OUTBOUND LOGISTICS NETWORK ANALYSIS AND DESIGN

Lappeenranta–Lahti University of Technology LUT

Industrial Engineering and Management Master's Thesis

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Inka Manninen

Examiner: Professor, Janne Huiskonen

ABSTRACT

Lappeenranta–Lahti University of Technology LUT

LUT School of Engineering Science

Industrial Engineering and Management

Inka Manninen

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Outbound logistics plays a very important role in the company's operations. Network design as a part of it enables the value creation both for the company itself and its customers if executed successfully.

The objective of this thesis is to analyse case company's current outbound logistics network and examine with different scenarios, how specific key performance indicators will behave when number of facilities is reduced in the network. Thesis aims to improve the network performance.

Thesis has been carried out utilizing Pareto principle, Centre of Gravity analysis and tool intended for Network Design optimization.

The key results state that with smaller number of facilities, even better results can be achieved in terms of delivery service. Last leg lead time was improved. However, by reducing number of facilities, there were an increase in logistics costs and CO2 emissions. Logistics costs increased the least when there were direct deliveries from mill to customer. In this case, CO2 emissions also increased less, as deliveries were more straightforward and made more use of low-emission transport modes, such as train. There were also increase in total delivery lead times. It was result of the concentration of port operations in the two most used ports. The reduction of facilities had no effect on the increase in delivery lead time, as the smallest increase occurred with the smallest number of distribution centers.

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Lähtevällä logistiikalla on hyvin tärkeä rooli yrityksen toiminnassa. Logistiikkaverkoston suunnittelu osana sitä, mahdollistaa parhaimmillaan arvon luonnin sekä yritykselle itselleen että sen asiakkaille.

Diplomityön tavoitteena on analysoida kohdeyrityksen nykyistä lähtevän logistiikan verkostoa sekä tutkia erilaisten skenaarioiden avulla, kuinka tietyt suorituskykymittarit käyttäytyvät, kun jakelukeskusten määrää vähennetään verkostossa. Diplomityössä pyritään parantamaan verkoston suorituskykyä.

Diplomityö on toteutettu hyödyntäen Pareton periaatetta, painopisteanalyysia sekä verkoston suunnittelun optimointiin tarkoitettua ohjelmaa.

Tärkeimmät tulokset osoittavat, että pienemmällä määrällä jakelukeskuksia, voidaan saavuttaa, jopa parempia tuloksia toimituspalveluiden osalta. Viimeisen toimitusvaiheen toimitusaika parani. Kuitenkin vähentämällä jakelukeskusten määrää, yhteenlasketut logistiikkakustannukset sekä CO2 päästöt nousivat. Logistiikkakustannukset nousivat vähiten silloin, kun mukana oli suoria kuljetuksia tehtaalta asiakkaalle. Tällöin myös CO2 päästöt nousivat vähemmän, sillä toimitukset olivat suoraviivaisempia ja hyödynsivät enemmän matalapäästöisiä kuljetusvaihtoehtoja, kuten esimerkiksi junaa. Myös kokonaistoimitusajassa näkyi nousua, mikä oli seurausta satamatoimintojen keskittämisestä kahteen eniten käytetyimpään satamaan. Itse jakelukeskusten vähentämisellä ei ollut vaikutusta toimitusajan nousuun, sillä pienin nousu tapahtui pienimmällä määrällä jakelukeskuksia.

ABBREVIATIONS

CO_2	Carbon dioxide
CoG	Centre of Gravity
KPI’s	Key Performance Indicators
SC	Supply Chain
TOD	Terms of Delivery

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1 Introduction

Outbound logistics network of any company in any field is very crucial for the success of the company. Companies' outbound logistics networks are responsible of delivering right goods to the right customers at the place and the time requested by the customer. (N. C. Hiremath, Sahu and Tiwari, 2013, p. 1071) For a company to succeed in this, their outbound logistics network must be designed to meet customer requirements and generate value for both the company itself and the customer.

Network design in supply chain is seen as a significant strategic factor by the most successful companies. Optimal facility locations and flows of products through the network facilities formulate the network design. Product flows and facility locations are evaluated to be responsible of most of the supply chain costs, even 80 %. (Watson et al. 2013, p.1) Since supply chain network is having this big of an impact to the company's whole supply chain costs, it is important to consider network design carefully and make it to be strategic asset for the company.

This Master Thesis gets acquainted with finding the new possible network design while improving network performance. In this chapter, background, aims and limitations as well as structure of the thesis are presented.

1.1 Background

This Master Thesis has been carried out for the large forestry company in order to streamline its current outbound logistics network and improve network performance. The company has identified challenges in managing a very extensive terminal network, which causes problems regarding standard delivery service, long and inconsistent lead times, cognitions in the nodes and old procedures that does not create any value. Target company's current outbound logistics network has numerous ports and inland terminals, which makes network management and delivery service difficult. When it comes to the network design and material flows from mills to customers, organization tends to stick to old habits and so-called legacy, leaving little room to new ideas and improvements.

One important thing to carry out in this Thesis is to maximize value creation in logistics. Existing outbound logistics network was built 10 years ago to meet the needs of the time. Situation must be re-evaluated in the current business environment.

1.2 Aims and limitations of the Thesis

In this Thesis, the target is to find out how to improve the target company's European distribution network with optimized number of facilities and with maximized network performance. To achieve the main target, it is important to understand target company's current outbound logistics network and material flows within it. The performance is measured by chosen KPI's. New network scenarios are developed and evaluated against chosen KPIs.

The desired result can be found with the help of the main research question and the supporting sub research questions.

The main research question is:

RQ: How to improve network performance?

Sub research questions are:

SRQ1: What kind of outbound logistics network does the company have and what are its most important development points?

SRQ2: How the KPI's change when number of facilities are reduced from the network?

SRQ3: What kind of value can be created with optimized outbound logistics network?

The examined outbound logistics network is limited to the customers in continental Europe. Material flows are limited to origin from company's Finnish, Swedish and Polish mills to the Europe. Even if the company has worldwide network, approximately 60 % of sales are directed to the Europe in the target division. Target company's target division produces two product groups, product group A and product group B, which both are included in the Thesis.

1.3 Research methodology

The research begins with a literature review by getting familiar with the theory and topics behind the actual research. Theoretical sources were searched from Google Scholar and LUT Academic Library Primo.

The actual research is carried out with different analysis and analysation tools. As-is scenario is mainly executed by Power BI data visualization tool, which is used to make logistics network mapping and visualizing flows on the network. Scenario analysis is executed with Log-hub Supply Chain app Excel add-in which includes used Centre of Gravity analysis and Network Design Optimization. All data was prepared for visualization in the Excel or Power BI. Data origin is mainly the target company's Enterprise Resource Planning system.

Interviews of the target company's logistics professionals have been used as supportive input. Interviews are considered as an opinion of interviewee, which is why the answers have been viewed and used critically. The interviewed professionals represent following areas of expertise: network and routing, network design, master planning, terminals and inbound coordination, service design, delivery service and customer service coordination.

1.4 Structure of the thesis

Figure 1 illustrates simplified research process this Master Thesis follows. The research begins with a theoretical framework and literature review. Next presented as-is analysis describes the current outbound logistics network. The selected KPI's have also been analysed in this phase of the study. After the current network has been identified and analysed, network design is done using the Centre of Gravity and Network Design Optimization methods. Finally, the evaluation of new network scenarios is carried out using the KPI's selected in the previous stages of the study.

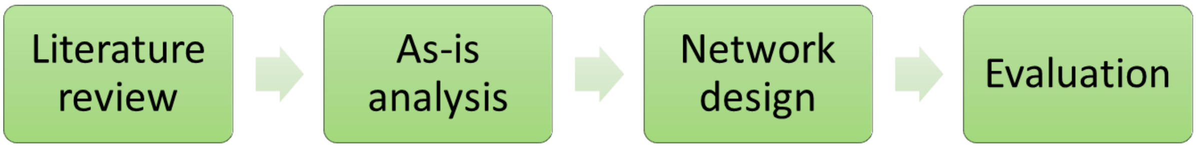


Figure 1 Research process.

Figure 2 presents input-output chart of the study. Chart includes input, the actual chapter and output. The inputs serve as the starting information for that chapter which processes input data. With the help of the content discussed in the chapter, the output is generated, i.e., the result of that chapter. In other words, the chart includes initial data for every chapter and the result of the same chapter in a visualized form.

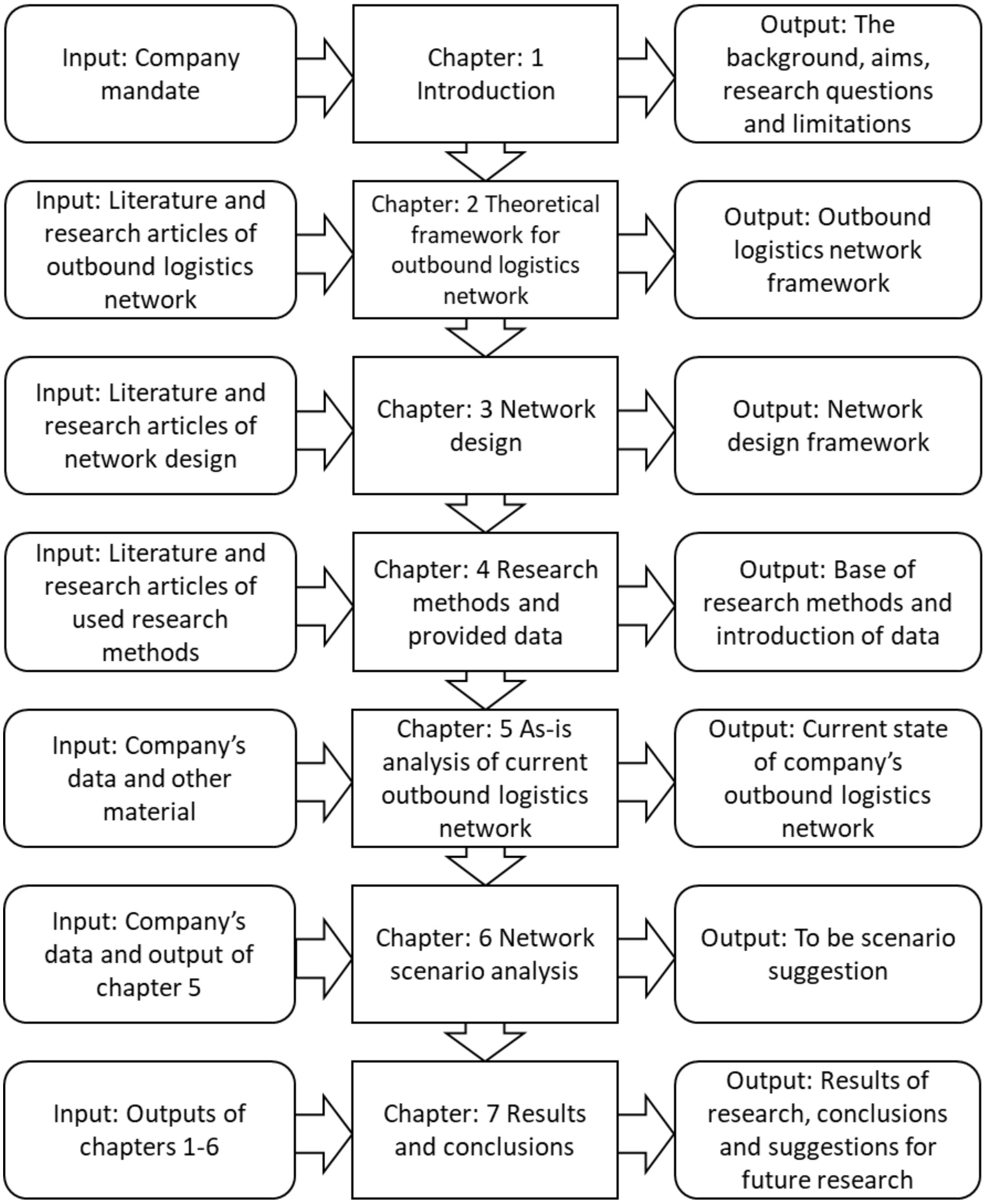


Figure 2 Input-Output-chart.

2 Theoretical framework for outbound logistics network

This chapter presents theoretical framework for outbound logistics network. Also, chosen KPI's are discussed in this chapter.

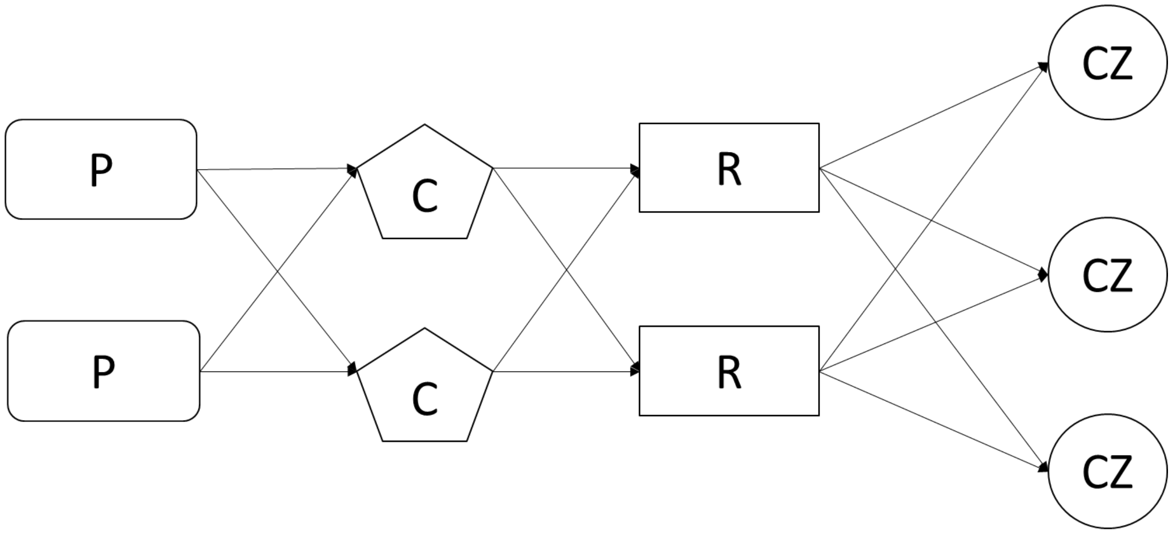
2.1 Definition of outbound logistics network

Fulfilling the needs of the industrialized society is the base purpose for an organization existence. When a right customer is served with a right product in the right time and place with right price and quality of the product, the customer's needs are being fulfilled. Outbound logistics plays a key role in meeting these needs. Customer's expectations lean on to these quality, cost, flexibility, and speed factors. These customer's expectations effect on organization's whole outbound logistics success. (N. Hiremath, Sahu and Tiwari, 2013, p. 1071)

Term logistics has been understood as an operational function, which includes delivery, inventory, and cost performance, for a long time now. Today when supply chains are global and logistics has become even more modern function, logistics has also begun to be perceived as a value-creating function. By optimizing productivity, costs, resource utilization and capacities, logistics creates competitive value for the organization. Competitive value for the organization should be created in cooperation with suppliers, customers, and logistics partners to succeed in it. (Ross, 2015, pp. 5–6)

Logistics network, also referred to supply chain, includes many individual factors that create the whole logistics network. Factories, warehouses and distribution centres stands for the factors, but logistics network includes also, raw material, semi-finished and finished product flows. (Li and Schulze, 2011, p. 1) In a Figure 3 below, is presented a traditional outbound logistics network. It includes plants, which are manufacturing factories, central distribution centres, regional distribution centres and customer zones. Traditionally, outbound logistics networks are multi-echelon networks, where there are several stages before products ending up to the end-customer. (N. Hiremath, Sahu and Tiwari, 2013, p. 1073)

As Figure 3 illustrates, material flows between the plants and central distribution centres, between central distribution centres and regional distribution centres and finally between regional distribution centres and customer zones.



