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Container Yard as a Complementary Warehousing Strategy

A Case Study Analysing the Implementation of a Container Yard at Northvolt

Master's thesis in in Supply Chain Management

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ABSTRACT

As society transitions from the use of fossil fuel towards electrification, a large volume of lithium-ion battery cells is demanded. An actor aiming to help meet this demand is Northvolt, a manufacturer of lithium-ion battery cells planning to commence large-scale production at the end of year 2021. As production volumes will rapidly grow over the years, the current warehouse capacity is projected to be exceeded by 2024. Northvolt thus face a decision to either expand the warehouse or implement a container yard to complement the warehouse in material storage.

This study aims to analyse the viability of complementing the current warehouse with a container yard, an intermediary storage point for inbound containers carrying raw material. The study provides a case example for manufacturing companies situated in similar situations of reduced storage capacity with a large inflow of raw material in shipping containers. Moreover, a deeper look into which ownership structure of a potential container yard would be most viable for Northvolt. Three potential solutions are evaluated: the in-house, the hybrid and the outsourced solution. They are evaluated from a strategic, tactical, and operational perspective using both qualitative and quantitative data.

The report concludes that a container yard is a viable complementing solution to a warehouse, from a high-level financial perspective. It further concludes that the most viable ownership structure of a container yard is the outsourced solution with minor adjustments in what is called the buffer chassis yard. This is a solution where container chassis for transport are parked in a buffer area outside the port ready to be picked up by transporting trucks.

Keywords: Container yard, strategic decision making in supply chains, container handling, inbound container flow, container terminal design.

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Carl Christensen & Robert Ellis, June 2021. Chalmers University of Technology

Carl Christensen

Robert Ellis

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1 Introduction

Below a general background and introduction to the problem at hand will be described followed by the aim of the study, specifications of issue under investigation, company description, and the research questions of the study. The chapter is concluded by the limitations of the research.

1.1 Background

The painful truth about warehousing – across all industries and geographical markets – is that most companies do not really know what their true costs should be. Worldwide, warehousing operations cost companies about €300 billion each year, and that amount is growing as global supply chains lead to greater complexity (Herrman, 2019). Increased competition in the global market, changing customer demands, and shorter product lifecycles have forced companies to focus on their supply chain. In many industries, inventory is a dominant costs (Richards, 2014).

Traditionally, production companies have warehouses for storing raw material before moving it to production. Warehousing is becoming a more critical activity in the supply chain to outperform competitors on customer service, lead times and costs (Faber, de Koster René, & van de Velde Steef, 2002). Building a warehouse, with the function of storing numerous materials needed for production raise challenges regarding multiple factors such as optimal service level, turnaround time and tied up capital to mention a few. This practice is known as inventory management. Inventory management is an important practice for companies to improve the management of stocks, increase profit and satisfy customer as well as supplier needs. The numerous benefits enjoyed by different stakeholders show that inventory cannot be overstated because it offers operational longevity and efficiency (Gills, Thomas, McMurtrey, & Chen, 2020).

As global demand for batteries increase, which perhaps can be best shown by the global 41% increase in registration of electric vehicles in 2020, according to IEA (2021), the demand for better inventory management naturally would follow. Handling this increase would arguably benefit from adapting modern strategies where innovative solutions are applied. Raw material for production of batteries contains several different components and arrive in large bulks. Handling these large, seemingly increasing volumes, creates issues for any large-scale manufacturer of lithium-ion batteries.

The overall problem for a manufacturer is how to coordinate activities such as supply of parts that go into production to become finished goods as well as distribution (Sawik, 2009). Thus, when implementing a design strategy for storing material, this challenge must be considered when evaluating different solutions.

Material storage or warehousing can be performed by the manufacturer itself, but other alternatives such as outsourcing is also common. According to de Koster and Warffemius (2005), there are strategic reasons to outsource warehousing or other logistics services to reduce costs or the amount of capital invested, to improve the service or quality, the need for strategic flexibility and focus on core competencies.

It is therefore important for top management to evaluate the manufacturer's different possible solutions to ensure that the most optimal supply chain design is developed. The inventory strategy, like all other activities in the company, is to contribute to the welfare of the whole organisation. The welfare is usually linked to the company's performance and the larger the company, the bigger are the expected profits (Wild, 2017).

1.2 Aim

The aim of the study is to analyse and provide decision support for the use of containers as intermediate stockholding in large scale manufacturing plants. Moreover, the study will provide a basis upon which strategic decisions can be made, specifically for logistical systems. The point of view is from Northvolt, a lithium-ion battery cell manufacturer, but the findings are to be applied in a general scene, especially for firms with a large inflow of goods in shipping containers. With scarce examples surrounding similar implementations in the industry it proves as a case study for other manufacturing firms in similar contextual environments when planning their supply chain design.

1.3 Specification of Issue Under Investigation

Currently, Northvolt is building a central warehouse which stores materials needed for production. However, as with any warehouse, problems and trade-offs arise with management of inventory, such as tied up capital and service level.

The process for inbound logistics consists of raw material arriving in containers at the Port of Skelleftea with feeder vessels every week. Later, these containers are to be transported and emptied at the central warehouse of Northvolt before the material is distributed to either the upstream or downstream production process in the factory. Nevertheless, shortage problems are expected by the year of 2024, since production volumes of 16 GWh surpass the warehouse capacity for holding stock a longer period (see Figure 1). In fact, depletion time is projected to last only a couple of days accounting for safety stock.

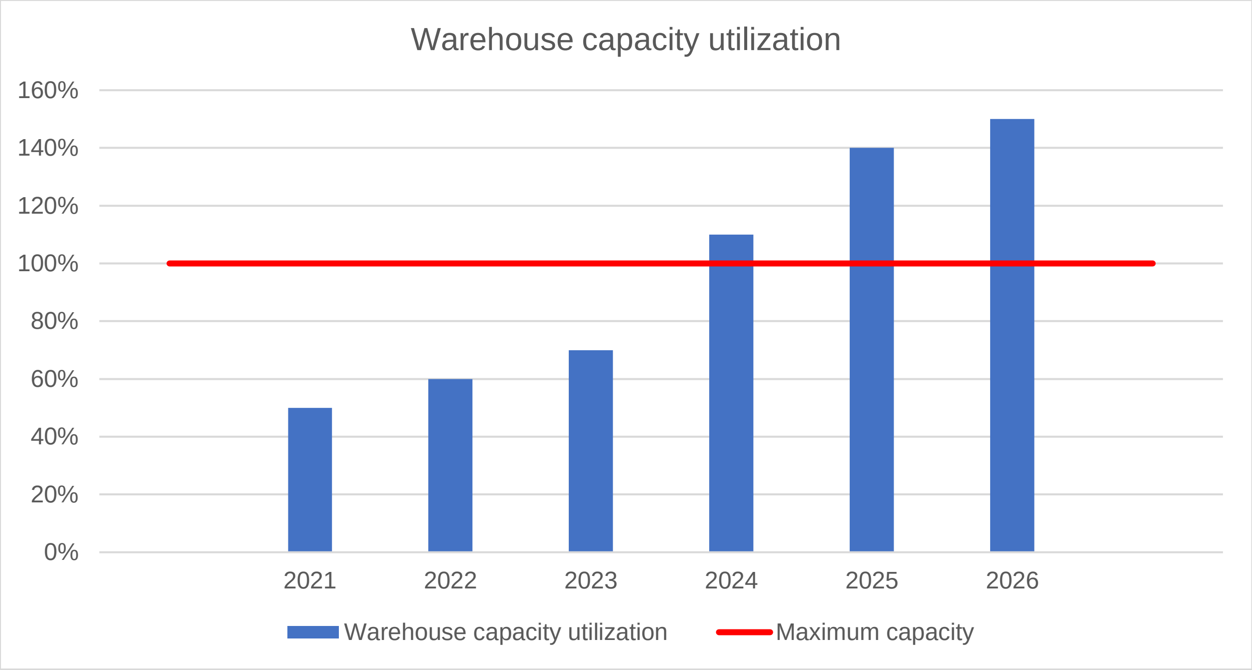

Figure 1: Diagram of expected warehouse utilization in comparison to capacity.

Hence, as Northvolt are preparing for larger production volumes, more storage space than the current central warehouse is designed to hold is required with little time to expand. Due to these circumstances, Northvolt wants to evaluate if there exist alternative solutions to expanding the current warehouse, specifically developing a container yard acting as an intermediate storage solution. The container yard will act as a storage point for material before it is sent to the central warehouse or similar upstream process. In Figure 2 below, potential placement of said container yard is depicted on the map. This includes the Port of Skelleftea and the Northvolt production facility inland.

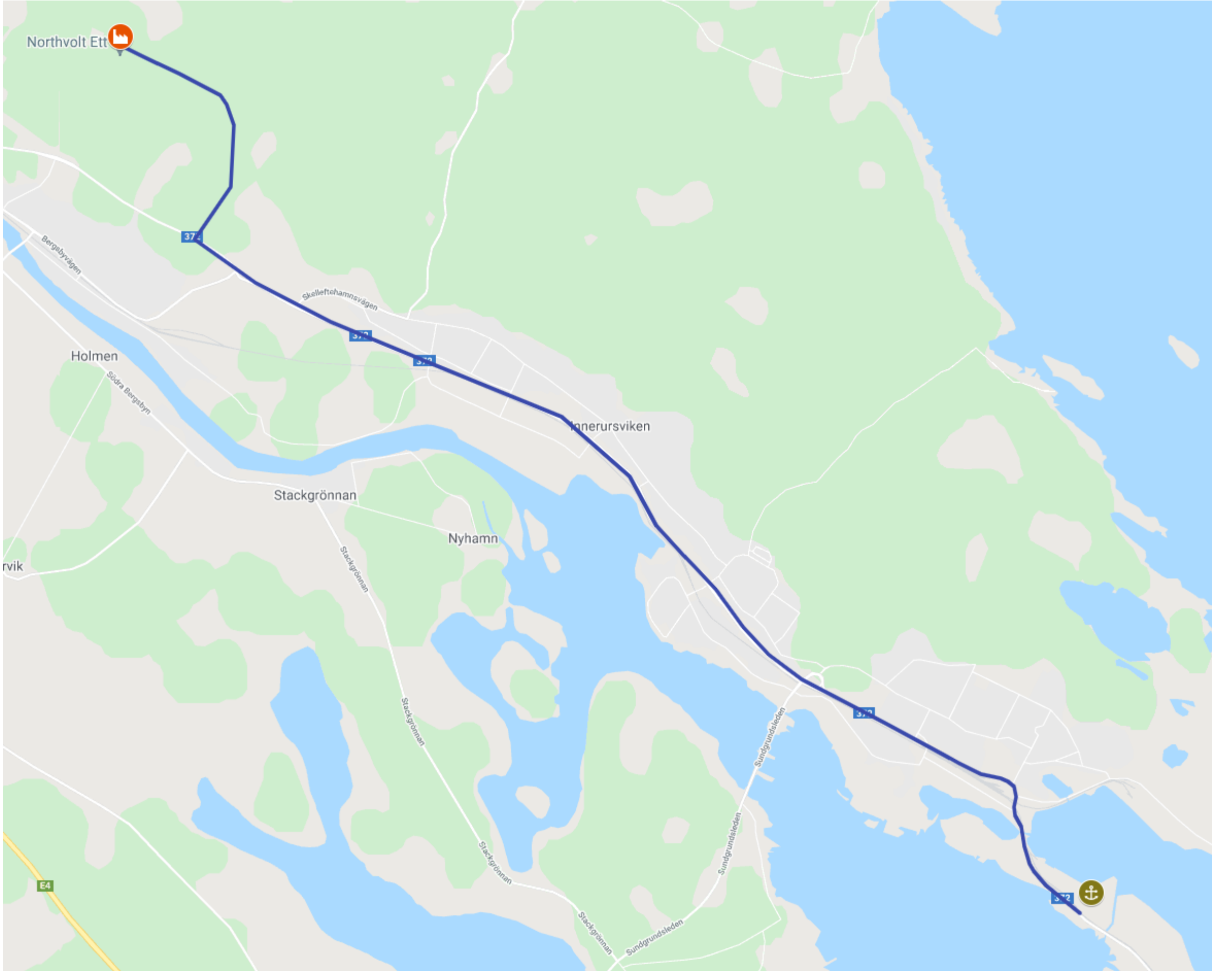

Figure 2: Depiction of the road between the production facility and the Port of Skelleftea (Google Maps).

An additional reason as to why Northvolt is even considering other options than expanding the central warehouse has to do with incentives for promoting operational expenditure (OPEX) over capital expenditure (CAPEX) in its current state as a start-up. Moreover, having heard of industrial companies adopting similar solutions, Northvolt has shown interest in exploring these themselves.

An implementation of a container yard involves leasing or acquiring land, construction costs as well as purchasing or leasing equipment resources (Hu, Liang, Chang, & Zhang, 2021). Easier said than done, complexity arises as to decide exactly where this container yard is to be placed, who is to own it and who is to operate it. A strategy will be evaluated to identify the most beneficial location for the operations to allow for long-term strategic growth. The alternatives to be evaluated consist of three different solutions defined as the in-house solution, the hybrid solution and outsourced solution.

The in-house solution refers to Northvolt constructing their own container yard near the production site as well as managing the operations at the container yard. This includes constructing a foundation, acquiring necessary equipment, and managing operations with own personnel.

The hybrid solution is similar to the in-house solution since it will also be located near the production site, thus it will also require construction of a container yard, but the operations will be outsourced to an external actor. Either by taking ownership for all resources and only hiring personnel or completely outsource the operations along with resources. A flow chart for the in-house and hybrid solution is depicted in Figure 3.

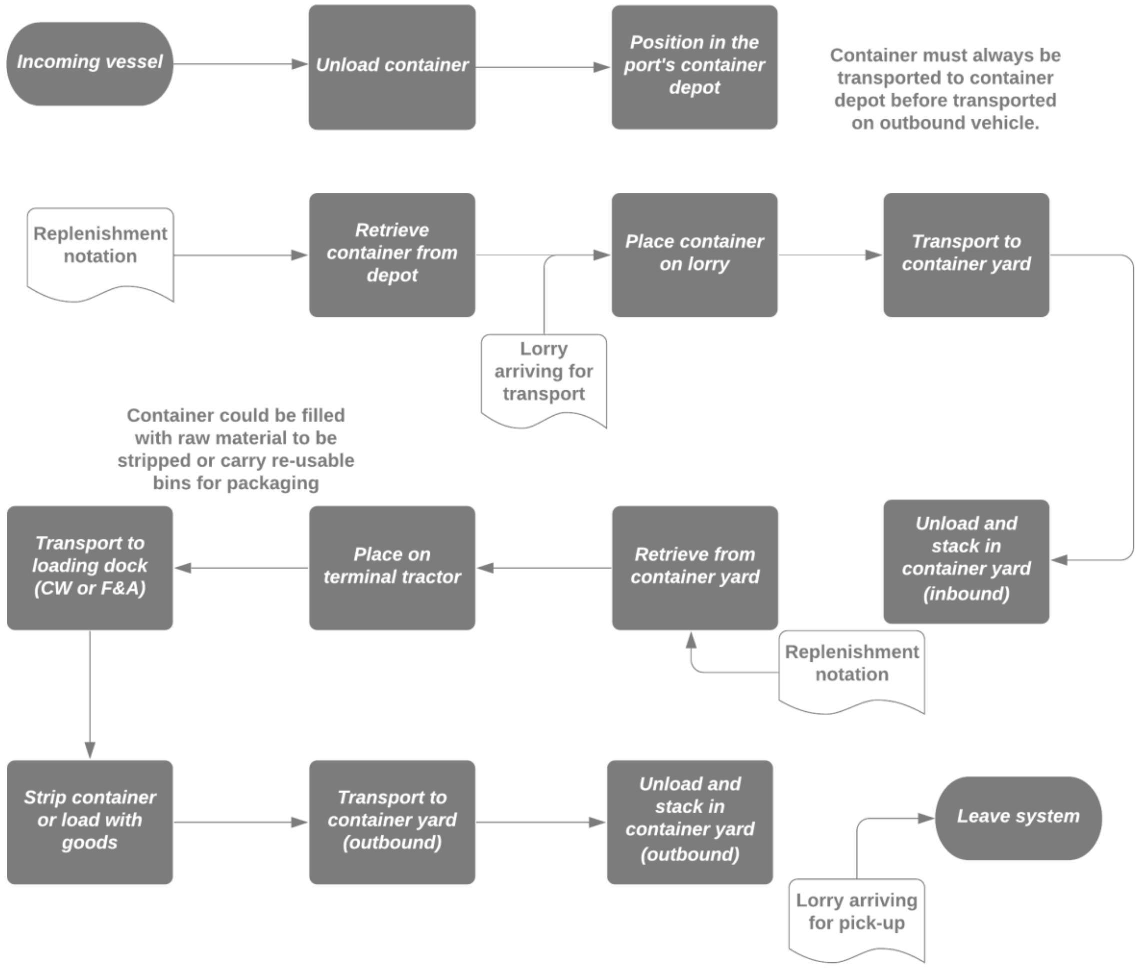

Figure 3: In-house and hybrid container yard simplified flow chart. CW in the figure above stands for Central Warehouse and F&A for Formation and Ageing.

The outsourced solution to be evaluated consists of both operations and location being outsourced to an external party. The considered location will be at the Port of Skelleftea, as this is where incoming material will arrive at. This implies that the external actor at the dock will perform all relating operations, provide the needed equipment as well as leasing space. A flow chart for the in-house and hybrid solution is depicted in Figure 4.

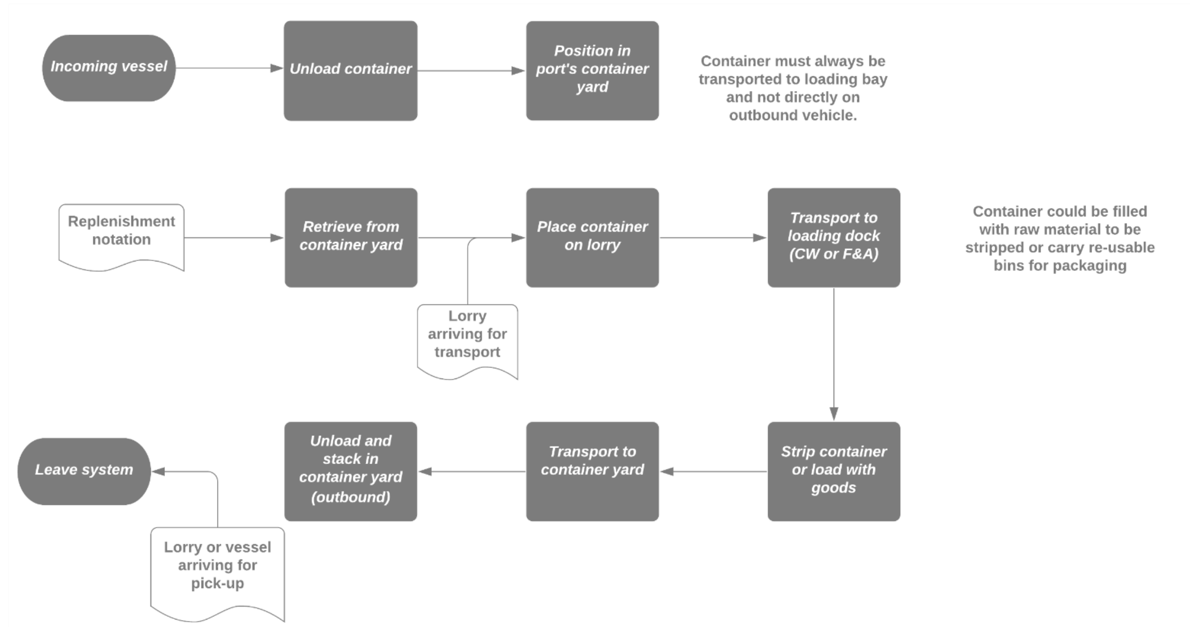

Figure 4: Outsourced container yard simplified flow chart.

The central warehouse is the main point of entrance for inbound goods although there in total exist around seven access points around Northvolt Ett. Formation and Ageing is the main access points for outbound goods and here containers are to be filled with finished goods intended for export to customers. All containers intended for export will arrive with re-usable bins in the containers as these are part of a cyclical route between Northvolt and its customers.

1.4 Company Background

Northvolt was founded 2016 with the mission to build the world's greenest battery to enable the European transition to renewable energy (Northvolt, 2020a). The batteries will be used for multiple markets, such as the automotive, energy and industrial sector, to mention a few. Northvolt are currently building a factory for large-scale production of lithium-ion battery cells in Skelleftea, known as Northvolt Ett. Further, Northvolt are establishing a robust ecosystem for battery recycling in order to close the loop on batteries. Hence, a recycling plant will be built at Northvolt Ett to secure a goal of 50% recycled material in cells by 2030 (Northvolt, 2020b). The large-scale production is scheduled to commence in 2021. Along with this mission, Northvolt will be facing numerous challenges.

To give the reader an understanding of the production magnitude, Northvolt Ett has a designed capacity of 32 GWh, meaning that Northvolt would be producing battery cells for around 600 000 electric vehicles per year (Northvolt, 2019). Additionally, In September 2019, a joint venture between Northvolt and Volkswagen Group was announced to establish a 20 GWh Gigafactory in Germany, Northvolt Zwei. Further, Northvolt signed an equity raise in September 2020 of $600 million to support development of production capacity, expansion of Northvolt Labs as well as a full-scale recycling facility at Northvolt Ett (Northvolt, 2020a).

Northvolt has also invested close to 1,6 billion SEK in an assembly factory in Poland which is due to commence in 2022 (SVT, 2021). As can be understood, Northvolt are expanding at a fast pace and being the first large scale battery producer in Europe, the demand for its products as society transitions to fossil free energy is ever growing.

1.5 Research Questions

Regarding the aforementioned solutions, a comparison will be made from a strategic, operational and financial standpoint regarding the different strategies, i.e., building/leasing a container yard, employee costs, purchasing equipment, etc., for different benchmarked volumes. Further, a comparison of the operational implications will be conducted regarding capacity as well as efficiency of handling container units. An analysis of the different activities associated with each respective solution will be conducted.

The initial research questions involve the viability of a container yard as an intermediate storage solution. This is to give a general understanding of container yards and if they are a suitable solution for intermediate stockholding compared to warehouses. It should be noted that the intent of the container yard is to complement the central warehouse for inventory, and not replace it. Research question 1 is thus framed:

RQ1: Is a container yard a viable option for complementary storage of goods compared to traditional warehousing?

The viability for this research question incorporates the dimension of financial analysis on a high level. This means that the study is to evaluate the financial cost of building and maintaining a container yard compared to expanding/constructing a warehouse and the limitations and benefits the stated solutions come with.

For the second research question, focus is shifted towards the different implementation styles of a container yard, more specifically what ownership structure is most beneficial for this case study.

RQ2: What ownership structure for the container yard is most viable?

This research question contains three alternatives mentioned in specification under issue of investigation, which are the options to operate everything in-house, a hybrid solution where the container yard is placed inside the company premises but operated by a third party, or a fully outsourced solution. The outsourced solution involves the container yard being located at the Port of Skelleftea. Here viability consist of both financial and operational factors, but more pressingly a strategic aspect as well.

1.6 Limitations

Since inventory has an impact along the entire supply chain it could be reasonable to make a distinction between material addressed for the upstream, as well as the downstream production process, and compare the solutions. However, to rightfully evaluate the three potential solutions of container yards (in-house, hybrid and outsourced) it is necessary to delimit the process to a certain scope where differentiators are clear. In all cases, container loads will be handled at the Port of Skelleftea and thus this brings a starting point of the inbound process. Subsequently, the solutions are delimited to the point of departure from the container yard, including outbound containers for distribution to customers or internally at for example Northvolt’s packaging plant in Poland. Within these boundaries the three different solutions have factors that differ, e.g., in transportation, handling, storage, and time.

Further limitations are made with regards to the capacity setting at which the factory is operating. Since the production plant Northvolt Ett, as of publishing, is currently not in operations, a base case will have to be assumed for the study. This is set at a steady production rate of 16 GWh yearly. A potential scenario analysis with upgraded capacity of 40 GWh will also be evaluated in accordance with expansion plans (Northvolt, 2020c). These stages are based on company forecasts and will further be evaluated at a steady state. Lastly, all cases will be evaluated from the scenario where one ship arrive once a week to cover the weekly production demand of containers. Hence, assuming constant flow of containers per day, i.e., the report will not consider scenarios where the volume peaks during a period.

2 Methodology

Edmondson and McManus (2007) suggest that theory in management research falls along a continuum, from mature to nascent. Mature theory concerns well-developed constructs and models that have been studied over time by a variety of scholars resulting in a broad agreement and cumulative knowledge. Nascent theory, in contrast, propose answers to novel questions in emerging areas. In between these theories, Edmondson and McManus (2007) position intermediate theory which present provisional explanations and constructs while relating to already established research. In short it draws conclusions from prior work, often from separate literature, to propose new constructs and/or provisional theoretical relationships.

From the introduction, it is stated the study aimed to explore and validate container yard as a functional method for intermediate stockholding at the production plant of Northvolt Ett. Although there are many studies performed on both inventory management in warehouses and container yards independently, a dedicated use case of container yards as part of an inventory strategy is scarce, if not non-existent. It could thus be argued the theoretical and practical contributions from the study is positioned between nascent and intermediate in the continuum described by Edmondson and McManus (2007).

2.1 Research Strategy & Design

A study positioned as intermediate along the theory continuum proposed by Edmondson and McManus (2007), frequently integrate qualitative and quantitative data in what can be referred to as an hybrid approach. Through this, triangulation can construct validity of new measures (Jick, 1979). The premise of the study was to explore the validity of container yards as intermediate stockholding, and in doing so, one method was arguably insufficient to provide clear answers. It was thus deemed necessary to strengthen findings of qualitative research with quantitative measures such as financial and operational data. It should be noted that the quantitative data, perhaps, is not what one would normally associate with quantitative data in a research setting. Mainly, due to it being gathered for a specific purpose and not statistically evaluated. However, since the data was specifically made to complement the qualitative data, it served the same purpose of quantitative data.

The appropriateness of combining qualitative and quantitative methods within a single research project is debatable. Issues addressed include whether qualitative and quantitative methods investigate the same phenomena, and can reasonably be integrated (Edmondson & McManus, 2007). Yauch and Steudel (2003), however, argue that using qualitative and quantitative data contribute to the validity of the results through triangulation and provide a more complete understanding. Furthermore, Yauch and Steudel (2003) discuss the notion of hybrid strategies as allowing researchers to test relations between variables of quantitative data and explain novel constructs with qualitative data. Finally, Edmondson and McManus (2007) argue careful analysis of both qualitative and quantitative data increases confidence in explanations of phenomena are more plausible than alternative interpretations.

With the aim of the study to explore a novel stockholding strategy in container yards and evaluate three different options, an exploratory research design was found appropriate (Sreejesh, Mohapatra, & Anusree, 2014). According to Sreejesh et al. (2014), exploratory research is performed, amongst other, to frame a working hypothesis from an operational perspective. It helps understand and assess the critical issues of problems but should not be used in cases where definite results are desired. This applied to our aim and allowed to evaluate the container yard solutions but not define a certain answer to all possible implementations of it. Exploratory studies are also conducted for three main reasons; to analyse a problem situation, to evaluate alternatives and to discover new ideas (Sreejesh et al., 2014). Arguably, all three reasons were applicable to as why the study was conducted. The exploratory study aimed to understand all aspects of the inbound process of handling containers and through qualitative and quantitative methods, evaluations and comparisons were made.

The last aspect of research design confers to the fact that it was a case study. The application of studying one case, i.e., Northvolt, is seen as having exemplary status rather than representative status but should give sufficient understanding of application to potential readers (Koulikoff-Souviron & Harrison, 2005). Denscombe (2018, p. 85) highlights case studies as "*aimed to illuminate the general by looking at the particular.*" Since the subject studied was novel in its nature, Northvolt Ett became the point of focus and could not reasonably be performed as a mass study, due to lack of other cases. Furthermore, the strength of studying one case is that it allows to research in great depth exemplary practices (Koulikoff-Souviron & Harrison, 2005).

Denscombe (2014) further argue that although case studies are more aligned with qualitative than quantitative research, one of the strengths is that it allows for a variety of methods (e.g., observations, interviews, documents) depending on specific needs and circumstances. The use of both quantitative and qualitative data is thus common which correlated to our study.

2.2 Research Process

The research process and its different phases are presented in Figure 5 below. The initial phase consisted of becoming familiarised with the case company, the case itself and the research area connected to the study. This involved rather open discussion with the assigned representative at Northvolt to specify the purpose of the thesis, limit the scope as well as clarify the research questions. Additionally, secondary data in internal projections for container volumes were given to be evaluated and initial literature review was conducted to get familiar with the subject and aid in formulating research questions.

