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Strategic advice on the placement of logistics activities in limited spaces

Providing a framework on the preferable location of storing, kitting and sequencing in the automotive manufacturing industry

Master's thesis in Supply Chain Management

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Abstract

Customization to respond to specific customer requirements within the automotive industry plays a crucial role in satisfying customer needs, which implies the need for the availability of a wide variety of parts. Furthermore, space is often limited in such manufacturing environments and considerations regarding whether to outsource or relocate specific logistics processes arise. However, it is not unusual that companies do not have strategic recommendations for which logistics process to prioritize to remain in-house but rather general guidelines, as expressed by Volvo Group. Therefore, this report provides a framework that proposes strategic advice on where to position logistics activities, including pallet storing, sequencing and kitting, in automotive manufacturing by examining numerical data provided by Volvo Group and benchmarking current practices within the industry. Hence, the study investigates contemporary logistics setups between assembly plants and external logistics centers in the automotive industry, complemented and supported by a literature review. The different perspectives of the literature review and benchmark are used to provide a priority list of which logistics activities to relocate when urgencies arise for releasing space in assembly environments. Our findings suggest that pallet storing should be performed in external logistics centers, whereas especially kitting and sequencing are generally preferred to be located within the assembly facility if possible. In addition to the priority list, two decision trees with additional aspects were further established for determining the most favorable location of processes. A final concluding remark is that the context of different manufacturing companies varies, making it essential to evaluate the specific conditions and apply the general framework accordingly.

Keywords: external logistics center, process positioning, storing, sequencing, kitting

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We also wish that our thesis work will be helpful and valuable for Volvo Group, including the Volvo Tuve plant and other manufacturing sites, as well as provide additional knowledge and further insights in the area of process positioning of logistics activities.

Finally, we would also like to sincerely express appreciation to our families and friends for encouraging and morally supporting us during the thesis work.

Azra Huskic & Mia Pranjic, Gothenburg, June 2021

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1
Introduction

This section includes a background of the project, the aim, research questions as well as a description of the limitations and a thesis outline.

1.1 Background

The background below includes a brief introduction to the automotive and manufacturing industry, logistics, warehousing and logistics activities. Finally, the company is described, as well as the problem statement.

1.1.1 The automotive industry

The automotive industry is one of the largest manufacturing sectors globally, generating both economic benefits and environmental concerns (Nieuwenhuis & Wells, 2015). Despite its size, the industry is relatively volatile, which can be explained by limited resilience to external impacts in highly efficient production systems. The automotive industry was previously characterized by declining profitability, overcapacity, plant closings and job losses. However, according to Nieuwenhuis and Wells (2015), the industry reemerged along with new technologies. Laine (1979) explains that the car and truck industries are principally similar in terms of manufacturing context. Also, the author defines trucks as self-propelled, wheeled vehicles designed for conveying goods (Laine, 1979), thus including Volvo Group's heavy-duty vehicles.

Nieuwenhuis and Wells (2015) explain that lean production has thoroughly influenced the automotive industry with its productivity improvements. Furthermore, Netland and Aspelund (2013) state that the trend of developing company-specific production systems among manufacturers has also been enforced by Volvo Group, constituting Volvo Production System (VPS). Bennett (2014) also points out the importance of manufacturing companies recognizing the industry context and market requirements for determining product strategies. Therefore, such implementation provides the potential of establishing competitive advantages through a unique fit (Netland & Aspelund, 2013). However, Vivid, Selvakumar and Ruvankumar (2020) explain that the truck assembling process includes many processes, hence entailing high labor intensity. Manufacturing also involves several safety risks for assemblers, for instance, related to material handling, lifting equipment, pneumatic guns or conveyors (Vivid et al., 2020). The industry is further experiencing shifts from ownership of products to offering services (Nieuwenhuis & Wells, 2015).

Greening supply chains is another prominent movement in the automotive manufacturing industry. Lin, Chen and Nguyen (2011) explain that initiatives within the area can reduce environmental issues and provide economic opportunities for manufacturing firms. The study further reveals that the cost-increase for purchasing environmentally friendly materials is the most influential causal criterion for sustainability performance in automotive manufacturing. Also, initiatives for pollution control are the most influential criterion (Lin et al., 2011). Regulatory pressures on sustainability are further considered to have the ability to reshape the industry and products (Nieuwenhuis & Wells, 2015).