P – Plants, C – Central Distribution Centers, R – Regional Distribution Centers,
CZ – Customer Zones

Figure 3 Traditional outbound logistics network. (N. Hiremath, Sahu and Tiwari, 2013, p. 1073)

Supply chains consist of different channels with different number of echelons. Between every echelon there is a transaction flow. In case of zero-echelon channel, the end-customer is receiving the order directly from the mill without any transactions between other actors. In case of the one-echelon channel, between manufacturer and end-customer is two transaction flows and the responsibility of the order is passed for example to the intermediate warehouse. Two-echelon channel has two echelons and three transaction flows. This continues accordingly depending how many echelons there are. The more levels there are, the more difficult it becomes to manage transactions. Information and cost accuracy as well as lack of timeliness are phenomena that makes transactional efficiencies difficult. (Ross, 2015, p. 67)

Figure 4 below shows five different channel levels, but there could be even more echelons in a channel depending on the network and the situation. Also, types of echelons can vary depending on the situation and the network. This figure has been adapted to suit the topic of this report using warehouses, ports and converting units as echelons. Warehouses in this figure are for the storing terminals and distribution centres.

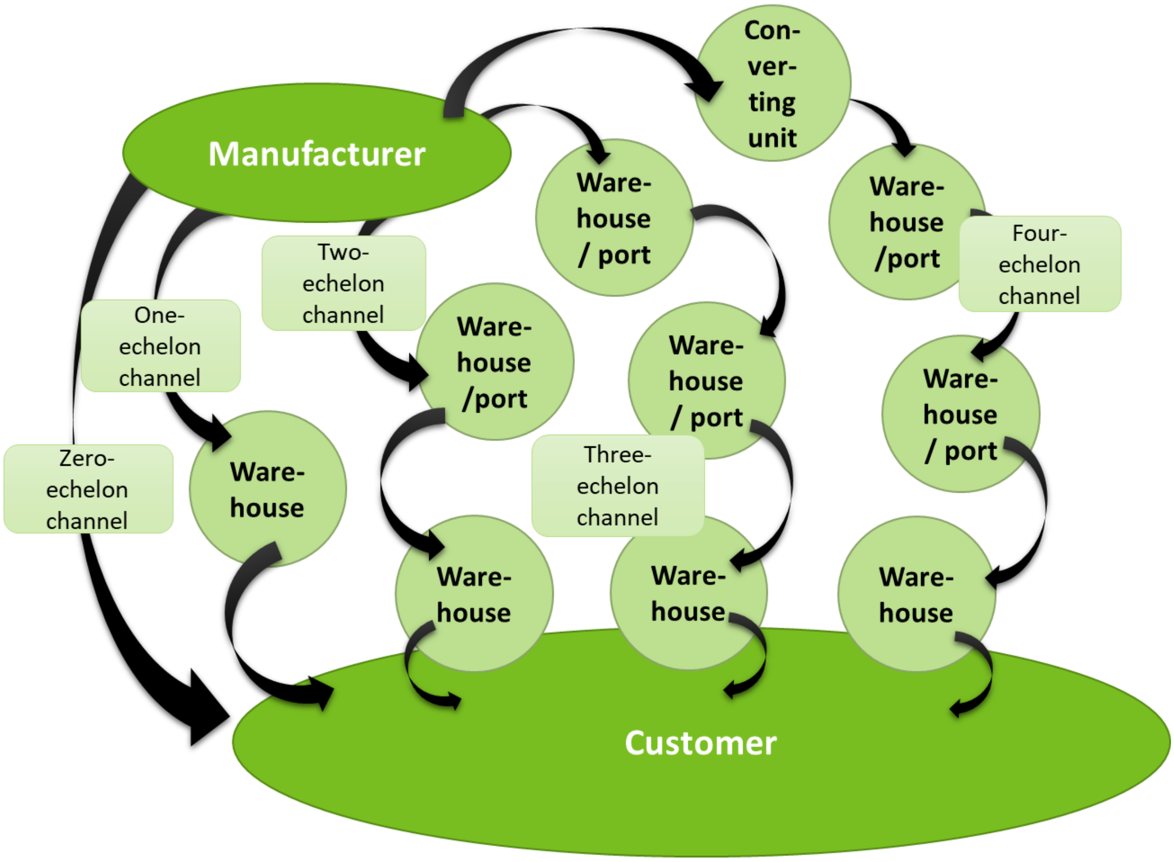


Figure 4 Structure of distribution channel levels. (Modified from Ross, 2015, p. 67)

Channel levels vary depending on the situation: what the exact customer needs or wants? Customer's various and complex needs and demands have achieved flexible, cost efficient and responsive options in outbound logistics. (N. Hiremath, Sahu and Tiwari, 2013, p. 1073) Naturally, organization's own needs and aims affect to the number of channel levels as well.

Material flows have big impact on the outbound logistics network. It includes raw material and finished product transportation and warehousing. It has a direct effect to delivery times and customer satisfaction in a positive and a negative way. Flow of information is also an important part of the material flow and the information must be correct as well to support successful material flows. ('Information, money and material flow – Logistiikan Maailma', 2022)

Outbound logistics comprises the material flow and storage from the mill to the customer. Final step on the outbound logistics delivery process is called the "last mile". This final step has critical role in the delivery process and is the factor whether the process will succeed or fail. (Liberatore and Miller, 2016, p. 1) Last mile can be also called last leg. Several elements, including the length of the last leg, accessibility of local transportation infrastructure, and the kind of road network have an impact on the last leg delivery (Halldórsson and Wehner, 2020, pp. 1–3). Last mile is the part that is most visible for the customer and that is why it is crucial part in outbound logistics. It also shows customer how organization performs.

2.2 Key Performance Indicators (KPI's)

Key Performance Indicators (KPIs) are used to measure performance in some process in the organization. Organizations try to choose the correct indicators to help to control and improve organization's processes. There are three the most important features that the correct indicators should have:

1. Process of interest should be represented appropriately;
2. Indicators should have acceptance of managers and employees and be understood easily;
3. Verification and trackability should be possible. (Franceschini, 2019, p. 7)

KPI's have also basic purposes in organizations. They need to control, communicate, and improve in the organizational environment. Evaluating and resources performance control are related to control function. Evaluating and performance control are for the management purposes. Performance communication to employees and managers as well as to stakeholders is the function of communication. Without communication, there would be uncertainty inside of the organization. Improvement relates to numbers that need to be improved to achieve the goals of the organization. (Franceschini, 2019, p. 9)

2.2.1 Lead time

Lead time is typically defined as a time from customer placing an order to the point the customer receives the order. (Zijm *et al.*, 2019, p. 443) This is the lead time from the customer point of view. And typically called as a total lead time.

While companies compete with short lead times, it is important to keep lead times consistent and reliable. It is not a good sign, if there is high variation in lead times. The total lead-time for specific unit can be calculated by determining the time that every individual part of the supply chain takes. For example, lead time for the supply chain could be (inventory at the factory 4.2 weeks + warehouse 2.7 weeks + sales office 1.8 weeks + transit for factory-warehouse 0.8 weeks + transit for warehouse-sales office 0.5 weeks) or 10 weeks total. (Avittathur, 2020, pp. 103–104)

Last leg lead time

Last leg lead time refers to last mile delivery, which is explained in a chapter 2.1. Last leg lead time is the time, delivery takes from the loading in the last distribution point to the time when goods arrive to the customer or to the other specified point required by customer.

Delivery lead time

Lead time from the logistics point of view is the same, but only part of the total lead time. It can be considered to start from the time when the product is ready from production and end when it arrives to the customer. That lead time is called delivery lead time.

There is a total lead time presented in the Figure 5 below. It is divided into three parts: supply lead time / order processing time, production lead time and delivery lead time. The total lead time consist of these three parts and it starts from the time when the customer places an order and ends when the customer receives the order. Supply lead time includes raw material procurement and order processing time. Supply lead time ends when the production process starts ergo when raw material is ready for production. Production lead time starts when the production process starts and ends when the product is ready for delivery. Usually, there is time between the production lead time and the delivery lead time when the product is in storage waiting to be delivered. Delivery lead time starts when product is ready for delivery and ends when customer receives the product, which is at the same time ending point for the total lead time. (Posteuca, 2019)

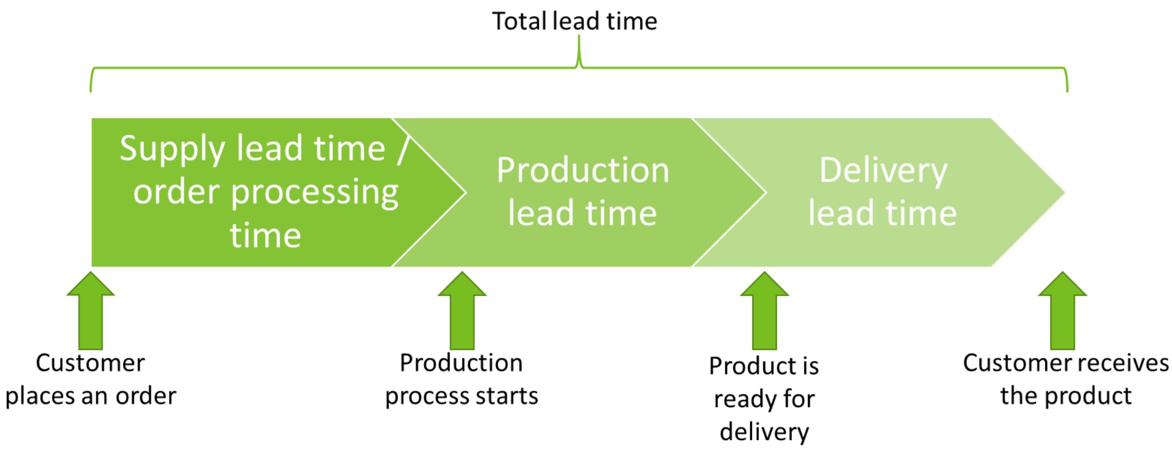


Figure 5 Total lead time (modified (Posteuca, 2019))

2.2.2 Logistics costs

Logistics related costs correspond to a significant part of all the company's costs (Englblom *et al.*, 2012, p. 29). Cost-efficiency is a measure which measures a maximum benefit achieved with minimal resources, like materials and workforce. It has been very widely used in logistics as well as in production for a long time. (Zijm et al., 2019, p. 35) Logistics as a total includes many cost types. These costs are transportation, warehousing, inventory carrying, logistics administration, risk and damage, handling and packaging. (Englblom *et al.*, 2012, p. 29) Handling and transportation costs are on focus of this research.

Warehousing and handling costs

Space costs, labour costs, equipment costs, overhead costs and miscellaneous costs are those typically related to warehouse operations. These cost types together form total warehouse costs. Space costs can be seen as a storage cost. These storage costs usually include following factors:

- Rent/lease costs
- Rates, building insurance
- Electricity, gas, water
- Building and racking depreciation
- Repair and maintenance

- Cleaning, security, other equipment depreciation. (Richards, 2014, pp. 276–279)

Labour and equipment costs are handling costs. Following factors can be included to handling costs:

- Wages, on costs, safety wear, welfare
- Handling equipment depreciation/rental. (Richards, 2014, pp. 276–279)

Above mentioned costs include fixed and variable costs. For example, in handling costs overtime and bonuses regarding the wages are variable as well as other running costs, e.g., fuel, in handling equipment. (Richards, 2014, pp. 276–279)

However, total cost structure of warehousing depends on the contracts and a pricing model that is used.

Transportation costs

Transportation costs are based on the product movement from its original location to the destination. The cost of transport is connected to the distance between departure and destination locations. Distance is not the only thing affecting to the cost. Also, accessibility from the facility to the transportation infrastructure, for example ports, railways, and highways, are affecting to the cost. The final destination, demand area, determines transportation costs as well and it is visible when comparing transport costs between different market areas. (Watson et al. 2013, p.5)

2.2.3 CO2 emissions

Social, economic and environmental dimensions are the three dimensions that are included to sustainability and sustainable development (Lazar, Klimecka-Tatar and Obrecht, 2021, p. 2). In this research, we will only focus on environmental dimension, especially to CO2 emissions, since it is an essential part of target company’s strategy.