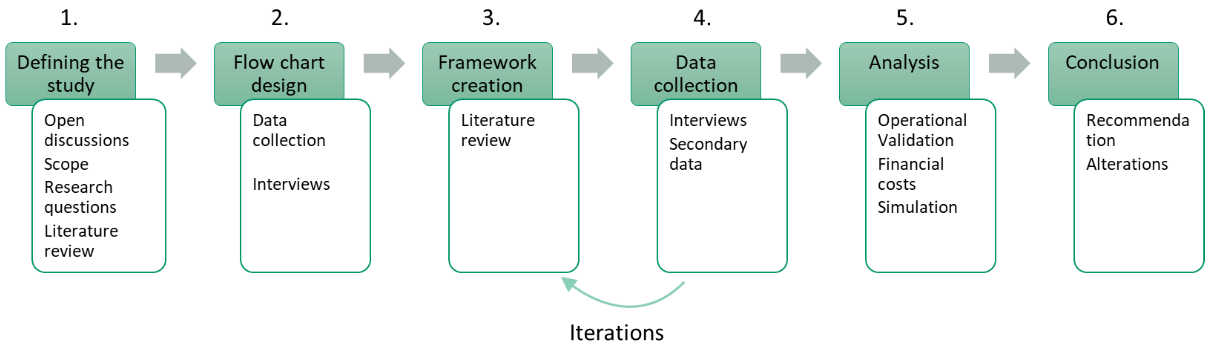

Figure 5: Illustration of research process.

The second phase comprised of clarifying the different flows of container yard handling that was initially proposed by Northvolt (see section 1.3). By interviewing both internal actors and external experts in a semi-structured fashion, an accurate flow was depicted allowing for greater understanding. Once an understanding of the operational flow at a high level was identified, the research progressed into discovering elements and dimensions of evaluation, fundamental for an objective comparison. To do so, a framework first had to be developed wherein literature review became the main point of inspiration. Data collected through initial interviews also guided the creation of a framework. Consequently, with a framework constructed, most of the interviews and data collection were conducted wherein both subjective and objective data was gathered. The former had the aim of strengthening a qualitative aspect of the analysis and the latter a quantitative aspect.

During the third and fourth phase, numerous iterations were made to both justify the operational flow and improve the framework, in line with new discoveries. This consisted of both limitations and benefits communicated by interviewees. Once enough data was collected and a robust framework contextualised, the analysis phase was initiated. The analysis phase consisted of comparing the different solutions with the framework as a fundament for comparison. It consisted of both qualitative arguments, quantitative calculations, and tools such as Value Stream Mapping and dynamic simulations in Excel, culminating in a final solution design.

Due to extensive data collection, certain aspects of analysis were initiated without having all data available. This was possible since all parts of analysis were not necessarily completely dependent. Examples are that of financial costs and operational time validation which could be performed separately.

2.3 Literature Review

Literature review was a key concept of this study and as argued by Bell, Bryman, and Harley (2019), it is one of the most important tasks for carrying out the research project. A literature review provide basis of justification for the research questions and research design, but also lay a foundation for how to collect data and informatively analyse it (Bell et al., 2019).

At an early stage, the literature search involved reviewing the main ideas and debates in our field of interest. Since we had little experience from the field of container handling and terminal operations, this provided a broad understanding of academic issues discussed, but also more operational issues. Bell et al. (2019) argue this avoids the problem of *"reinventing the wheel"* and building upon already existent knowledge.

Later on, the literature review was aimed towards building a theoretical frame of reference in for which the analysis could be built upon as well as provide the reader knowledge of concepts discussed. This included a more thorough review of literature regarding container terminals, warehousing, and operational performance in ports.

The search for academic literature was performed using the databases Google Scholar and Chalmers Library, connected to EBSCO host. Keywords searched for were; warehousing costs, warehousing operations, container terminals, supply chain strategy, decision making in supply chains, logistical performance comparison, port terminal productivity, simulation, and Value Stream Mapping.

2.4 Data Collection

The data collection occurred through interviews, observation, and secondary data gathering. The methods of collection gave outcomes of both qualitative and quantitative data.

2.4.1 Primary Data

For research question one, which involved exploring the viability of the container yard, the exploratory approach made interviews a suitable method for data collection. To be able and understand the issue at hand, semi-structured interviews with different stakeholders were conducted. Subjects found most interesting to interview were any type of logistics coordinator at ports in Sweden with a relatively large and stable container flow. Benefits of semi-structured interviews are that they are flexible and allow for the interviewee to elaborate deeper on assigned topics (Denscombe, 2014; Sreejesh et al., 2014). Semi-structured interviews are prepared with a clear list of issues to be addressed but allow the interviewee to answer more freely and develop ideas (Denscombe, 2014). From the interviews both qualitative and quantitative data were recorded. Qualitative in that it provided detailed descriptions of container yard operations as well as benefits and limitations to these. Quantitative in the sense that cost data and productivity data for machines was communicated by the interviewees. One could consign the qualitative data as subjective since they were based on the interviewees own experience with container handling. Likewise, the quantitative data carried a more objective theme as it was based on real cost of equipment and operational productivity experienced in the interviewee's workplace.

For the interviews, a divide between external and internal interviews were made. External interviews were more formal yet semi-structured and are presented in Table 1. Subjects for these interviews consisted mainly of professionals from the Port of Skelleftea and its current stevedore Shorelink, but also operations coordinators at other ports in Sweden. Additionally, several follow up interviews were conducted with people from the Port of Skelleftea, stevedores Shorelink, and the Port of Norrkoping. The reason being was as the research progressed, new findings were discovered, naturally posing new questions needed to be discussed. All interviews were performed digitally. Various internal interviews with employees of Northvolt were also conducted to grasp and gather information on previous projects related to logistics at Northvolt and is presented in Table 2. Since the container yard touches upon several areas of Northvolt's operations, interviews were conducted with representatives from different departments. These provided similar results as interviews conducted with external parties but could be more open-ended in that the interviewees knew of the situation explored and could provide even deeper insights and personal reflections.

Table 1: Anonymised interview schedule with external participants.

Company	**Title**	**Date**
Port of Skelleftea	Port Master	*February 9th, 2021*
	Port Master	*April 29th, 2021*
ShoreLink	Sales Manager	*February 11th, 2021*
	Sales Manager	*March 10th, 2021*
	Sales Manager	*April 28th, 2021*
Yilport	Operations Manager	*March 17th, 2021*
Port of Norrkoping	Sales Manager & Operations leader	*March 22nd, 2021*
	Operations leader	*April 15th, 2021*
NC Nielsen	Sales representative	*April 6th, 2021*
Bilfrakt	Logistics Sales manager	*April 21st, 2021*

All meetings were conducted digitally due to the ongoing pandemic. For Table 2 below, the dates indicate first contact with employees at Northvolt. However, with several of them a continuous dialog through digital chats were followed. As with the external interviews, often new questions would surface when the analysis progressed in which case dedicated questions could be asked in the chat or through email rather than conducting a full interview.

Table 2: Anonymised interview schedule with employees at Northvolt.

Position at Northvolt	**Date**
Purchasing Manager	*January 27th, 2021*
Dangerous Goods Specialist	*February 16th, 2021*
Logistics Developer	*February 18th, 2021*
Industrial Business Development	*March 22nd, 2021*
Material Flow & Robotics	*April 16th, 2021*
Logistics – Information systems	*April 15th, 2021*
Site Infrastructure	*April 16th, 2021*
Director of Compensation	*April 21st, 2021*
Logistics Coordinator	*May 6th, 2021*

Beyond interviews, primary data was also gathered through observations. The visit to the Port of Gothenburg gave a general understanding of the premises upon which the operations are based. Visits to other ports and Northvolt itself were planned but not accomplished due to the pandemic. Observations are regularly associated with social sciences with the intent of recording behavioural patterns (Sreejesh et al., 2014). However, Denscombe (2014) mentions that qualitative and quantitative data can be acquired from observations and implied in this study a better understanding of container related operations. Time measured observations of quantitative character were not performed.

Table 3: Site visits.

Location	**Site**	**Date**
Gothenburg Port	Lundby Container Terminal	*April 12th, 2021*

2.4.2 Secondary Data

A major contributor to the study came from secondary data sources. According to Sreejesh et al. (2014) secondary data sources can be classified into either internal or external. Internal sources encompass information available within the organization. Examples of internal sources of secondary data are departmental reports, financial and accounting reports etc. For this study, data acquired internally were transportation and warehouse data as well as currently known development costs at Northvolt Ett. This was used to estimate future flows of containers at the container yard as well as investment costs. For this study, the internal sources were central in that they lay foundation to the premise on which the container yard were evaluated from.

External sources of secondary data are those that exist outside of the company and in many forms, such as government publications, books, and periodicals, to name a few. These were used to complement and strengthen argumentation for findings in primary data sources. Certain data was not readily available from internal sources as secondary data or primary data altogether. In such a case, secondary data can generate important information for better creativity and insights (Sreejesh et al., 2014). In particular, price tariffs in ports.

2.5 Simulation

For this study to have a realistic adaption, the implementation of a simulation was found necessary. The main argument for this was using static calculations does not portray natural variation which occurs in real life operations, such as traffic. This refers particularly to research question two, for which three storage solutions are evaluated. According to Pegden et al., (as cited in, Chung, 2003, p. 95), simulation modelling and analysis of different types of system are, amongst other, performed for the sake of:

- Gaining insights into the operations of a system
- Developing operating or resource policies to improve system performance
- Testing new concepts and/or systems before implementation
- Gaining information without disturbing the actual system

In this study, testing a new system before implementation was central. Since the container yard does not exist, a simulation model can help evaluate a proposed system's performance as well as save cost compared to investing in a system and then evaluating performance (Chung, 2003;

Kurdve, Sjögren, Gåsvaer, Widfeldt, & Wiktorsson, 2016). Due to the nature of the system and its complexity, it could be difficult to reasonably understand the problem without a dynamic simulation model (Chung, 2003). There are certain benefits and disadvantages to simulation models that are necessary to take in consideration. Benefits are experimentation in compressed time due to computers, reduced analytical requirements with respect to simulation software, and easily demonstrated models through animations (Chung, 2003).

Disadvantages to simulation consist of: accurate results depend on good input data, simulation cannot provide easy answers to complex problems, and simulation alone cannot solve problems (Chung, 2003). The first disadvantage is sometimes referred to "garbage in, garbage out". It is thus important to make sure that data is collected first-hand if possible, and not dependent on external historical data. As for the second statement, the more interactions and elements, the more complex answers. Here it is possible to make simplifying assumptions for the purpose of developing a reasonable model in a reasonable amount of time (Chung, 2003).

The dynamic model was created in Excel which has the drawback of not being animated. Additionally, not all interactions were made available in the model. The main argument for this was that simulation was not the focus of the research project and there were clear points of decoupling in the shape of the container yard, i.e., storage point. With the complement of conceptual modelling and Value Stream Mapping, which are explained in the coming section, the potential shortcomings of a simulation model were argued to be offset by these methods.

2.6 Conceptual Modelling and Value Stream Mapping

To aid the creation of a simulation and improve the outcome, certain aspects in methods for conceptual modelling and Value Stream Mapping (VSM) were used. From a definition standpoint, Gesvret and Foltin (2019) argue a conceptual model is a specific description of the real system, processed outside the simulation software which describes inputs, outputs, assumptions and methods of simplification. From this view, a lot of similarities can be drawn to VSM and consequently, the method used for analysing the different container flows was a mixture of VSM and conceptual modelling methodologies. The reason being is that the conceptual model was created for visualising the flow and later as blueprint for the simulation, whereas VSM methodologies were used to calculate cycle time and any discrepancies causing slack.

The method of VSM focuses on value streams which naturally involves both value-adding and non-value-adding activities (Arbulu, Tommelein, Walsh, & Hershauer, 2003; Cavdur, Yagmahan, Oguzcan, Arslan, & Sahan, 2019; Rother & Shook, 2003; Villarreal, 2012). The act of transportation and storage could, according to definitions by Monden and Ohno (2011), be considered waste or non-value-adding activities advantageous to eliminate. However, as Villarreal (2012) claims, it is rarely the case in real-life that manufacturing plants, that suppliers and retailers are located next to each other making transport an act of moving goods closer to customers and can thus be said to be value-adding. While VSM is tightly associated with material flow in, for example, manufacturing and assembly lines, the container yard will be part of the value stream from supplier to production and was thus equally relevant to map (Cavdur et al., 2019; Rother & Shook, 2003). Quite often VSM encompasses “door-to-door” production, considering delivery of supplied raw material but not in detail at process level, as was performed for this case study. By focusing on the stream of containers from port to production the VSM was shifted towards supply of material, rather than production. Additionally, examples of VSM used in supply chain case studies is brought up by Arbulu et al. (2003) and Villarreal (2012), where the latter not only mention VSM as useful for eliminating waste in logistics operations but applies VSM for transportation operations.

In order to gain an understanding of the material flow at the potential container yard, a flow chart was initially created (see Figure 3 and Figure 4) which then set a foundation for the conceptual model and subsequently VSM. The flow chart allowed to map out individual processes and later decide which relates to the same area of process categories, as described by Rother and Shook (2003). This means that processes were divided based on similarities such as lifts or transport of containers. The flow chart was first created by hand, and later in the diagram software Lucidchart. Once the flow chart had been completed the conceptual model used for VSM, and blueprint for the simulation, was created in Excel.

VSM methodology has the end goal of not only making the user understand the current material flow by an current-state map, but also create improvements through a future-state map (Rother & Shook, 2003). For this case study, the latter action was not completed, partly due to the current state not existing. This could be argued to be dismissive for the method. However, as main benefits of VSM are visualising flow and waste it was deemed advantageous for the study (Rother & Shook, 2003). Nevertheless, complemented with simulation, which can be used to test out systems before implementation, it was deemed a valid method (Chung, 2003). The combination of VSM and simulation is also argued effective by Cavdur et al. (2019) and Solding and Gullander (2009).

2.7 Quality of Method

The method presented consists of several sections, in parts because it consisted of solving both a practical problem and academic problem. Issues confined with this, and something found challenging, is the act of assessing both these problems adequately. It also made the method become quite broad since many areas had to be touched upon, whereas from an academic operations strategy standpoint, the most important aspect could be confined to strategic matters rather than large focus on solving a logistical problem within a firm’s context. Albeit it did prove to be a great example to study.

Both literature review and the framework applied handle many areas and aimed to find inspiration from settings not necessarily, instinctively applicable to the container terminal context. By reviewing both academic journals and papers, but also incorporating business case reports, it was deemed to give a foundation contributing to both academic and professional areas.

Although a limited on-site observation was completed at the Port of Gothenburg, more visits would have been constructive as well as if they occurred at an earlier stage in the research. The visit to the Port of Gothenburg undoubtedly provided immeasurable experience easily translated into the study but was delayed due to the COVID-19 pandemic. Planned visits to Northvolt Ett in Skelleftea was also scheduled, however, due to the pandemic none was possible since restrictions were put in place. This undeniably led to difficulties recognizing the entire situation and prolonged the time of understanding.

Using both internal and external data collection provided a deeper and more saturated result. From interviews, points made by Northvolt could at times be contradicting to those of external experts in ports. However, through the analysis it often showed that different statements often complemented each other, providing more beneficial and well appreciated nuance to the method.

3 Theoretical Frame of Reference

Decision making in supply chains and the design of such involve many dimensions and parameters which shape and affect the outcome. This section of the thesis aims to present theories and develop a framework for decision making when designing supply chains. More specifically, providing underlying theory for how the design process and decision making could be constructed for the case of a container terminal.

Below, in section 3.1, the topic of strategic decision making in supply chains and logistical networks is brought up with its three levels of analysis described. This is followed by, 3.1.1 Collaboration in Supply Chains, in which the collaborative nature of supply chains is reviewed. Furthermore, section 3.1.2 Background to Strategy approach different literary views of strategy which then in section 3.1.3 Supply Chain Strategy, culminates in a suggested framework for strategy in supply chains. Thereafter, in section 3.2 Supply Chain Operations and 3.3 Costs of Supply Chain Operations, two parameters deemed valuable for decision making in supply chains: a financial dimension, and an operational dimension, are elaborated on, respectively. Finalising the theoretical chapter in section 3.4 Summary of Framework: Designing the Container Terminal, a broad design process for container terminals is discussed tying together the different elements of strategy, operations, and costs to present a framework aimed at facilitating future terminal projects but also for the broader supply chain.

3.1 Strategic Decision Making in Supply Chains

Today we see several examples of companies, where logistics has a clear role in the strategy of the firm and is a driver for corporate-level profitability and growth (Sandberg & Abrahamsson, 2011). The importance of logistics is determined at the materials flow segment level. This is the level upon which one competes and the level which one can operationalise the importance of logistics. It is further the level which one may discuss the strategic choices and evaluate various possibilities to utilize logistic systems strategically (Persson, 1991).

Logistical networks can be designed and analysed at three different levels according to Van Landeghem (2009). These are (1) strategic, (2) tactical, and (3) operational levels (see Figure 6). The strategic level involves decisions regarding the structure of the network (i.e., echelons, number of sites and functionality of the logistical platforms at each site). The tactical decision level involves determining what operating mode to use inside the existent network (i.e., it encompasses transportation mode, carrier fleet mix, inventory level, etc.). The operational level is the lowest level of analysis and design which focuses on day-to-day operations. The operation tools (e.g., scheduling) used here are limited by the framework created by strategic and tactical decisions made. Examples are routing optimization and minimising operating costs (Van Landeghem, 2009). Shapiro (1999) further argues tactical analysis can be divided into short-term and long-term. Short-term constitutes production planning and logistics optimization for the supply chain with a time horizon normally of a quarter year. Long-term in turn consists of plans concerning supply, manufacturing, distribution, and inventory on a yearly basis (Shapiro, 1999).

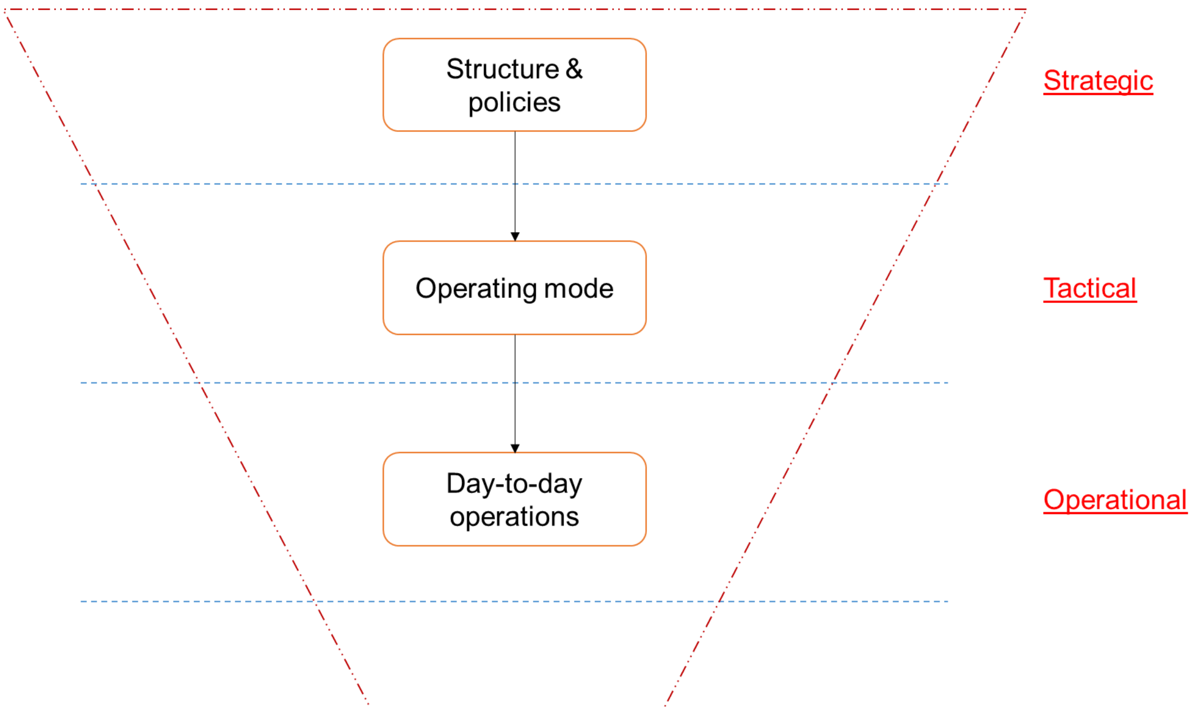

Figure 6: Depiction of the decision-making hierarchy in supply chains.

The notion of strategic and tactical decisions is connected to uncertainties, which thus becomes prominent to mitigate. Van Landeghem and Vanmaele (2002) provide a framework for in which the different hierarchical levels of decision making are most prominent to mitigate these uncertainties. A problem with operational and strategic planning respectively, is that the former often leads little time to react to the uncertainties whereas the latter lack concrete information to justify long-term decisions and is inflexible to adoption. Van Landeghem and Vanmaele (2002) thus, argue that much of the uncertainty can be handled adequately at the tactical level.

For any logistical system being designed or altered, it therefore becomes important to realise there are different levels of impact to the decisions being made. As suggested by Van Landeghem and Vanmaele (2002), it begins with an overall strategic level of decision, which then dwells down to tactical decision and finally operational decisions.

3.1.1 Collaboration in Supply Chains

Supply Chain Management (SCM) is concerned with coordination of material, information and financial flow across separated organizational units (Stadler, 2009). An important aspect of achieving coordination is the alignment of future activities within the supply chain and its members, i.e., coordination of plans. Stadler (2009, p. 10) brings up the notion of collaborative planning (CP). Ideally, a CP scheme should contain a set of activities and rules applicable to a wide range of decision problems. A framework consisting of three broad categories are presented as below:

1) The structure of the supply chain and relationship among its members
2) The decision situation facing each member of the supply chain
3) The characteristics of the CP scheme itself

Structural elements considered are number of tiers in the supply chain, number of members in each tier and the business functions member of the supply chain fulfil (Stadler, 2009). Additionally, relationship characteristics brought up by Stadler are the power of each supply chain member, to what extent of self-interest governing a supply chain members behaviour there is, learning effects and rolling schedules. Planning schedules play a role in that they allow for coping with uncertainty of orders (Stadler, 2009).

The second category, the decision situation, concerns *which* decisions take place, *when*, with *which* objectives and *which* information (Stadler, 2009). All members of the supply chain rarely have the same decision models (EOQ, LP, etc.) and constraints also might not even make it possible to mimic, in which case a standard decision model might not be applicable. Something that is clearly important to pay attention to and common ground must be found.

Regarding the objectives of the decision problem it, in broad terms, consist of profit maximization or cost minimization (Stadler, 2009). Stadler (2009) continues by mentioning that advocating cost minimization is most common, however, objectives of time-oriented matter are also to be acknowledged.

The last category in the decision framework is the characteristics of a collaborative planning scheme. Structural elements of the scheme define the parties involved, the starting point as well as their "interface". Shortly put, Stadler (2009) brings up the elements of how unbiased planning should be conducted to create an initial solution, which should be updated when new information comes into play.

The expected number of rounds and offers should be small (no more than ten) to increase chances of acceptance by the decision makers and allow for interactive work. Otherwise, collaboration planning becomes a burden and most likely needed to be automated (Stadler, 2009). The final results of a collaborative planning scheme can be described by the quality of solution and the use of compensations. An optimal solution for a CP scheme would be a win-win for all parties but bounded by the context in which the members work it is not always possible. In such cases, compensation for other members losses could be covered by other members profits to create a collaborative chain in where all parties work for a common and holistic solution.

3.1.2 Background to Strategy

In order to understand strategy and its impact in the supply chain context, background to the strategy concept is reviewed here. In the article *"Strategic thinking and the IMP approach: A comparative analysis"* by Baraldi, Brennan, Harrison, Tunisini, and Zolkiewski (2007), six different strategic schools of thought are brought up, central to strategic management. These have distinct features that set each other apart and can be adapted in strategic thinking. Below a discussion of prominent features are presented to be used as groundwork for a strategy model.

Rational Planning Approach

Ansoff published in 1965 a book on corporate strategy in where he declared strategy relates the firm to its environment (Baraldi et al., 2007).

"*Strategy can be seen as intelligence activity that centres on understanding the firm's external competitive position and ensuring that a firm's products and markets have been carefully chosen and researched"* - (Baraldi et al., 2007, p. 882).

This is generally referred to as a rational planning approach due to its underlying optimization framework. Key features of this approach are a series of prescribed logical steps, the identification of strategic alternatives and application of a choice routine to identify the best strategy, and the emphasis that is placed on analysing the competitive environment and responding appropriately by acquiring and deploying organizational resources (Baraldi et al., 2007, p. 882). Weaknesses connected to the rational planning approach is that it could be considered too broad, time consuming and takes the perspective of only the single organization (Baraldi et al., 2007). Additionally, studies have shown that rigorous optimal choice decision is not possible in real life organization (Gigerenzer & Selten, 2001).

Positioning Approach

Michael Porter (1979) was another important author of strategy who brought up the notion of strategic positioning. Strategy, can according to Porter (1979), be viewed as building defences around competitive forces and position oneself in the market where the sources are the weakest. Thus, gaining long-term competitive advantage against others in the market (Baraldi et al., 2007). In essence, to Porter strategy is choosing to perform activities differently from rivals or perform different activities compared to rivals.

Resource-Based View

According to (Barney, 1991), rational planning and positioning strategy make the simplifying assumption that relevant resources are not strategically controlled neither are they heterogenous. The resource-based view concentrates on factors 'internal' to the firm whereas rational planning and position strategy focus on 'external' factors (Baraldi et al., 2007). With this, Barney (1991, p. 101) argues that by controlling all assets a firm possess to improve efficiency and effectiveness, a firm can obtain competitive advantage. A competitive advantage is implementing a value creating strategy which cannot be imitated or duplicated by a potential competitor (Baraldi et al., 2007).

The resource-based view concludes that a firm can only build a sustained competitive advantage if it controls assets (physical, human, or organizational) that are valuable, rare, inimitable, and non-substitutable. In contrast, Ansoff and Porter focus primarily upon the external environment and assume that resources can be acquired and deployed to respond to environmental forces. The resource-based view advises organizations to concentrate on their unique resources and seek business opportunities that enable them to exploit these (Barney, 1991).

Learning and Configuration

Mintzberg developed his views of strategy in opposition to the linear and rational view of the previous strategic thinkers. He proposes an organic and incremental view of strategy (Baraldi et al., 2007; Mintzberg, 1993). Baraldi et al. (2007) further writes that Mintzberg describes strategies as the patterns of actual behaviours of organizations that emerge and become ordered over time. Business markets are too complex and uncertain to be fully analysable and therefore controllable before actually acting within (Mintzberg, Ahlstrand, & Lampel, 1998). Hence, it makes more sense to take small steps and rely on accumulated experience and mistakes to improve action for the next stage (Baraldi et al., 2007).

Trials and error become an important driver in strategy and Mintzberg claim learning by doing is superior to learning before doing. Furthermore, he discusses that thinking, as in strategy formulation, and acting, as in strategy implementation, often happen simultaneously (Baraldi et al., 2007). Conclusively, Mintzberg's perception of strategy is that it emerges overtime by learnings and incremental steps. In fact, the formulation of a strategy is never really a strategy in a full sense: it is simply the conception and possibly the expression of a set of goals and means, typically formalized in a plan. But there are millions of plans that never became reality, remaining in large part analytical exercises. These are what Mintzberg call "intended" strategies, wherein many of these intentions become "unrealised" strategies (Mintzberg, 1987). Only the version of the plan that becomes executed results are referred to as "deliberate" strategy. Much of what organisations do and many of their actions are not necessarily formally planned and elope without any formal planning or analysis, referred to as "emergent" strategies. The collection of "emergent" strategies and "deliberate" strategies thus become "realised" strategies.

Strategy as a Social Practice

Strategy-as-practice focuses on how practitioners of strategy really act and interact (Whittington, 1996, p. 731). It conveys that strategy is formed by the daily practices performed by strategists and thus is the centre of attention in this approach. Whittington (1996) realises the importance of analytical techniques in planning, the appropriate options of policy as well as the process of decision and implementation. He concludes, however, that strategists skilfully use practices as their day-to-day domain of success. Strategy practice takes place within the organizational context of the individual and is hence localized. Focus on studying the activities performed by individuals is the main level of analysis (Baraldi et al., 2007).

The IMP Approach

The IMP group, which stands for Industrial Marketing and Purchasing group was founded in 1976 by European researchers (Gadde, Håkansson, & Persson, 2010). This approach is not necessarily strategic in essence, but concerns more with the business network in which the company functions. Ford and Håkansson (2006), in fact, argue that relationships are primary asset of companies. Similar to the resource-based view on strategy, the IMP approach consider current resources of the firm to be the key factor in determining its strategic behaviour (Baraldi et al., 2007). However, where the resource-based view focuses on more tangible resources such as physical and human capital, the IMP views identifies the firm's portfolio of relationships and its network positional resources as the key factors in strategy formulation. Gadde et al. (2010) explain this as recombining resources, in which companies are continually utilising the business network's current resource constellation in the best possible way. These resources can be within the boundary of the firm but also external. They can be tangible or intangible, but the point brought up is that they can be 'controlled' through the relationship in the network (Ford & Håkansson, 2006).