1.1.2 Manufacturing companies

In recent years, the manufacturing industry has gradually shifted towards including intelligent and advanced technologies, referred to as the fourth industrial revolution, industry 4.0 (Nikolic, Ignjatic, Suzic, Stevanov, & Rikalovic, 2017), triggered by the Internet of Things (Yavas & Ozkan-Ozen, 2020). Such systems, e.g. predictive manufacturing systems, require large amounts of data, algorithms, artificial intelligence and pattern recognition for creating self-aware, predictive, maintaining and learning manufacturing systems. The potential benefits of the systems include operational efficiency, cost reductions and improved product quality (Nikolic et al., 2017). However, some uncertainties and suggested initiatives needed for a smooth transition toward industry 4.0 include establishing process integration, access to real-time data and predictive maintenance of machines by using sensors (Khan & Turowski, 2016).

Logistics highly impacts the performance of a manufacturing organization. Tracey (1998) shows that logistics affect a manufacturer's ability to satisfy the needs of customers and the overall firm performance. Customer service further means responding to customer's needs through customized and high-quality products, which requires manufacturing flexibility (Tracey, 1998). Responding to customer's specific needs and preferences can further be accomplished through mass customization, according to Fogliatto, Silveira and Borenstein (2012). However, in the automotive industry, increased mass customization results in an increased variety of parts, leading to increased levels of needed inventories to avoid stockouts, which is negatively related to financial performance (Fogliatto et al., 2012). Blecker and Abdelkafi (2006) exemplify this through an empirical study showing that doubling the number of offered products increased the unit cost by 10-35% depending on the level of plant automation.

Moreover, Blecker and Abdelkafi (2006) states that the proliferation in product variety can reach many variants despite modularisation, typically seen in the automotive industry (Blecker & Abdelkafi, 2006). Modularization has the potential of handling the split between economies of scope and economies of scale by developing complex products into collections of parts, modules and sub-assemblies, making up the end-products (ElMaraghy, Azab, Schuh, & Pulz, 2009). Process flexibility is further crucial for delivering individualized products cost-efficently, meaning the production environment should be adaptable at a process level, according to Khan and Turowski (2016). Therefore, companies' aspirations of meeting more diversified customer demands may require additional material and storage, i.e. logistics operations.

1.1.3 Logistics and warehousing

The purpose of logistics is to bring value for customers by optimally supplying materials, making or breaking a firm in a competitive environment (Dede & Çengel, 2020). Besides offering excellent customer service, firms should perform logistics operations cost-efficiently. However, there are several goal conflicts mentioned by Jonsson and Mattsson (2016). For instance, more comprehensive inventories can increase customer service by having desired items in stock, but the tied-up capital will increase, leading to higher costs (Jonsson & Mattsson, 2016). Warehouse management and material handling are two examples of activities with opportunities for contributing to the company's overall performance through logistics, according to Dede and Çengel (2020).

In most industries, warehousing refers to storing goods for different reasons (Hompel & Schmidt, 2007). The authors also explain warehousing as a planned process for bridging differences in time and quantity needs. There are also other reasons for operating warehouses in supply chains, such as optimizing logistic performance, ensuring productivity, reducing transport costs, utilizing economies of scale, balancing quantities needed and received, and using the warehouse as a process step (Hompel & Schmidt, 2007). However, such operations are costly if not managed efficiently. Moreover, companies must not use inventories to compensate for inefficient processes, according to Hompel and Schmidt (2007). Except for providing storage, warehouses also provide opportunities for value-addition, for instance, assembly, packaging and repair processes (Koster, Johnson, & Roy, 2017).

1.1.4 Logistics centers

Logistics centers include logistics activities such as warehousing, handling, transportation, distribution and information services (Yavas & Ozkan-Ozen, 2020). Yavas and Ozkan-Ozen (2020) further point out strong relationships between digital information platforms, autonomous vehicles, smart mobility, intelligent transport systems and real-time locating systems as essential criteria for the impact that industry 4.0 brings to logistics centers.

There are various types of logistics centers fulfilling different purposes in different supply chains. The paper by Higgins, Ferguson and Kanaroglou (2012) aims at differentiating between such concepts. The fundamental function ranges from providing a place for storage or inventory to more complex setups, including performing distribution, maintenance and more value-adding activities (Higgins et al., 2012). However, this study considers warehousing as storage while logistics centers perform a broader set of additional and value-adding activities. Value-added services are further regarded as unique or specific activities developed by firms for enhancing efficiency and customization capabilities (Chen & Notteboom, 2012). In the context of logistics centers, such activities refer to performing certain activities besides storing, such as sequencing, kitting and pre-assembly. This report will cover the concept of logistics centers further in section 2.1.