Nowadays customers expect logistics solutions that are sustainable, especially regarding the carbon emission impact in distribution. In outbound logistics, minimizing the emissions is seen as a very important responsibility in companies. (Zijm et al., 2019, p. 308) Logistics and supply chains are part of the global dependence on fossil fuels, which is one of the primary reasons to cause climate changes. Sustainability is a critical condition for competitiveness internationally and logistics as well as supply chain are strongly related to it. (Lazar, Klimecka-Tatar and Obrecht, 2021, p. 2) There is a strong connection between volume of CO_2 emissions and country's logistics performance, as how big are the logistics volumes. Also, Gross domestic product (GDP) has a strong relationship with logistics volumes and CO_2 emissions. When GDP increases, also CO_2 emission volumes increases. (Polat, Kara and Yalcin, 2022, p. 222)

3 Network design

Supply Chain structure has a big impact on the competitiveness and performance of the whole supply chain. Done successfully or poorly makes a huge difference to one way or another. Successful supply chain network design requires strategic and tactic decision making. (Ghomi-Avili et al., 2021, pp. 1–2; Vishnu et al., 2021, pp. 1–2)

Network design is a strategic decision including optimization of number of activities within a supply chain network. (Rahmani and Mahoodian, 2017, p. 607) Creating an effective network is the main goal of supply chain network design. It could be done by redesigning existing network or designing totally new structure of entities. Either way, there are multiple decisions to make to get the whole supply chain work decided way. In addition to such aspects as the type of location of facilities, environmental complexity factors and relationships within the network structure must be considered, when company designs its supply chain network. (Reich et al., 2021, p. 3)

3.1 Influencing factors to network design decisions

There are many factors to be considered when designing network structure. These factors include strategic, competitive, political, infrastructure, customer response time and service level, total logistics costs and macroeconomic factors.

Strategic factors

A company's strategy has a huge impact to decisions made of logistics network design. For example, if a company has a strategy to lower their costs, then cost aspect is one of the driving factors in network design. If a company has strategy to provide better service to customers and be responsive, then responsiveness is the driving factor finding the network design close to the customer. (Chopṛa, 2019, p. 119)

Competitive factors

Locating facilities close to the competitors or not is something to consider when doing network design. Also, competitors' location, size and strategy should be understood. (Chopṛa, 2019, p. 120)

Political factors

Political situation is significant factor when doing network design decisions. Politically stable country or region is more preferrable place to locate facility. Global Political Risk Index (GPRI), which measures government, society, security and economy shocks and crises, is usually used for evaluating the location from the political point of view. (Chopṛa, 2019, p. 121)

Infrastructure factors

Infrastructure factors such as rail service, highway accesses, labour, local utilities etc. are important factors when designing network. With poor infrastructure, good network performance is not possible. (Chopṛa, 2019, p. 121)

Customer response time and service level

When aim is to provide shorter response time to the customers, it is preferred to have facilities closer to them. Response time is also in line with service level. A company could provide certain response time with certain service level, but when increasing the service level, the company will need more facilities to cover that. (Chopṛa, 2019, p. 121)

Total logistics costs

Inventory, facility, and transportation costs are altogether total logistics costs. Inventory costs represent costs from storage, when facility costs are from labour, equipment and building costs. These two cost types tend to increase when number of facilities increase. Transportation costs are costs generated from inbound logistics to the facility as well as outbound logistics from the facility. Number of facilities influence to transportation costs decreasing to the certain point, which after costs start to increase. (Chopṛa, 2019, p. 122) Affects to logistics costs by number of facilities are presented further onward on the next chapter.

Macroeconomic factors

Exchange rates, tariffs and taxes are macroeconomic factors that affects to network design decisions. Total costs and profits are the facts that macroeconomic factors affect. (Chopṛa, 2019, p. 122)

3.2 Relationships within the network structure

When designing or redesigning the network structure, relationships between the number of facilities and different measures should be understood. These relationships are reviewed in this subsection.

There are multiple indicators that network structure influences. These are following measures:

- Response time
- Product variety
- Product availability
- Customer experience
- Time to market
- Order visibility
- Returnability
- Inventory costs
- Transportation costs
- Facilities
- Information (Chopṛa, 2019, p. 85)

Figure 6 illustrates relationship between required number of facilities and desired response time. When shorter response time is wanted, the number of facilities should be bigger, since they must be located close to each customer. These facilities need only low volume capacity. When number of facilities is low it affects to response time by extending it since the facility locations are far from the customer. These facilities need also bigger capacity. (Chopṛa, 2019, p. 85)

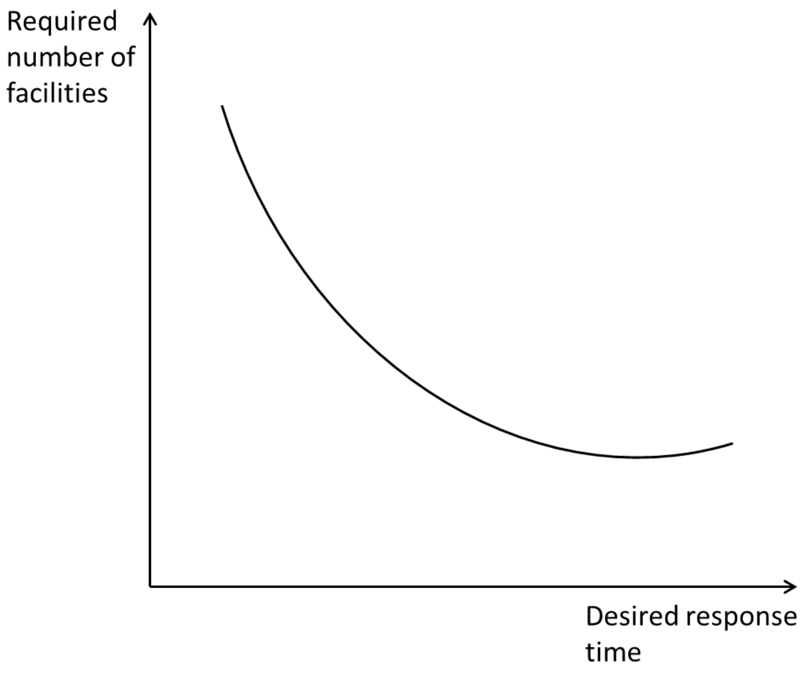


Figure 6 Relationship between required number of facilities and desired response time. (Chopṛa, 2019, p. 86)

Figure 7 illustrates relationship between number of facilities and inventory costs. By reducing number of facilities, inventory costs reduce as well, whereas increasing the number of facilities, inventory costs are increasing as well (Chopṛa, 2019, p. 86).

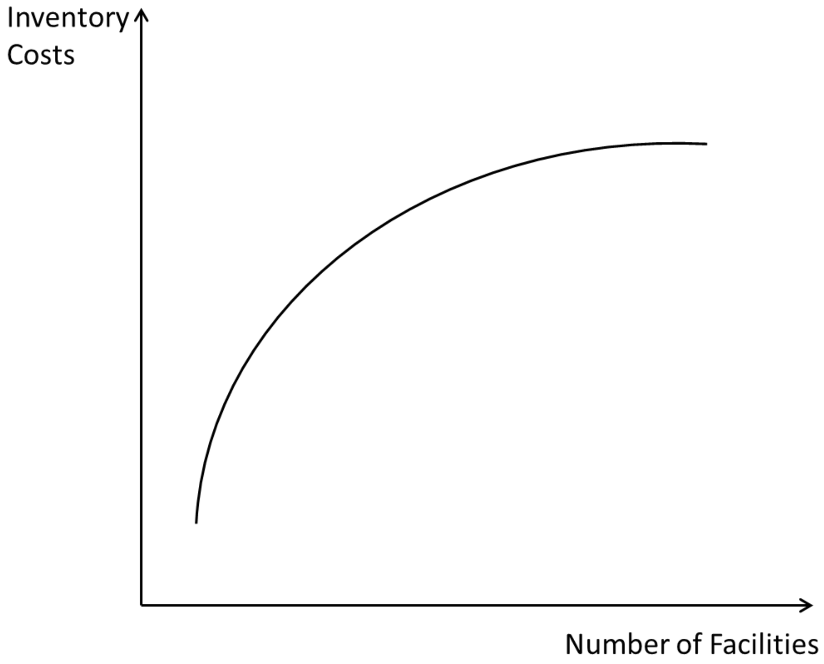


Figure 7 Relationship between number of facilities and inventory costs. (Chopṛa, 2019, p. 86)

Figure 8 below presents relationship between number of facilities and transportation cost. Inbound transportation costs are usually smaller than outbound transportation costs. Example when there are deliveries from mill to warehouse, inbound will be big since warehouse is the distribution point and not yet the final location. Outbound transportation from warehouse is significantly smaller since it is directed to the specific customer at the customer's desired time. When the number of facilities increases, transportation costs decrease as well to the certain point if large inbounds can be maintained. After the point when inbounds start to become smaller, transportation costs will increase aboard the number of facilities. (Chopṛa, 2019, p. 86)

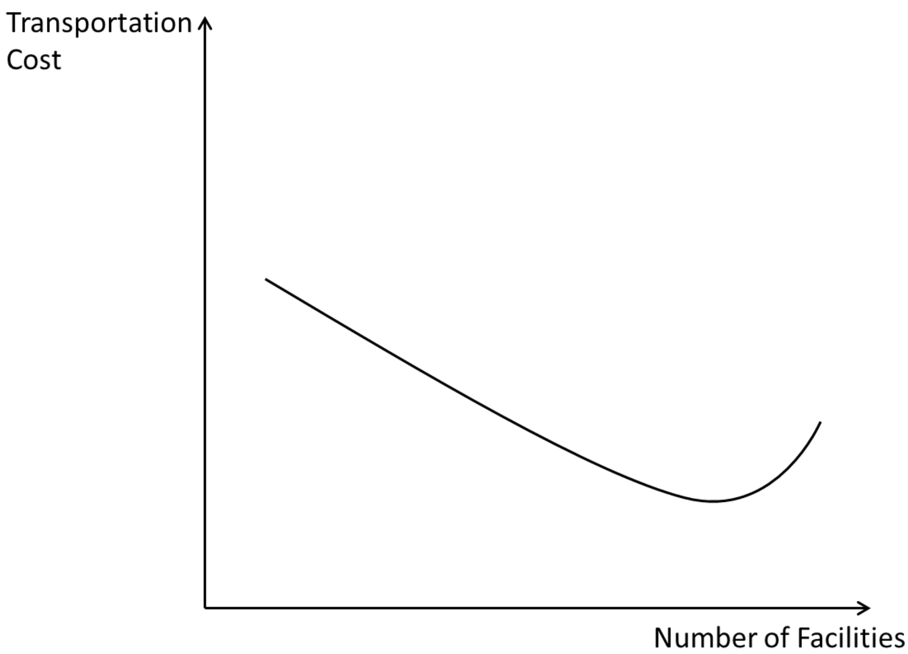


Figure 8 Relationship between number of facilities and transportation cost. (Chopṛa, 2019, p. 87)

Figure 9 below presents relationship between number of facilities and facility costs. When number of facilities increases, increase facility costs as well, whereas number of facilities decrease, facility costs will decrease. (Chopṛa, 2019, p. 87)

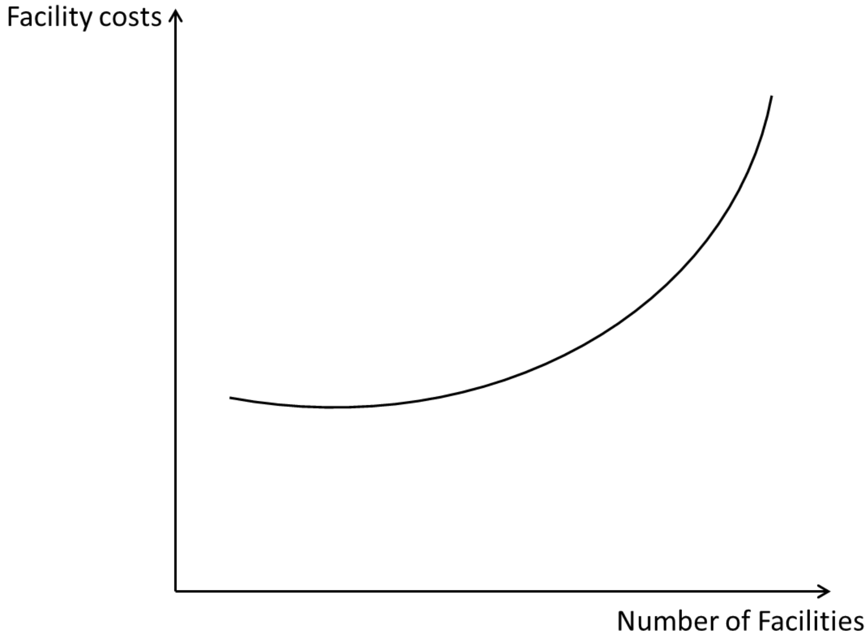


Figure 9 Relationship between number of facilities and facility costs. (Chopra, 2019, p. 87)

All in all, number of facilities influence significantly to facility, inventory, and transportation costs as well as to response time. Optimally, balance between all these factors should be found. Inventory and facility costs both increase along with the number of facilities but in different ways. Transportation costs behave very differently compared to other costs and is significantly more difficult to find optimal point for best transportation costs. Response time extends accordingly when number of facilities is increasing. Putting all these factors altogether, in a theoretical level, totally centralized network design is not the best possible. There should be facilities close to the customer but still not that close that every customer would have their own facility. Number of facilities should be kept small but at the same time close to the customers.

3.3 Other aspects to consider in network design

There are still some other factors that could be considered in new network design. These factors are typically related to company's strategy and goals.

Environmental factors

So called "green network" affect supply chain network's sustainability. There are many environmentally friendly actions in a green supply chain that can be taken over. Those are for example minimization of transportation or production sourced pollution, waste management or remanufacturing process. These are considered as operational decisions. Other actions could be usage of environmental innovation in a supply chain. (Rahmani and Mahoodian, 2017, p. 608) Often when facility locating is made by minimizing the distance between the facilities, also carbon emissions are reduced at the same time (Watson et al. 2013, p.6)

4 Research methods and provided data

In this chapter, used methods for the research are presented and explained. Used methods are Pareto principle and Centre of Gravity analysis. Also, used data and data sources are presented.

4.1 Pareto principle – ABC-analysis

Name Pareto originates from Vilfredo Pareto who was an Italian social scientist in the nineteen-century. Pareto principle is based on the statement that 20 % of the items will account for 80 % of the transactions. In inventory management it indicates that small number of items are more important than the rest of the items. That small group of items bring most of the revenue, and they are ordered more often. (Ross, 2015, p. 337) This principle, which is also known as 80-20 rule, can be used for many phenomena, for example in management, economics and business, computer science and in human activity. It describes mathematically unequal distribution, which is also called Pareto distribution. Pareto principle simplifies mathematical logic behind the Pareto distribution. (Dunford, Su and Tamang, 2014, pp. 140–141)

Typically, ABC classification is used within Pareto analysis:

- Class A: Class A items need special attention, and they can be expensive or high transaction volume.
- Class B: Class B items come in large quantity, and they are considered to be in medium use and sales.
- Class C: Class C items have very low transaction volumes, and they are typically inexpensive. (Ross, 2015, p. 338)

In a (Mota *et al.*, 2015, pp. 22–23) research, ABC-analysis have been used in the purpose of reducing warehouse locations with giving ABC classifications to the customers. The research identified 20 % of the customers, which are responsible of 80 % of the annual sales. This showed the customers that influenced to the company sales most, which means they are more important in the case of economic importance. In that way, the warehouse locations these customers use, should be included in a new warehouse network. By using ABC-analysis, researchers were able to reduce warehouse locations from 278 to 84.