It is difficult to put a concrete definition to the IMP approach. This can be explained at least in part by the nature of the unit of analysis in industrial network theory (the interaction, the relationship and the network) which is different from the standard unit of analysis in strategy research the firm (Baraldi et al., 2007, p. 881). However, the central understanding of the IMP approach is helpful in formulating strategies from a network context.

3.1.3 Supply Chain Strategy

Before Mintzberg, Whittington, and the IMP approach, strategy was seen more as a planning process, thought to be optimized for a long time. In contrast, the latter three bring up strategy as being dynamic and consists of incremental changes over time. These three approaches have inspired our suggested framework of supply chain strategy. Specifically, Mintzberg (1993) discussed strategy as organic and incremental. What Mintzberg's arguments lack is perhaps the view of collaboration and presence of other parties that affect the cycle of business. These things are on the other hand more clearly acknowledged by the likes of Ansoff, Porter, and Barney. Similarly, IMP is centred around networks and how relationships form the basis of strategy in which a firm operates.

However, none of these strategies are directly applicable as a strategic framework in a logistical context such as this. Nevertheless, the above discussed literature can be used as ground for the theoretical framework which not only can be applied to the case of strategy in container yard cases but also broader in relations to supply chain issues.

From an initial standpoint, the importance of understanding a firms' position in the supply chain creates a fundament to stand on for strategy. If a firm is downstream, close to the final user, the responsibilities and activities will clearly differ from a firm upstream. That is, the position in a network and what relationships they entitle play a difference, however, leveraging that position is likewise different from other actors. Goals and/or objectives, even though broad, needs to be realised for the strategy to have any sense of success when developing. Whether there is benefit of the goals and/or objectives being stipulated top-down or bottom-up, is hard to argue for. Still, it is important to acknowledge that strategic decisions in different areas can have unique impacts. For example, logistical strategy is not the same as overall business strategy. Additionally, the maturity of a company impacts whether a company needs, or even benefits, more from a top-down approach or bottom-up. Linked to Mintzberg (1993), there is not necessarily a proposed set of steps put rather incremental improvements that creates strategy. It is thus important to allow for re-iteration and evaluating the strategy as time develops.

An attempt to contextualize a framework for strategy in a logistical and supply chain context, with the intent to be applied for the purpose of our thesis focusing on container yards, is displayed in Figure 7. It begins with acknowledging which decisions can be sorted into strategic, tactical, and operational as in accordance with Van Landeghem and Vanmaele (2002). In the strategic part, overall goals and objectives become a central part of the underlying strategy. In a logistic context this could involve objectives of no shortages allowed of inbound goods, no obsolescence and so on, but also consideration of firm identification factors. For example, sustainability could be one the confines a firms' course forward. The objectives might be broad but sets out a starting point for the strategy. Here, collaboration plans and key relationships with actors also need to be acknowledged. Depending on what level of maturity the company is in (i.e., start-up or established firm), there could already be established relationships or developing ones. Regardless, establishing early on what the firm expects from their position makes all decisions more transparent and will allow for development of a better strategy. This is in line with Stadler (2009) and what has been discussed in section 3.1.1 Collaboration in Supply Chains. Finally, resources internal to the firm and realising how to utilise them are important. A firm must thus decide what resources to allocate for this certain strategy and why. This is similar to the resource-based view, but having already considered the resources of relationship, the picture becomes clearer.

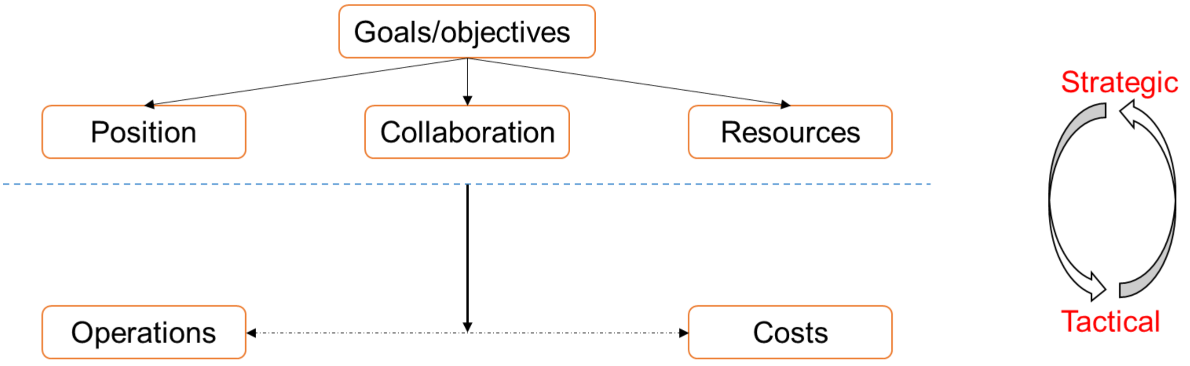

Figure 7: Framework for strategy in supply chains

Although, there are many steps involved in the suggested framework, it is necessary to point out the application comes from a logistical context. A similar strategy could be too broad for general business strategy and the steps mainly require acknowledgement of certain factors, not planned analyses. The main reason for this is the iterative nature of strategy formulation that must be considered for any existing business. Any network a firm act in is dynamic and changing, so expecting the status quo to remain is not only ignorant but potentially even devastating. As to why the circular arrow between tactical and strategical decisions is displayed. Over time, reviewing implications of tactical decisions can affect top-line strategic decisions.

3.2 Supply Chain Operations

Below, multiple operational dimensions are presented in a warehouse/storage context as well as container terminal context to break down the different and similar activities conducted in these business functions. This is deemed relevant for analysing the case described in section 1.3.

3.2.1 Warehousing & Inventory Operations

Inventory can appear as three different types of inventory: raw material, work in process (WIP) inventory and finished goods inventory (Choi, 2014). Warehouses are used for many important supply chain functions. For example, a raw-material warehouse hold inventory near or in factory where the timely support of production and assembly schedules is the key to success. Further, finished goods warehouses typically hold large quantities of finished goods awaiting deployment to customers or distributions centres. However, although the roles and names may differ, the internal activities are remarkably similar. Those activities include the following, according to Dr. Edward (2016):

1. *Receiving* is the collection of activities involved in the orderly unloading and receipt of all materials coming into the warehouse as well as assuring that the correct quality and quantity are as ordered
2. *Put-away* is the act of placing merchandise in storage. It includes moving material and placing material in assigned put-away locations.
3. *Storage* is the physical containment of merchandise until it is demanded. This method depends on the size and quantity of the items in inventory as well as the handling characteristics of the items/containers.
4. *Order picking* is the process of removing items from storage to meet a specific demand
5. *Shipping* typically includes*:*
    a. Sorting batch picks into individual orders.
    b. Checking orders for completeness and accuracy
    c. Packaging merchandise in an appropriate shipping container
    d. Preparing shipping documents
    e. Weighing and cubing shipments to determine shipping charges
    f. Accumulating orders by outbound carriers
    g. Loading trucks

Warehouses facilitate production economies of scale and mitigate supply-chain and business risk by holding contingency and disaster inventory (Dr. Edward, 2016). Warehousing is a concept that includes multiple dimensions i.e., storage and retrieval operations, organizational aspects, mechanization equipment for material handling, media for material storage and the building itself for protecting the goods' necessary environments.

The methodology of warehousing is information-oriented and requires the use of efficient media to store and handle data about the movement of goods. Hence, according to Gunasekaran, Marri, and Menci (1999), managers need to ensure that, for each item:

1. The correct stock level is available
2. No unnecessary money is tied up in inventory
3. The warehousing capacity is efficient and economical; and
4. The goods are properly kept.

As storage is a central activity of warehousing, it fulfils the purpose of locating where the goods are deposited and held, until they are demanded for usage. Since items are of many different shapes and sizes, there is also different usage rates of the storage space. This also imposes different problems and can be handled by using different methods, such as first-in-first-out (FIFO) system, a stock or even using containers as a dedicated storage mechanism. Further, when material is stored, it is beneficial to minimize the time expended in retrieving the material by storing it closest to the shipping area, while slow-moving items should be kept at the other end (Gunasekaran et al., 1999).

3.2.2 Container Terminal Operations

Generally speaking, there are three types of containers at a container yard: Inbound, outbound and transhipment. Where inbound containers are usually stored at the yard for a couple of days before being picked up by an external truck and moved on to another location. The outbound containers are usually sent to the yard by the customers, where they will also be stored for some time before loaded onto a vessel. The third containers are the transhipment, which are discharged from a vessel and stored at the yard before loaded onto the next vessel (Yu & Qi, 2013).

A container yard needs to maintain a high service level to stay competitive. One important measure is the turnaround time for the arriving external trucks, which will pick up the inbound containers. The turnaround time consists of two parts: the time of driving in the container yard and the time of waiting for the desired container to be retrieved. The turnaround time for external trucks may also affect other operational measures. However, a segmentation can be made by separating storage of inbound and outbound containers into different blocks. In such a case, the operations in both segments will not be conflicted and a separate analysis can be made for both blocks. The average turnaround time is dependent on the physical layout of the container yard, since it is roughly constant (Yu & Qi, 2013).

The traditional layout of a container yard allows external- and internal trucks to drive in the lanes between the containers to pick up and deliver containers. This system is flexible for scheduling trucks but also requires careful traffic control and occupies more space for truck pavement, which results in less space for container storage. Opposed to the traditional layout, a new design layout consists of restricting the trucks to only drive along one lane at the end of the block, relying more on retrieving and delivering the containers by automated systems. This allows for more storage space and fewer manual operations. This is deemed as the future of container terminals as it can increase the efficiency as well as reduce the operational costs (Yu & Qi, 2013).

Apart from turnaround time, there are other container handling operations conducted in the container yard. For example, the transfer operations include the loading operation and the discharge operation, which ultimately influence the efficiency of the ship operation. The container yard functions as a storage area, where export containers are waiting to be loaded while imported containers are stacked before being associated with land or rail vehicles.
Operations within the container yard have the appearance of simplicity, but the complex demands require a high standard of management (Chen, 1999).

Traditionally, terminal operations, according to Chen (1999), are organized into three different groups and managed by three duty managers.

- Ship operation managers who organize the stacking of the import containers and the unstacking of the export containers of the containership to/from the yard.
- Receipt managers who organize the receipt operation and decide upon the storage planning for all the containers received, to ensure that they are stacked in the correct order.
- Delivery managers who organize the delivery operation and plan the procedures to deliver the requested import containers.

Further, Chen (1999) discuss the operations in a container yard from a container-import perspective. The container yard's major task is to stack the import containers in the yard efficiently, then, afterwards, to deliver them from the yard to the inland hauliers efficiently. However, before they can be transferred, the containers need to undergo multiple procedures, such as documentation, customs inspection etc. Hence, they need to be stored for a period until they are cleared through all procedures.

A challenge with the incoming containers could be that the imported container must be stacked above or mixed with previously stacked containers, while the previously stacked container is demanded for delivery. In such a case, shifting moves become inevitable. Another challenge is the stacking height of the containers in the yard. In practice, there is a direct relationship between the stacking height and the number of shifting moves of containers. Lower stacking is thus preferred to improve efficiency.

In planning the procedures for the storage of the anticipated import containers, there are several steps to be taken, according to Chen (1999), which are described below:

1. The first step is to discover the anticipated import containers that will be arriving via the vessel. This information is obtained from the shipping lines several days before the arrival of the containership. They will provide information such as:
    - Number of import containers to be discharged and stacked in the yard.
    - Number of types of containers (20ft, 40ft etc.)
    - Storage position in the containership.
2. The second step is to pre-plan the necessary arrangements and procedures in advance for the storage space required.
3. The third step is to set aside blocks available for storage. If there are no available blocks for storage capacity, housekeeping moves will have to be taken to make necessary storage space available.

All these steps need to be carried out before the ship operation commences to ensure efficient container yard operations (Chen, 1999).

3.2.3 Container Terminal Productivity

In the most general sense, productivity measures output per unit of input. Container terminal productivity deals with the efficient use of labour, equipment, and land. The limits of the productivity of a container terminal may be imposed by either physical or institutional factors or a combination of both (Dowd & Leschine, 1990).

The physical limitations include the area, shape and layout of the terminal, the amount, and the type of equipment available. Further, lack of cranes, insufficient land, odd-shaped container yards and difficult road access are all physical limiting factors (Dowd & Leschine, 1990).

Institutional factors include such things as union work rules, import/export mix, container size mix, container availability, customs regulations, safety rules and various requirements imposed on the container yard operator by various stakeholders. An example is that a carrier may require that the terminal accepts the arrival of containers for late arrivals and last-minute adjustments. Further institutional limitations could be a union work rule, stating that all operators have breaks at the same time, thus limiting the operations to continue during this time (Dowd & Leschine, 1990).

However, these limiting factors can be mitigated or eliminated. Usually, this means an increase in costs or a rearrangement in priorities to do so. As an example, if a labour work rule that is limiting productivity is to be amended or abolished, it may require an increase in manning or compensation of existing workforce. The same is true for the physical limitations. Productivity may be increased by adding another piece of equipment, or by replacing a serviceable piece of equipment with a newer, more efficient model. But a decision to do so means that the terminal operator must determine that it is worth the added costs and that the whole system would ultimately benefit from it (Dowd & Leschine, 1990).

3.3 Costs of Supply Chain Operations

Most literature on financial aspects of storage operations concerns the use of dedicated warehouses in where goods are stored. This aspect certainly differs from a container yard seeing that goods stored in warehouses are mainly in manageable pieces for picking and the volume of goods is preferably not excessive due to space constraints. Nevertheless, similarities between a container yard and storage in warehouses is profound. The larger difference between the two is the size of the goods being handled. Containers in themselves are declared as goods and used as storage. Thus, literature concerning storage operations and financial aspects of this will have information applicable on a container yard. The literature below is based on that presumption.

3.3.1 Storage and Warehousing Costs

According to (Rushton, 2017) the major cost breakdown for storage and warehousing is between building, building services, labour, equipment, and management/supervision. The relationship of these costs varies depending on the circumstances such as industry, volume throughput and location. Size is one factor that often is related to economies of scale, where the larger the warehouse the lower cost of operation per unit is required. Diseconomies of scale is however also a factor to consider, in that excessive internal travel and management problems can occur (Rushton, 2017).

Outside of the warehouse itself costs also incur. Especially prevalent are road transportation costs. The two most important categories of transport costs are primary transport and delivery transport (Rushton, 2017). Primary transport is often referred to as trucking or line haul and supplies products in bulk (i.e., FTL or FCL). Transport is usually completed using road; however, bulk products use all modes of transport. The number of sites affects the overall cost of this type of transport. In this instance, the effect is not a particularly large one, but it does result in an increase in primary transport costs as the number of distribution centres (DCs) increases. The effect is greatest where there are a smaller number of sites (Rushton, 2017).

Delivery transport is concerned with delivering products from warehouse to customer. This can be performed using a company's own fleet or by a third-party logistician. The cost of delivery is essentially dependent on the distance that must be travelled.

3.3.2 Inventory Holding Costs

Another important cost factor in warehouses is inventory holding cost. The costs can be broken down into four main elements according to Rushton (2017):

Capital cost – the cost of the physical stock. Usually described as the opportunity cost of capital in tying up capital that might otherwise be producing a better return if invested elsewhere. This is commonly the largest cost of inventory.

Service cost – stock management and insurance cost. The cost of servicing the inventory.

Storage cost – Not always incorporated but involves the cost of space, handling and associated warehousing costs with the actual storage of the product.

Risk cost - this occurs because of pilferage, deterioration of stock, damage, and stock obsolescence. This is often underestimated by companies and becomes especially prevalent for industries with short product life cycle and inventory turnover rate.

3.3.3 Information System Cost

These costs represent a variety of information or communication requirements ranging from pick lists for warehouse pickers to order processing. It is common for some type of computerized information system to provide these requirements (Rushton, 2017). Costs here are obviously dependent on size of the warehouse and if there are many locations of DCs that must be able and cooperate. The costs level out after a certain magnitude and size of network according to Rushton (2017).

3.3.4 Total Logistics Cost

Since logistical systems are dynamic and their environments can quickly change, it is difficult to estimate how changes in one cost element can affect the whole system. A way to approach this is by adopting a 'total' view of the system, to try to understand and measure the whole system as well as the relationships between the different structural elements (Rushton, 2017).

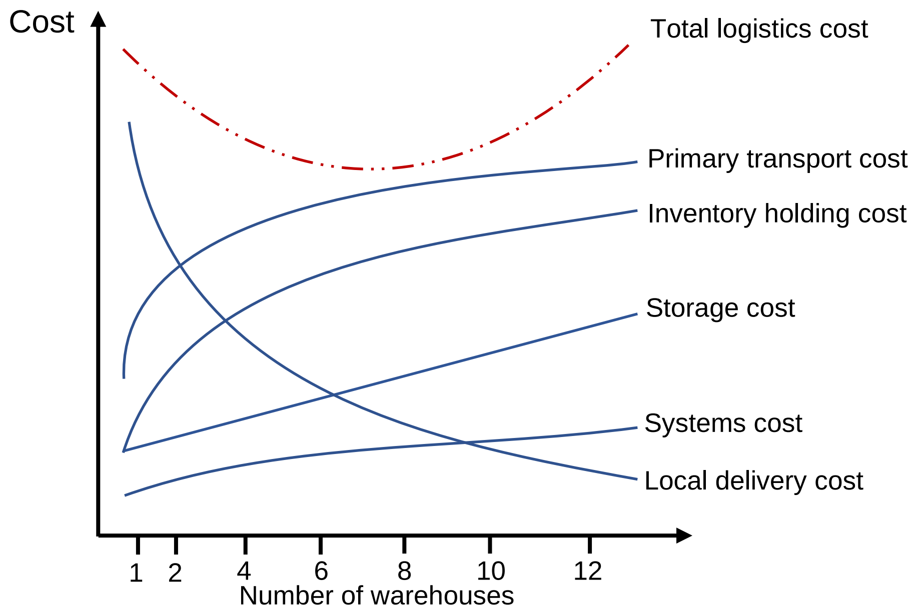

Figure 8: Total logistics cost based on number of warehouses in a network (redrawn from Rushton (2017)).

In this example, see Figure 8 above, the individual functional costs and the total logistics cost for an operation change as the number of warehouses in a network change. The top curve presents total logistics cost, and at the minimum point the lowest cost solution is found. At the edges of the graph, some elements increase in price whereas other decrease.

Helpful to total cost approach within logistics planning is trade-off analyses. As argued before and according to Rushton (2017), any change in one of the elements within a logistics system is likely to have a significant effect on the costs of both the total system and the other elements. It is, therefore, possible to create total cost savings by making savings in one element and increasing costs in another, but in the end reduces the total cost.

Cost and service trade-offs within any logistics system will vary from one company to another, much depending on the role the company it plays in the supply chain. According to Rushton (2017), some of the major costs and their associated trade-offs that need to be considered are production costs, transportation costs, information system costs and inventory costs.

Richards (2014) takes another approach to warehousing costs. The author argues warehousing makes up around 22 per cent of a company's total logistics costs with inventory carrying costs at a further 23 percent. As a result, warehouse management is undoubtedly important but nonetheless a complex issue to tackle. Compared to Rushton (2017), Richards (2014) brings up similar cost drivers of warehouse operations but mention them in the following categories:

1. *Space costs*:
    a. Rent/leasing costs on building/land.
    b. Insurance
    c. Repairs and maintenance
    d. Building depreciation

2. *Direct labour costs (fixed): warehouse operators*

3. *Indirect labour costs (fixed): warehouse management including supervisors and administrators*

4. *Labour costs (variable):*
    a. Overtime, bonuses

5. *Equipment cost (fixed):*
    b. Depreciation/lease/rental costs

6. *Equipment costs (variable):*
    c. Running costs

4. *Overhead costs (management, finance, human resources, IT and administration)*

5. *Overhead costs (sales and marketing in 3PLs)*

6. *Miscellaneous costs*

Each category can be further split up into sub-costs but are not presented for the framework as it is the general conception that is of importance.

3.4 Summary of Framework: Designing the Container Terminal

To contextualize a framework that would be not only be befitting for a general supply chain context but more specifically a container terminal, the process of designing a container terminal will be discussed. In the report, *Designing Future-Proof Container Terminals,* by Alho, Kuipers, Vermeiren, Welvaarts, and Broeck (2019), a design process is reviewed that can incorporate the three levels of decision making discussed: strategic, tactical and operational (Van Landeghem & Vanmaele, 2002).

Container operations are to bring a total value to their user, and this include amongst other strategic and financial value (Alho et al., 2019). Strategic value is to be evaluated over a long-term horizon and reflects a terminal's ability to adapt towards changes in the market and broader operating environment. Options to expand, reduce or exit operations over time is considered as flexibility, as well as saving on scarce resources such as land (Alho et al., 2019).

Financial value is primarily derived from investment and operational expenditure. Here alternative design options are typically compared against their financial performance measured in Pay Back Period or Internal Rate of Return. Business cases can help in understanding how financial value can be improved through savings in operational expenditure and capital expenditure (Alho et al., 2019). Trade-off analysis as discussed by Rushton (2017), is also a good complement for evaluating financial value.

The report brings up additional values in customer value and social value. The former regards to which value users of the terminal experiences, such as equipment availability, speed, and reliability. Customer value is accordingly linked to financial value through loss or gains in market shares and pricing levels (Alho et al., 2019). Social value encompasses the benefits for third party and social economic health in general for the region. This includes employees, the population, economic systems, and the surrounding scarce natural resources (Alho et al., 2019).

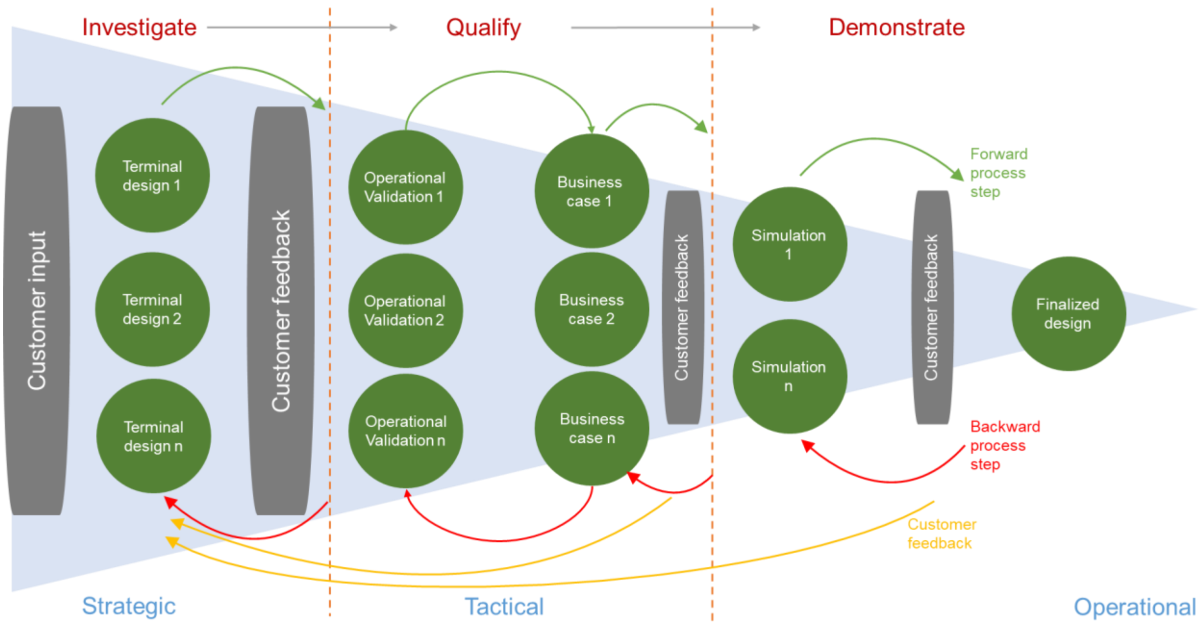

Figure 9: Container terminal design process (redrawn from Alho et al. (2019)).

With the elements of total value discussed, the design process can be clarified for a container terminal. Alho et al. (2019) divides the design process into investigate, qualify, and demonstrate (see Figure 9). As can be seen the design process is iterative and initially considers several different design ideas. But as time transpires, options are narrowed down until a finalised design is found. To put the figure into context with previous discussions in 3.1.3 Supply Chain Strategy, Figure 10 shows elements of analysis in the different phases.

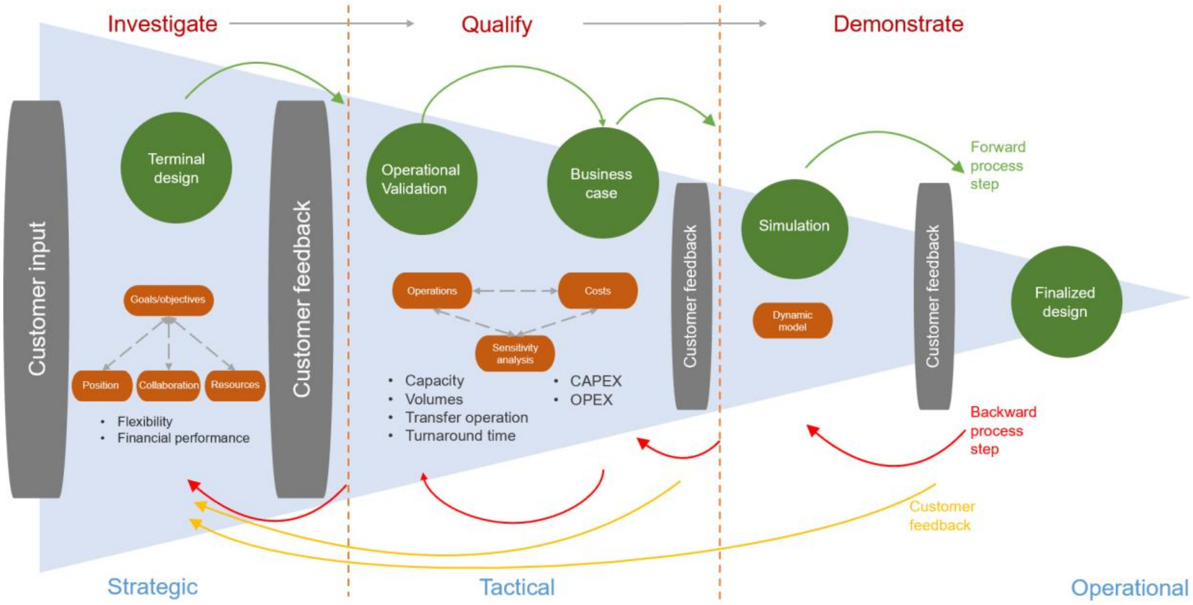

Figure 10: Container terminal design process with elements of analysis.

The component of investigation involves proposing different design layouts wherein long-term strategic decisions have to be incorporated (Alho et al., 2019; Gharehgozli, Zaerpour, & De Koster, 2020). As presented in Figure 10, this includes designing initial layouts that reflects goals and objectives of the terminal. As mentioned in 3.1.3 the goals can consist of no shortage allowed for inbound goods, but also the flexibility of adapting the terminal to market changes. Collaboration with key actors should be acknowledged during this phase of designing a terminal. Furthermore, the company's position in the value chain results in different expectations on the container terminal. By early on stating the purpose of the terminal, the focal firm can use it to differentiate itself and strengthen its market share. Lastly, the firm must acknowledge how to utilise internal resources to the best of the company's abilities. Broad financing calculations can here be examined to compare evaluated terminal designs in financial performance measures. At this point no terminal design concept is locked down but optimistically some can be disregarded (Alho et al., 2019).

Through input and feedback from parties involved, the design process can move on to qualification involving operational validation based on certain business cases, for example projected volume. Here, medium-term tactical decisions are considered to find the design layout optimised for operations. Operational validation in areas such as capacity calculations, turnaround times, transfer operations as well as the terminals potential productivity, are areas of interest for analysis. Additionally, a more comprehensive numerical analysis of CAPEX and OPEX can be conducted during this stage (Alho et al., 2019). Sensitivity analysis is considered a natural step in this phase, exploring effect of changes in various parameters such as volumes, dwell time and so on. The goal towards the end of this phase is to begin constructing a solution robust enough to allow for changes while upholding the long-term strategical goals set. With regards to Figure 10, the tactical level parameters of operations and costs are thus an umbrella term to cover the analysis done in this phase.