1.1.5 Logistics activities

According to Jonsson and Mattsson (2016), a part of the material flow in the logistics system consists of various material handling processes which are referred to as storing, kitting and sequencing. These principles are related to the activities carried out at Volvo Group facilities.

In this report, storing refers to storing full pallet loads, meaning a larger package of a selection of items where no picking for a process is performed (Jonsson & Mattsson, 2016). Storing thus implies that the goods are delivered to the factory in full pallets and are then stored in the same packaging or smaller packages. However, the pallets can later be delivered from the inventory area to various processes such as sequencing, kitting or directly to the assembly line since the material flow takes place to and from inventories (Jonsson & Mattsson, 2016). Jonsson and Mattsson (2016) further state that handling and storing full pallets minimize warehousing costs and handling costs. Storing of pallets can achieve low costs through a high fill rate and low operating costs since most storage space is used.

According to Sali, Sahin and Patchong (2015), kitting is a principle where material items for specific manufacturing objects are picked together into containers for kits and delivered to the point of consumption, e.g. an assembly line. Sequencing instead refers to sort components by both assembly object and product family (Fager, 2018). Hence, the assortment differs between kitting and sequencing since the material in sequencing consists of a particular type of part family fed in the sequence items are needed in the production. Both kitting and sequencing are commonly applied in contexts of high product diversity. Such material handling principles enable specific parts to be prepared and delivered to the point of use (Sali et al., 2015). Therefore, reductions in storage space in the assembly are possible since only the components needed for an assembly object are presented to the assembler, according to Fager (2018).

1.1.6 Company description of Volvo Group

Volvo Group is one of the world's leading manufacturers of vehicles with production of, e.g. trucks, buses and construction machinery. The corporate group has almost 100 000 employees and is active in 190 markets with its 12 brands, including Volvo Penta, UD Trucks, Terex Trucks, Renault Trucks and Mack Trucks. By offering products with different brands, the corporate group provides solutions to various customer and market segments. The company offers transport solutions for multiple types of businesses and is constantly working on solutions to the global challenges the world is facing, with the vision of contributing to increased prosperity with transport solutions as well as being the prime supplier of transport solutions (Volvo Group, 2019).

The entire Volvo Group product portfolio is developed to contribute to efficient transport and infrastructure solutions and create value for customers. The corporate group drives the development of electrified vehicles and automated solutions to benefit customers, society and the environment. Such solutions are further aligned with the company's core values, including quality, safety and environment, which is the foundation and permeates the entire business (Volvo Group, 2020b). As for electrification, Volvo Group's ambition is to deliver all-electric versions of Volvo's heavy-duty trucks in 2021. This huge step in electrification is essential to reach the goal of fossil-free transportation and a step closer to the sustainability goals (Volvo Group, 2020b).

The Volvo Tuve Plant, located in Gothenburg, is one facility included in Volvo Group. The plant produces premium heavy-duty trucks, including different types of trucks; Volvo FH, Volvo FM, Volvo FH16 and Volvo FMX. Although four types of trucks are produced, more than half of all trucks are highly adapted to meet specific customer requirements. In addition to trucks, frame members are also produced in Tuve and sent to other assembly plants in the world (Volvo Group, 2020a). Moreover, various material handling processes are performed in the plant, for example storing, kitting and sequencing. However, even if the plant manages many handling and storing activities, some activities are done externally by a logistics provider. The logistics provider is located approximately 10 km from the Volvo Tuve plant and handles mainly sequencing activities.

1.1.7 The context and problem statement

As previously mentioned, the truck industry is characterized by a high degree of product variation to accomplish customer-specific requirements, quality and safety. The assembly processes of Volvo Group's heavy-duty trucks are also labor-intensive. This labor intensity is expected to increase further when introducing new product ranges and increased variation levels within products. It is expected to limit the possibilities to improve efficiency, quality and ergonomics. Increased product diversity also contributes to additional requirements on material availability for the assembly process. However, limitations in space inside the Volvo Tuve plant give rise to implementing concepts such as plant extension logistics center (PELC), which is a part of the supply material process to cope with space issues near the assembly. Volvo Group principally considers a PELC as an external logistics center for material handling purposes separated from the manufacturing facility, corresponding to a logistics center. A PELC allows opportunities to prioritize which materials are positioned inside the plant, either closer to the assembly line or further away, for instance, in the PELC or at suppliers. Therefore, the PELC can support the mixed-model assembly concept at Volvo Group to meet more diversified demands from end customers.