Based on the available studies, ABC-analysis of warehouses has not been commonly used for warehouse optimization.

4.2 Centre of Gravity analysis

Centre of Gravity analysis is a method to find optimal locations for warehouses. The method is based on the distances between the warehouse locations and the customer destination as well as handled volumes. Volumes represents the demand of that specific area and is used as a weight in the simulation. The centre points that are simulated in this method are the optimal points for the warehouse. (Zhao, 2014, pp. 585–586)

It is important to understand that this method does not take into account cost differences of the geographical locations or future cost variations or benefits. (Zhao, 2014, pp. 585–586) The method is good tool alongside other methods and research, but not a tool to use alone if other aspects, such as costs, are needed to consider while designing the network.

The basic principle behind the centre of gravity method is as follows:

The distance between P and A:

$$D(A,P) = k\sqrt{(Xi - a)^2 + (Yi - b)^2}$$

P = distribution centre,

P (a, b) = corresponding position coordinates

A (Xi, Yi) = demand point, (of which i= 1, 2, 3, ….n)

k = proportionality coefficient. (Zhao, 2014, p. 586)

4.3 Network design optimization

This research focuses to optimize continental Europe distribution network. Ports, inland terminals, and customer locations act as facilities in the used analysis tool.

Network design optimization utilizes information of facilities as well as each transportation legs. The Network design optimization tool gives cost driven solution for the distribution network. Every facility contains information of their location (coordinates: latitude and longitude). Also, warehouse capacities and warehousing costs are included. In this research, handling costs in warehouses were used. Fixed costs were not used as the target company does not often have them. Capacity of warehouses was set as infinite. Increasing storage capacity is not seen as a problem and it is interesting to see how volumes will divide if there are no limitations. Customer variable also utilizes number of shipments and average weight of each shipment. Network design optimization tool also utilize transport cost table, which must include departure and destination locations, transport capacity of unit and costs per unit. Truck acts as an optimization unit in this analysis.

Calculation of Network design optimization needs parameter specification and choices regarding consolidation. These parameter decisions are distance unit, which in this research is kilometres, and calculation level, which in this research is street level. For the consolidation the range for number of warehouses can be chosen. For example, if the range is chosen from 1 to 10, the calculation will choose the optimal number from that range.

In this analysis number of distribution centres were chosen based on the Centre of Gravity analysis and every distribution centre was defined as fixed location. The optimization tool calculates optimal solution considering the entered distribution centres as mandatory in the new network scenario.

4.4 Used data and data sources

The data for the analysis was originated form two data sources: company’s Enterprise Resource Planning system (ERP) and Structured Query Language (SQL) server database. Also, company’s readymade Power BI datasets were used for some analysis, but the original data source was ERP or SQL database. Additionally, some data was collected from the experts of the field.

Data was always filtered to match right division, mills, and product types. Also, delivery countries were always filtered to match the target countries. Other data cleaning was done depending on the data source and the purpose of usage.

Data verification was done by cross checking between the data sources and by checking with the experts.

4.5 Implementation of network design optimization

The main simulation is implemented with using Log-hub's Supply Chain app's Network Design Optimization tool. This tool requires specific form of data tables to be able to run simulation. Every facility of network is listed on the tables, for example mills, warehouses, distribution centres and customers, as well as transportation information.

Basic steps of implementation of network design optimization are following:

1. Creating the structure of the data
2. Calculation
3. Import results
4. Analysing the results. ('Supply Chain Apps', 2022)

First, correct data is imported to tables in a correct form the SC optimization tool requires. Mandatory information was filled in and some optional data was filled in as well when available. After that, tables are linked to the tool, which make data calculatable. Next, calculation is executed with chosen parameters and consolidation choices. As a result, tool gives output data tables with the info of open warehouses, factory-warehouse assignment, customer-warehouse assignment and KPI's. Lastly, tool provides map visualization of new network design and KPI dashboard. KPI dashboard includes output KPI's, which are optimal number of warehouses, total costs, average customer warehouse distance and average number of customers per warehouse. Also, result analysis and flow analysis are provided in KPI dashboard. Final step of network design optimization is analysing of the results, which is executed in this report.

5 As-is analysis of the current outbound logistics network

In this chapter, the case company, and as-is situation of terminal network and flows are presented. As-is analysis is the analysis of the company's outbound logistics network as it is right now. Also, Pareto principle of terminals and ports and customers is used in this as-is analysis.

5.1 Outbound logistics of the case company

Case company's outbound logistics network consists of different actors: mills, ports, terminals, warehouses, distribution centres and customers. In addition, different types of transportation take place between the actors. These transportation types are road, rail, maritime, multimodal, and intermodal. Road and rail as a transportation mode are truck and wagon, except road could be also a shortsea container. In maritime, there are three different ways to deliver: liner vessel, break bulk and ocean container. Multimodal and intermodal transport modes are utilizing multiple transport modes depending on the situation. The difference between multimodal and intermodal is that intermodal is one type of multimodal transportation mode but goods remain for example in the same container when transportation vehicle is changed when multimodal just combines different modes of transport under one carrier (Kubanova and Schmidt, 2016, p. 105)

5.1.1 Outbound logistics network: finished products

There are three types of outbound logistics scenarios with case company's finished products. The first one is where reels and pallets are transported by vessel at some point on their way to customers. In the second one delivery is made by truck or rail, but products are stored between before they reach customers. And in the third type goods are transported directly to the customer by truck or rail without storing in intermediate warehouses.

The outbound logistics network starts from the board mills in every scenario. Mills are located in Finland, Sweden and Poland. In Finland, there are five mills, in Sweden, two mills and in Poland one mill. Both mills in Sweden and two mills in Finland produce product group A and the mill in Poland and other three mills in Finland produce product group B.

As seen from the Figure 10 below, from Finland and Sweden, products are delivered by truck or train to the ports, where they are loaded to the vessels and are being shipped to the receiving port in Europe. One mill in Finland is a special in this case. That mill has its own port next to the mill, so they do not need to transport products within Finland.

After, the products have been shipped to a European port, they will be delivered by truck to the inland terminals. Inland terminals are warehousing locations from where customers call-off their orders. Some of these inland terminals provide free storage for a predetermined period of time. Inland terminals can also be considered as distribution centres as they distribute goods to the customers. If the customer is located near a port, port can also act as a final warehouse before the goods arrive at the customer. Finally, customers receive the products by truck from the final warehouse. These scenarios with sea freight do not contain deliveries from the Polish mill as it is inland.

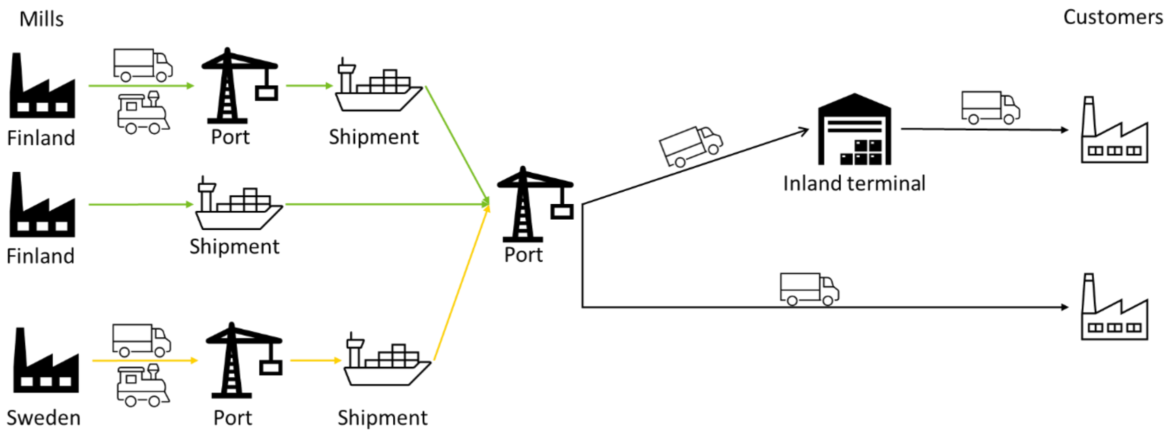


Figure 10 Case company's outbound logistics network in case of a sea transport.

In the Figure 11 below, is presented case company's outbound logistics in case of truck and train delivery via warehouses. This scenario contains all mills in Europe: Finland, Sweden, and Poland. When products are ready from the production, they are delivered to the inland terminals or port for interim storage. When delivering from Finland and Sweden, trucks are loaded to vessels for the sea delivery. From warehouses, customers get their orders same way as described above. What differs this type of distribution from the first one, is that this transportation has fewer transportation legs and is usually faster. From Finland and Poland delivery is executed by truck and from Sweden delivery is executed to the warehouse either truck or rail. From the warehouse, products are being delivered by truck to the customer.

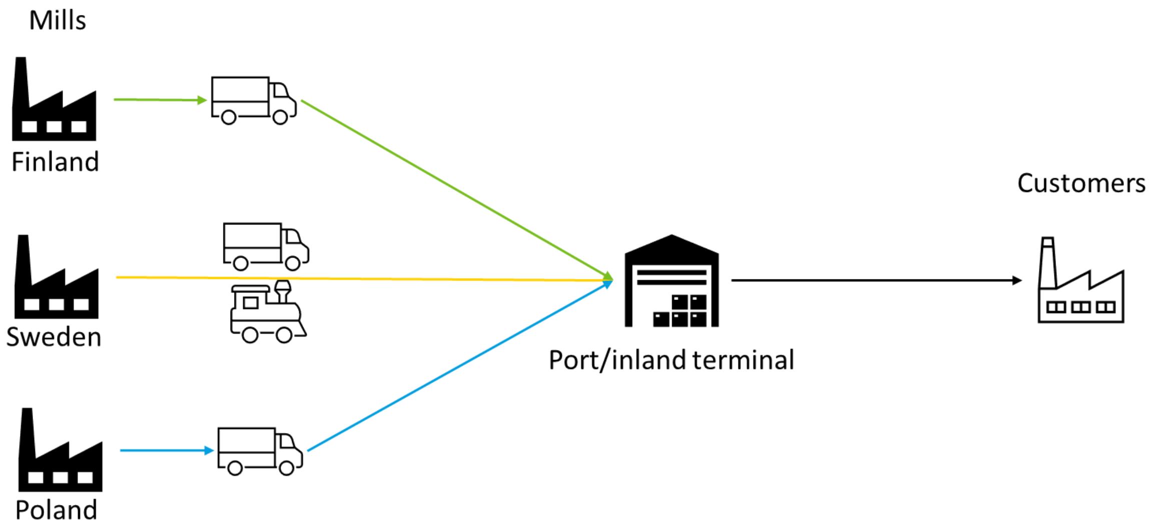


Figure 11 Case company's outbound logistics in case with the truck and rail delivery via warehouses.

As seen in the Figure 12 below, finished products can also be delivered by truck directly from Finnish, Swedish and Polish mills to a customer without any warehousing between. In Sweden, direct rail or direct truck could be used.

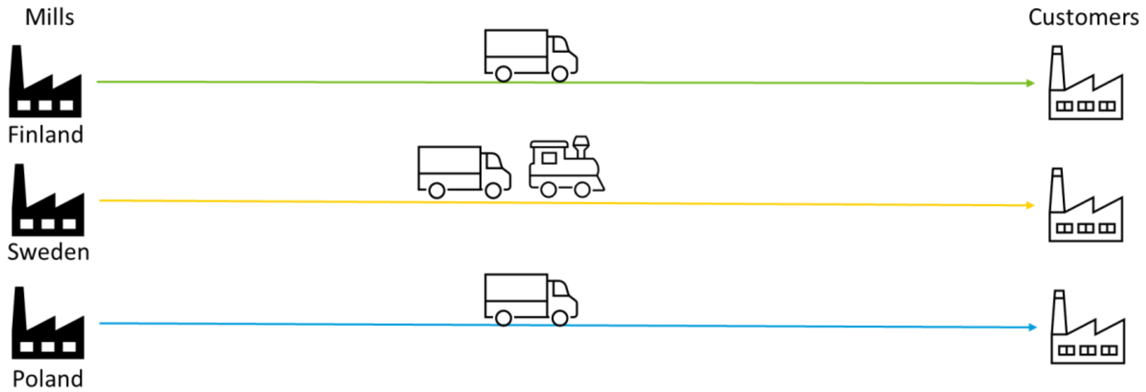


Figure 12 Case company's outbound logistics in case of a direct delivery to the customer.

5.1.2 Outbound logistics network: semi-finished products

Material flows from Finland and Sweden to continental Europe contains also semi-finished products, which use term raw materials since they are not yet finished. These products are converted into finished products in external and internal converter mills in continental

Europe. In the converter mills raw material reels are rewinded to smaller reels or they are cut into sheets depending on customer needs.

As seen on the Figure 13 below, raw materials are being delivered by vessel from Finland and Sweden like finished products. When raw materials have been delivered to the port in continental Europe, they are being delivered to the external or internal converter in continental Europe. After converting, the products are finished. Finished product can be delivered to inland terminals as in finished products example. After converting, the finished products can also be delivered to customers directly by truck.