For the last phase, demonstration, a careful validation of selected design is performed making sure it meets it long-term strategical goals. Here it is common to use simulations based on real data to depict the design and verify operations in different scenarios (Alho et al., 2019). It is vital to address the benefit, dynamic nature of operations in simulations compared to static excel models or value-stream mapping that work better for high-level modelling. The analysis should at this phase provide better knowledge and impact of potential bottlenecks, fleet sizes, equipment productivity, etc (Alho et al., 2019). Lastly, understanding the iterative nature of the design process is crucial. In the initial phase information is continuously made available but decision can have large impact if anything is overlooked, and they are committed to. By allowing to go back in the design stage, any impact of wrongdoings is decreased, and better decision making can be made as depicted in Figure 11. Furthermore, by putting extra time and effort into high-level design and analysis, can bring large future savings.

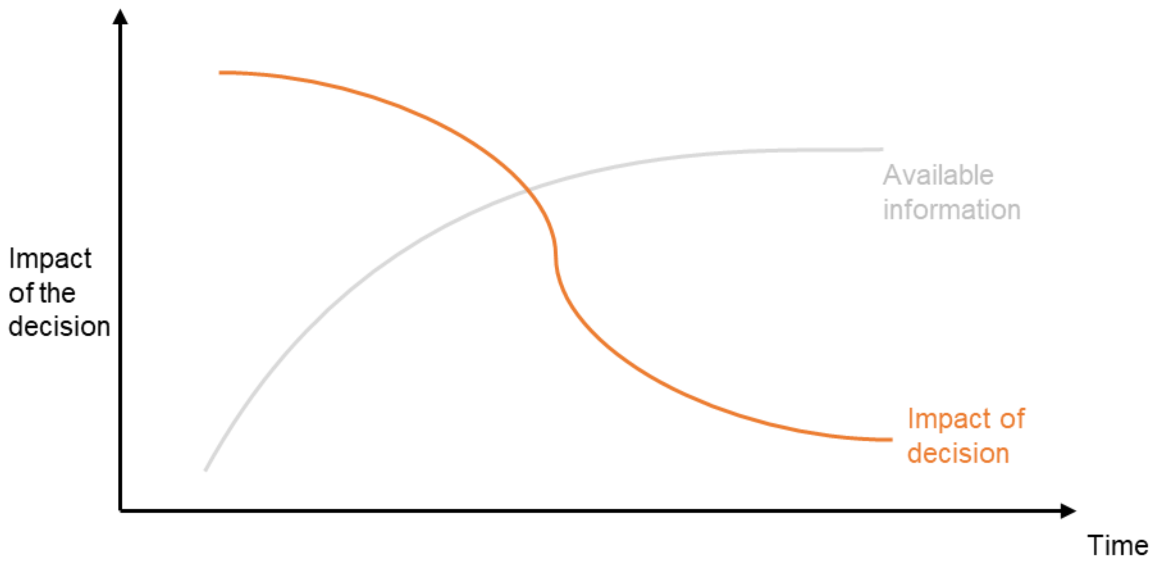

Figure 11: Impact of decision over time as information is made available (redrawn from Alho et al. (2019)).

This last phase of the design process confers to tactical level more so than the operational level. However, as mentioned in section 3.1, Van Landeghem and Vanmaele (2002) argue that uncertainties are best mitigated at the tactical level which coincides with the fact that the demonstration phase is the last step in finalising the design. Operational level decision making consist more of operations planning and control, which Gharehgozli et al. (2020) argue is more befitting to use with decision tools such as linear programming. These can also be run once the terminal is operative since the design system should allow for some degree of freedom internally. Furthermore, traditional manually operated terminals allow experimenting on production systems since any changes only affect operating procedures and personnel (Alho et al., 2019).

4 Presentation of Data Underlying the Analysis

In this chapter, data collected from interviews is presented below for the reader to both clarify arguments and explore data necessary for calculations in the analysis to answer *RQ1* and *RQ2*. From the top down, the structure begins with strategic factors, brought up through interviews necessary to elaborate on, followed by operational factors such as expected productivity from industrial vehicles. Lastly, costs associated with any sort of container handling is discussed creating a wholistic picture of the design process. The factors have been identified from an ongoing dialogue with Northvolt as well as external professionals who have shared insights for the study. The collection has been in accordance with chapter 2 Methodology, where theory from chapter 3.1 and 3.4 has been used as fundamental information to determine which factors are necessary.

4.1 Strategic Factors

The premise of the container yard is constrained initially by strategic factors put on by Northvolt but also fundamental principles, or institutional factors as coined by Dowd and Leschine (1990). Concerning the latter, these regard actions such as minimizing the number of times a container is being handled, i.e., avoiding double handling as communicated by several external experts in ports. This could be logically implied but also brings the notion of trying to find the optimum solution.

Representatives in the logistical department at Northvolt states that the most important objective of the container yard initially is to make sure production never stops. Meaning there always must be an inbound flow of containers available, due to production stops being extremely costly. Currently, volume projections of containers found in internal reports at Northvolt do account for safety stock for this reason. A representative at Northvolt further confirmed this in an interview. As production scales up the objective could shift towards a leaner approach where the same safety stock perhaps is not as necessary but rather a Just-In-Sequence approach.

With regards to the placement of the container yard (see Figure 2) other strategic aspects are brought up. First, the placement in the port entitles dependency on other logistical parties. Northvolt, which strives for vertical integration thus need to take this into account (Northvolt, 2020a). The port naturally would function as a container yard due to incoming containers having to be handled there regardless of later placement. Second, infrastructure in the port is already being developed by the municipality as a result of large economic growth in the region, with Northvolt being one of the main drivers. Considering this, leveraging the situation could be resourceful. From interviews with representatives in the Port of Skelleftea it was communicated that no current container handling is taking place in the port which does reduce the potential leverage.

When it comes to assets, Northvolt has spoken of minimizing capital expenditure in favour of operational expenditures. The argument for this is that financers do not want to have capital tied up in resources and machines beyond what is necessary. Northvolt is as of writing, a start-up and is cautious with tying up capital in its initial faces as a firm. Finally, sustainability permeates Northvolt in all aspects of their business. Trying to be fully carbon neutral means actively taking charge when possible and would in this instance mean promoting container handlers such as reach stackers and other transportation vehicles fuelled by renewable energy.

It was also noted that due to handling raw material classified as dangerous goods, certain restrictions and precautions needed to be considered. From representatives at Port of Skelleftea and Northvolt, SEVESO regulations were mentioned which limits the freedom in what is possible in storage and handling. Although, a dangerous goods specialist at Northvolt proclaimed that if a material is allowed to be transported in a container, safety measures must already have been accounted for. Since the material in containers are not to be stripped until at the production facility, it does only provide physical limitation in placement of containers. Certain material must be placed at a safety distance from one another in case of an emergency resulting in a potentially larger yard needed.

4.2 Operational Factors

To understand the operational restraints and opportunities, it is necessary to be aware of the activities and how they will occur. The operational activities related to the container yard will be carried out by different vehicles, hence data has been collected from different stakeholders within the organization of Northvolt as well as outside of the organization, by professional experts within the industry of ports in Sweden.

4.2.1 Shunting Fleet

According to professionals at Northvolt, a shunting fleet will be implemented to transport the imported containers, arriving at the Port of Skelleftea, to the production facility. Hence, a transport time will be considered. The transport time consists of driving between the port and the production facility Northvolt Ett, which is approximately a distance of 10 km. The trucks will receive a container in the port and drive back up to Northvolt Ett where the transported container will be discharged and eventually drive back to the port. This round trip, including loading and unloading the container, is estimated to take one hour.

Further, restrictions on the transport capacity have been identified. According to a Northvolt representative, the primary road of transport in Skelleftea has a weight limit of 74 tonnes. According to professionals at Yilport, 40-foot container weigh up to 30 tonnes, technically allowing two containers to be transported per truck. However, legislation from the Swedish Transport Agency, Transportstyrelsen (2020), declare that it is only allowed for a vehicle to span 25.25 m on public roads, regardless if the total weight fall below maximum capacity. Consequently, the shunting fleet can only pull one 40-foot container per travel with a 20-foot container on a smaller chassis if need be. Although the same representative from Northvolt working with logistics development sees a potential future allowing two 40 ft containers being pulled simultaneously, the current situation does not allow for it.

The shunting fleet is assumed to be available 16 hours per day, according to representatives at Northvolt, while the remaining 8 hours will include refuelling/charging and maintenance of the fleet. The distribution of usage is unknown and could be spread in intervals. Regardless total expected time of usage is 16 hours per day for each vehicle.

The delivery points at the factory are loading docks and designed to receive only one container at the time. Through both interviews and internal documents from Northvolt it has been discovered there are several of these delivery points, however, the main one to be used are that at the central warehouse consisting of three loading docks, and two at outbound which is Formation & Ageing (F&A).

Figure 12: Container yard at the port

If the container yard is placed at the Port of Skelleftea, the shunting fleet can transport the containers from the container yard and deliver them straight to the central warehouse, see Figure 12. Since the delivery point only allows for one container at the time, the capacity of each roundtrip will be one container.

Figure 13: Container yard on-site

Also, if the container yard is placed onsite, at Northvolt Ett, the shunting fleet will mainly be transporting from the Port of Skelleftea to the container yard (see Figure 13). Therefore, the limit will be stipulated by maximum length allowed by Transportstyrelsen, i.e., transport one 40 ft container at the time.

A logistics developer at Northvolt additionally discussed that Northvolt in the future hope to make the transportation between the port and facility autonomous. A projection for how long this might be was not communicated but having this in mind for the solution was advocated.

4.2.2 Reach Stacker

The handling of containers in the container yard will be performed by a reach stacker (see Figure 14). The reach stacker is identified to perform one main activity, moving container to/from vehicle from/to stack. According to professionals at Yilport, the activity can be performed at a rate of 10 – 15 containers/hour. The activity will be dependent upon the physical layout of the container yard. In between these activities, the reach stacker might also have to perform excessive lifts in case a demanded container is stacked below another container, according to representatives from the Port of Norrkoping. The performance levels can be illustrated in Table 4.

Figure 14: A reach stacker lifting a container (Wikimedia Commons).

Table 4: Reach stacker performance levels.

Performance interval	Low performance	Medium performance	High performance
Container lifts/ hour	10	12	15

4.2.3 Terminal Tractor

A terminal tractor can be of use if the container yard is located onsite, in which case a terminal tractor will be able to transport the demanded containers from the container yard to the central warehouse, as well as return it after it has been emptied (see Figure 15). A dialogue with representatives at Northvolt has presented us with the location of the container yard onsite, which is approximately a distance of 1,5 km from the central warehouse. The speed of transportation will be at most 30 km/hour, but a more reasonable average is 20 km/h. The transport time can therefore be calculated in minutes as well as the roundtrip. As the performance can vary, an interval is presented in Table 5 below where the varying variable is the process of loading / unloading the containers.

Figure 15: Terminal tractor pulling a chassis with a container onboard (Wikimedia Commons).

Table 5: Terminal tractor performance levels.

Terminal tractor	Low performance	Medium performance	High performance
Speed km/h	20	20	20
Distance km	1.5	1.5	1.5
Transport time (min)	4.5	4.5	4.5
Loading / unloading (min)	3	2	1
Roundtrip (min)	15	13	11

4.2.4 Loading Dock

The delivery points at the factory, mentioned as access points in internal documents, exist at seven places around the facility with varying number of loading docks at each access point. The central warehouse, where inbound containers will be stripped, has three loading docks, and will handle a large majority of inbound flow. Formation & Ageing (F&A) is the access point where the outbound containers will be dedicated to being filled with finished goods. F&A is designed with two loading docks. Additionally, the process of stripping/filling the containers is estimated to take between 30 – 60 minutes, according to professionals at Northvolt. Figure 16 shows an example of a loading dock with a container parked in front.

Figure 16: Loading dock with a parked trailer (Wikimedia Commons)

4.2.5 Container Chassis

In order to transport a container via road back and forth efficiently, all external interviewees have recommended a container being placed on what is called a container chassis. These are specially designed chassis for container transportation and can be used by semi-trucks (shunting fleet and terminal tractor). The containers vary in length depending on the main type of container it transports (20 ft or 40 ft), but some also come with extension functions for length adjustment. An example of such a chassis is depicted in Figure 17.

Figure 17: Container chassis (Wikimedia Commons)

4.3 Cost Factors

Numerous investments have been identified, deemed necessary to handle the forecasted flow of goods in the container yard. The investments will be categorized into capital expenditure and operational expenditure. Capital expenditure (CAPEX) implies that the organization will have to do a one-time purchase while operational expenditure (OPEX) implies a running cost will be paid on a continuous basis.

4.3.1 Warehouse Expansion

A base case to compare the container yard with, is the expansion of the warehouse which includes construction and purchasing equipment. Due to confidentiality, true numbers will not be presented in this report found in internal documents, but rather numbers that give and adequate comparison. The current warehouse will have only a few days storage capacity for a production of 16 GWh and have an approximate equipment cost of 70 400 000 SEK for. A linear increase in cost is deemed realistic and thus a warehouse of double capacity, 32 GWh, would amount to a total cost double of that.

Beyond the actual equipment, construction of the warehouse needs to be taken into account. Again, using fictional numbers, but still reasonable comparative to those found in internal financial reports, construction cost of the current 16 GWh warehouse is estimated to be 77 000 000 SEK. From discussion with numerous employees at Northvolt in the logistics department, plans of constructing a new warehouse is under investigation. Its footprint would be approximately 150% larger than the current central warehouse and hold even more days of stock. The expansion combined with the original central warehouse would then hold inventory for a combined production of 40 GWh. The costs are presented in Table 6 below.

Table 6: Costs for central warehouse at 16 GWh production.

Warehouse costs (16 GWh)	**SEK**
Construction cost	77 000 000
Equipment cost	70 400 000
Total cost	147 400 000

4.3.2 In-house

For the in-house container yard solution, four different cost drivers have been identified. The first one, that goes under the category capital expenditure, is the container yard foundation. This is the area to construct in which the containers will be placed and includes, among other things, building a cement foundation, fences, and outlets to allow electric power for refrigerated containers sensitive to temperatures in the northern climate. The area needed for this is very much dependent on how containers are stacked. From interviews with representatives at Norrkoping port, the notion of excessive lifts is brought up as a central factor. This regards to how many lifts are necessary to reach intended container. A common rule brought up by the representative is that 2-4 excessive lifts are deemed reasonable. The former means a stacking procedure of two containers wide and two high (see Figure 18). Same logic applies to stacking two wide and three high, which would then require a maximum of four excessive lifts. Additionally, stacking more than ten containers in a row by its length is not financially viable due to running costs, unless there are entrance points on both ends of the corridor according to representatives from the Port of Norrkoping. The second cost driver is industrial vehicles. This consists of reach stackers (see Figure 18) to move and stack containers on the actual yard, and terminal tractors with chassis to transport the containers from the yard to the loading docks of the production facility (see Figure 15).

Figure 18: Depiction of reach stacker having to perform two excessive lifts to reach the intended container (Wikimedia Commons).

Under the category of operational expenditure, we find costs of personnel to operate the vehicles in the container yard, and operational costs for the reach stacker as well as terminal tractors. Running costs for these vehicles are extensive in both tires and fuel and presented on an hourly average cost. Due to the cost of running these machines, they are used in dedicated areas for optimal performance and long transport stretches are not viable. Information systems is a key to operating any logistical operation and this is no exception. From internal sources it has been communicated that an existing WMS-system is already in place and if additional licenses are necessary, they would be added costs, in the form of monthly licensing fees. For this reason, they are not incorporated here. The entire cost schedule is presented in Table 7.

Table 7: Cost drivers for in-house solution.

In-house	
CAPEX	**SEK**
Reach stacker (RS)	4 338 700
Used Reach Stacker (RS)	2 169 350
Foundation	1 750/m²
Chassis per unit	225 000
Terminal tractor (TT)	1 816 200
OPEX	**SEK/day**
Reach stacker driver	1500
Terminal tractor driver	1500
	SEK/h
Maintenance RS	151
Tires RS	101
Fuel consumption RS	264
Maintenance TT	76
Fuel consumption TT	144
Tires TT	50

The foundation has several components, but an estimated cost was given by a representative at the Port of Skelleftea for 1 500-2 000 SEK/m^2. Using an average, we obtain a cost of 1 750 SEK/m^2. A reach stacker was quoted in the range of € 420 000 – 430 000 by a representative from NC Nielsen, a distributor of reach stackers in Sweden. Used reach stackers are expressed as a need for backup in the case of any breakdowns and are assumed to have a purchase cost of 50% compared to new ones. Additionally, a terminal tractor can be purchased for € 170 000 – 180 000 by the same distributor. The same need for a backup terminal tractor is not present due to being more easily replaced in the event of a breakdown by regular trucks. The price range is owing to optional addons, but the highest estimated price is shown in Table 7, converted to SEK in line with exchange rates of April 2021 (€1=10.09 SEK). Running costs for reach stackers are as mentioned rather high. For example, a single tire costs around 50 000 SEK to exchange and the vehicle itself need continuous maintenance. Expected hourly costs for tires have been communicated by the same representative of NC Nielsen as approximately € 8-12/h. As for fuel consumption, normal range is 15-18 litres/h. Based on fuel prices as of April 2021 that leaves an hourly cost of 264 SEK/h (OK-Q8, 2021). A maintenance service program is offered by NC Nielsen at approximately € 15/h or 151 SEK/h. This includes all necessary services and is found representative of carrying out the same service in-house.

The terminal tractors have a general maintenance cost of € 7.5/h and fuel consumption of 8-10 litres/h. From the representative at NC Nielsen, additional estimation of tire costs land at € 5/hour or 50 SEK/hour. Although it might be interpreted odd to present costs in hourly rates this is the status quo in the industry as stated by NC Nielsen. The main reason for this is that reach stackers and other heavy-duty equipment has a lifespan of thousands of production hours and not years per se.

Further, container chassis will be demanded and can be purchased for approximately 225 000 SEK according to representatives at ShoreLink, stevedores in the Port of Skelleftea. Cost of staff is estimated by HR at Northvolt to be around 1 500 SEK/day including social fees and workers compensation.

4.3.3 Hybrid

The capital expenditure for the hybrid solution is similar to the in-house solution when it comes to constructing the container yard on site at Northvolt Ett, the production plant. However, the ownership structure can differ in two ways. Either Northvolt own the complete fleet of vehicle equipment necessary for facilitating transport and rely on a third-party logistics company for running operations and their expertise. Alternatively, Northvolt can construct the container yard and outsource the operations to a third-party logistics company. The former alternative is presented in Table 8 and the latter in Table 9 .

Table 8: Cost drivers of hybrid solution with ownership at Northvolt.

Hybrid with Ownership	
CAPEX	**SEK**
Reach stacker (RS)	4 338 700
Used Reach Stacker (RS)	2 169 350
Foundation	1 750/m²
Chassis per unit	225 000
Terminal tractor (TT)	1 816 200
OPEX	**SEK/day**
Reach stacker driver	2250
Terminal tractor driver	2250
	SEK/h
Maintenance RS	151
Tires RS	101
Fuel consumption RS	264
Maintenance TT	76
Fuel consumption TT	144
Tires TT	50

Firstly, the foundation will have to be constructed at 1 750 SEK/m^2 to allow for operations. The necessary vehicles could be purchased at the aforementioned price presented in 4.3.2. Similarly, the running costs of the machines are displayed above. The difference will be the staff not belonging to the organization and will therefore occur as an external transaction. Obtaining first-hand sources on quoted prices are difficult since it usually comes from negotiation based on needs. Data from the Port of Ahus, shows an hourly fee of around 500 SEK/hour for normal workdays (Ahus, 2019). This does, however, not consider overtime and are subject to shorter contracted hours. Additionally, port labour is strictly regulated and estimating pay based on these numbers with the expected overtime pay would lead to astronomical figures. A more realistic assumption used is thus basing the daily salary at 1.5 times that of an in-house worker.

Table 9: Cost drivers of hybrid solution with ownership outsourced.

Hybrid without ownership	
CAPEX	**SEK**
Foundation	1 750/m²
OPEX	**SEK/day**
Reach stacker driver	2250
Terminal tractor driver	2250
	SEK/day
Terminal tractor rent	12 000
Chassis rent	4 080
Reach stacker rent *-Full utilization*	24 000
Reach stacker rent *- Half utilization*	24 000

In the hybrid solution where handling on site is outsourced to a third party (see Table 9), vehicles necessary for transporting the containers will be provided by said party. Nevertheless, the container yard itself will be constructed at the same cost of 1 750 SEK/m^2. The operational costs will instead be based on renting equipment and hiring personnel. In ports, the status quo is to charge a price per lift. In the hybrid case, however, when a third party is to operate the entire operations around the clock an hourly or daily cost is more likely to implemented since no other customers are involved. From port tariffs in the Port of Norrkoping and Ahus, rental costs for reach stacker, terminal tractor and chassis are found (Ahus, 2019; Norrkoping, 2020). In Table 9 above, rental costs are presented as daily charges without drivers. Personnel is assumed to have the same costs as the hybrid solution with ownership. Two reach stackers are presented following the same argumentations as both previous solutions, i.e., for safety measure and being able to aid in case of high demand.

4.3.4 Outsource

The fully outsourced solution is placed in Port of Skelleftea and will differ the most from the other two solutions. Capital expenditure will only exist in the shape of container chassis used as a transport carrier between the port and the production facility. Land for the container yard will be leased by the port in Skelleftea at a yearly rate per square metre. From interviews with representatives at different ports in Sweden (see Table 1), containers can for a period be stored in the port depot area for free (usually a week). This allows for customs clearance and permit the stevedores sufficient time to strip any incoming vessels. To avoid port congestion and discourage the practice of late pick up from consignees, storage fees are charged after the free period. These fees are rather hefty and from stevedore Shorelink, prices are quoted at 80 SEK/TEU and day. From interviews with logistics coordinators at Northvolt it was stated that some inbound containers will likely have to be stored for up to three weeks before delivery to

Northvolt. Therefore, leasing a private depot area in the port removes the uncertainties of storage fees accumulating and instead create a fixed leasing fee. The costs are displayed in Table 10.

Table 10: Cost drivers for outsourced solution.

Outsourced	
CAPEX	**SEK**
Chassis/unit	225 000

OPEX	**SEK**
Leasing yard	70/m² per year
Inbound	
RS - Lift	300
Outbound	
RS - Lift in	300
Avg. shift cost per day (16h)	13 700/day

Chassis cost have been communicated through stevedores ShoreLink at 225 000 SEK/chassis. The cost of space will be leased from the port and charged at a rate of 70 SEK/m^2 per year based on estimations by a representative from Port of Skelleftea. A major part of operational expenses will be cost of lifts. These are lifts out of the container yard inbound for the production facility, and likewise outbound containers lifted into the container yard outbound for customers or placed in empty container depot.

For the price, stevedores assure enough resources are available to perform the lifts in given time. Additionally, they assure for stacking procedures and potential sweeping of snow in the port. All containers must be unloaded from an incoming vessel to the depot area; however, this lift cost is outside of the scope of the container yard and will regardless also be present in all solutions.

In Sweden, regulations for working hours in Sweden are kept strict and normal working hours at the Port of Skelleftea are between 07:00 am to 16:30 (Stuveriavtalet, 2020). This time slot includes at least 1 hour and 30 min total break for workers. Any operations beyond this are subject to overtime compensation unless local agreements are set. Since Northvolt are producing 24 hours a day, closing the port during weekends will not be possible based on discussion with representatives from Northvolt. Containers will have to be transported at least for a few hours every day into the production facility. Although new agreements to extend weekdays operations to 16 hours a day seems likely according to representatives from the Port of Skelleftea and Shorelink, weekends are still up for discussion and come with a hefty price tag. The rate for this has been expressed by a representative from ShoreLink as 3 000 SEK/h if scheduled in advance and under the condition that at full eight-hour shift is completed. By assuming 16 hours per weekend day, we get 96 000 SEK. Splitting this into daily average cost it is around 13 700 SEK/day.

4.4 Volume

Different inbound volumes will be relevant depending on the production state. The study is primarily to focus on the steady state of 16 GWh, which will not be in place until 2024. Volumes for this period are only projected on a quarterly basis. An assumption to present a case is thus splitting volumes into expected weekly and consequently daily demand. Secondary data shows that projected weekly volumes is approximately 210, 40-foot containers inbound per week. Since production at Northvolt is supposed to run 24 hours a day, 330 days a year, a daily demand is split into 30 containers per day. Outbound volumes are also relevant but are much less and projected for 10 outbound 40-foot containers filled with goods per day. Outbound containers to be filled with goods are part of a cyclic system with re-suable bins in them. Northvolt has continuous finished goods going outbound and use containers in a cycle being returned with empty bins. Using these bins to fill up finished goods, it is projected that 10 containers need to come inbound with the bins in them. Totalling the daily inbound demand to 40 containers. For outbound, 10 will be filled with goods whereas the remaining 30 will be empty. For the inbound containers, the volume is accounting for some safety stock, but exact figures were not found in the internal documents.

For the 40 GWh case, the inbound flow will be assumed to consist of 2.5 times that of 16 GWh, i.e., 100 inbound containers and 25 outbound containers. The same relation as mentioned above will apply, i.e., 25 of the 100 inbound containers will be used for outbound shipments, while the remaining 75 will leave the system empty.

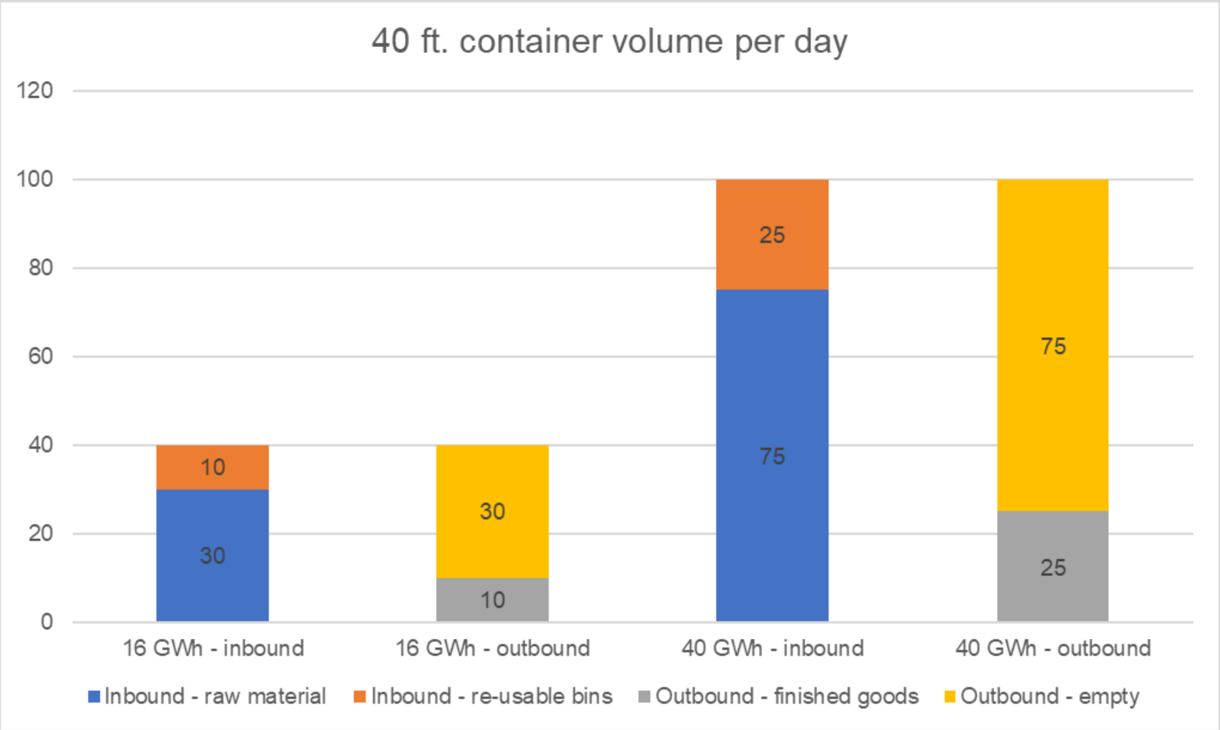

Figure 19: Container volume per day.

5 Analysis

The analysis will be presented in chronological order. Initially with respect to the first research question, i.e. *Is a container yard a viable option for complementary storage of goods compared to traditional warehousing?* This question is evaluated from a financial perspective to get an insight, on a high level in accordance with the strategic level presented in the theoretical framework. Sequentially, the analysis will consider the second research question i.e., *What ownership structure for the container yard is most viable?* By evaluating the three different solutions from a strategic, operational, and financial perspective. The strategic section will combine all three solutions in one but followed by the financial and operational analysis separately. A summarised comparison is later conducted for the three solutions evaluated. A simulation is also performed on selected sections to detect bottlenecks in the container flow. Moreover, a complementary solution is presented, which was developed during the analysis-process by iteration, as presented in the theoretical framework in section 3.4 and research process, Figure 5. Conclusively a comparison is presented between two selected solutions regarding a 40 GWh scalability case, as a sensitivity analysis.

