 %	13 %	13 %
S12	8 %	8 %	8 %	8 %	8 %	8 %	8 %	8 %	8 %	8 %	8 %	8 %
S13	8 %	9 %	9 %	9 %	8 %	8 %	9 %	9 %	8 %	8 %	8 %	9 %
S14	6 %	6 %	6 %	6 %	6 %	6 %	6 %	6 %	5 %	6 %	6 %	6 %
S15	4 %	4 %	4 %	4 %	4 %	4 %	4 %	4 %	4 %	4 %	4 %	4 %
S16	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %

J Percent reduction. Cycle inventory and ordering cost. North

Percent reduction

Order Cost

	10 %				20 %				30 %			
Scenario\ Order cost	kr 250	kr 500	kr 1 000	kr 1 500	kr 250	kr 500	kr 1 000	kr 1 500	kr 250	kr 500	kr 1 000	kr 1 500
S01	37 %	38 %	38 %	38 %	37 %	37 %	38 %	38 %	37 %	38 %	38 %	38 %
S02	28 %	28 %	28 %	29 %	27 %	28 %	28 %	28 %	27 %	28 %	28 %	28 %
S03	26 %	26 %	26 %	26 %	25 %	26 %	26 %	26 %	26 %	26 %	26 %	26 %
S04	21 %	22 %	22 %	22 %	21 %	21 %	22 %	22 %	22 %	22 %	22 %	22 %
S05	23 %	24 %	24 %	24 %	23 %	23 %	24 %	24 %	23 %	23 %	24 %	24 %
S06	18 %	19 %	19 %	19 %	18 %	18 %	19 %	19 %	18 %	18 %	19 %	19 %
S07	17 %	17 %	17 %	17 %	16 %	17 %	17 %	17 %	17 %	17 %	17 %	17 %
S08	15 %	15 %	15 %	15 %	14 %	15 %	15 %	15 %	15 %	15 %	15 %	15 %
S09	14 %	14 %	14 %	14 %	14 %	14 %	14 %	14 %	14 %	14 %	14 %	14 %
S10	11 %	12 %	12 %	12 %	11 %	11 %	12 %	11 %	12 %	11 %	12 %	12 %
S11	13 %	13 %	13 %	13 %	13 %	13 %	13 %	13 %	13 %	13 %	13 %	13 %
S12	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %
S13	8 %	8 %	8 %	9 %	8 %	8 %	8 %	8 %	8 %	8 %	8 %	8 %
S14	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %
S15	5 %	5 %	5 %	5 %	4 %	5 %	5 %	5 %	5 %	5 %	5 %	5 %
S16	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %

Inventory

	10 %				20 %				30 %			
Scenario\ Order cost	kr 250	kr 500	kr 1 000	kr 1 500	kr 250	kr 500	kr 1 000	kr 1 500	kr 250	kr 500	kr 1 000	kr 1 500
S01	38 %	38 %	38 %	38 %	37 %	38 %	38 %	38 %	37 %	37 %	38 %	38 %
S02	28 %	29 %	28 %	28 %	27 %	28 %	29 %	28 %	28 %	28 %	29 %	29 %
S03	26 %	26 %	26 %	26 %	25 %	26 %	26 %	26 %	25 %	25 %	27 %	26 %
S04	22 %	22 %	22 %	22 %	21 %	22 %	22 %	22 %	22 %	21 %	22 %	22 %
S05	24 %	24 %	24 %	24 %	23 %	24 %	24 %	24 %	23 %	23 %	24 %	24 %
S06	19 %	19 %	19 %	19 %	18 %	19 %	19 %	19 %	19 %	19 %	19 %	19 %
S07	17 %	17 %	17 %	17 %	16 %	17 %	17 %	17 %	17 %	16 %	18 %	17 %
S08	15 %	15 %	15 %	15 %	15 %	15 %	15 %	15 %	14 %	15 %	15 %	15 %
S09	14 %	14 %	14 %	14 %	14 %	14 %	14 %	15 %	14 %	13 %	14 %	14 %
S10	11 %	12 %	12 %	12 %	11 %	11 %	12 %	12 %	12 %	11 %	12 %	12 %
S11	13 %	13 %	13 %	13 %	12 %	13 %	13 %	13 %	12 %	13 %	14 %	13 %
S12	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %
S13	9 %	9 %	9 %	9 %	8 %	9 %	9 %	9 %	8 %	8 %	9 %	9 %
S14	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %	7 %
S15	5 %	5 %	5 %	5 %	5 %	5 %	5 %	4 %	4 %	4 %	5 %	5 %
S16	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %	0 %

K Distances between warehouses

South					
Distances	**Førde**	**Ålesund**	**Molde**	**Trondheim**	**Verdal**
Førde	0	235	277	524	612
Ålesund		0	74	290	376
Molde			0	216	303
Trondheim				0	88
Verdal					0
North					
Distances	**Narvik**	**Finnsens**	**Tromsø**	**Hammerfest**	**Kirkenes**
Narvik	0	159	255	641	1017
Finnsens		0	160	546	922
Tromsø			0	538	914
Hammerfest				0	532
Kirkenes					0

L Savings per added ton kilometer

	North	South
S01	kr 7.31	kr 6.06
S02	kr 12.58	kr 5.89
S03	kr 6.26	kr 8.99
S04	kr 7.29	kr 6.81
S05	kr 15.12	kr 7.90
S06	kr 23.07	kr 6.83
S07	kr 10.89	kr 17.93
S08	kr 5.38	kr 9.56
S09	kr 11.03	kr 7.21
S10	kr 11.76	kr 6.62
S11	kr 12.87	kr 20.91
S12	kr 28.29	kr 4.78
S13	kr 29.27	kr 18.96
S14	kr 6.95	kr 21.05
S15	kr 6.13	kr 26.43
S16	kr -	kr -