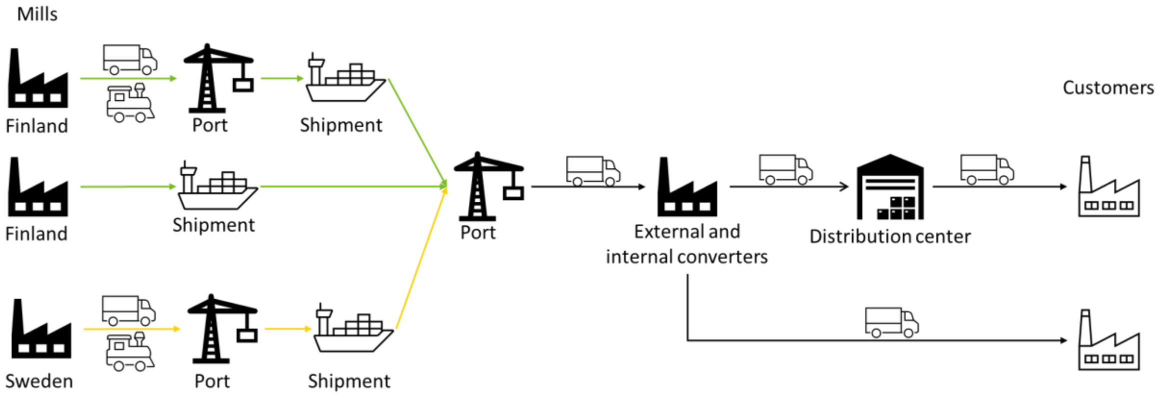


Figure 13 Case company's outbound logistics in case of a semi-finished products and sea transportation.

In the Figure 14 below, is presented how outbound logistics works when semi-finished products are delivered from Finnish, Swedish and Polish mills by truck or rail to the converters in continental Europe. The process from the converter mill to customers is the same as it was in the scenario above.

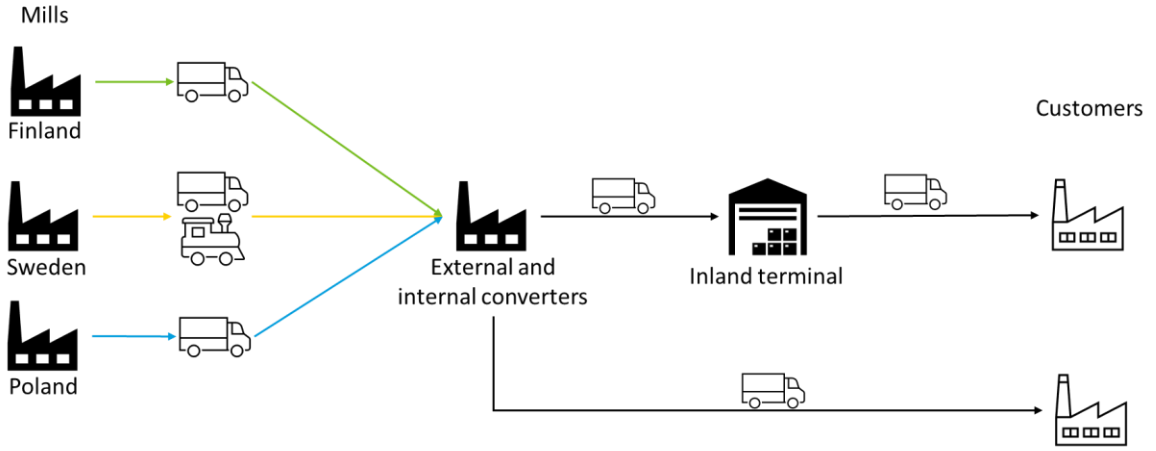


Figure 14 Case company's outbound logistics in case of a semi-finished products and land transport.

5.2 Current terminal network

Case company's terminal network includes ports, inland terminals, and converter mills. Ports can function as ports or they can also act as warehouses depending on the facility. Ports used as warehouses are in Great Britain, Germany, Belgium, Spain and Denmark. Inland terminals are for warehousing purposes and from there material is being distributed to customers. Mills represents different converting mills which convert raw material into different reel sizes or cut into sheets. Mills are mostly located in Poland.

Below is presented a Table 1 of every country location with count and % of total volumes of ports and terminals. Germany has the highest count of facilities in the network. After Germany, comes Poland and Turkey. Even if other countries have a smaller number of facilities, the total number is still high considering the size of the Europe and ability to operate effectively inside the network. Notable is that Germany and Belgium have quite close shares of volumes to each other, but in Belgium the volume can be handled with much smaller number of warehousing locations.

Table 1 Count and % of total volume of storage locations in every storing country.

Country	Count of locations	% of total volume
Germany	17	24,83 %
Belgium	3	22,08 %
Poland	8	13,67 %
Spain	6	8,45 %
Great Britain	2	7,53 %
Italy	2	6,46 %
Turkey	8	5,14 %
Netherlands	2	3,88 %
Austria	3	3,04 %
Greece	3	1,75 %
Hungary	1	1,56 %
Denmark	1	0,94 %
Portugal	3	0,36 %
Cyprus	1	0,19 %
Czech Republic	1	0,09 %
Albania	1	0,03 %
Malta	1	0,00 %
France	1	0,00 %
Total	64	100,00 %

5.3 Pareto principle and analysis of terminal and customer network

As discussed earlier, Pareto principle and ABC-analysis have been used before for the warehouse network planning. There are different ways to use the theoretical framework, and in this project, it is used for finding the most important storage locations and customers from the current network.

ABC-analysis is often used for items in stock, but it can be used also to classify warehouses or customers using the same Pareto principle, 80-20 rule. This is also implemented in this research. Case company's ports and inland terminals are analysed to find the ports and inland terminals with highest material flow. Also, the customers with the biggest volume were recognized and located.

A-class ports and inland terminals contains 80 % of one-year volumes. These A-class places are Zeebrugge, Tilbury and Gdynia ports and terminals in Travemünde and Verona. B-class ports and inland terminals are mainly located in Germany and Mediterranean. B-class warehouses are responsible for 15 % of the volume flowing through terminals. C-class ports and terminals fill the Europe for the most part. Especially in Germany there are a lot of C-class terminals. C-class is responsible of 5 % of the volume, which means that there is a lot of warehouses in Germany compared to percentage of total volume. Also, plenty of C-class ports are in Turkey and few in Portugal with small volume.

5.4 Volume flows to the facilities in outbound logistics network

Huge volume of materials is flowing through the outbound logistics network all the way from mills to customers. Some of the volumes go straight to customers and some are delivered via port or inland terminal.

The biggest flow measured in volume (tons) is from Gothenburg port in Sweden to Zeebrugge port in Belgium. This volume is originated from Swedish mills. The second biggest flow is from Kotka port in Finland to Travemünde port in Germany. This volume is originated from Finnish product group A mills. The third biggest volume is from one product group B mill in Finland to Travemünde port in Germany. These results are in line with ABC-analysis which pointed that Zeebrugge and Travemünde are the biggest ports/terminals measured in volume (tons) and belonging to A-class in classification.

5.5 Last leg framework

When importance of the customer service in warehousing locations is estimated, annual volume and number of customers per each location are considered. Figure 15 below presents last leg framework of inland terminals and ports. The chart sets the last leg warehouse locations in four fields, taking into account the volume of the warehouse and the number of customers. In the upper right corner are warehouses that are high service providers, when in the lower left corner are warehouses that has less service importance. In the lower right corner are warehouses that serve many customers but have low volume. In the upper left corner are warehouses that serve few customers but with high volume.

As can be seen from the Figure 15, majority of the warehouses have no service importance in the last leg framework. These warehouses serve very few or even only one customer with low volume. These kinds of warehouses are for example Gdansk in Poland, Trier in Germany, and Lisbon in Portugal. There are still warehouses which are high service providers. These warehouses are for example Travemünde in Germany, Zeebrugge in Belgium, and Verona in Italy. Even if this is just a last leg approach and does not take into account interim storing before last warehouse, these results are in line with results of the ABC-analysis.

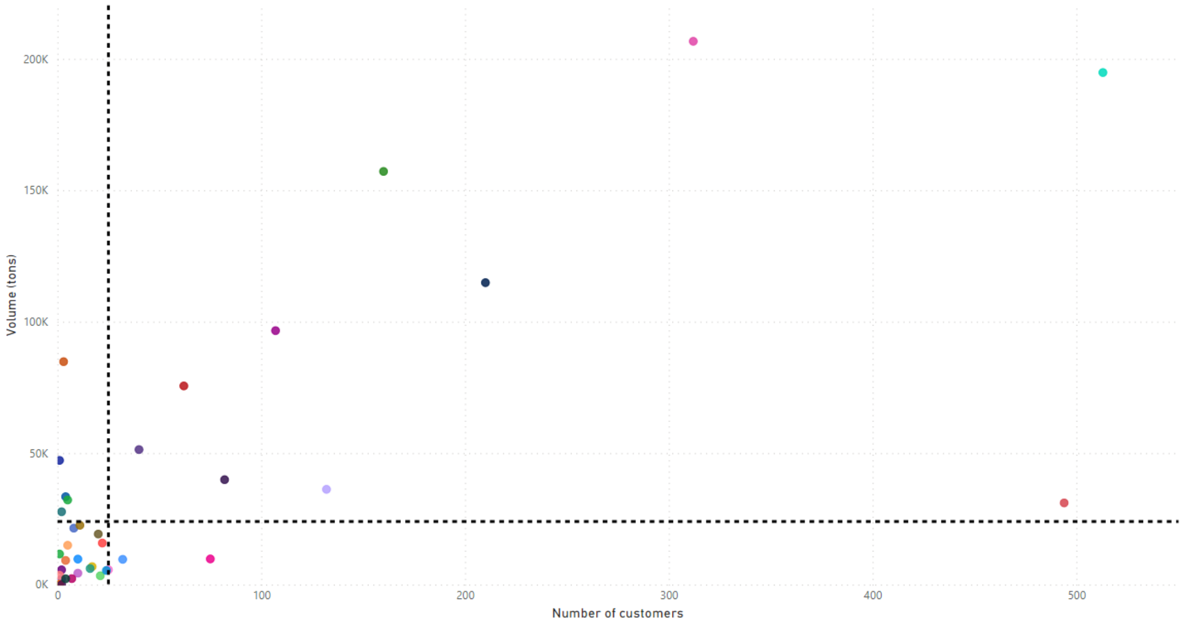


Figure 15 Last leg framework for ports and inland terminals.

5.6 Analysis of current KPI's

In this sub chapter, all calculated KPI's are presented and analysed. These KPI's are On-Time In-Full (OTIF), lead time, costs, and CO2 emissions. These KPI's are chosen to represent three important value creating factors: service, cost-efficiency, and sustainability. On-Time In-Full and lead time represents service, costs represent cost-efficiency and CO2 emissions of transport represents sustainability.

5.6.1 Lead time

Lead times are calculated and analysed for last leg as well as for the whole delivery. Both lead times are important metrics and represent service aspect in this research.

Last leg lead time

Last leg lead time is an important KPI when it comes to service customers at good level. It is the transport leg which is visible for customers and that way has a huge influence how customers feel about the delivery service. Last leg lead time is calculated from the time the order was loaded to the final truck to the time when the order was delivered to customer or other TOD location. This is purely logistic point of view, and for customers delivery time shows from the point they call off the order, to the point it is delivered. Anyway, if the customer wants the order to be delivered within 24 hours, the last leg lead time should be then maximum 8 hours, and it is the driving time. If customer wants the order to be delivered in 48 hours, last leg lead time should be up to 20 hours. If the order is wanted to be delivered within 72 hours, then the last leg lead time is up to 32 hours. Which delivery time can be promised to the customer, depends on the distance between the warehousing location and the location of the customer. In the ideal situation for the fastest service and from the customer point of view, terminal should be located maximum 600 kilometres from the customer, so that driving time could be 8 hours when truck is driving in average 80 km/h.

Delivery lead time

Delivery lead time is calculated from the time the order was totally manufactured to the time when order was delivered to the TOD location. This time frame comprises the time that was taken for the total delivery including all interim storage phases and all transport legs. There can be suppliers that do not have that stable delivery service, different transport modes are used for same country, material can spend different times in storage etc. Also, the time frame between the time when the order is ready from production and when the vessel will departure affect to delivery lead times significantly. There are only few days of vessel shipments per week which extends the delivery lead time if the order is produced on a date which does not fit perfectly to the vessel shipments.

5.6.2 Sustainability – CO2 emissions

From the sustainability perspective, CO2 emissions from transportation are the most important KPI. CO2e emissions are calculated by using following formula:

*Volume (ton)*Distance (km)*CO2e emission factor (g/tkm) = CO2e emissions*,

Where *volume* represents transported volume in tons for the transportation leg. *Distance* represents transported distance in kilometres. *CO2e emission factor* depends on the transport mode and most common equipment type in different geographical areas. Factors are industry average factors. Every leg of transportation is calculated separately and finally summarized together to get total CO2e emissions per transportation.

Biggest CO2 emissions per ton are from the farthest of Finnish mills and the farthest of Swedish mills, when smallest CO2 emissions per ton are from Polish mill. Small emissions of Polish mill are explained with the fact that Poland is located in continental Europe which means that it is closer to customers than other mills in Finland and Sweden are. Often, there is also no sea to cross in between to reach the customers which makes routes from Poland mills simpler. Polish mill has fewer transportation legs, mostly one but also two and three leg routes occur. Also, there is not that much used converters in the production chain or if is used, the used ones are located in Poland as well, which is not adding CO2 emissions assigned to these mills. When delivering from Sweden to continental Europe, first leg is very long which makes emissions increase. Northernmost mill in Finland also has bigger distance to continental Europe comparing for example other locations in Finland which increase emissions.

Road transports cause most of the emissions total and especially in the first three legs. The next most emitting form of transport is ship transport (MARITI). However, road delivery has significantly bigger CO2 factor, so it’s the most polluting mode of transport if not considering air since it has been used so little in Europe. Road is the most polluting transport mode but still very important mode of transport in Europe. There are some countries from and to where is not possible to deliver with train because of the different infrastructure or there are not possibilities to load wagons from some terminals. However, having multiple storage locations all the way from mill to customer and because of that having multiple transport legs, CO2 emissions increase by having these “unnecessary” movements within Europe. However, this is just sustainability point of view, and there are other factors that affect to store in many locations, for example cost aspect.

Detailed info of the most important customers’ CO2 emissions is handled in the quadrant chart approach, in the next chapter.

5.6.3 Quadrant chart approach of last leg lead time & CO2 emissions

CO2 emissions and last leg lead times are put into quadrant chart to find which customers’ deliveries are the winners and the losers. If customer is in the lower left corner, its’ deliveries are performing well on average. If customer is in the upper right corner, its’ deliveries are performing poorly, and there will be some issues that has to be fixed. On the other corners, there is one actor that is performing poorly and the other one is performing well. These kind of a situations needs improvement for poorly performing part.

Figure 16 below presents quadrant chart of A-class customers, which are the most important customers, with CO2 emissions and last leg lead times. Upper right corner includes poorly performing customers when lower left corner includes best performers. Target level for last leg lead time is 8 hours since it is the maximum driving hours to be able to provide 24h delivery service for customer. For CO2 emissions per tonnage is given 0.08 for a target value.