5.1 Cost of Warehouse Expansion

The underlying analysis to be made with respect to *RQ1* of the thesis, is that of expanding the warehouse or implementing the container yard. As stated in section 4.3.1, a 16 GWh warehouse has an estimated construction cost of 77 000 000 SEK. Subsequently, costs of equipment for handling the operations in said warehouse is estimated to be 70 400 000 SEK. Discussions and plans for a new warehouse, capable of handling more days of stock for a 24 GWh production capacity have been estimated at occupying 1.5 times that area. With that data a total investment cost of 221 MSEK is calculated as seen in Table 11. The combined capacity of the current warehouse and the potentially constructed one would altogether allow production of 40 GWh, but only with a few days' worth of stock.

Table 11: Cost of constructing a second central warehouse 1.5 times larger than the original one.

Warehouse expansion	**SEK**	**Expansion factor**	**SEK**
Construction cost	77 000 000	1.5	115 500 000
Equipment cost	70 400 000	1.5	105 600 000
		Total Cost	221 100 000

As proclaimed by Rushton (2017), the major cost breakdown for storage and warehousing is between building, building services, labour, equipment and management/supervision. The relationship of these costs varies depending on the circumstances such as industry, volume throughput and location. Size is one factor that often is related to economies of scale, where the larger the warehouse the lower cost of operation per unit is required. Diseconomies of scale is however also a factor to consider, in that excessive internal travel and management problems can occur (Rushton, 2017).

The warehouse is currently being implemented with automatic systems meaning that it is not nearly as labour intensive as a container yard nor a traditional manual warehouse. Cost accrued here are thus mainly broken down into buildings and equipment. Compared to the container yard where labour and equipment amass most costs, with the container foundation also having an impact. Although some manual handling will happen due to inbound goods being stripped off containers in the warehouse, it is not comparable to that of the container yard. Operations in warehouses are quite complex and estimating an average operating cost is beyond this thesis. However, comparing the expected capital expenditures and the operational expenditures of the container yard can give a breakdown of the difference in costs between the two.

5.1.1 Road Transportation Costs

In section 3.3, different aspects of warehousing and storage costs were brought up. Although the different solutions have certain aspects more prevalent to them, some are present throughout all. Herein falls road transportation. The two most important categories of transport costs are primary transport and delivery transport (Rushton, 2017). Primary transport is often referred to as trucking or line haul and supplies products in bulk (i.e., FTL or FCL). For all cases, FCLs are transported from the port to Northvolt via a dedicated shunting fleet. This fleet consists of electric trucks capable of transporting one 40-foot container. Since these transports are identical for all solutions, it is not necessary to go in greater detail in their costs unless any anomaly occur. These anomalies could be additional transport units or more frequent ones. As for all 16 GWh solutions, nevertheless, Northvolt plan to operate four electric trucks that can for 16 hours of the day transport containers back and forth.

5.1.2 Inventory Holding Costs & Information Systems

As proclaimed by Rushton (2017), inventory holding cost can be divided into four elements of capital cost, storage cost, service cost and risk cost. For the evaluation of container yards, the most prevalent element is that of storage cost. The reason being that cost of space is dependent on the dedicated yard being leased or not. In ports, storage fees are charged per day after a certain free period if placed in a general depot. However, if leasing an area, storage fee will not fluctuate and is befitting given a longer storage time.

Capital cost and service costs are not subject to detailed analysis due to them being existent and having the same cost structure in all solutions. Capital cost due to inbound containers being subject to similar flow and storage regardless of solution. Service costs fall under the same argument, and furthermore the only dedicated service cost would be power supply to refrigerated containers, something current data does not provide in detail enough. Risk costs could be argued for but since stock is carried in containers, the likelihood of anything happening to the goods is arguably smaller given the metal construction of a container providing protection. It is touched upon with arguments regarding double handling, although no quantitative measure is presented.

Information systems follow a similar path as the aforementioned holding costs. Rushton (2017) speak of these costs as growing with the number of DCs, whereas in this case, several container yards are not evaluated to be concurrently running. But rather one or the other. Northvolt does currently run a WMS-system which should technically be adaptable for the solution after interviews with representatives and not need further investment. Implementation and integration between the port and Northvolt Ett is however a problem not discussed in this research as it is very much a practical implementation.

5.2 Strategic Analysis of Container Yard Ownership

With an analysis made upon the high-level financial implications of warehouse expansion and its viability, the ownership structure of three potential container yards alluding to *RQ2* is to be evaluated.

The case study, being based on the only large-scale production facility within Northvolt's supply chain, makes the decision a strategic one since it encompasses the whole current network but also tactical in that in that it is tightly coupled to logistics optimizations as explained by Shapiro (1999).

As stated in the theoretical framework section 3.1.3, Figure 7, there are certain parameters of strategy which can be applied in the case of the container yard. First, goals and or objectives must be clarified in order to help shape the system and is the highest priority at the strategic level. Proclaimed in section 4.1, an initial objective of avoiding production stop is prioritized due to the high costs of downtime. This means the volumes handled at the production site would reasonably have to be large to accommodate greater safety stock. Once the operations improve and the production scale expands, shifting the objective more towards a lean approach with lower safety stock is possible.

Northvolt's position as a producer is rather far downstream in the supply chain of battery production. Albeit there are not necessarily copious amounts of steps prior it still serves a different understanding of responsibilities and activities. As clarified in section 3.1.3, understanding one's position can help gain leverage. For example, if Northvolt wants to build upon the vertical integration it is necessary to promote their independence. It would accordingly advocate for them to operate the container yard themselves and not rely on the port solely for the inbound flow. Nevertheless, as Porter (1979) discusses, through knowledge of the company's capabilities and of the causes of the competitive forces, areas will be highlighted where the company should confront competition and where to avoid it.

Provided that Northvolt, in its current start-up phase, have not handled containers in large scale it could be contended that they will experience difficulties in handling and even becoming proficient at the container yard in swift time. Even so, the same issue pertains to the Port of Skelleftea since up to date, the port does not handle container vessels. However, the port does currently handle vessels with different cargo than containers and shipping cranes are in operation. Additionally, development in the port is under way and will be finished around the end of 2024 to better allow container ships handling. But it does currently insinuate a position where no party has a great advantage. Although, arguably, benefits could be accrued at a shorter time in the port due to infrastructure already in place. Moreover, Shorelink which is the operative stevedore in charge in the port have experience of container handling at other ports in the north-eastern region of Sweden.

From a viewpoint of strengthening the supply chain, collaboration is deemed beneficial and could provide synergy effects. Placing the container yard in the port would not only allow direct stacking of containers in the yard but also the opportunity of consolidation with other actors. The expansion of the port is not only in place due to increased inflow of goods for Northvolt but other large industrial players in the regions, mainly the timber industry. With exports and import of containers, a balanced flow could be pertained, improving trade in the region with other export heavy industries in demand for empty containers. A role Northvolt happily would provide. The obvious drawback is that Northvolt is not interested in becoming a logistical provider as it does not align with neither their objective as a company nor their strategy. Resulting in, that any operations in the port naturally will be performed by a terminal operator. Regardless, the opportunity for synergy in a container yard is possible even at the Northvolt production site seeing that empty containers are in demand from export heavy firms in the timber industry.

A different aspect of collaboration is the uncertainty that comes with it. Especially when relying on other parties to perform activities for one. The situation of outsourcing the solution completely to the port could very well prove a more efficient solution to begin with but as externalities play in, stevedores could increase prices affecting the situation. As acknowledged in section 3.1, Van Landeghem and Vanmaele (2002) discuss issues with strategical planning as often lacking concrete information to justify long-term decision and is inflexible to adoption. Much uncertainty can thus be tackled at the tactical level. However, to not worry about price gains and other externalities affecting the situation of the container yard one could argue for the placement of the container yard in-house for better control. In that case, tactical adjustment could be left in the hands of Northvolt to mitigate uncertainties that arise.

The last element of the strategic framework in Figure 7 pertains to resources. Barney (1991, p. 101) describes firm resources as "*all assets… controlled by a firm that enables the firm to conceive of and implement strategies that improve its efficiency and effectiveness*". A container yard at the site of Northvolt could result in resources in the shape of machines such as reach stackers, terminal tractors, and container chassis. These all provide direct efficiency and effectiveness to the inventory strategy of reducing the warehouse. Additionally, due to the versatility of reach stackers, it could assist in other areas. Mainly as industrial vehicles for moving parts but realising that during the implementation of the container yard, Northvolt will still be in a continuous process of expanding the production plant which would allow resources to be used elsewhere on the premise when less busy at the container yard.

The hybrid situation comes at an in-between position depending on how the ownership structure is arranged. Northvolt will stand for the infrastructure in constructing a yard with all necessary additions such as possibility to store refrigerated containers and fencing the area. However, if a third-party logistics company are to run the operations their machines will most likely be used and cost will be charged per hour. Compared to owning the necessary vehicles themselves and involving a third party for personnel and expertise. In the latter situation vehicles could be used as resources in the same way as stated in the paragraph above.

Having the container yard completely outsourced in the port, leads to no direct resource benefits seeing that no vehicles or land will be owned. Obviously, this does lead to less tied up capital but on the other hand amplifies uncertainties involved with outsourced ownership and difficulties mitigating any problems occurring in the harbour. Arguably, the volume flow is not necessarily large enough to create any major downtime for operations in the port which in turn promotes the use of an outsourced solution from a cost perspective. Purely operational expenses cannot compare to the capital expenditures needed for constructing the site and with that in mind the payback time could potentially not be worth it. However, since the production capacity is to increase from 16 GWh to at least 40 GWh within a few years it might still be worthwhile locating the yard on-site. Especially, since with larger flows of inbound goods, the risk of downtime does increase and would be more possible to directly mitigate by Northvolt in-house.

It must also be considered that Northvolt already has plans to implement an electric shunting fleet between the port and the site. Currently, only one 40-foot container can be transported at a time according to Swedish law (Transportstyrelsen, 2020). Possibilities for transporting one 40-foot container and one 20-foot container is technically feasible though. This resource would benefit from high utilization if the container yard were placed on site due to the ability of transporting two containers (cumulative weight of maximum 74 metric tonnes) simultaneously. In contrast if the container yard is placed in the port no more than one container at the time can be transported since loading docks do not allow for this. The shunting fleet would therefore be underutilized compared to capable capacity. It should, regardless, be noted that the expected size of containers is 40-foot in which the above argument does not hold the same power.

The last strategical issue to bring up is the implementation of information systems to operate the container yard. For own purposes, Northvolt would like to continue using the already existing warehouse management system in place for better visibility, easier handling of inbound goods and smoother planning. As presented in the data section, representatives do believe this is possible but becomes more of an implementation issue than design issue.

To summarise, from Northvolt's perspective there are several benefits to the in-house solution compared to the others. The flexibility and independence have been argued for in the data collection and holds great weight. It aligns with the goals of the container yard, sustains collaboration with the port well enough while creating its own yard for competitive advantage compared to the port. Resources does take a hit since scarce land and more machinery will be needed. However, from a longevity standpoint, the container yard can be expanded which could promote the solution further. From the framework of designing the container terminal (see Figure 10) the phase of investigate has now been performed but the demonstration phase is to be presented next.

5.2.1 In-house Container Yard: Operational Analysis

The operation regarding the in-house solution considers the location of the container yard to be onsite at the production facility at Northvolt Ett. A premise for the in-house solution is that the port is only open during weekdays. The reason for this is to avoid operational costs in the port during the weekends since these are charged at a much greater rate. A logical function of the in-house solution would thus be to transport and store the weekends demand for containers over the five weekdays. This would result in the weekly demand of 280 containers having to be transported over five days, which comes out to 56 containers per day (see Appendix G). An additional notation for the in-house solution is, as the incoming ships arrive in the port, after releasing the containers with cranes and thereafter move containers to an import area before being picked up by Northvolt. It is unavoidable to utilise space in the port for containers, thus a complete replacement of a container yard, when located onsite, is not possible.

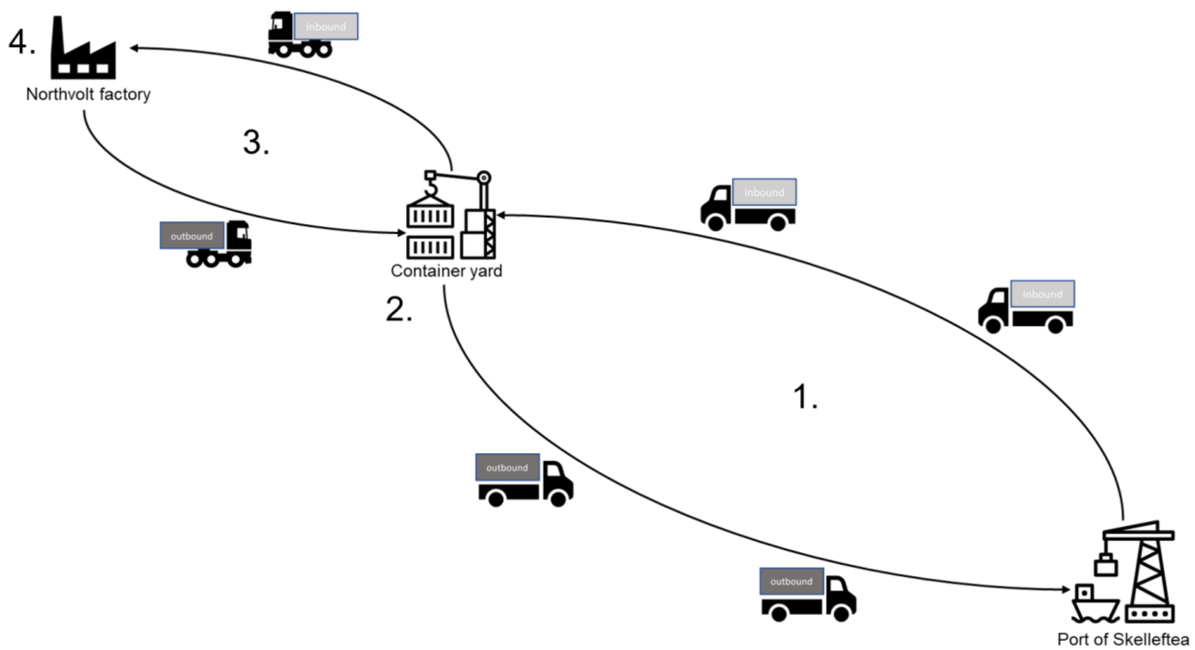

Figure 20: In-house container flow.

As presented in Figure 20, the in-house solution can be analysed from four different activities that occur from a container arriving in the port, utilised by Northvolt and returning back to the port for export.

The first sequence consists of loading the shunting vehicle with a container. As mentioned in section 4.2.1, there are restraints consisting of maximum length of the vehicle as well as maximum weight in the road. Since the majority of containers are 40ft, the lengths will be the limiting each transport to one container per transport. This is seen as a physical limitation, according to Dowd and Leschine (1990).

The shunting fleet will transport the container to the container yard. As presented in section 4.2.1, a full roundtrip is estimated to take one hour. By breaking this time down to the shunting fleet's different activities, results in the loading/unloading activity taking 7.5 minutes respectively, and transport time taking 15 minutes between the port and Northvolt Ett. This roundtrip is an important measure to stay competitive and ensure a high service level for Northvolt. Recall that the turnaround time, consisting of both the time driving in the container yard and the time of loading/unloading a container are important factors when designing an efficient yard (Yu & Qi, 2013). An estimate of four shunting vehicles will be required to handle the volume of 56 containers for both the inbound and outbound flow. Roundtrips are estimated to take 1 hour, wherein transport of a container to and from the container yard is included. The capacity per roundtrip is thus 1 container per hour and truck, resulting in 16 containers per 16 hours for a shunting vehicle.

The second sequence is when the container arrives at the container yard onsite, a reach stacker is needed to lift off the transported container from the shunting fleet and place it in a designated stack. The productivity level, as for how many containers can be handled by one reach stacker, is mainly dependent on the transported distance within the container yard. Thus, if a container needs to be transported for a longer distance, less containers will be handled per hour. Additionally, complications with retrieving or placing containers arise when they are stacked. According to Chen (1999), containers will be mixed with previously stacked containers and in cases where a container is demanded but is beneath another container, shifting moves will be inevitable. Thereby, the process for picking and placing containers is rather complex and requires planning.

Analysing the data presented in section 4.2.2, Table 4, a reach stacker with a productivity of lifting 10 containers/hour is assumed (lowest performance level) at the start since the workers will need to be trained and the flow needs to be optimized over time, as no current system exists. With this information, a calculation of 240 lifts per day can be conducted presuming full utilisation and running time, as shown in Table 12. In reality, both maintenance and fuelling are needed reducing operational hours.

Table 12: Reach stacker productivity analysis.

Performance interval	Low performance	Medium performance	High performance
Loading/unloading vehicle/ hour	10	12	15
Operational hours / day	24	24	24
Total handling / day	240	288	360

As the production state of 16 GWh implies 56 inbound containers per day and each container requires four activities; lift into the container yard, lift out for production, lift back into the container yard (outbound) as well as lifting out of the container yard (outbound), a total of 192 lifts will be performed each day. Whereas 112 lifts from/to the shunting fleet and 80 lifts from/to the terminal tractor. A productivity level that is difficult for one reach stacker to uphold during peak hours.

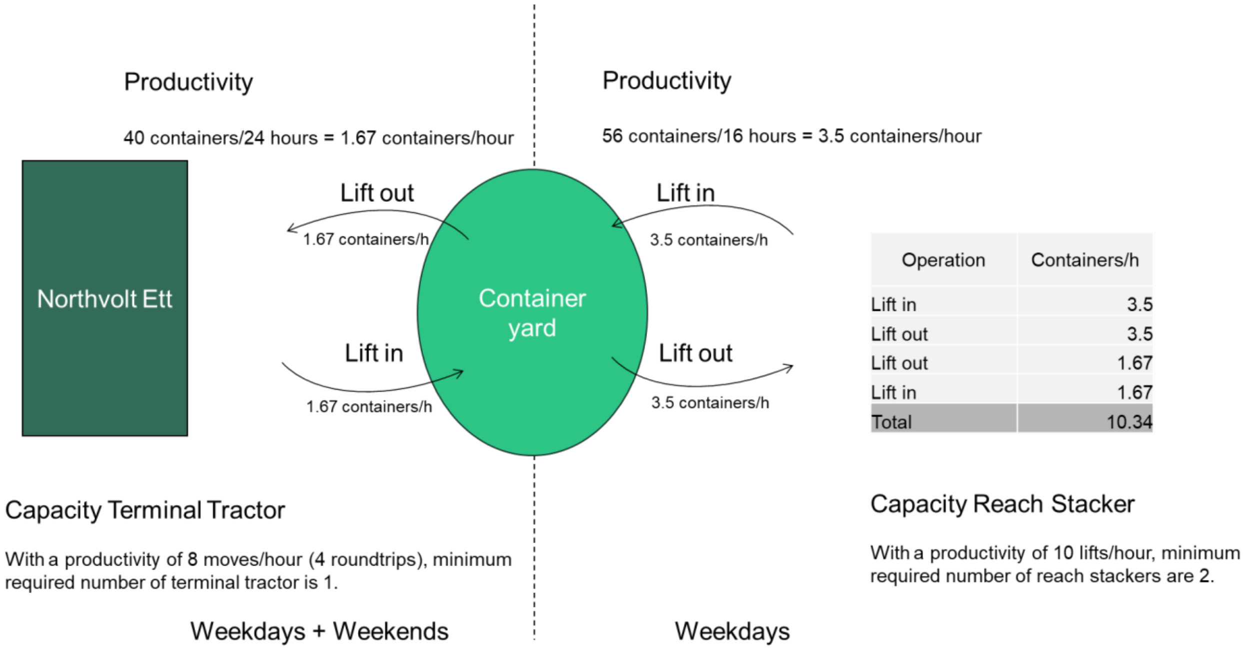

Figure 21: Scheme of container yard operations capacity.

As seen in Figure 21, during weekdays when the port is open, a maximum productivity of more than 10 lifts/hour is needed. According to our performance level, two reach stackers would be required, if we assume a low performance level. All containers are assumed to be stacked in the container yard before outbound transport to the dock. Further, since production at the factory will be performed during all hours of the day, there will be an imbalance the flow handled by the terminal tractor to and from the facility, and with the shunting fleet, to and from the port. The terminal tractor handles 40 roundtrips per day for 24 hours (daily container demand) and the shunting fleet handles 56 roundtrips per weekday for 16 hours to allow stock for the weekend.

The container yard is dimensioned to receive 56 containers per day, during weekdays, from the port to the container yard at Northvolt Ett. The size of the container yard depends on the planned buffer needed to mitigate the risk of stoppage in production, described by Dr. Edward (2016) as holding contingency and disaster inventory. But also, how stacking is decided upon. Logically, the size of the container yard needs to be dimensioned for the maximum possible volume stacked for one day, i.e., 80 containers (see Appendix G).

The third sequence is a roundtrip between the container yard and the factory, where the container will be either stripped from material or filled with outbound goods. The terminal tractor has, as the reach stacker, also a performance interval which has been estimated from evaluating the speed of transport and the distance from the container yard to the central warehouse as well as the loading/unloading time.

Table 13: Terminal tractor analysis.

Terminal tractor	Low performance	Medium performance	High performance
Speed km/h	20	20	20
Distance km	1.5	1.5	1.5
Transport time (min)	4.5	4.5	4.5
Loading / unloading (min)	3	2	1
Roundtrip (min)	15	13	11
Container roundtrips/ day	96	111	131

As shown in Table 13, if we assume an operating time of 24 hours per day, a terminal tractor will be able to perform a minimum of 96 roundtrips per day from the container yard to the central warehouse and back again.

For the 16 GWh steady state, the inbound demand is 40 containers per day, resulting in 40 roundtrips, which one terminal tractor will be able to handle, even at the lowest performance level. As the outbound flow will have the same volume of containers per day, i.e., 40 containers, these will be handled by the same terminal tractor in the opposite direction, i.e., after delivering one container to the factory it will transport an emptied/filled container back to the container yard.

The fourth sequence is the loading dock, depicted in Figure 22, which will receive the containers to either be stripped or filled. This process is estimated to take between 30-60 minutes and hence an average of 45 minutes will be used for this analysis. There are three loading bays at the central warehouse, which means, if it is operated 24 hours per day, it can receive 96 containers per day if the dock is evaluated from a static point of view (see Appendix H). Thereby, this is not a restraint for the 16 GWh case, which implies 30 inbound containers per day. The F&A section for outbound goods, having two loading docks can similarly handle 64 containers per day. Again, leaving a lot of room for the daily demand of 10.

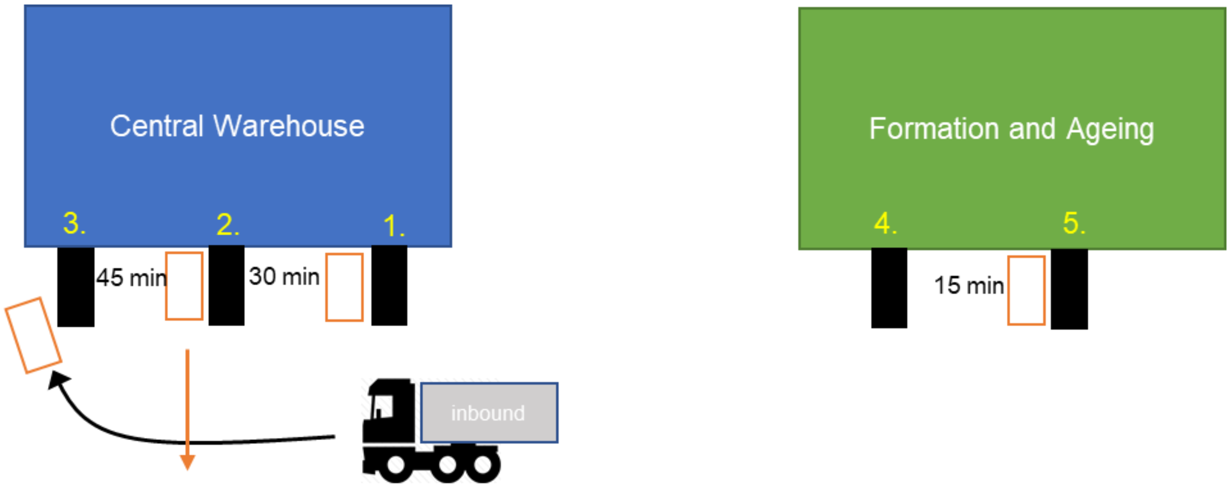

Figure 22: Loading docks at the Central Warehouse and Formation & Ageing. The vehicle in use is a terminal tractor implemented in the in-house and hybrid solution.

Using simulations, it was evaluated what could realistically be handled in the loading docks of the central warehouse based on process time of uniform distribution within the interval 30-60 min, $X \sim U(30{,}60)$. Using 500 iterations it was found that the three loading docks can handle on average handle just under 71 containers within 24 hours which is presented in Figure 23.

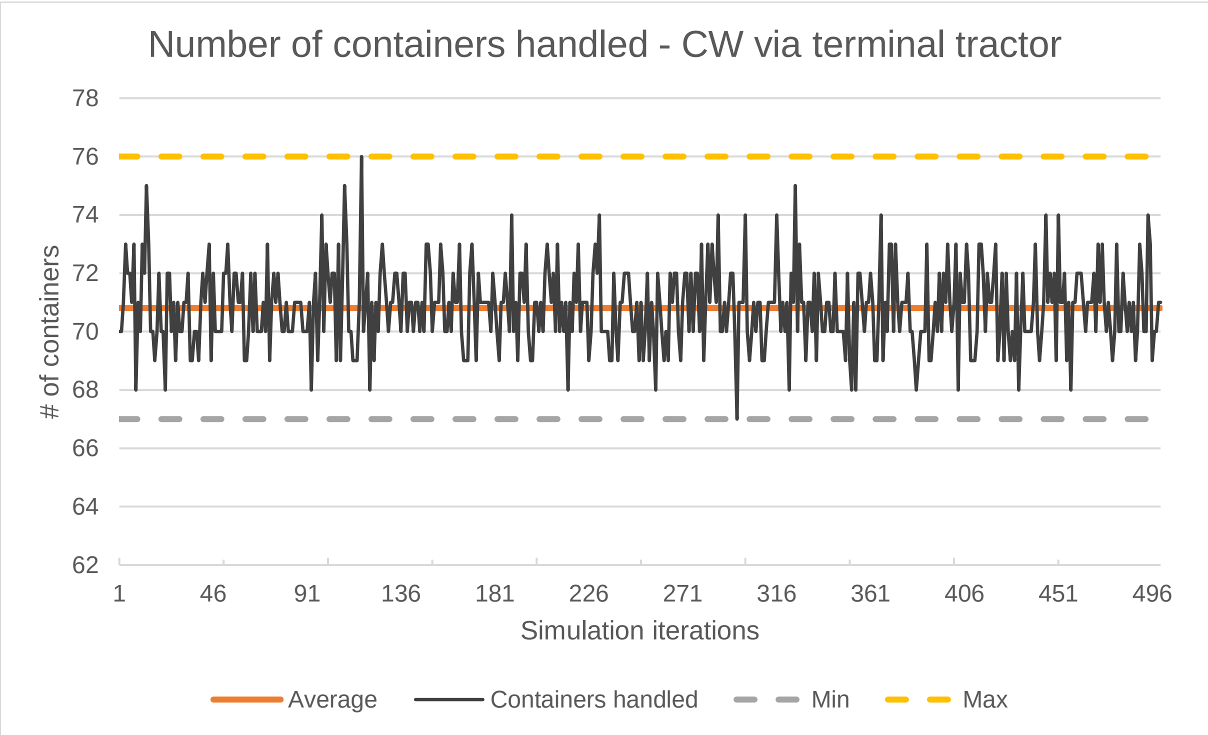

Figure 23: Simulation of containers handled at loading docks by CW using terminal tractor.

Compared to static calculations, less than 75% of the ideal state is attained. Fluctuation also exists with a maximum handled of 75 containers and minimum of 67.

The return flow back to the port will be performed according to section 1.3, hence a further analysis of this flow will not be conducted since the previous activities are dimensioned in accordance with this, thus only increasing the vehicles utilization.

Lastly, the number of chassis needed for this solution would be a minimum 10 in total. The bottleneck is the capacity of the terminal tractor which is stated to handle four roundtrips per hour. Five containers would be circulating between the container yard and the central warehouse, whereas the sixth would be waiting at the container yard (see Appendix I). An additional four would be circulating between the port and the container yard, handled by the shunting fleet, as the shunting vehicles will have one chassis each.

To summarise, this solution will require the following equipment and extra number of container lifts, which is interesting since it will be correlated to the costs occurring during the process.

Table 14: In-house equipment.

Equipment required	
Shunting vehicles	4
Container truck	2
Terminal tractor	1
Chassis	10

Table 15: Lifts performed with in-house solution.

Container lifts by reach stacker	
Lift from shunting vehicle to container yard	1
Lift from container yard to terminal tractor	1
Lift from terminal tractor to container yard	1
Lift from container yard to shunting fleet	1
Total extra lifts	4

Table 14 presents the equipment needed to handle the in-house flow, which Northvolt would need to invest in. This table does not consider the equipment required to operate in the port of Skelleftea, since it will be foreseen by the terminal operator in the port. Table 15 considers the extra number of lifts needed in the container yard, compared to not having a container yard onsite, since the container yard onsite implies extra lifts as the lifts in the port will be performed no matter which solution is chosen.

5.2.2 In-house Container Yard: Cost Analysis

The main costs of the in-house container yard have been described in Table 7. These are especially equipment and construction of the container yard. Based on calculations presented in Appendix A and arguments given in section 4.3.2, an inbound flow of 56 containers per day occupies a maximum of 10 500 m². The same flow also demands two reach stackers for handling the inbound volume. One for continuous usage and one extra to assist during peak hours and act as a back-up in case of breakdowns. One terminal tractor is sufficient to handle volumes between the container yard and warehouse. The minimum amount of trailer chassis needed to sustain operations are 10 (see Appendix I).

Usage for the different vehicles, which in turn results in average daily cost of running, is further explained in Appendix B. The reach stacker, having higher productivity than the terminal tractor, can operate similar number of movements, in lesser time. Regardless, the flow handled by the reach stacker (56) during weekdays will be higher than that of the terminal tractor (40) consequently resulting in higher usage time. Both vehicles will, however, experience idle time not accruing operational costs. Nonetheless, the drivers are to be present 24 hours a day since production is assumed to request even replenishment over the day. Given a 40-hour work week, we can calculate that for each vehicle, the equivalent of 6.2 and 4.2 Full-Time Employees (FTEs), respectively, are needed (Appendix C). Based on operational data presented in section 5.2.1, we can in Table 16 estimate operational costs per day at the container yard.

Table 16: Total costs of in-house container yard, 16 GWh production.

In-house			
CAPEX	**SEK**	**# of units**	**Total cost**
Reach stacker (RS)	4 338 700	1	4 338 700
Used Reach Stacker (RS)	2 169 350	1	2 169 350
Foundation	1 750/m²	10 500	18 375 000
Chassis per unit	225 000	10	2 250 000
Terminal tractor (TT)	1 816 200	1	1 816 200
		Total CAPEX	28 949 250
OPEX	**SEK/day**	**# FTE**	**Total cost**
Reach stacker driver	1500	6.2	9 300
Terminal tractor driver	1500	4.2	6 300
	SEK/h	**avg. hours of usage**	
Maintenance RS	151	16	2 422
Tires RS	101	16	1 614
Fuel consumption RS	264	16	4 224
Maintenance TT	76	10	757
Fuel consumption TT	144	10	1 440
Tires TT	50	10	500
		Total OPEX per day	26 557

5.2.3 Hybrid Container Yard: Operational Analysis

From an operational standpoint, the flow of goods will be equal to the inhouse solution as shown in Figure 20. The location of the yard will be onsite at Northvolt Ett. The shunting fleet will pick up the containers at the Port of Skelleftea and deliver them to the container yard onsite. Thereafter, the reach stacker(s) will unload the container and place it in the yard. As mentioned before, a container will be placed on a container chassis before it is moved by a terminal tractor to the central warehouse. Thereafter, containers will be transported back to the port for export on either sea or railway distribution.

The hybrid solution is founded on the ability of hiring external personnel to operate the container yard, hence the flow will not be affected. An operational distinction between having the container yard placed onsite rather than in the port could be the institutional limitations, such as working hours and union working rules (Dowd & Leschine, 1990). Hence, if the working hour in the port is limited to 8 hours per day, more operational benefits can be achieved by having the yard onsite, which could be different from working laws in the harbour. However, from multiple interviews in with representatives from the Port of Skelleftea as well as Norrkoping, the port will stay open if the customers pay the additional costs for working after ordinary hours. Although, when hiring external personnel to work at the container yard onsite, they may not be limited to the union work laws, which they are covered by for operations in the port.

5.2.4 Hybrid Container Yard: Cost Analysis

The hybrid option where ownership of vehicles is at Northvolt, has a very similar cost-structure to that of the in-house solution. The only difference in costs is that of the drivers, which are assumed to charge 50% more than own personnel. In total, the costs of the hybrid solution with ownership at Northvolt, is thus more expensive in operational expenditure. One could, however, argue that using experience stevedores could lead to shorter learning time and consequently less hiccups farther down the stream of production. The number of chassis needed, terminal tractor and reach stackers, as well as hours operated have the same underlying argument as presented in section 5.2.2 and can be found in Appendix B, Appendix C and Appendix I.

Table 17: Cost of hybrid solution with ownership of vehicles.

Hybrid with Ownership			
CAPEX	**SEK**	**# of units**	**Total cost (SEK)**
Reach stacker (RS)	4 338 700	1	4 338 700
Used Reach Stacker (RS)	2 169 350	1	2 169 350
Foundation	1 750/m²	10 500	18 375 000
Chassis per unit	225 000	10	2 250 000
Terminal tractor (TT)	1 816 200	1	1 816 200
		Total CAPEX	28 949 250
OPEX	**SEK/day**	**# FTE**	**Total cost (SEK)**
Reach stacker driver	2250	6.2	13 950
Terminal tractor driver	2250	4.2	9 450
	SEK/h	**avg. hours of usage**	
Maintenance RS	151	16	2 422
Tires RS	101	16	1 614
Fuel consumption RS	264	16	4 224
Maintenance TT	76	10	757
Fuel consumption TT	144	10	1440
Tires TT	50	10	500
		Total OPEX per day	34 357

With regards to personnel cost, arguments could be made that this number is rather high, but it acts as a frame of reference. This calculation takes into account personnel with already license to drive vehicles such as reach stackers and terminal tractors. Without these, an additional cost for Northvolt in the case of the in-house solution, would require paying a fee for the license education. A cost that would set back the time for breaking even between the two solutions.

The second edition of the hybrid container yard is where operations is left out to stevedores. Machines are here rented on an hourly rate by stevedores. Only cost of constructing the foundation at 1 750 SEK/m^2 is given as a capital expenditure.

Table 18: Cost of hybrid solution with ownership outsourced.

Hybrid without Ownership			
CAPEX	**SEK**	**# of units**	**Total cost (SEK)**
Foundation	1 750/m²	10 500	18 375 000
		Total CAPEX	18 375 000
OPEX	**SEK/day**	**# of FTE**	**Total cost (SEK)**
Reach stacker driver	2250	6.2	13 950
Terminal tractor driver	2250	4.2	9 450
	SEK/day	**# of units**	
Terminal tractor rent	8 160	1	8 160
Chassis rent	4 080	10	40 800
Reach stacker rent *-Full utilization*	24 000	1	24 000
Reach stacker rent *- Half utilization*	24 000	0.5	12 000
		Total OPEX per day	108 360

Personnel costs are similar to the hybrid with ownership solution. From port tariffs at the Port of Ahus and Norrkoping hourly rental rates for different machinery were found excluding crew (Ahus, 2019; Norrkoping, 2020). For example, terminal tractors are charged at 340 SEK/h and reach stackers at 1000 SEK/h. The half units of reach stacker have to do with one reach stacker being operational only 5 days x 16 hours/day, resulting in 50% utilisation. These operational expenditures are considerably larger than any of the previous solutions discussed. Yet, costs are not the only factors to considered as we have previously declared. Using stevedores, one could expect much quicker handling and no to little learning curve. Additional benefits are the fact that using a stevedore entitles agreements that services will be met an Northvolt will not have to worry regarding breakdowns of machinery given actors such as Shorelink own a fleet of them in the northern region. Labour could also more swiftly be increased based on greater predicted inflow of containers and larger delivery.

5.2.5 Outsourced Container Yard: Operational Analysis

The outsourced solution will differ from aforementioned solutions. This solution implies that the container yard is located at the Port of Skelleftea. The port is assumed to only be open for 16 hours per day; hence all daily inbound containers must be transported to Northvolt Ett and emptied or filled during this 16-hour interval. Thereby, a problematic identification is the mismatch of opening hours between the production at site and the port. As the operations in the container yard will be completely outsourced for this solution, an analysis for equipment required will not be conducted for the port.

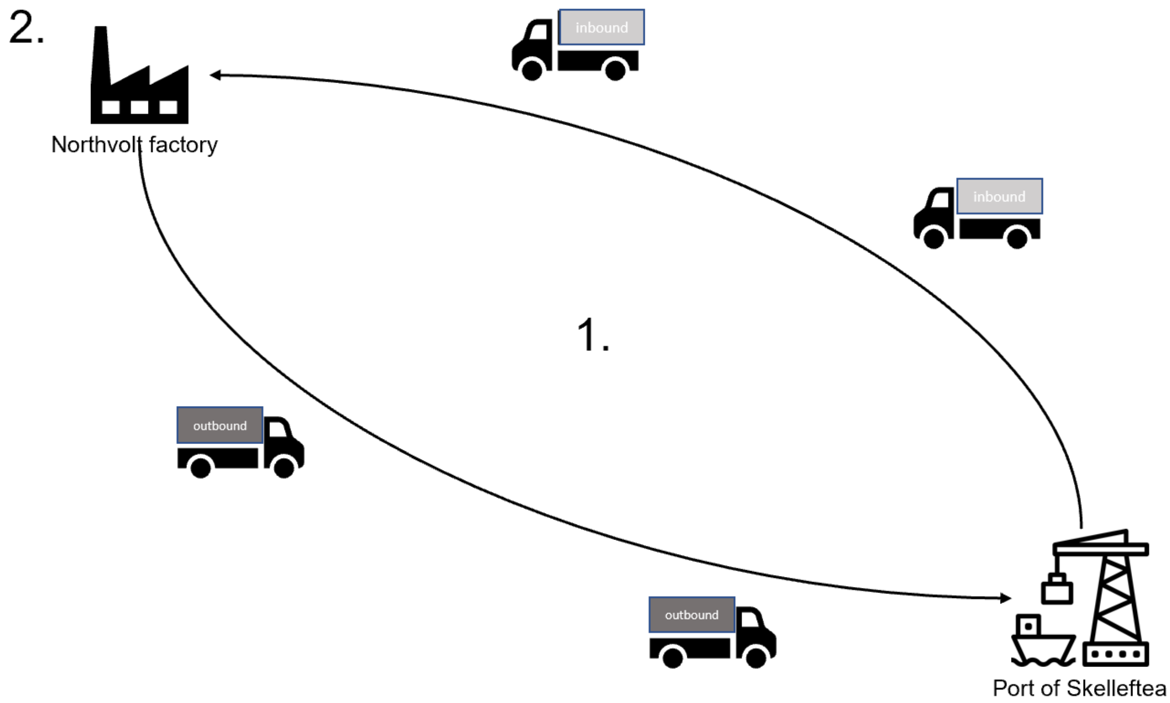

Figure 24: Outsourced solution flow

As analysed earlier, the flow of container can be divided into different sequences. For this solution, two sequences are evaluated.

The first sequence consists of the shunting fleet transporting the containers from the container yard to the factory and later back again. Once again, the roundtrip of one hour can be broken down into loading/unloading time of 7.5 minutes, respectively, as well as transport time being 15 minutes.

When analysed regarding the 16 GWh case, where the number of inbound containers is 40 and demanded during 16 hours, a mismatch can be identified between the opening hours of the port and production at Northvolt Ett. The factory is planned to be producing battery cells evenly over 24 hours per day, demanding 40 containers of raw material per day in total. However, this solution presumes that all 40 containers can be delivered and emptied during an interval of 16 hours, perhaps higher productivity of emptying containers and capacity of storing material in the warehouse than planned. Moreover, due to round the clock production, limiting the supply of containers for goods to be filled is not possible in the same way as for inbound flow.

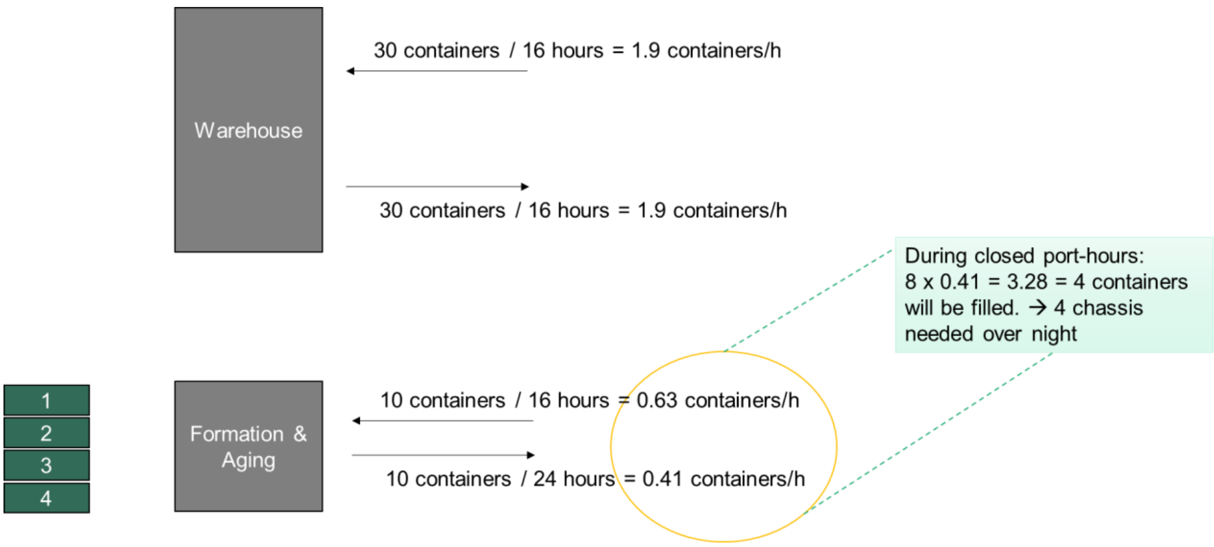

Figure 25: Outsourced solution operations.

Additionally, as seen in Figure 25, the productivity of filling containers with finished goods will require additional containers available during closed port hours. Thus, three vehicles will be needed during the open port-hours (16 hours) to handle the foreseen demand of 2.5 containers/hour (see Appendix D) and an additional vehicle will be needed to move the containers at Formation & Ageing during the closed port-hours, as the other three are only available for 16 hours per day. Resulting in four shunting vehicles.

The second sequence is the loading dock, depicted in Figure 26, which is no different from the analysis conducted in 5.2.1, with a capacity of receiving 96 containers per day, when evaluated from a static view, hence not seen as a restrain for the 16GWh. Only difference being the shunting fleet delivering the containers instead of a terminal tractor.

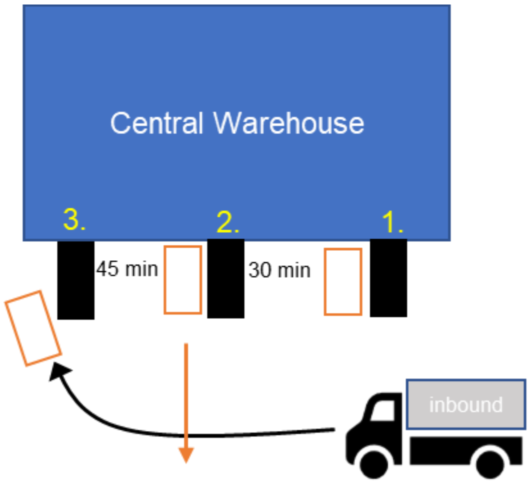

Figure 26: Loading docks at the central warehouse and formation & ageing. The vehicle in use is a trailer truck implemented in the outsourced solution.

Using simulations yet again, it was evaluated what could realistically be handled in the loading docks of the central warehouse based on process time of uniform distribution within the interval 30-60 min, $X \sim U(30,60)$. Using 500 iterations it was found that the three loading docks can handle on average handle just under 59 containers within 24 hours which is presented in Figure 27.

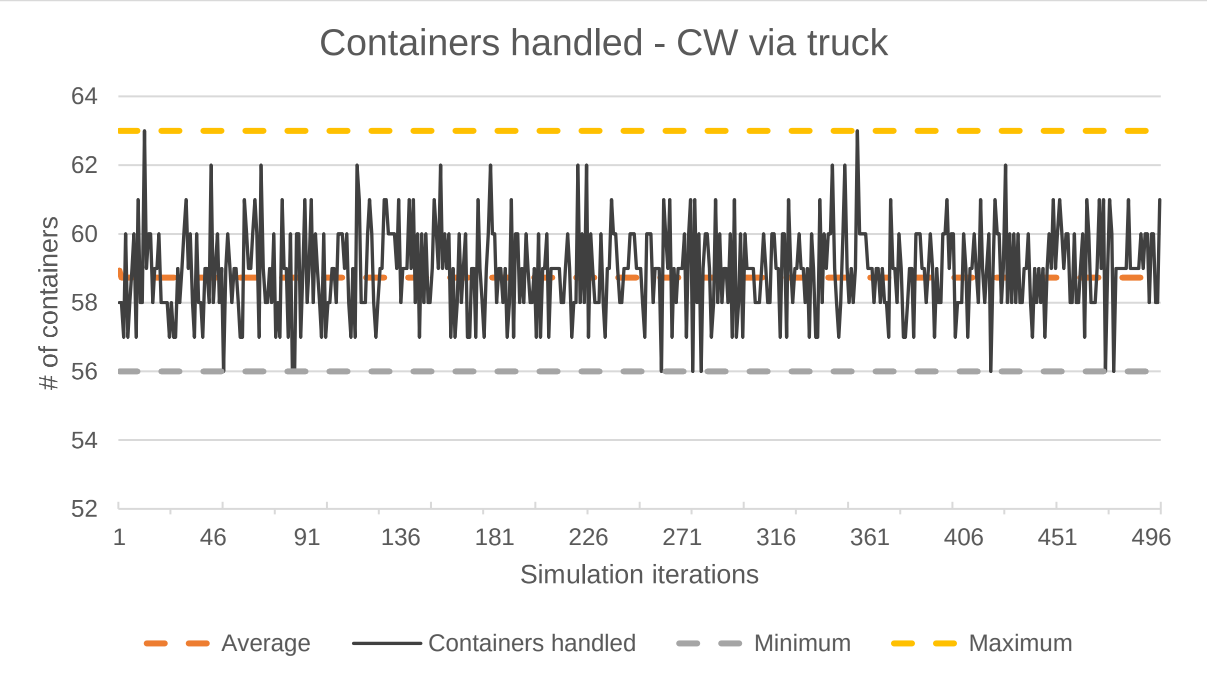

Figure 27: Simulation of containers handled at loading docks by CW using trailer trucks.

Compared to static measures, approximately 62% of the ideal capacity is reached using this method with a maximum value of 63 and a minimum of 56. Reasons as to the difference compared to the in-house and hybrid solution will be discussed later.

In terms of chassis required to transport the containers from the container yard in the port to the central warehouse onsite at Northvolt Ett, the identical number is calculated. As the shunting fleet will consist of three operated vehicles during open port-hours, they will use three chassis when making the first deliveries to the Northvolt Ett factory which will be emptied for approximately 45 minutes, during which the shunting fleet will return back to the container yard in the port and receive three additional containers and will therefore need three more chassis. The shunting fleet will trade the inbound container chassis for outbound container chassis at each visit at the factory. The shunting fleet will deliver the outbound containers at the container yard and receive an inbound container on its chassis. As shown in Figure 25 an additional four chassis will be needed to store the outbound containers which will be filled during the closed port-hours and transported to the container yard the next day. Resulting in a total of ten chassis (see Appendix I). The summarized equipment needed for this solution is shown below.

Table 19: Equipment required for the outsourced solution.

Equipment required	
Shunting fleet	4
Chassis	10

As can be seen in Table 19, this solution would require less equipment needed than the in-house/hybrid solution. Further, as the container yard is operated in the port, no extra lifts will be performed after the containers have left the container yard. It is hence a more beneficial and lean system since it creates the same value for the process, but with less material handling i.e., lifts compared to the in-house/hybrid solution. However, this solution demands that chassis with containers can be stored near the factory during the night when the port is closed, as well as emptying the daily demand of containers during 16 hours instead of 24 hours, which could be optimistic to implement as the factory is designed to operate evenly during 24 hours.

5.2.6 Outsourced Container Yard: Costs Analysis

With the outsourced solution the largest change is to be seen. Here, Northvolt will not be in ownership of any operations apart from transport between the port and the production facility. Road transportation costs, as described by (Rushton, 2017), are full container loads in bulk which, in this case, occurs between the port and the facility. Transportation was elaborated on separately in section 5.1.1, due to being present in all three solutions. The minimum number of chassis needed are ten as discussed in above section 5.2.5. This has to do with trailer chassis having to be exchanged at the two points in the route, the port and Northvolt Ett but also allow for transportation overnight when the port is closed.

The costs are displayed in Table 20 and the structure is that capital expenditure only exists of container chassis, an equipment expenditure. Operational costs are charged per lift and leasing costs for land. The area needed for storing weekly demand of containers is calculated to 25 000 m^2 and follows the same logic as in Appendix A. Each container will be lifted out from the container yard onto a truck inbound for Northvolt. Once the container has been exchanged at Northvolt Ett, a new chassis with a filled or empty container is exchanged and transported back from Northvolt to the port and lifted into the container yard. In total two lifts are optimally performed per container. In Table 20 below, costs are split into inbound and outbound costs for a total volume of 40 containers per day.

Table 20: Cost for the outsourced solution in the port.

Outsourced			
CAPEX	**SEK**	**# of units**	**Total cost (SEK)**
Chassis	225 000	10	2 250 000
	Total CAPEX		2 250 000
OPEX	**SEK**	**# of units**	**Total cost (SEK)**
Leasing yard	70/m² per year	25 000	1 750 000
Inbound			
RS - Lift	300	40	12 000
Outbound			
RS - Lift	300	40	12 000
Avg. shift cost per day (16h)	13 700/day	1	13 700
	Total OPEX per day		37 700

The last cost driver concerning labour is that of the overtime shifts. It was communicated by representatives from the stevedore Shorelink that overtime shifts have and average cost of 3000 SEK/h when scheduled. Assuming that weekday operations can be extended to 16 hours through local agreements, overtime costs will only be charged for weekend shifts. A 16-hour shift costs as much as 48 000 SEK per weekend day but splitting it on average daily costs we get 13 700 SEK per day.

Operational expenditure would be high compared to in-house and hybrid solution with ownership, however, less than the hybrid with outsourced ownership. The capital expenditure needed is clearly less and would thus be in line with promoting operational expenditure. Shift costs are a driver up for discussion since it is very much subject to negotiation and the assumption of 16-hours shift in place during weekdays is to be negotiated. However, as stated in section 4.3.4, representatives from Shorelink and the Port of Skelleftea deem it reasonable to extend working hours to 16 hours during weekdays in the near future. The reason the same shift costs would not be extended for weekdays has to do with the Port and Stevedore union allowing local agreements to be made, but mandate overtime costs at twice the rate on weekends compared to weekdays. Assuming additional shift costs on weekdays as well, shift costs per day would average 34 000 SEK, making the solution financially the most expensive.

5.3 Comparison of the Three Stated Solutions

From a strategical perspective, it has been discussed earlier how vertical integration is beneficial for a company to increase its control and flexibility of its assets, however, even if the container yard was located onsite, the operations in the port will not be eliminated but instead add an extra step in the process. Nevertheless, this extra step could decrease the risk of production stoppage if the port fails to deliver the demand for a short period of time, which could be an even worse outcome than having the extra non-value adding process. Further, since Northvolt is a start-up with no previous experience of operating a container yard as well as it being outside the objective of the company’s focus, it could be strategically beneficial to allocate the operations to a stevedore and utilise their resources, whom have previous experience of container handling. The drawback of the outsourced solution is the mismatch of operating hours between the port and the factory, resulting in storage of containers onsite during the night shift when the port is closed.

Although, as mentioned earlier from an operational perspective, as shown in Table 21, the outsourced implies a smaller number of lifts per container, which is more effective and decreases the complexity of the process. Correspondingly, less amounts of machines will be involved in the outsourced solution and eliminates the need to educate personnel and reduces the extent of coordination needed for information flow, as would be the case for the inhouse and hybrid solution.

Table 21: Operational comparison.

Comparison	**In-house**	**Hybrid**	**Outsource**
Extra container lifts	4	4	0
Terminal tractor	1	1	0
Reach stacker	1	1	0
Shunting vehicles	4	4	4
Chassis	9	9	10

Dwelling deeper into the details of operations, it is possible to describe the flow and its shortcomings. Especially interesting is looking at processes where slack can be found, or alternatively no slack leading to constraints.

One of the most interesting aspects of the flows is that of loading docks on the Northvolt site and the capacity for these. As previously stated, most inbound containers will be stripped in the central warehouse and goods outbound filled in the Formation & Ageing section of the facility.

In section 5.2.1 and 5.2.5, results of 500 simulation iterations were presented. These declared a higher productivity for the terminal tractor than that of the truck (shunting fleet) which is shown in Table 22.

Table 22: Simulation results for containers handled at the three loading docks by the central warehouse.

	Simulation using terminal tractor	**Simulation using truck**
Average	71	59
Min	67	56
Max	76	63

The logical reason for the difference is based on the process times for the two separate vehicles. Especially, the time it takes to exchange chassis are higher for trucks than that of the terminal tractor. As can be seen in Figure 28 and Figure 29 respectively, the process of exchanging chassis for the terminal tractor is assumed to be 1.5 min compared to the trucks 7.5 min.

This is not a coincidence as the terminal tractors are specifically made for these quick moves in terminals without the need of a driver to get out of the vehicle at any point.

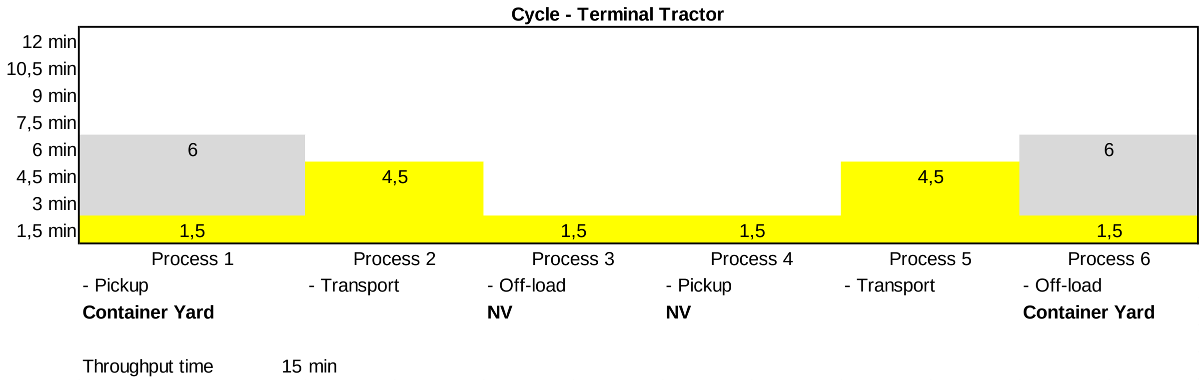

Figure 28: Process times in the cycle of a terminal tractor. The grey marking is the process time for a reach stacker. NV stands for Northvolt.

It should, however, be noted that since the change-over time for the truck is 7.5 min whereas the assumed process time for a reach stacker is 6 min, 1.5 min per cycle is slack. Meaning that the outsourced solution comparatively allows for more slack. It should regardless be stated that the in-house and hybrid solution use both the truck and terminal tractor when transporting containers. That is, one delay does not exclude the effect of the other.

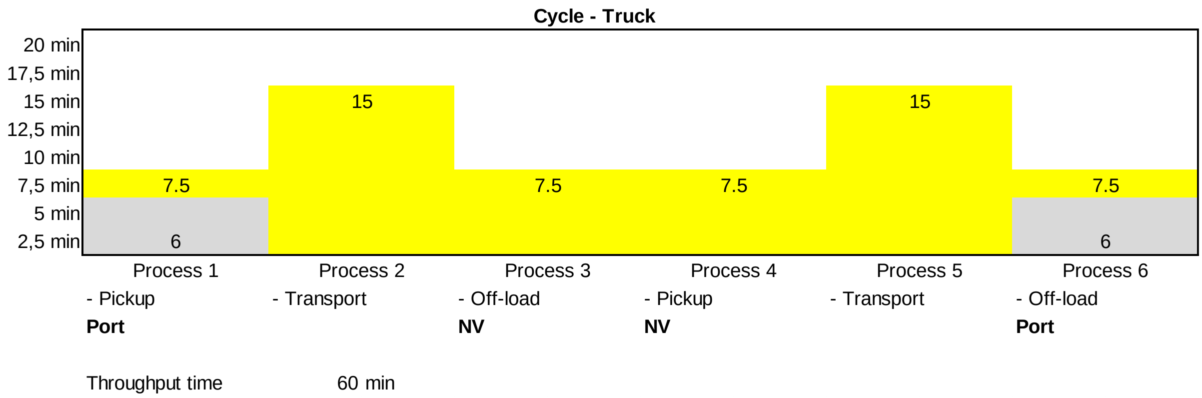

Figure 29: Process times in the cycle of a truck (shunting fleet). The grey marking is the process time for a reach stacker. NV stands for Northvolt.