There are multiple factors affecting to last leg lead times. These factors are transport mode, distance between last storage location and the customer and supplier's performance. Customers whose deliveries performed poorly was taken into closer scrutiny. It turned out that there were considerable differences between the last leg lead times of the deliveries of the same customer. These differences were sometimes caused by the terminal that was used as the last storage location, and in this kind of a situation distance is determining factor. There were still situations where last leg lead times were varying even when delivering from the same terminal. The reason for this was for example usage of rail or road transportation. Rail is significantly slower option and has more variating lead times. Road delivery was stable, and the orders were delivered with hours. In some cases, there could have been effects on the used supplier, but relation is not clear. Shortest and longest last leg lead times used different suppliers. Within one supplier there were a lot of changes in delivery time even when delivering from the same location.

CO2 emissions per ton was evaluated as a part of this approach. What is common to these customers with bigger CO2e for ton is that they usually have multiple legs on the route of delivery. Even five legs are used, but more commonly four. Multiple legs compared to usage of most polluting transport modes, road, or sea, together form high CO2 emissions.

All in all, performance in terms of CO2 and last leg lead times are varying a lot and there are significant room for improvement.

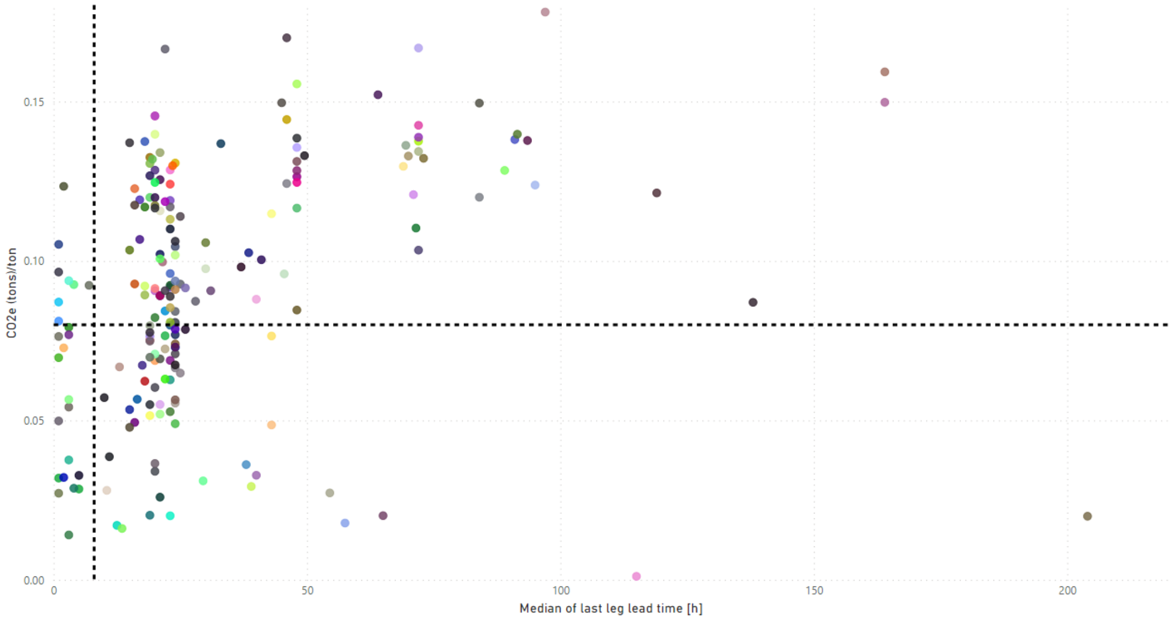


Figure 16 Quadrant chart of CO2e/ton and median of last leg lead time by A-class customers.

5.7 Conclusions of as-is scenario

The outbound logistics network in the case company is very complex and includes many different arrangements with different modes of transport and different routes, referring to many options of channels. The route for the specific delivery depends on the needs of the customer. In the simplest case, order is delivered directly from the mill to the customer. Still, in the most cases, orders are delivered via one or several storing locations, which are either ports or inland terminals.

There are altogether 64 ports and inland terminals in Europe without Finland, Sweden, Norway, and Iceland. This is a huge number of storage locations only for European orders. Even Germany alone, there are 17 storage locations. In a sum up, the terminal network is very wide, and in today's situation materials are stored very close to the customers. That is very good thing from customer point of view as large number of warehouses gives flexibility for the transportation. When the distance between customer and storing location is short, the customer is more likely getting orders in a shorter delivery time. However, it is not efficient to the organization to keep dozens of terminals close to the customers just for flexibility alone.

Terminal and port locations were classified into A, B, and C-classes to find out, which terminals are responsible for 80 % of the volume. It was discovered that there was a big number of C-class terminals, especially in Germany and in other places in the Central Europe. This means that these 17 terminals in Germany, are not important. Perhaps, there should be rather one or two bigger distribution centres in Germany instead of several small ones. Germany has large volume through all these terminals, but the volume could be centralized.

Customers were as well classified into most important A-class, using the same Pareto principle as for the terminals and ports. Mainly the most important customers are in the central Europe, but also in Spain and Italy. As a conclusion, central Europe needs bigger storage locations in the future.

There are differences in used storages between the mills even when they could use same storages. Differences are also between the product types, product group A and product group B. Product type differences can partly be explained with customer locations, but there are also old habits based on selections. Some product group B mills are also used to be paper mills, which is why they have kept their own habits on distribution. Old habits are also in the background of differences between Finnish and Swedish mills. These habits are not necessary to keep as there are not any limitations on possibilities to storage the specific type of the product in a specific terminal. Every product in any form, reel, or sheets or any product type, could be storage in any terminal on the network. That is why, streamlining the network is doable.

As-is scenario contained chosen KPI’s to represent service, costs, and sustainability. Lead time for service, handling and transport costs for costs and CO_2 emissions of transportation for sustainability. It was notable that several KPI’s indicate stable deliveries, while they are actually unstable. By streamlining the terminal network, deliveries could come more stable and delivery times more predictable. This would improve customer service and bring value to the company making service as competitive advantage. Corporate strategy urges to reduce CO_2 emissions. Removing “unnecessary” legs, especially on multi-leg routes, can reduce CO_2 emissions as well as improve service to customers.

Logistics costs are a difficult subject to analyse, as the quality of the data varies. However, actual last leg transportation costs can be considered reliable as well as standard pre carriage costs. Generally, the further material is delivered from mills, the more expensive transportation costs there are for direct deliveries. If customer is located closer to mills, it would be cost-efficient to include direct deliveries as a transportation mode in addition to vessel deliveries.

6 Network scenario analysis

In this chapter, Centre of Gravity analysis and Network Design Optimization are implemented. Different possible future terminal network scenarios will be presented with new network design, including possible KPI's generated from each new network setup. Chapter also includes comparison of presented new network scenarios and suggestion for the optimal one.

6.1 Centre of Gravity analysis

Centre of Gravity (CoG) utilizes locations of each customer and their demand. Annual (1.9.2021-31.8.2022) delivered quantity in tons is used as a demand giving weight for the customer. CoG calculates the optimal warehouse location using weight and customer location. CoG analysis is implemented by using Log-hub Supply Chain (SC) app.

CoG is a great tool to find optimal location for warehouse based on the customers location and demand, but it does not take into account any costs or other important aspects for network design.

For this research, CoG analysis was made for A-class classified customers. Since, A-class customers are responsible for 80 % of the demand, they are important to be taken into account when determining the network design. Other research limitations made were limitations to the volumes delivered from mills to customers without converters. Volumes that are delivered to the converter in continental Europe, are included in the analysis. Then converter is considered as customer.

CoG was implemented for ten scenarios. Since the analysis is based only on customer demand and location, the choices have been made based on these factors. In order to serve customers well, the delivery takes place no later than the next day after customer order. 600 kilometres is used as a standard value when estimating the distance. The value is based on the assumption of driving speed of 80 km/h and maximum driving time of 8 hours per day, after which driver must take a longer break. If driving time is less than 4 hours, possible driving distance is estimated to be 300 kilometres, and then order could be delivered within the day of customer request. Next day delivery can be achieved, when driving distance is maximum 600 kilometres between the last storing location and the customer. That makes approximate last leg lead time to be from 4 to 8 hours, which appears to customers as 24 hours delivery service. Since CoG is based on linear distance and standard value of 600 kilometres is road distance, 25 % of linear distance has been added to the CoG result distance value. This way the distance between the customer and warehouse corresponds as closely as possible to road level distance. With plus 25 % rule, 600 kilometres in road distance is 480 kilometres in linear.

In the Figure 17 below, relation between number of centres and percentage of customers served with 24 hours delivery is illustrated. As can be seen, until the point of three centres, percentage of customers served is increasing remarkably all the way up to be 90,91 %. After the point of three centres, a slight dip occurs which after small increase is visible again. After fifth centre, which seems to be optimal, the percentage will remain the same until eighth centre. The biggest percentage of customers served with 24h delivery service is with 9 centres, when percentage is 95,45 %. To be able to serve 100 % of customers with 24h delivery service, there should be bigger number of centres in a central and Eastern Europe. This is not desirable.

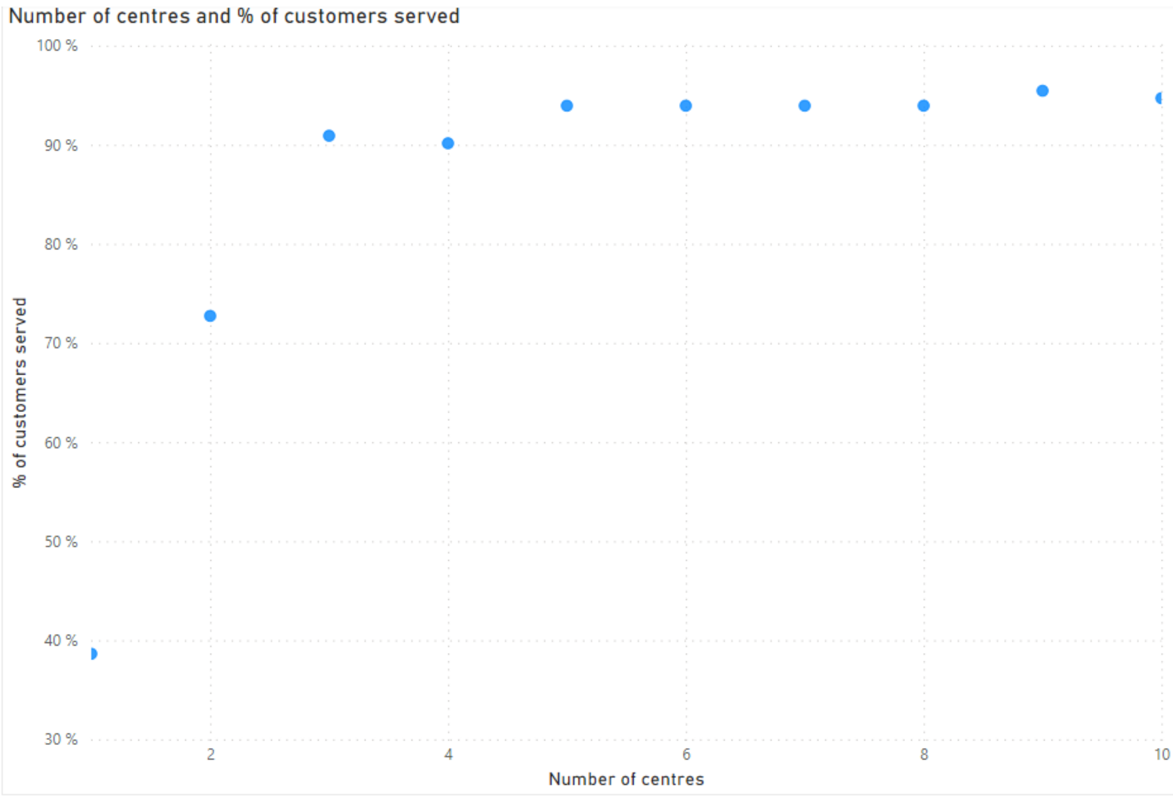


Figure 17 Relation between number of centres and % of customers served.

A point worth noting is that the results represent a situation where the warehouses are ideally located purely based on the demand and distances between customer and centre. In a real situation, the results may not correspond exactly to what was represented because of the available existing inland terminal locations and transportation infrastructure.

6.2 Scenario analysis

Scenarios for the network design optimization was chosen mainly based on the CoG analysis results. Some additions had to be made regarding entry into continental Europe by sea from Finland and Sweden. Taking these things into account, networks with 4, 6 and 9 distribution centres were selected as scenarios.

The scenarios were made using two different transportation scenarios. There are also scenarios for cost and service driven solutions. Transportation scenarios are the following:

1. All volumes are delivered from Finland and Sweden by liner vessels. Polish volumes are delivered as they have been delivered now, which is either directly to the customer or via interim storage.

2. Direct delivery volumes delivered as they have been delivered, and rest of the volumes from Finland and Sweden are delivered by liner vessels. Polish volumes are delivered as they have been delivered, which is either directly to the customer or via interim storage. If there were specific inland terminals used in direct deliveries, that are not included in the network scenario, those were changed to closer ones within the network. If the inland terminal was found in the scenario, the same one was still used.

Cost and service driven scenarios are the following:

1. Cost driven: Data run without defining warehouses to each customer. Zeebrugge defined as a port for Swedish volumes, but for Finnish volumes port was not defined. Optimization tool gives cost optimized result.

2. Service driven: Data run with defined warehouse for each customer. Warehouse was chosen based on the CoG result or the closest one. Zeebrugge was defined as a port for Swedish volumes, but for Finnish volumes port was not defined. Distance between last leg inland terminal and customer was considered primary as a condition for the result. By choosing the closest inland terminal for the customers, the shortest possible last leg lead time is guaranteed in a network. Optimization tool gives cost optimized result based on these conditions.

An average of standard pre carriage €/ton by mill and discharging port was used because it was not in the scope of this research to define which ports or transport modes should be used in Finland or Sweden. Also, for CO2 emissions, average of CO2e (kg) /ton was used, and same division for rail and road transportation in Finland and Sweden as in a current situation. That is how more comparable values could be obtained. Last leg lead times were calculated based on the driven kilometres and to an assumption that truck drives 80 kilometres per hour. Averages represents driving hours and does not consider longer breaks. Maximum driving hours for one driver is 8 hours per day.

The presented last leg lead times were calculated as weighted averages, using volume (tons) as a weighting factor. In this way, the most important last leg lead times have the greatest impact on the performance of the entire network.

The presented delivery lead times are numbers of the best possible situation, when the transport proceeds seamlessly without additional waiting in the port or in any inland terminal. In order to achieve the best possible level of delivery lead time, the total manufacturing day of the order should be as close as possible to the vessel's closing date, also the order would not delay from the shipment and there should be enough transportation capacity on the vessel. If the closest shipment date will not be reached in a day, there might be wait up to a week for the next ship departure. However, to be able to optimize transportation between manufacturing date and vessel shipment, it would require closer study to the manufacturing cycles which is outside of the scope of this research. Delivery lead time is for the deliveries that are transported by liner vessels from Finland and Sweden, because completely direct deliveries remain the same as in a current network when direct deliveries are used. Theoretically, using the best possible delivery lead time tells the ability of network's performance, even if in a reality, deliveries are affected by multiple factors. Delivery lead times are presented as weighted values.

6.3 Scenario 1 – 4 distribution centres

Four distribution centres were selected as the first network scenario. Three of the distribution centre locations were based on the existing inland terminal locations near by the centre points from CoG. One additional distribution centre location was selected based on the high usage in the existing network and based on the need for additional port location in continental Europe.

Two port locations are Zeebrugge in Belgium and Travemünde in Germany. Another two inland terminals for the scenario are Verona in Italy and Teresin-Gaj in Poland.

6.3.1 Network design – 4 distribution centres

In this subchapter all four scenarios for four distribution centres are presented with KPI's and material flows illustrated in a map.

Cost driven solution – transportation scenario 1

Cost driven solution was based purely on transportation costs and handling costs at warehouse. In this scenario, all volumes from Sweden and Finland are delivered into continental Europe by liner vessels. Only Zeebrugge as a port was defined for the Swedish volumes since liner vessel delivery from Sweden to Travemünde is not possible. Otherwise, network design optimization tool decided port for each customer based on the most cost optimal solution. All four ports and inland terminals were defined as fixed which means that optimizer tool calculates the most cost optimal solution while having four distribution centres in a network. Both ports are distributing material to both of the inland terminals which distribute material further, but mainly to the customers that are located in the same country as inland terminal. Most of the deliveries are delivered from ports, Zeebrugge and Travemünde, to the customers. If customer is located in Eastern Europe, last leg lead time increases very long and that way these customers cannot be served with 24h delivery service. Average of last leg lead time in driving hours in this scenario is 6,85 hours. At its best, average of total delivery lead time is 6,27 days. Getting to this level requires seamless transportation without any waiting at the port. Delivery service is in a low level in this scenario, but cost aspect instead is better. In general delivery process will shorten in case of some customers when majority are delivered directly from port. Long last leg lead time and distance will most probably have an impact in customer satisfaction surveys. In worst case this might lead to loss of customers. In some cases, especially in Germany, Poland and Italy, last leg lead times remain short, and those customers will be better served in this scenario. CO_2 emissions are high in this scenario. When delivering by liner vessels, CO_2 emissions arise high since it is the most polluting sea delivery option. However, if these ports are desired with increase liner vessel deliveries, increase of CO_2 emissions is expected.

Cost driven solution – transportation scenario 2

This scenario is cost driven as well, but the part of the deliveries earlier delivered directly from mill to the customer, or by truck via interim storage, will remain that way. In that case, network design optimization tool did not take into account those customers or shipments that were not delivered by liner vessels. This changed material flows within Europe and from Zeebrugge port, nothing will be delivered to inland terminals, whereas from Travemünde, material will still be delivered to Teresin-Gaj and Verona. If this scenario is compared to the one with transportation scenario 1, total logistics costs are 14 % smaller in this scenario. Based on this, if costs savings are desired, part of the volumes should be delivered with direct trucks, especially, when talking about central and eastern Europe. Last leg lead time decreased in this scenario compared to transportation scenario 1, because of the reduction of long delivery times from ports to customers. Average of last leg lead time in driving hours is 5,91 hours. Average of total delivery lead time is at its best 6,41 days. CO2 emissions are high in this scenario as well, but still 5,4 CO2e (kg) lower than in transportation scenario 1. The difference arises from the fact that the transport distance of direct trucks is shorter and more linear than transport by ship, which allows emissions to decrease. Also, some of the direct deliveries were made with multimodal or rail transportation which has remarkably lower CO2 factors than in sea or international road delivery. When delivering all volumes by liner vessels, it is not possible to utilize other modes of transportation that much.

Service driven solution – transportation scenario 1

This scenario is a service driven solution when all volumes from Finland and Sweden are delivered by liner vessels to the continental Europe. Both ports, Zeebrugge and Travemünde distribute material to both inland terminals. Network is also more structured, and customers can be provided with more accurate information about delivery time. However, logistics costs increase because handling costs will increase by using more inland warehouses. In this service driven scenario average last leg lead time in driving hours is 4,85 hours. This means that for most customers, material could be delivered at the latest next day if they have called off their order until 12 p.m. Some of the orders can be delivered even during the same day when customer call offs the order. Driving time should be then maximum four hours, in order that same day delivery could happen. Average of total delivery lead time as its best is 6,55 days. Getting to this level requires seamless transportation without any waiting at the port. CO2 emissions are also high in this scenario and even higher than in corresponding scenario with cost optimal solution. This is based on the fact that truck deliveries increase along with transportation leg increase. This phenomenon is in line with the findings of the as-is analysis regarding CO2 emissions.

Service driven solution – transportation scenario 2

This service driven solution is otherwise the same as one before, but those volumes that has been delivered directly from mill to customer, or by trucks via interim storage, will remain the same than in as-is situation. Network design is the same excluding those customers' material flows that has been used only direct deliveries before. Delivering part of the orders by direct trucks logistics costs even 18 % smaller compared to service driven solution with transport mode scenario 2. Average of last leg lead time in driving hours is 5,24 hours. Average of total delivery lead time as its best is 6,67 days. Including direct deliveries to material flows and network, it will decrease CO2 emissions even by 8M CO2e (kg) if compared to corresponding scenario with transportation scenario 1. It is because rail and multimodal transportation modes arise, and they have significantly smaller CO2 emission factors. Even if international truck deliveries have the biggest CO2 emission factor, total transportation distances will shorten which decreases total CO2 emissions as well.

6.4 Scenario 2 – 6 distribution centres

In a scenario 2, 6 distribution centres are used in a network design. Ports in Zeebrugge, Belgium and Travemünde, Germany were chosen to be ports as well as distribution centres like in the scenario before. Other distribution centres are Teresin-Gaj in Poland, Budabest in Hungary, Weingarten in Germany, and Balsorano in Italy. There are not any distribution centres in use in Balsorano currently, so Balsorano mill is used as an example location in that part of Italy for the possible distribution centre. That decision was made to be able to calculate possible transportation costs for notional distribution centre. Also, handling cost level for the possible distribution centre in Balsorano is unknown, which is why same handling cost was used as in Verona. However, actual handling cost in Balsorano is presumably lower than in Verona.

6.4.1 Network design – 6 distribution centres

In this subchapter all four scenarios for six distribution centres are presented with KPI’s and material flows illustrated in a map.

Cost driven solution – transportation scenario 1

First scenario for six distribution centres is cost driven and all volumes from Finland and Sweden are delivered by liner vessels. Cost driven solution includes all six distribution centres and optimization tool has pointed all customers for each distribution centre in the most cost-optimal way possible. Most of the material flows are distributed directly from ports to the customers. Only small number of customers are served from inland terminals. Numerically, Balsorano distribution centre would serve smallest number of customers, only five, which is why it might not be reasonable have it in a network desing. Since inland terminals are not used much for the distribution, last leg lead times are remarkably high.

Average of last leg lead time in driving hours is 6,01 hours. Average of total delivery lead time as its best is 6,36 days. Getting to this level requires seamless transportation without any waiting at the port. From the delivery service point of view, this scenario is performing poorly. CO_2 emissions are also high because all volumes are delivered by liner vessels and driving distances are long within continental Europe.

Cost driven solution – transportation scenario 2

This scenario is cost driven as well, with only defined port for Swedish orders. Also, part of the deliveries that has been delivered directly from mill to the customer, or by truck via interim storage, will remain that way. Material flows from Travemünde port remain same as in the transportation scenario 1, but material flows from Zeebrugge port will be a bit different. When in transportation scenario 1, Zeebrugge port distributed to all inland terminals, now it is distributing only to Budabest and Balsorano. Costs are 13 % smaller compared to transport mode scenario 1, when delivering part of the orders via land or completely directly. So, in case if costs are wanted to save even more, direct deliveries should be kept in a network and material flows. Average of last leg lead time in driving hours is 4,60 hours. Average of total delivery lead time as its best is 6,50 days. CO_2 emissions decrease by 7,5M CO_2e (kg) in this scenario compared to corresponding with transportation scenario 1. This is based on the facts of using other transport modes than truck and vessel, also more linear and shorter transportation distances were used by truck as explained in a corresponding situations above.

Service driven solution – transportation scenario 1

This scenario is executed by defining specific distribution centers for each customer and is that way a service driven solution. All volumes from Finland and Sweden are delivered by liner vessels. Material flows in the network are more structured and better service can be provided to the customer. Zeebrugge port is distributing to all inland terminals whereas Travemünde port is distributing all except Balsorano. This scenario solution is more expensive than the comparable one with cost driven solution, even 12 %. Average of last leg lead time in driving hours is 3,34 hours, which is very good. That means that even bigger amount of volume could be delivered during the same day customer call off their order from the warehouse. Average of total delivery lead time as its best is 6,98 days. CO_2 emissions are high in this scenario as well but only 1,4M CO2e (kg) higher than corresponding scenario with cost driven solution. However, CO2 emissions are the highest of all analyzed scenarios.

Service driven solution – transportation scenario 2

This scenario is solution driven like the one before. Only those customers whose orders are delivered from Sweden are defined to use Zeebrugge as a port. Port was not defined to those customers whose orders are delivered from Finland as liner vessels can be discharged both in Zeebrugge and Travemünde. In addition, for every customer there is defined distribution center from which their orders are being delivered. In this scenario part of the deliveries that has been delivered idirectly from mill to the customer, or by truck via interim storage, will remain that way. Average last leg lead time in driving hours in this scenario is 3,20 hours, which is a very good value as well. Average of total delivery lead time as its best is 6,67 days. Compared to other service driven solution with six distribution centers, this solution has even 18 % smaller costs. Also, CO2 emissions are 7,9M CO2e (kg) smaller than in corresponding scenario with transportatio scenario 1.

6.5 Scenario 3 – 9 distribution centres

In a scenario 3, 9 distribution centres are used in a network design. Ports in Zeebrugge, Belgium and Travemünde, Germany were chosen to be ports as well as distribution centres like in the scenarios before. Other distribution centres are Teresin-Gaj in Poland, Kokotow in Poland, Budabest in Hungary, Weingarten in Germany, Limburg in Germany, Verona in Italy, and Balsorano in Italy. As in the six distribution centre scenarios above Balsorano mill is used as an example location in that part of Italy for the possible distribution centre to be able to calculate possible transportation costs. Also, handling cost level for the possible distribution centre in Balsorano is unknown, which is why same handling cost was used as in Verona. Actual handling cost in Balsorano is presumably lower than in Verona.

6.5.1 Network design – 9 distribution centres

In this subchapter all four scenarios for nine distribution centres are presented with KPI’s and material flows illustrated in a map.

Cost driven solution – transportation scenario 1

First scenario for nine distribution centres is cost driven and all volumes from Finland and Sweden are delivered by liner vessels to the continental Europe. Cost driven solution includes all nine distribution centres and optimization tool has pointed distribution centres for each customer in the most cost-optimal way possible still retaining all distribution centres. Only those customers whose orders are delivered from Sweden are defined to use Zeebrugge as a port but otherwise there are not any rules used to calculate network. Zeebrugge port will distribute material to all inland terminals except one, Weingarten. Travemünde will distribute all except Limburg and Balsorano. In this scenario, network includes several inland terminals that are not distributing material to many customers because it is not the most cost-optimal way. These are for example Kokotow, Weingarten and Balsorano. So, if this would be the scenario utilized, those inland terminals might not be that important to keep in network, and then the number of distirbution centres would decrease to six. Average of last leg lead time in driving hours in this scenario is 5,25 hours, which is quite good for the cost optimized scenario. Average of total delivery lead time as its best is 7,84 days. Level of CO2 emissions is still high as it is in all the other earlier scenarios as well.

Cost driven solution – transportation scenario 2

This scenario is cost driven as well, with only defined port for Swedish orders. Also, part of the deliveries that has been delivered directly from mill to the customer, or by truck via interim storage, will remain that way. Travemünde port distributes all inland terminals except to Limburg and Balsorano and Zeebrugge port distributes only to both of the Polish inland terminals and Budabest, Verona and Weingarten. This scenario is the most cost-efficient one and has even 16 % lower costs than the corresponding cost driven scenario where all volumes are delivered by liner vessels. Average of last leg lead time in driving hours is 4,31 hours. Average of total delivery lead time as its best is 7,85 days. CO2 emissions are the lowest in this scenario as well. The decrease in CO2 emissions was achieved by maximized direct transport, including low emission transport modes.

Service driven solution – transportation scenario 1

In this service driven solution, all volumes from Finland and Sweden are delivered by liner vessels to the continental Europe. In a service perspective network design, last leg distance is considered as a priority, and for each customer are defined distribution centre based on the CoG analysis or otherwise closest. Only for Swedish volumes were defined utilized port, which is Zeebrugge. Otherwise, optimization tool decides the most cost-effective port for customers. Distribution centres are close to customers. Zeebrugge port distributes to all of the inland terminals, whereas Travemünde distributes all except Limburg and Balsorano. Average of last leg lead time in this scenario in driving hours is 2,72 hours, which is very good average, the best of all scenarios. That means that more and more volumes could be delivered even within the same day from their call-off. Average of total delivery lead time as its best is 7,81 days in this scenario. Logistics costs are 7 % higher than in corresponding transportation scenario with cost driven solution. CO2 emissions are 3,5M CO2e (kg) higher as well when compared to corresponding transportation scenario with cost driven solution. Truck deliveries and kilometres increase in this scenario which explains CO2 emission increase.