What the simulation has shown is realistic values for capacity in the warehouse, which is the most central access point for inbound containers. In case of breakdowns, or delayed arrival of vessels, such numbers give an intuition of what flows can realistically be handled when there is pressure. Using cycle time, the shunting fleet can be proven to possess greater slack compared to the terminal tractor. Something which has both advantages and disadvantages. The former in that the shunting fleet may improve its process time of exchanging chassis over time.

When it comes to the financial aspect, we have presented the solutions in isolation, i.e., discussed them at a focal point ignoring the port apart from the outsourced solution. In such a case, the cheapest solution would become the in-house solution due to having a lower operational expenditure as presented in Figure 30.

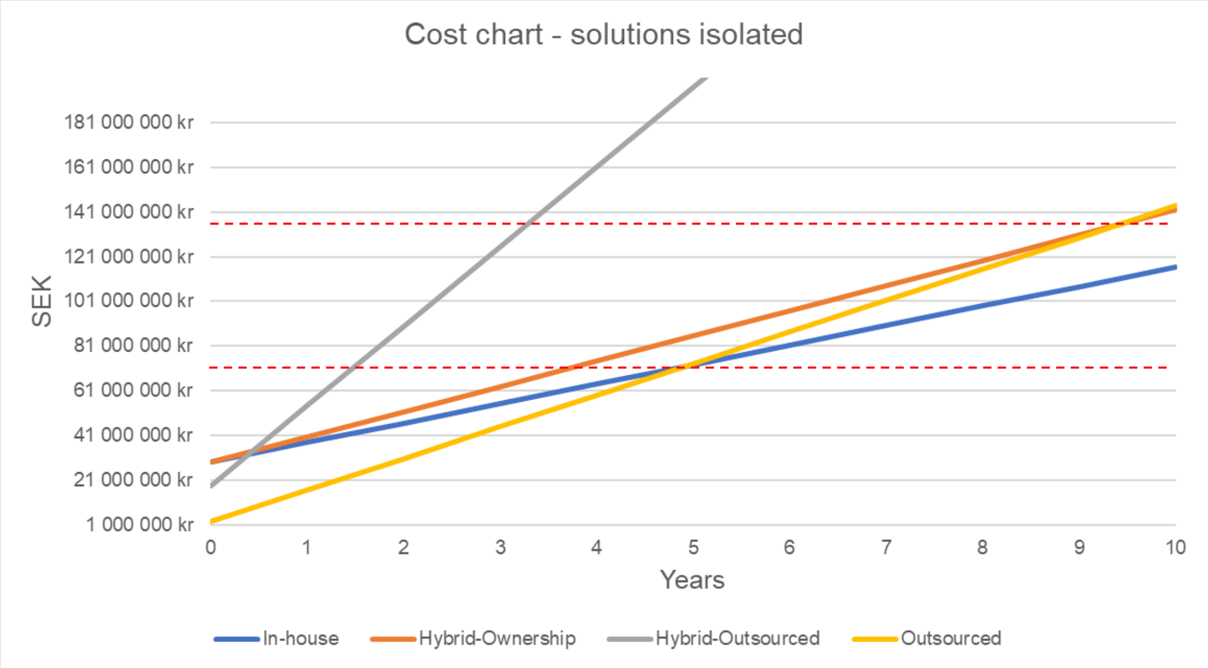

Figure 30: Accrued cost chart over the isolated solutions. In-house solution break even after approximately 5 years.

However, as continuously discussed, all containers must be handled in the containers prior to being moved towards Northvolt. This would be considered the total cost as discussed by Rushton (2017) and to no surprise, the difference between the in-house solution and the outsourced one always stay linear as can be seen in Figure 31 below.

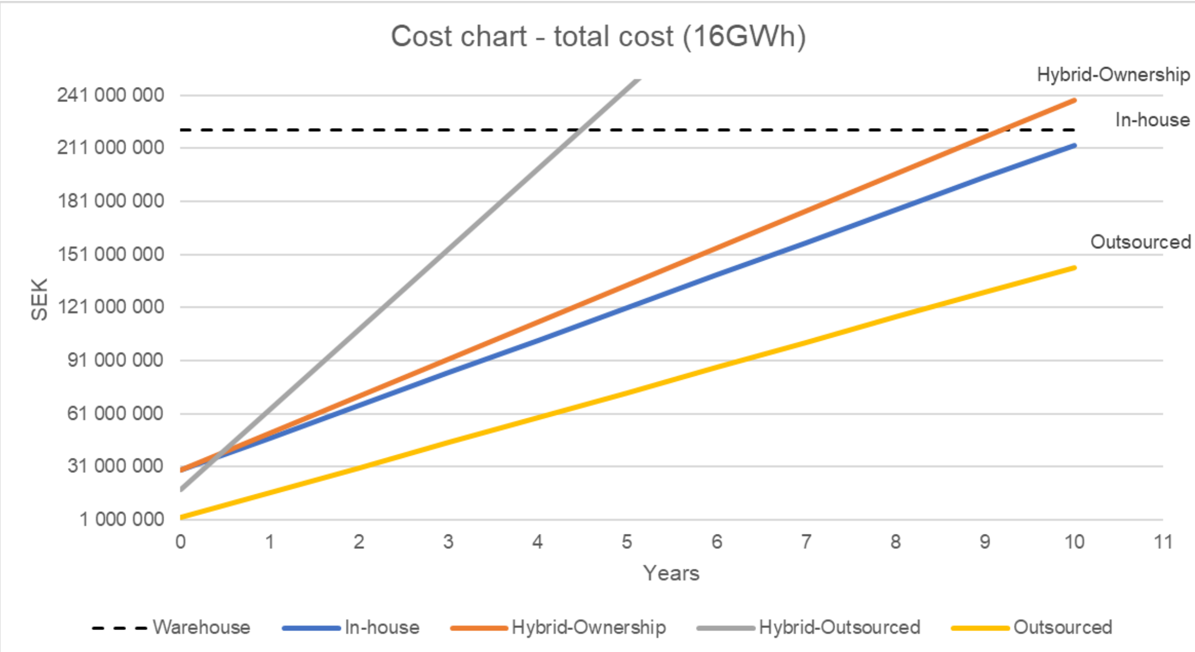

Figure 31: Accrued total costs for the different solutions.

Given the costs, it would be easy to promote the outsourced solution for the costs accrued. Not only does the in-house or hybrid solution occupy more land, a resource that should always be considered scarce with terminal operations according to Alho et al. (2019), it also demands more lifts. When handling containers, minimising the number of movements greatly reduces risk of wrongdoing and any potential damage to goods. Points of disruption would consequently also be reduced.

A point of concern does arise in the ports opening hours and being so dependent on an external actor. Since Northvolt would promote having access to containers 24 hours a day, what makes financial sense and logistical sense in number of moves, might not prove operationally possible. The assumption of being able to move all daily demand into the production facility in 16 hours a day does not necessarily work, in which case the port would have to be open 24 hours a day. Something that proves to be more expensive at a cost of approximately 28 MSEK in OPEX per year compared to the in-house plus port costs of approximately 20 MSEK. Meaning this solution would be more profitable in the long run.

As can also be seen, all solutions cost well below that of the warehouse expansion. This does answer *RQ1* in that the container yard is viable on a financial level. It should also be noted that the capital expenditures of a warehouse are only accounted for, meaning break even need not be at the same year as above.

A potential improvement of the outsourced solution, where no in-house container yard is needed but neither are 24 hours operations in the port, have been discussed during interviews with representatives of different ports and will be further discussed as the buffer chassis yard solution.

5.4 Outsourced with Chassis Buffer Yard

The outsourced solution with a buffer yard lies in between the fully in-house and outsourced strategy, fulfilling both Northvolt's demand for flexibility and autonomy while avoiding double lifts. Moreover, Northvolt will not need to invest in heavy industrial equipment required for container handling on site nor take up valuable land on the site. In Figure 32 the solution is depicted with the container yard located at the Port of Skelleftea but including a small buffer site for the chassis near the port. The buffer would consist of containers placed on chassis available for pickup by the shunting fleet. The buffer's main function is to decouple the process in the port and Northvolt's as much as possible. By creating two separate flows, one from the port to the chassis yard and one from Northvolt to the chassis yard, congestions are to be avoided and smooth transitions between inbound and outbound containers possible. Additionally, as the port is only opened 16 hours per day, the chassis yard can be used to store the containers needed during the remaining eight hours, thus avoiding the dependency the port being open all night.

Strategical benefits of such a solution would be the flexibility and decreased dependency of the port. Since other customers exist in the port apart from Northvolt, congestions could be minimised as well as allowing the stevedore to plan for flows between the chassis yard and the port. Additionally, as the shunting fleet is assumed to be electric, charging stations could beneficially be placed at the buffer area as well as at the factory. Furthermore, as the shunting fleet may be autonomous in the future an easier process for loading/unloading chassis with containers is important, which can be achieved with a buffer area in a controlled environment.

Like the previous solutions, an analysis can be conducted on the different sequences of activities performed for such a solution. Where each sequence refers to the numbers in Figure 32.

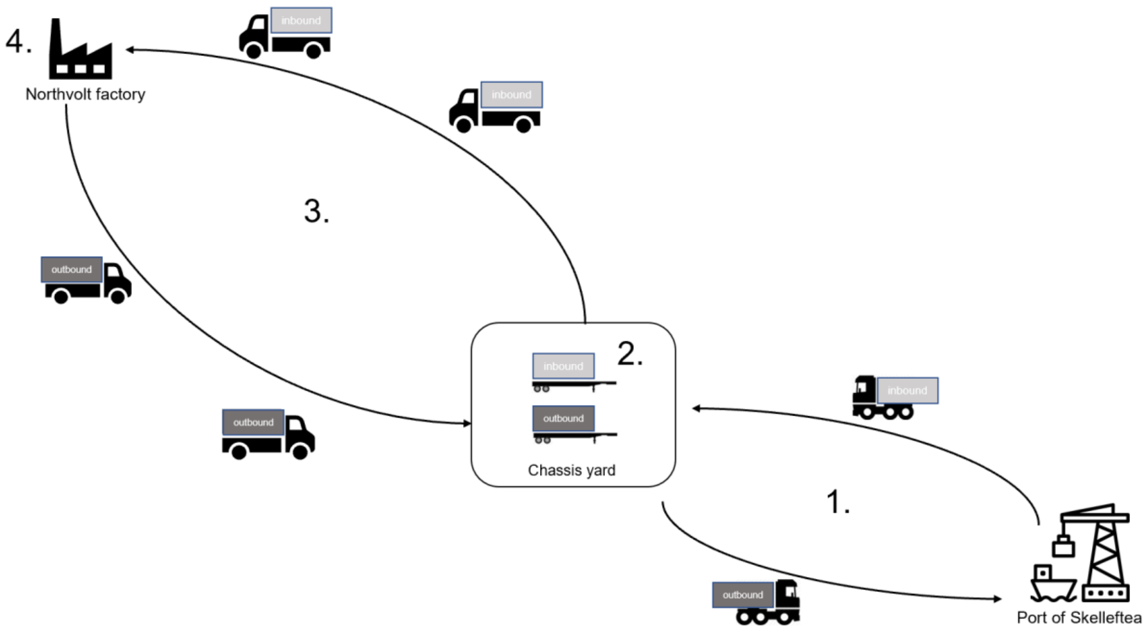

Figure 32: Chassis yard solution at 16 GWh production.

The first sequence, in such a case, is the stevedore in the port would ensure that there are inbound containers ready for transport up to the factory during each cycle as well as space to park an outbound container in the buffer area (chassis yard in Figure 32). The stevedore would then receive the outbound container from this buffer area, parked by the shunting fleet, and not directly lift of containers from the chassis. Depending on the distance from the port, these deliveries will be handled by terminal tractors or reach stackers. A spokesperson from the Port of Skelleftea did point towards a potential spot 1 km from the port, at the beginning of the bay, where the yard could be placed. Although, as this operation will be performed by the stevedore no further analysis of this sequence will be conducted, we do however se given the same productivity for terminal tractors in Table 13, five containers per hour could potentially be move. A higher number than the demand.

The second sequence is the buffer area, which could potentially be placed directly near the container yard in the port for a reach stacker to place containers straight onto the chassis, which will then be ready for pick-up. However, placing the buffer area at the periphery of the port, reduces the need for the shunting fleet to drive into the port area, thus eliminating the need of traffic control. The promoted solution thereby involves a terminal tractor delivering the chassis with containers to the buffer area and circulate between the port and the buffer area.

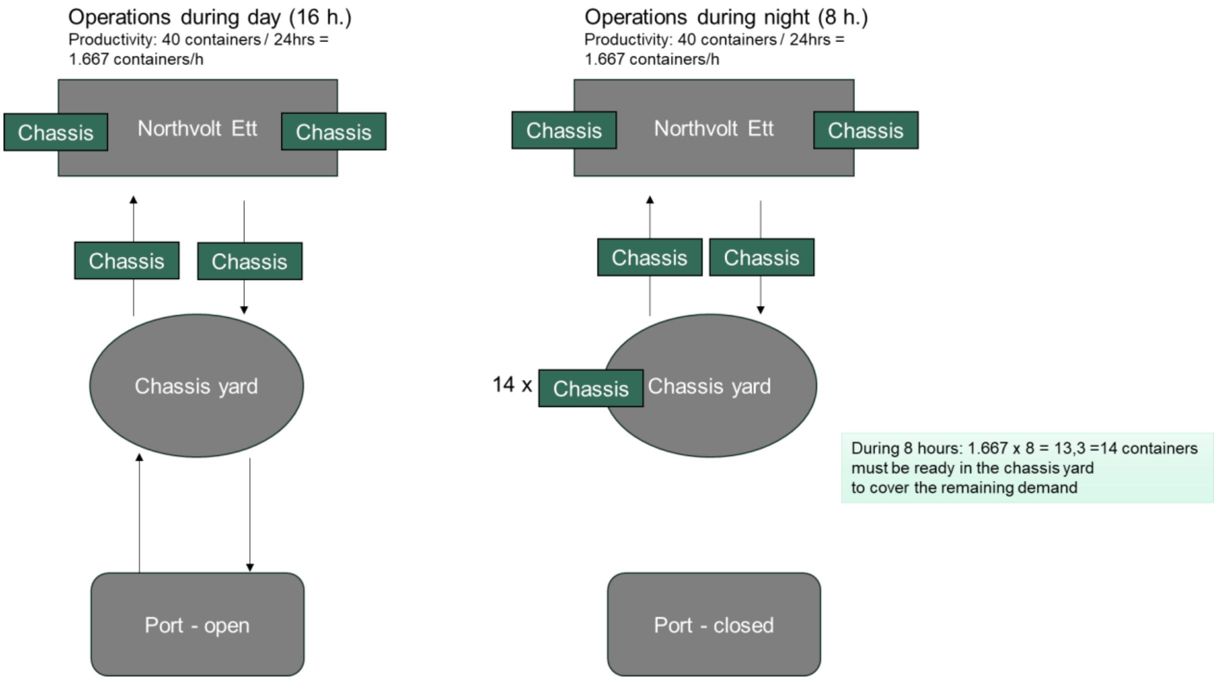

Figure 33: Chassis yard operations for daytime operations (16h, left) and night-time (8h, right).

Moreover, as the chassis yard will function as a storage point while the port is closed, a planned number of containers with chassis will have to be stored in the yard. As shown in Figure 33, the productivity is stretched over 24 hours, resulting in 14 containers with chassis needed during closed port hours. Additionally, two chassis will be used by the shunting fleet and two will be emptied at the loading dock, resulting in a total of 18 chassis for this solution (see Appendix I).

For *the third sequence*, *the* shunting fleet will similarly only receive the inbound container from the buffer area and not directly from reach stackers in the port. The chassis yard would require two shunting vehicles to operate during 24 hours per day, but since the vehicles are available for only 16 hours per day, it would require four vehicles in total to handle the demand (see Appendix J).

The fourth sequence will be equal to the capacity as presented in section 5.2.5, as it will be the shunting fleet managing the deliveries, which is not seen as a restraint concerning the daily container demand for 16 GWh.

From an operational standpoint, as shown in Table 23, four shunting vehicles as well as 18 chassis would be required to invest in to handle the activities.

Table 23: Chassis yard equipment

Equipment required	
Shunting fleet	4
Chassis	18

Identical to the outsourced solution, this solution will not require any extra lifts besides the once taking place in the port. Extra chassis would be needed, primarily to store the containers needed during the closed port-hours. This is similar to the outsourced solution but differ as inbound containers are also transported during closed hours in the port. The operational benefits would be the flexibility and being less dependent on the port's operations. For example, stevedores in port can plan and transport chassis in advance if they now there will be a busy period ahead and reach stackers will not be available for demand.

From a cost perspective, it would be more expensive than the outsourced solution as it would require more chassis for the sole purpose of holding containers demanded overnight. However, the number of lifts is the same as the outsourced solution, hence the operative costs will be similar. In Table 24 below, costs for the chassis yard solution are displayed showing that additional expenses are 18 chassis for transporting containers but also storing them on the chassis yard. Moreover, a terminal tractor would have to be operational for the entire 16 hours the port operates. Costs for this, including a dedicated driver have been found in the price list at the Port of Ahus as estimation (Ahus, 2019). The buffer yard is expected to provide no extra costs as this is under the ownership of the port and could be used by other customers. If not, a leasing cost would most likely be paid.

Table 24: Cost table for the outsourced buffer chassis yard solution.

Outsourced with buffer			
CAPEX	**SEK**	**# of units**	**Total cost (SEK)**
Chassis	225 000	18	4 050 000
		Total CAPEX	4 050 000
OPEX	**SEK**	**# of units**	**Total cost (SEK)**
Leasing yard	70/m² per year	25 000	1 750 000
Inbound			
RS - Lift	300	40	12 000
Outbound			
RS - Lift	300	40	12 000
Terminal Tractor	825/hour	16	13 200
Avg. shift cost per day (16h)	13 700/day	1	13 700
		Total OPEX per day	50 900
		Total OPEX per year	18 496 100

The buffer chassis yard does mitigate the identified problems with the completely outsourced solution, having mismatched production hours. Moreover, it also applies to the strategic goals and objectives Northvolt has communicated. The buffer chassis yard is operationally beneficial compared to the in-house/hybrid solution as it does not demand extra lifts. From a financial perspective it has lower OPEX, and CAPEX compared to the in-house/hybrid solution and thereby constitutes as a viable solution of ownership structure, presented as *RQ2*.

5.5 40 GWh Scalability

As Northvolt scales up their production to 40 GWh in the near future, such a case should be considered as part of a sensitivity analysis discussed in chapter *3.4 Summary of Framework: Designing the* . This would correspond to 100 inbound containers, as well as 25 outbound containers per day, as shown in Figure 19.
The two evaluated alternatives are the in-house alternative since it requires the same operations as the hybrid case but is less expensive. Additionally, the outsourced chassis yard solution is evaluated since it was argued an overall more beneficial solution, relative to the other alternatives.

In-house

Starting with the in-house case, the containers would undergo extra lifts in the container yard onsite. Further, the number of heavy industrial vehicles such as reach stackers and terminal tractors for such as solution can be calculated similarly as shown in Figure 21 (see Appendix F). Resulting in three reach stackers and two terminal tractors. The shunting fleet would be dimensioned to 9 shunting vehicles during 16-hours to handle the 40 GWh volume, (see Appendix J). Further, costs are displayed in Table 25 below. As can be seen there are no changes in cost drivers, only the number of units needed. Noted should be the average hours of usage as this pertains to multiple vehicles usage but summarised for simplicity in the table (as to why they exceed 24 hour per day). See Appendix B for details.

Table 25: Costs for in-house solution at 40 GWh production.

40 GWh			
In-House			
CAPEX	**SEK**	**# of units**	**Total cost**
Reach stacker (RS)	4 338 700	3	13 016 100
Used Reach Stacker (RS)	2 169 350	1	2 169 350
Foundation	1 750/m²	22 600	39 550 000
Chassis per unit	225 000	14	3 150 000
Terminal tractor (TT)	1 816 200	2	3 632 400
		Total CAPEX	61 517 850
OPEX	**SEK/day**	**# FTE**	**Total cost**
Reach stacker driver	1500	8,2	12 300
Terminal tractor driver	1500	4,4	6 600
	SEK/h	**avg. hours of usage**	
Maintenance RS	151	40	6 054
Tires RS	101	40	4 036
Fuel consumption RS	264	40	10 560
Maintenance TT	76	25	1 892
Fuel consumption TT	144	25	3 600
Tires TT	50	25	1 250
		Total OPEX per day	46 292
		OPEX per year	15 230 027

Moreover, the land needed for storing is increased but still, since operations are initiated in the port, land will have to be occupied there, as well as being charged for lifts in the port. Land calculations on site are show in Appendix A. Costs for port operations are displayed in Table 26 below.

Table 26: Operational costs for 40 GWh production in the port.

Port Operations			
CAPEX	**SEK**	**# of units**	**Total cost (SEK)**
	Total CAPEX		0
OPEX	**SEK**	**# of units**	**Total cost (SEK)**
Leasing yard	70/m² per year	46 000	3 220 000
Inbound			
RS - Lift	300	100	30 000
Outbound			
RS - Lift	300	100	30 000
	Total OPEX per day		60 000
	OPEX per year		22 960 000

Notably, the area needed in both the port and at the site is larger. It is reasonably possible that in the port, not nearly as much space is necessary, but it does consider the area being dedicated for usage by Northvolt. Taking away storage space for one day's demand, the area would still take up around 40 000 m^2. As with the fully outsourced solution, it is further assumed that 16-hour workdays for weekdays will not be charged as the port will see increased demand from other customers in the region as well.

Outsourced Chassis Yard

For the outsourced buffer yard case, the containers would undergo the same number of lifts as shown for 16 GWh, i.e., less lifts than the in-house solution. Minimum of ten vehicles will required to perform the transports between the port and the factory since the demand will be 100 containers during a 24-hour interval (i.e., available hours for the shunting fleet), which would require 10 shunting vehicles instead of 4 in the 16GWh case (see Appendix J). The number of chassis would be 44 (see Appendix E). However, a challenge would be to foresee the space needed to store 44 chassis. As mentioned by Dowd and Leschine (1990), the limiting factors is the equipment as well as space, as this would require a larger chassis yard to store the containers overnight. A proposed location to store the additional chassis would be at Northvolt Ett. The reason being that approximately 34 chassis would need be stored for the nightly demand. It is estimated that a potential placement of the chassis yard in the port can only store up to 14 chassis, thus an extra chassis yard is required. In such a case, a shunting fleet would only transport between the chassis yards in the port and at the site allowing for terminal tractors to pull the last mile to the factory. As shown in section 5.3, the delivery to the loading dock with the terminal tractor increases the maximum capacity at the loading dock and can therefore be considered a more robust solution. The flow of containers is depicted in Figure 34.

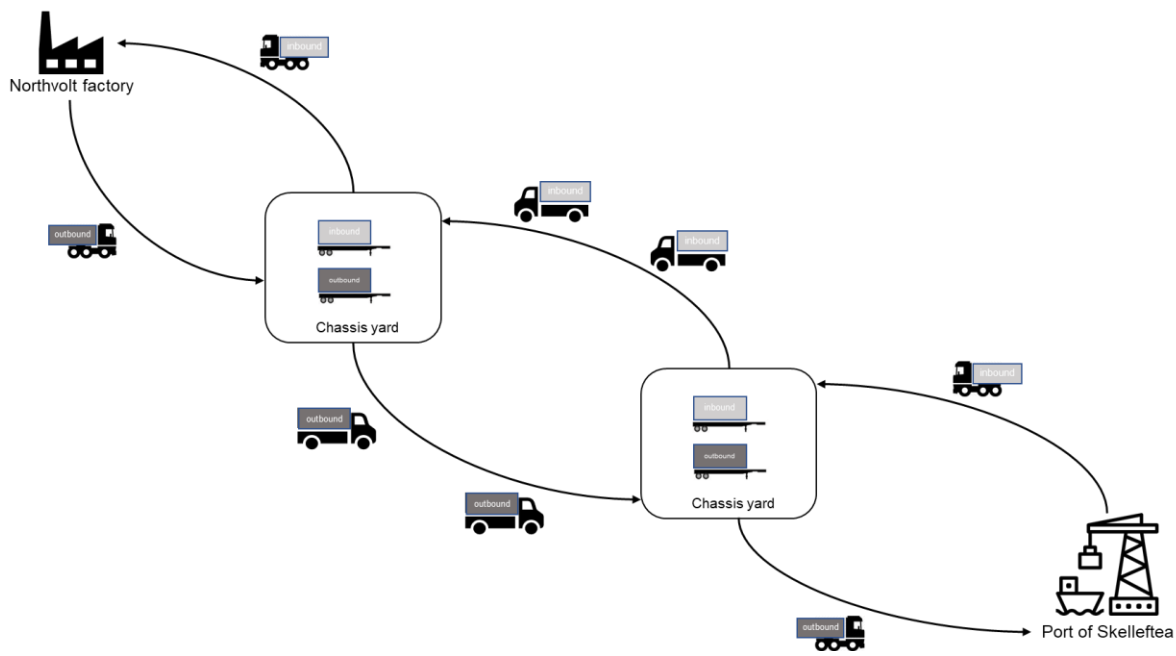

Figure 34: Chassis yard solution at 40 GWh.

For the 40 GWh outsourced solution with the implementation of a chassis yard for buffer, costs are displayed in Table 27. Foundation costs refers to the second chassis yard at Northvolt which needs to be constructed and occupy approximately 10 000 m^2. This is based on area measurement from satellite photos on similar layouts in ports around Sweden.

Table 27: Costs for buffer chassis yard at 40 GWh production.

40 GWh			
Outsourced with buffer			
CAPEX	**SEK**	**# of units**	**Total cost (SEK)**
Chassis/unit	225 000	44	9 900 000
Foundation	1 750 SEK/m²	10 000	17 500 000
Terminal tractor (TT)	1 816 200	2	3 632 400,00
		Total CAPEX	27 400 000
OPEX in port	**SEK**	**# of units**	**Total cost (SEK)**
Leasing yard	70/m² per year	46 000	3 220 000
Inbound			
RS - Lift	300	100	30 000
Outbound			
RS - Lift	300	100	30 000
Terminal Tractor	825 per hour	16	13 200
Avg. shift cost per day (16h)	13 700 per day	1	13 700
OPEX at Northvolt	**SEK**	**# FTE**	
Terminal tractor driver	1500	4,4	6 600
		Avg. hours of usage	
Maintenance TT	76	25	1 892
Fuel consumption TT	144	25	3 600
Tires TT	50	25	1 250
		Total OPEX per day	100 242
		Total OPEX per year	36 199 577

As can be seen in Table 28, the buffer yard solution is financially the best however, one might argue if the in-house, considering its drawbacks, might overall be of the best interest for Northvolt.

Table 28: Cost comparison of in-house and buffer chassis yard solution.

40 GWh in-house solution (SEK)		**40 GWh chassis yard solution (SEK)**	
CAPEX	63 093 000	**CAPEX**	27 400 000
OPEX per year	38 190 000	**OPEX per year**	36 200 000
Difference in cost from 16 GWh production rate (SEK)			
CAPEX	34 144 000	**CAPEX**	23 350 000
OPEX per year	19 807 000	**OPEX per year**	17 704 000

Although investments and operational expenditure is less, the largest missing piece for the buffer yard (chassis yard) solution is impacts of breakdowns or time critical deliveries. With the initial strategic objective of no shortages in production, if at any point, a time critical delivery is needed at night when the port is not operating this leaves an issue difficult to resolve. While emergency openings are possible at a cost, it does have an uncertain lead time which technically can be avoided with an in-house solution. However, the counter argument would be that if anything critical needs nightly deliveries it is due to poor operational planning and should be avoided altogether. Moreover, the outsourced chassis solution would require more accurate planning of chassis to ensure no bottlenecks are created. From that perspective, the in-house solution requires less complex planning.

6 Discussion

Referring to research question one, *is a container yard a viable option for complementary storage of goods compared to traditional warehousing?* The first distinction to make is realising that the solutions are complements to each other. The use of a container yard does not exclude a warehouse but can help complement storage and defer expansion needs. Inbound containers must at some point be stripped of their content and when this happens, storage inevitably must occur. Throughout the analysis, however, it has been concluded that it is possible to postpone the construction of a new warehouse, in the given context of Northvolt, and utilise a container yard. In a more general scene for other firms, the same arguments would suffice since material arriving with goods in containers will most likely not be moved straight from the container to the production line, but rather into another storage point, such as a warehouse. A firm, however, would continuously have to receive a substantial number of inbound materials via shipping containers to apply the same analysis as performed in this study. Otherwise, it would be easy to suggest optimising said firms' inventory management initially.