Service driven solution – transportation scenario 2

This scenario is solution driven like the one before. Only those customers whose orders are delivered in Sweden are defined to use Zeebrugge as a port. In addition to that, for every customer is defined distribution center from which their orders are being delivered. In this scenario part of the deliveries that have been delivered directly from mill to customers, or by truck via interim storage, will remain that way. If logistics costs are compared to service driven solution with transport mode scenario 1, with delivering part of the volumes by truck directly to the customer or via interim storage, costs would be 16 % lower. Also, material flows are divided a bit different than in transport mode scenario 1. Zeebrugge port would be distributing to Teresin-Gaj, Limburg, Budabest and Balsorano, whereas Travemünde port would be distributing to Teresin-Gaj, Kokotow, Budabest, Weingarten and Verona. Avergae of last leg lead time in driving hours is 2,88 hours, which as well is very impressive. Average of total delivery lead time s its best in this scenario is 8,14 days. CO2 emissions are even 8,7M CO2e (kg) lower in this scenario than in service driven solution with transportation scenario 1.

6.6 Comparison of scenarios

Logistics costs, including transportation cost and handling cost, last leg lead time and delivery lead time as well as CO_2 emissions for each scenario were calculated and evaluated. From the Table 2 below, can be seen percentage of change for each scenario and how they are compared to the current network values.

If costs are considered in general, it can be shown that with this limited area in Europe, costs decrease when direct deliveries are involved in a scenario. The closer customer is to Finnish and Swedish mills, the cheaper it is to deliver with direct trucks. This concerns especially central and eastern Europe customers, whereas, for example, to Italy and France, it is more expensive to deliver with direct trucks than via liner vessels.

In general, it can be shown that service driven solutions have better last leg lead times than corresponding scenario with cost driven solution. Percentage of customers served with 24h delivery service is also remarkably higher with service driven solution. It can be also seen that increasing the number of distribution centres, average of last leg lead time in driving hours decreases. Based on that the more distribution centres there are, the closer it is possible to get to the customer. Target company's customers really value service and company's ability to be close to its customers. Still, delivery times are an important thing that customers have asked for improvement. Closeness to customers is preferred to remain even if the number of terminals is reduced. Since the target company wants to provide its customers high level service and customers also value that, it should be clear to prioritize it. High level service in logistics, will give company competitive advantage as well as create value both the company and the customers. Based on that, target company should invest in service even if it would momentarily increase costs.

Table 2 compares current network KPIs to scenarios that were explained above. Unfortunately, costs increase in all scenarios. However, the more distribution centres there are in the network, less the costs increase. The biggest increase in costs is 47 % for service driven solution with transportation scenario 1 in the network of four distribution centres. The smallest increase of costs was 10 % for cost driven solution with transportation scenario 2 in the network of nine distribution centres. The increase in costs may be partly affected by the quality of the data and estimates of the costs of certain transport legs that were not previously used in the network. However, the increase in costs is very much in line with the theory. Smaller the number of facilities, the higher are transportation costs. When network does not have fixed warehousing costs, only variables, there are not facility or inventory costs to reduce in the network. Those costs would decrease while decreasing number of facilities. However, in all of these scenarios, volumes have been centralized to fewer number of distribution centres which gives target company bargaining power over costs in distribution centres. That way cost reducing is possible in handling costs in a long run.

Service aspect, last leg lead time, improves in every scenario even if the solution of the scenario was cost driven. By transporting orders close to customers and leaving optimally placed distribution centres in the network fast delivery service is enabled. In the current network, warehouses in Finland were used as a call-off warehouses for some customers in Italy and the one in Ukraine. However, this kind of procedure does not guarantee good delivery service since it is way more difficult to estimate delivery time when driving distance is long and delivery time from call-off is long as well. Also, it is not an option to deliver from Finland to Ukraine by truck via Russia anymore since transportation across Russian should be evaded. The biggest improvement in last leg lead time is 61 % in service driven solution with transportation scenario 1 in the network of nine distribution centres.

No clear pattern of behaviour in delivery lead times can be observed when comparing the number of distribution centres in network. However, delivery lead times increase clearly when there are nine distribution centres in network. Reducing the number of distribution centres does not affect negatively to delivery lead time. It is more about which locations will remain in the network.

CO2 emissions increase in all scenarios as well, but the increase is smaller than costs increase. The increase is smaller with those scenarios that includes direct deliveries. Those scenarios are also less polluting than corresponding scenarios where all volumes are delivered by liner. Route is more straightforward and less kilometres which decreases emissions. Also, train deliveries and multimodal deliveries were used much more in these scenarios than in the scenarios where all volumes were delivered by liner vessels. Train and multimodal transport modes are way less polluting modes of transportation than liner vessel and truck.

Table 2 Comparison of network design scenarios.

Scenario	Logistics costs total €	Delivery lead time [d] liner vessels	Last leg lead time [h]	CO2 emissions
4 DC - cost driven, transportation scenario 1	36 %	4 %	-1 %	19 %
4 DC - service driven, transportation scenario 1	47 %	9 %	-30 %	22 %
4 DC - cost driven, transportation scenario 2	16 %	7 %	-15 %	13 %
4 DC - service driven, transportation scenario 2	21 %	11 %	-25 %	13 %
6 DC - cost driven, transportation scenario 1	31 %	6 %	-14 %	21 %
6 DC - service driven, transportation scenario 1	46 %	16 %	-52 %	22 %
6 DC - cost driven, transportation scenario 2	14 %	8 %	-34 %	13 %
6 DC - service driven, transportation scenario 2	19 %	11 %	-54 %	14 %
9 DC - cost driven, transportation scenario 1	31 %	30 %	-24 %	17 %
9 DC - service driven, transportation scenario 1	41 %	30 %	-61 %	21 %
9 DC - cost driven, transportation scenario 2	10 %	31 %	-38 %	8 %
9 DC - service driven, transportation scenario 2	18 %	35 %	-59 %	11 %

All in all, the more distribution centres there are in the network, the smaller costs are, and the better last leg lead time can be provided to the customer. Of course, solution type, cost or service driven, also affects to the last leg lead time, so it can be worse in cost driven solution with multiple distribution centres than in service driven solution with fewer distribution centres. CO2 emissions does not have a clear rule how they behave when number of distribution centres are increased. However, when direct deliveries are increased, CO2 emissions decrease at the same time.

7 Results and conclusions

The first goal was to find out, what is the structure of the current outbound logistics network and how it is performing. Current network has remarkably high number of ports and inland terminals which causes spreading of volumes across the Europe. This makes logistics hard to control. Also, not all mills utilize the same ports and inland terminals even if material is transported from the same country. This affects to customer promise of last leg lead time, because even many of the biggest customers order products from different mills and even from different countries. Even the same customer might be served unequally if the products are produced in different mills or countries.

What comes to logistics costs, the current logistics network is mainly designed to them minimize costs. As network design theoretical framework presents, until certain point, logistics costs decrease the more facilities are in the network. And when the network does not have much fixed warehousing costs, reducing them does not save so called facility costs. If direct deliveries from mill to customer are compared to transportation via liner vessel, there is following location-based behaviour. If customer is located in eastern or central Europe, direct delivery would be cheaper, but the further west or south of Europe it is transported, the more expensive direct transports become.

More detailed research limitations were made for the network scenario analysis. First volumes were limited to consider Europe without Great Britain and Turkey, as focus is set on continental Europe. After that, volumes were limited only for the volumes, that did not use converter in Finland or Sweden. These are so called finished products. However, volumes that were delivered to the converters in continental Europe were considered in analysis as they have their own order numbers and converters are internal customers for the target company even if these products are not technically finished. After limiting the volumes to that, ABC-analysis were made for the customers to be able to define the most important ones. A-class, 80 % of the volume, was taken as the group to be analysed. For the network scenarios, limitations were still made geographically. Spain, Portugal and Greece were limited from the analysis since they are considered as separate cases from the other part of continental Europe.

Network scenario analysis started with Centre of Gravity analysis which was based on demand and location of the most important customers. In other words, network design and performance were analysed from the customer service point of view first. Customers value the location of warehouses and service is seen as one of the most important strategic factors in the target company. Centre of Gravity analysis was made for one to ten centres since target company truly wants to reduce the number of facilities in continental Europe to improve management and to provide more stable delivery to the customers. Centre of Gravity results were analysed by calculating level of how big part of the customers were able to be served with 24h delivery service. Results from Centre of Gravity analysis indicates that it is possible to reach even 90,91 % level in 24h delivery service only with three centres, if they are located ideally. The maximum level was reached with nine centres, when the level was 95,45 %. However, in reality, it is not possible to achieve the same results. To be able to serve all customers with 24h delivery service, it would require remarkably more centres in a network, which then would not correspond with the idea of significant terminal reducing. Based on the Centre of Gravity analysis and considering entering the continent by vessels, four, six and nine distribution centre scenarios were chosen to be analysed more detailed.

In a network scenario analysis, Network Design Optimization tool from Log-hub was utilized to find the most cost optimal network solutions. Decision was made based on the costs inland, so the tool did not consider liner vessel costs.

In this analysis scenarios were made for four, six and nine distribution centres. In addition, two different scenarios related to the optimization solution method were made. These are cost driven and service driven solutions. In both solutions, only Zeebrugge was defined as a port for Swedish volumes since sea delivery to Travemunde is not possible for Swedish volumes. For Finnish orders, the optimization tool decided the most cost-optimal port since liner vessel delivery from Finland is possible to each port. In a cost driven solution, other definitions were not made. In a service driven solution, definitions for ports were same as in cost driven solution, but distribution centre was defined for each customer. That way optimal distance between customer and distribution centre was ensured. The optimization tool calculated the most cost optimal solution based on these definitions. In addition, two different scenarios of transportation were combined to each cost and service driven scenarios. Transportation scenario 1 is the situation where all volumes from Finland and Sweden were delivered by liner vessels to continental Europe. Polish volumes were delivered as they have been before. In transportation scenario 2, all volumes that were delivered directly from mill to customer or by truck via interim storage to customer were delivered as they have been before. All the other volumes from Finland and Sweden were delivered via liner vessels. Polish volumes were delivered as they have been before. Altogether, 12 scenarios were made and analyzed.

Overall, in all scenarios, logistics costs increased. The more distribution centers were in the network, the less logistics costs increased. This is in line with the theoretical approach of how transport costs behave in relation to number of facilities in network. However, cost increase was not as big when part of the volumes was delivered directly to the customer from Finnish and Swedish mills or partly directly when they were delivered by truck or train directly to the interim storage. Based on that note, performance is more cost-optimal when direct deliveries are used especially when network is limited to this scope.

CO2 emissions increased as well in all scenarios, but significantly more in those where all volumes were delivered by liner vessels. Scenarios where direct deliveries were included, CO2 emissions did not increase as much since these scenarios included more multimodal and rail deliveries which has significantly lower CO2 factors. Delivered kilometers were also less in these scenarios, which also affects the amount of CO2 emissions.

The service aspect instead improved in all scenarios. At worst the last leg lead time improvement was 1 %, and at best it was 61 %. In all scenarios, the best improvements were obviously in service driven solutions. The best result, 61 %, was in service driven solution with transportation scenario 1 in the network with 9 distribution centers. The more distribution centers there are, the closer we get to the customer and the better delivery service can be offered to the customer. It is remarkable that better last leg lead times can be offered with smaller number of distribution centers than before if they are wisely located to match customers location and demand. So, in conclusion, the network does not need dozens of inland terminals to be able to serve customers well.

Delivery lead time did not improve in any new scenario. At a minimum, the increase was 4 %, when at a maximum it was 35 %. This is partially explained by the fact that only two ports in continental Europe were used in the scenarios, which increased the delivery lead time of some deliveries due to the absence of the Polish ports in the network. The increase in delivery lead times cannot be explained by the reduction of distribution centers, as the smallest increase occurred in the scenarios of four distribution centers. However, this is an important consideration, because reducing the number of distribution centers does not in itself affect the increase in delivery lead time, but which warehouses or ports are left in the network.

Even if many of the KPI’s did not improve, the network can be seen to have improved in terms of service for any scenario. At the same time, it creates value for both the customer and the company when the delivery service is at good and improved level.

To be able to make decisions about redesigning the network with the idea of improving network performance, some further research should be executed in the future. However, in this research, valuable information has been gained in relation to how certain metrics behave when the number of distribution centers is decreased significantly. As in this study, probably even after further studies, when decisions are made about the implementation of a new network, compromises must be made regarding the performance of the network. As can be seen, by improving service level, other aspects may not improve at all. And conversely, when the cost and emission perspective is improved, the service does no improve that much. It is about finding the right balance between metrics and deciding which metric to improve at the expense of other metrics.

In the future research, there are numerous options to develop network design and optimization research in the same area. First of all, now the range of customers and volumes were limited quite strictly, so in the future, if more detailed results are desired, should all customers take into account as well as outbound volumes from converters. However, in an early phase of this research, CoG analysis was made for all customers and volumes within the Europe and results from that analysis were quite close to each other even if number of customers were totally different. Because volume of each customer counts in this kind of an analysis, it might not give huge differences to the analysis, but might be worth to try if more detailed results are desired.

In the future would be important to clarify exact close to the truth transportation costs for the transportation legs that have not used before in the target company. Same should be done with handling costs for the inland terminals that does not exist in a network at the moment. In this research rough estimations were used based on handling cost in a same country or based on the € per kilometre of closest transportation leg. Lack of right cost data might have affected the results even remarkably, which is why in the future real costs should be clarified with suppliers by sourcing team.

As stated in the research, trucks have the highest CO2 emission factor, which is why utilization of other transport modes should be thought. Multimodal and train as a transport mode are significantly less polluting transport modes. Also, possibilities to utilize electronic trucks should be studied. Direct trucks might be in some cases cheaper and faster option but also more polluting. Which factor is preferred to highlight in the future?

Network design research should be expanded more widely in the future. Mediterranean areas were not researched in this study but should be in the future, especially Spain and Portugal. There were left out many possible existing inland terminal locations that could have been chosen instead of the ones that were chosen in this research. In the future, if more possibilities are desired to research, other locations could be chosen and then compared if cost level would be more beneficial. Service level might not even change that much. Interesting would be also, what happens if used ports are not always Zeebrugge and Travemünde, but some others instead. With the scope of this study, it was not possible to find out every possible terminal and port location and effects of using one instead of another one.

Also, things related to competitive, macroeconomic, political, and infrastructural factors should be examined in the future. These things have an effect on network performance and possibilities to company succeed.

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