The main element of analysis for research question one concerns the financial aspect. Underlying cost analysis by Richards (2014) and Rushton (2017) exemplify several components common for warehouses. Components that were translated as best could into container yards for comparison. Throughout the analysis it has been clearly shown that at no point will any of the 16 GWh solutions surpass the investment cost of a warehouse, even in the far future and that is including operational costs. However, as the container flow is steadily expected to increase, some sort of expansion is reasonable to assume. A major point of worry is the loading docks by the central warehouse being a main point of access. Applying simulation to the communicated process times for stripping and filling containers, it was shown that less than 72 containers are to be expected being processed per day. Something that can cause issues in the future when expected daily demand arise to 100 containers, wherein 75 containers are to be emptied. To summarise, there are sufficient arguments for seeing a container yard as a viable option for complementary storage. Surely, more detailed operational analysis for operations inside the warehouse and how this affects should preferably be performed. But from the frame of the study the answer provided is clear.

Referring to research question two i.e., *what ownership structure for the container yard is most viable?* Conferred, initially, to the three solutions: in-house, hybrid and outsource, a fourth option was evaluated in the analysis as the buffer chassis yard solution. Using the framework of Alho et al. (2019) in combination of theory with regards to decision making by Van Landeghem and Vanmaele (2002), as seen in Figure 10, strategic, tactical, and operational factors was brought up in chronological order according to the design process stages of investigate, qualify, and demonstrate.

The in-house solution, although not the most optimal solution from a tactical perspective, has a large benefit of increasing the independence from the Port of Skelleftea. As part of the strategic phase, the goal/objective of no shortages promotes this solution further. Collaboration with the port and its actors is not broken but the flexibility remains, especially when the port is closed. Resource usage is, however, great in taking both up space in the port as well as valuable land on the site. Moreover, the number of industrial vehicles increase, proving a less optimal solution. Twice as many lifts also must be performed which several external interviewees brough up as a great risk. A sensitivity analysis proven through simulation does benefit the usage of terminal tractors for transport between the container yard and facility. However, for 16 GWh the daily demand is not large enough to be considered a devastating issue.

The hybrid solutions consist of two different ownership structures. One where Northvolt possess most of the ownership but hire external personnel to perform the operations. Another, where almost all ownership is outsourced to a third party. The costs are, to no surprise, higher than the in-house solution, especially for a solution where ownership is outsourced. The benefits would be the expertise and knowledge external personnel would bring to the operations, assumably reducing the risk of disruption or poor planning to occur. There is an aspect of transitioning that could be of interest, if choosing the container yard to be onsite. A hybrid solution could be of short-term interest while the in-house is then seen as better for the long-term. In financial terms it is the only way this solution makes logical sense. Beyond this, the same benefits and drawbacks of the in-house solution befall the hybrid solution. The strategic benefit of greater independence from the port holds, but the issue of double handling is still pertinent. Lastly, operating a container yard could be argued not being a core competence area by Northvolt, which makes outsourcing the operations sensible, even though it comes with a higher price.

The analysis of the outsourced solution showed great potential, yet a potentially devastating issue was the opening hours in the port. Although, interviews provided clear suggestions that 16 hours opening would be possible during weekdays, at weekends it would come at a hefty cost. Additionally, such a solution would lead to 8 hours where no operations occur in the port, a mismatch with data arguing production occurs over 24 hours. An imbalance in the demand for containers and its supply is thus created. To mitigate such an issue, nightly demand of containers would have to be stored over the night which transitioned into the outsourced solution with a chassis yard for buffer.

The chassis yard solution is the most economical one (as shown in section 5.4) and it further does not require extra lifts, which would increase the risk of damaging the containers. However, if the chassis yard is located at the periphery of the port, it will require the shunting fleet to make the final delivery of the containers to the factory, which as mentioned before, decreases the capacity of container delivery. Nevertheless, this is not seen as a problem since the daily demand of container for the 16 GWh is arguably low enough to not exceed the maximum delivery capacity by the shunting fleets. Thereby, this solution is likewise the most beneficial form a tactical perspective. From a strategic perspective, this solution is not as independent from the port as having a container yard onsite. Arguably, the solution takes a stance in-between, where some flexibility is sacrificed for gains in areas such as reduced lifts and cost. Calculations for number of chassis needed were completed using static data. Conceivably, the planning of chassis will be more complex, however, if more chassis would be needed than calculated, renting options from suppliers of chassis would be possible with some foreseeable preparation.

Adjusting the solution to which scales the best, i.e., 40 GWh production, in-house and the chassis yard solution were compared since they were the two most competitive solutions. In theory the outsourced solution was the best but in practice it proved difficult. In line with the analysis for the 16 GWh solutions, the chassis yard solution was found the most economical as well as operationally better. Due to restriction with the storage capacity of chassis at the inlet of the bay being approximately 14, an additional chassis yard placed on the site of Northvolt was needed. This still promoted the benefits the shunting fleet could experience with goals of autonomous driving as it would be between two points in a controlled environment. Additionally, terminal tractors would then perform last-mile deliveries which simulations proved had a higher capacity.

Other things to consider would be the handling of dangerous goods. Several inbound containers will contain dangerous goods which needs to be considered when designing the flow, especially if an in-house solution is opted for as reactive material should be stacked in a safe distance apart from each other to avoid chain reactions in case of emergencies. Furthermore, Northvolt also need to consider risks with disruption in the flow of goods, as late deliveries, potential road blockage during transport or damage of material which would put pressure on the system's robustness. The simulation was to prove what could be expected to be completed in a days' time if productivity were slacking and more than the daily demand needed be moved.

The arguments regarding the operations would be applicable in a general case for manufacturing firms situated in similar environments. Extra lifts of containers should be avoided if possible. Thus, an extra container yard can be deemed negative in that aspect, however, manufacturing companies having their factory located more inland would also have to consider the longer transport times, thus making the container yard more tempting. Further, the financial arguments are also applicable in a general scene, since the outsourced solution implies less activities performed, thus lower costs follow. Although, the overtime required by the ports can be decisive for when the in-house solution becomes less expensive than the outsourced solution. The prices for the overtime operations must therefore be treated carefully for the relevant port(s) where the goods will be imported and exported.

7 Conclusion

Conclusively, a container yard is a viable option for complementing storage of goods compared to traditional warehousing, since the financial analysis shows that expanding the warehouse is much more expensive. It should be noted that as Northvolt scale up their production to a steady state surpassing 16 GWh, a warehouse expansion could be viable, however, not for the volumes indicated for this case study.

It is further concluded that the outsourced buffer chassis yard is the most viable ownership structure of a container yard, out of the potential solutions, i.e., the in-house, the hybrid, the outsourced, and the chassis yard. From the financial analysis, this ownership structure is shown to be the most economical. This is concluded for containers being handled by Port of Skelleftea, as prices have been obtained from here. Additionally, this solution requires less capital expenditure (i.e., investments in heavy industrial vehicles and land), relative to the other solutions, which was promoted by Northvolt as financially important. It is further seen that this solution avoids double handling of containers (i.e., no extra lifts) which reduces the risk for damaging containers and reduces number of non-value-adding activities in the flow of containers. In a general scene, this does not incorporate the distance a manufacturer is located from the port, since Northvolt Ett is located close to the Port of Skelleftea. Moreover, strategic benefits are achieved by utilising the stevedore’s knowledge in container handling and storage optimization, thus relieving Northvolt from becoming its own stevedore. Furthermore, this ownership structure is scalable since chassis yards can be added, presumably closer to Northvolt Ett. Thereby, synergies can be found for the shunting fleet, being planned to be autonomous and electric in the future. This will be achieved by implementing charging stations as well as ease the route for the fleet by performing transports solemnly between the two chassis yards.

8 Suggestions for Further Research

To gain a deeper understanding of the implications of using a container yard, certain aspects should be researched more deeply. A natural steppingstone would be to dwell deeper into simulations as to improve sensitivity analysis. Throughout the study, static measurements were the main component of analysis but realistically, vehicles such as reach stackers and terminal tractors can have different productivity levels depending on distance and placement of containers. A simulation would thus aid and provide more nuanced insights.

As for the viability of a container yard versus expansion of a warehouse, research into the operative costs and how the combination of the two can work better together is suggested. Only comparing high-level financials gave an overlook but it does not provide a holistic picture.

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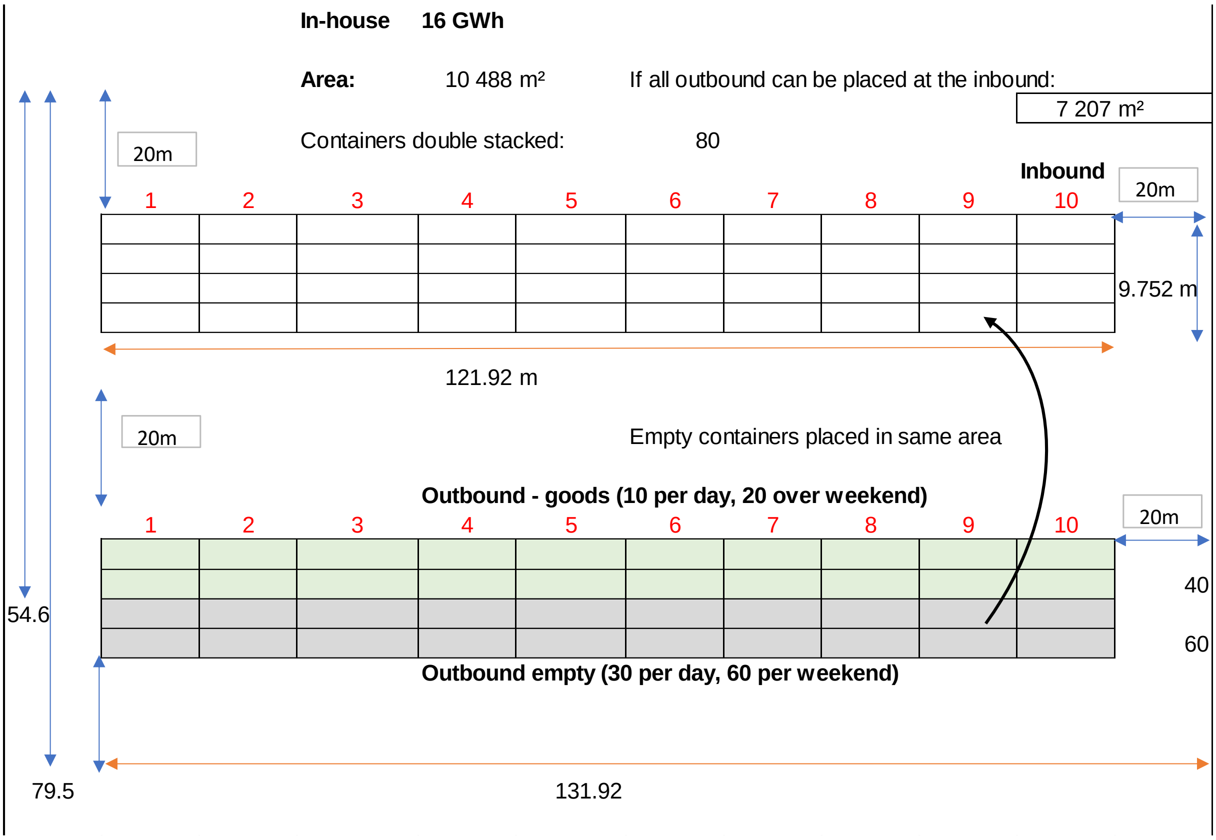
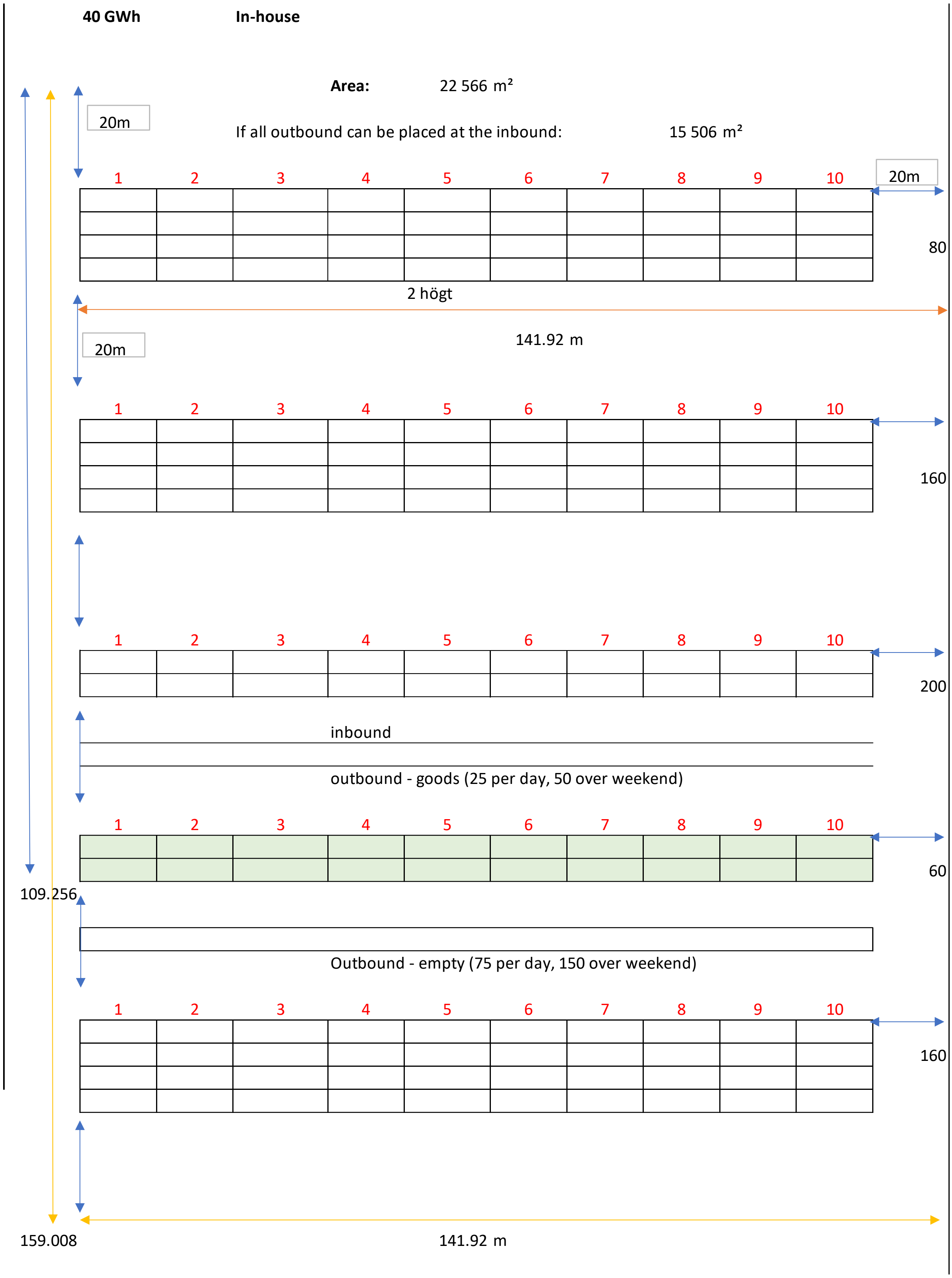
Appendix A



Expected area needed for 80 inbound containers and 80 outbound (16 GWh). Inbound is stacked with two in height, outbound with goods two in height but outbound empty three in height. 20 m distance between stacks allows reach stackers to enter and turn around inside the ally.



Expected area needed for 200 inbound containers and 200 outbound (40 GWh). Inbound is stacked with two in height, outbound with goods two in height but outbound empty four in height. 20 m distance between stacks allows reach stackers to enter and turn around inside the ally.

Appendix B

16 GWh	Weekdays	Weekend
RS_1 - 16 h	11.2	5.33
RS_2 - 16 h	5.33	0
RS_1 - 8 h	2.67	2.677
RS_2 - 8 h	0	0
Sum (h)	19.2	8
	Average daily usage (h)	16

16 GWh	Weekdays	Weekend
TT_1 - 24 h	10	10
Sum (h)	10	10
	Average daily usage (h)	10

40 GWh	Weekdays	Weekend
RS_1 - 16 h	14	0
RS_2 - 16 h	14	0
RS_3 - 24 h	20	20
Sum (h)	48	20
	Average daily usage (h)	40

40 GWh	Weekdays	Weekend
TT_1 - 24 h	24	24
TT_2 - 1 h	1	1
Sum (h)	25	25
	Average daily usage (h)	25

Usage for reach stacker (left) and terminal tractor (right) for 16 and 40 GWh production, respectively. Applicable for in-house/hybrid solution and chassis yard (right, terminal tractor) at 40 GWh.

Appendix C

16 GWh	**Reach Stacker**	**Terminal Tractor**
Working hours per year	11 680 h	7920 h
40-hour work week	1 880 h	1 880 h
FTE	6.2	4.2

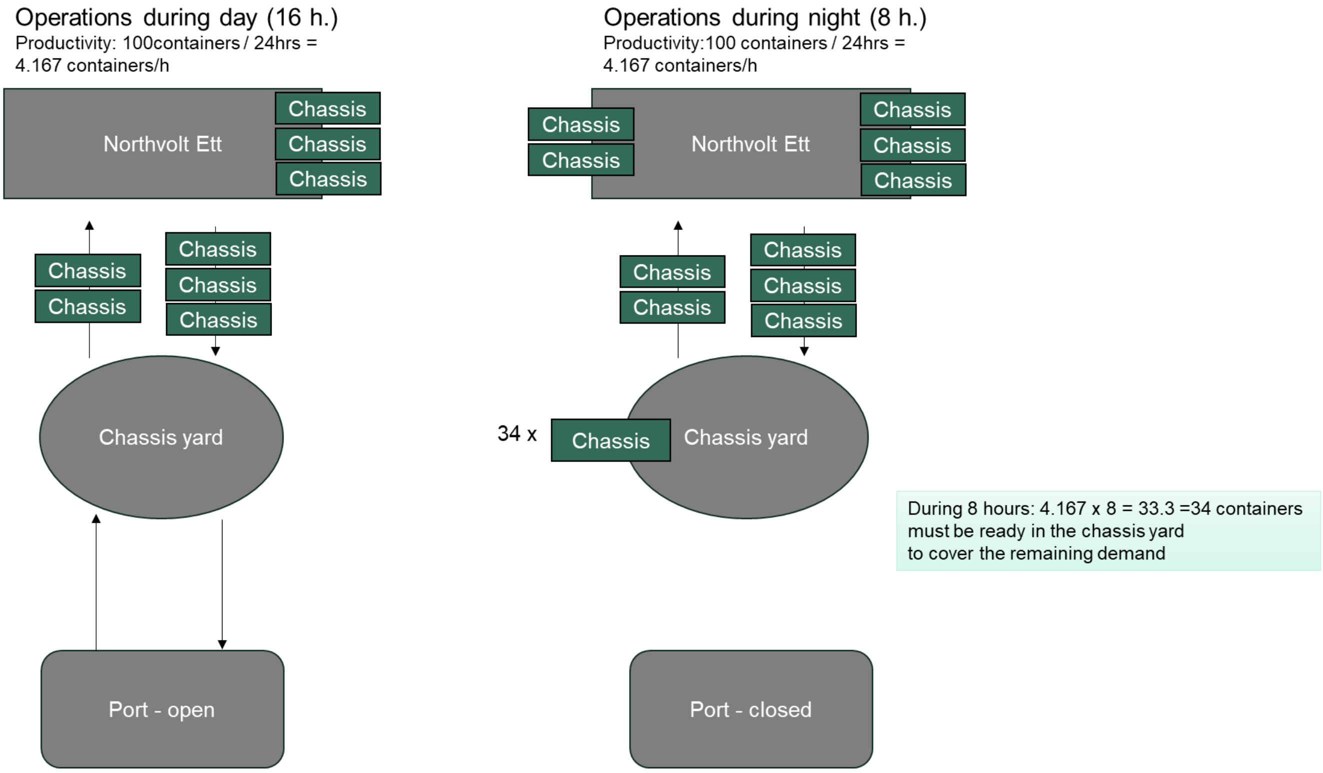
40 GWh	**Reach Stacker**	**Terminal Tractor**
Working hours per year	15 416 h	8 225 h
40-hour work week	1 880 h	1 880 h
FTE	8.2	4.4

FTE for in-house/hybrid solution at 16 and 40 GWh production, respectively. Terminal tractor hours for chassis yard at 40 GWh is also applicable.

Appendix D

Daily container demand – 16 GWh	40
Operating hours – shunting fleet	16
Demand/hour	2.5

Appendix E



Expected number of chassis needed for 40 GWh case, chassis yard.

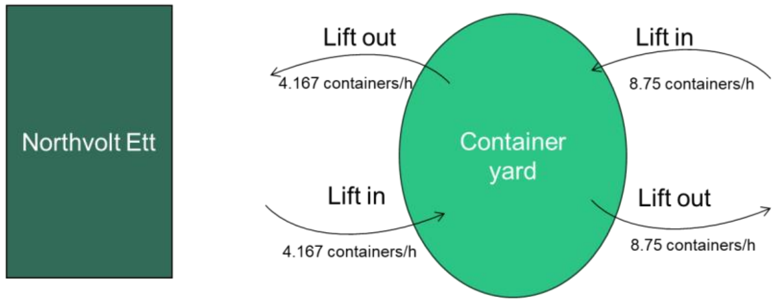
Appendix F

Productivity

100 containers/24 hours = 4.167 containers/hour

Productivity

140 containers/16 hours = 8.75 containers/hour



Operations	Containers/h
Lift in	8.75
Lift out	8.75
Lift out	4.167
Lift in	4.167
Total	25.834

Capacity Terminal Tractor

With a productivity of 8 moves/hour (4 roundtrips), minimum required number of terminal tractors are 2.

Capacity Reach Stacker

With a productivity of 10 lifts/hour, minimum required number of reach stackers are 3.

Weekdays + Weekends

Weekdays

Analysis of lifts performed by reach stacker in a 40 GWh case. Terminal tractor has a capacity of 4 containers/hour. An additional terminal tractor will be needed to handle 4.167 containers/hour.

Appendix G

16 GWh	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Inbound	56	56	56	56	56	0	0
In to prod.	40	40	40	40	40	40	40
YARD (IN)	16	32	48	64	80	40	0
Outbound	56	56	56	56	56	40	40
Out empty	42	42	42	42	42	30	30
Out goods	14	14	14	14	14	10	10
YARD (OUT)	64	48	32	16	0	40	80

Storage split of containers for in-house container yard at 16 GWh. This avoids any opening hours in the port over the weekend.

40 GWh	Monday	Tuesday	Wednesday	Thursday	Friday	Satuday	Sunday
Inbound	140	140	140	140	140	0	0
In to prod.	100	100	100	100	100	100	100
YARD (IN)	40	80	120	160	200	100	0
Outbound	140	140	140	140	140	100	100
Out empty	105	105	105	105	105	75	75
Out goods	35	35	35	35	35	25	25
YARD (OUT)	160	120	80	40	0	100	200

Storage split of containers for in-house solution container yard at 40 GWh. This avoids any opening hours in the port over the weekend.

Appendix H

$$\frac{1\ hour \times Number\ of\ bays}{Emptying\ or\ filling\ time\ (h)} \times\ Operting\ hours\ per\ day$$
$$=\ Number\ of\ emtied\ or\ filled\ containers\ per\ day$$

Appendix I

Outsourced 16 GWh

Demand/16hrs	2.5
Cont. /h	3
Chassis needed by shunting fleet	3
At loading dock	3
Store 8 hrs	4
Total chassis	**10**

Chassis Yard 16 GWh

Demand /24hrs	1.66666667
Cont./h	2
At loading dock	2
Chassis needed by shunting fleet (circulating)	2
Front (8hrs)	14
Total chassis	18

Chassis Yard 40 GWh

Demand/24hours	4.16667
Cont./h	5
At load dock	5
Chassis needed by shunting Fleet (circulating)	5
Front 8hrs	34
Total chassis	44

In-house 16 GWh

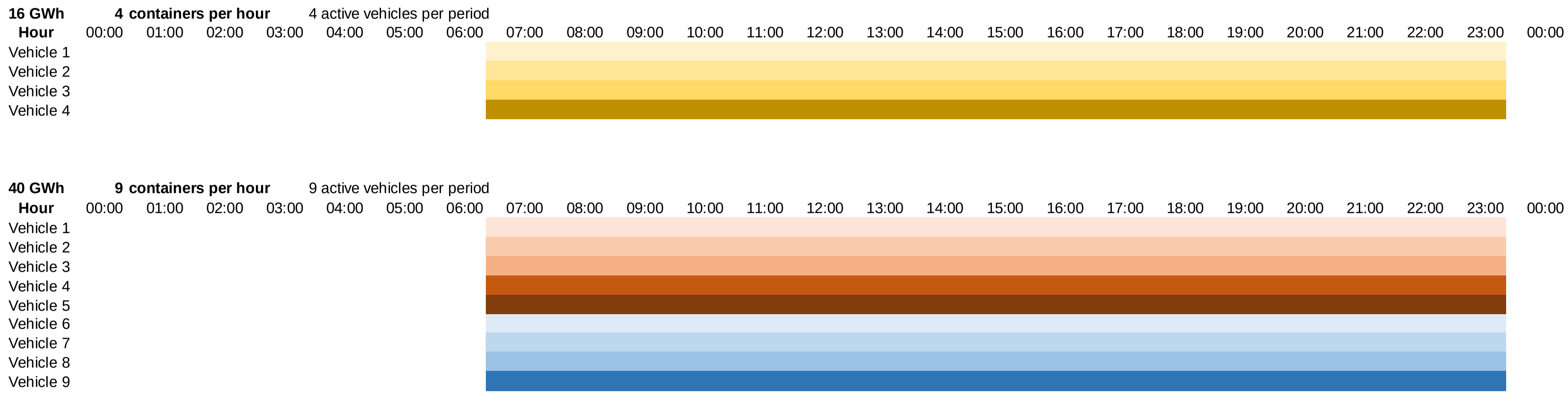
From port to container yard	
Demand/hour	3.5
Cont./h	4
Chassis needed by shunting fleet	4
From container yard to factory	
Demand/hour	1.666666667
Cont./h	2
At loading dock	4
Transfer by TT	1
Mitigate bottleneck	1
Total chassis	10

In-house 40 GWh

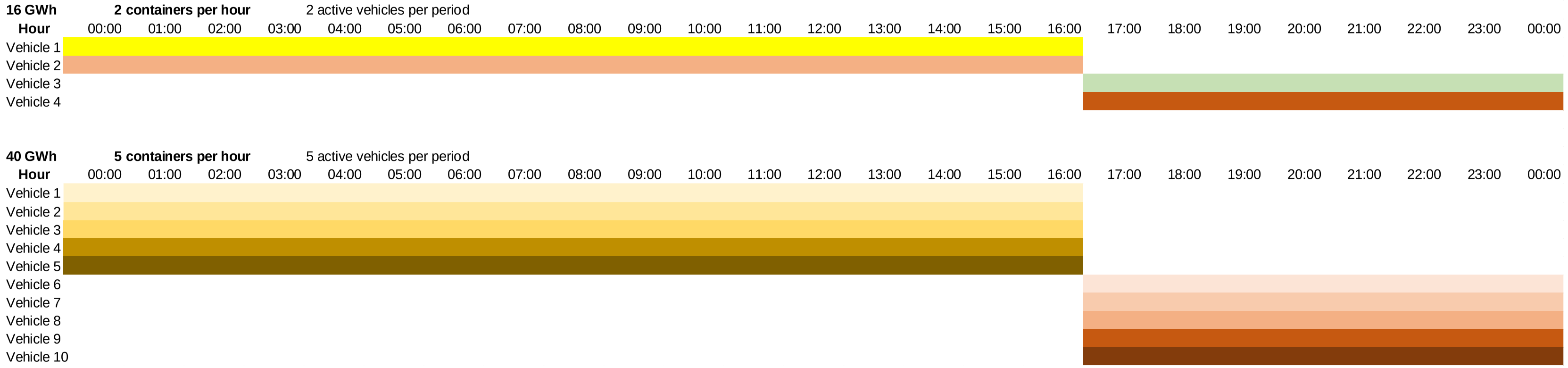
From port to container yard	
Demand/hour	8.75
Cont./h	9
Chassis needed by shunting fleet	9
From container yard to factory	
Demand/hour	4.16667
Cont./h	5
At loading dock	8
Transfer by TT	2
Mitigate bottleneck	2
Total chassis	21

Appendix J

Shunting vehicles needed. In-house solution



Shunting vehicles needed. Chassis buffer yard



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