Currently, there is not a PELC facility in place in connection to the Tuve plant. However, Volvo Group recognizes the need to investigate future possibilities of optimally utilizing an extended inventory, which can support and fulfill the demands of end customers. However, the logistics provider, referred to as Volvo Managed Logistics Center (VMLC), is currently considered similar to a PELC facility. VMLC executes some sequencing for certain parts of the assembly. Volvo Tuve plant is currently partly integrated into the practices of VMLC, owning some material that is handled at VMLC and has insight into certain stock balances. However, Volvo Group desires to obtain more control and insight over such activities due to potential monetary savings and improved quality. Also, a PELC could provide opportunities for improving the flows of information between the plant and the logistics center if using Volvo Group's IT systems, performing additional logistics activities, e.g. storing, and reducing the stock levels, implying lower tied-up capital.

The recommended setup must consider variables of cost, flexibility and quality to be feasible for Volvo Group. Hence, the main issue is determining which internal logistics activities should be performed within the Tuve plant or at the PELC, especially with the increased complexity of electromobility.

The term *PELC* is used when describing Volvo Group's view of an external logistics center, mainly throughout chapters 1-4. Moreover, the term *logistics center* is used for describing the logistics setup of the benchmarking companies, mainly in chapter 5. Finally, the term *external logistics center* is used when discussing a generic facility performing logistics activities externally.

1.2 Aim

The study aims to increase the understanding of utilizing logistics centers by providing a framework with guidelines for logistics activities, including storing, sequencing and kitting, to include in a PELC and/or in a plant. Various material characteristics and other aspects will be considered throughout the study and when determining the location of the material handling processes.

Volvo Group is chosen as a case company and the study will focus on the Volvo Tuve factory to provide a foundation for the guidelines. However, the recommendations will be generic and therefore applicable to other companies within the automotive industry.

1.3 Research questions

The research questions have been formed for fulfilling the aim. RQ1 has been formulated in order to understand the context that Volvo Group operates to establish a current state. It also provides a basis for understanding improvement potentials in the processes.

> **RQ1:** Which logistics activities are currently performed inside the Volvo Tuve plant and what is being done externally in the logistics center?

Answering RQ2 contributes to further insights into current practices of manufacturing companies' complex material supply for cost-efficiently assuring quality for end-products. A benchmark will be conducted, including companies with logistics centers, principally functioning as PELCs. This question contributes to broadening the understanding of material supply setups by including additional aspects from the industry.

> **RQ2:** How have other similar companies in the industry designed their logistics set-ups and what are the perceived advantages and disadvantages?

Finally, RQ3 is formed to establish a framework for decision-making related to managing different materials based on their characteristics, where Volvo Group serves as a case company and Volvo Tuve as their factory. Answering RQ3 will further allow for generalized implications on recommended activities for material arrangement.

> **RQ3:** How should the Volvo Tuve plant prioritize the location of their storing, sequencing and kitting based on the characteristics of the material items?

The provided recommendations for the location of the material handling processes will be based on critical material characteristics identified through answering RQ1 and RQ2. Other essential aspects of the guidelines will include cost, flexibility and quality requirements.

1.4 Limitations

In terms of the current state, benchmark and recommendations of the study will be limited to the internal logistics i.e. the following activities: storing, sequencing and kitting. Thus, only the activities performed in the factory and in the current logistics center (VMLC). It will also be limited to activities related to the production and the logistics center. External activities performed at suppliers are not taken into account.

The study will neither include improvement work for performing the various activities and not investigating which parts that should be kitted or sequenced. The study focuses on which improvements to make in terms of the activity's location based on the transportation cost and inventory cost, quality seen from the end customer's perspective and flexibility including volume, variation and deviation, i.e., which activities should be performed where.

In terms of limitations for data collection, the study will be based on a selection of specific kitting and sequencing areas believed to represent all the kitted and sequenced materials. This will be done despite the results being presented as general guidelines since it is impossible to perform a study at the entire factory and take each specific area into account. Furthermore, the priority list will be based on several parameters such as handling frequency, space and transportation frequency. Also, several assumptions are made and will be described throughout the report.

1.5 Thesis outline

First, a theory chapter, chapter 2, is presented describing the subject based on what is mentioned in the literature about the area. This is followed by chapter 3, describing the method used to answer the questions. Answer for the first research question, RQ1, is presented in chapter 4 where the current state is described. Furthermore, RQ2 is answered through a benchmark in chapter 5 and discussed in more detail in section 6.1. Finally, the third research question, RQ3, is answered in the framework, i.e. chapter 7, and the various parameters are described earlier in chapter 6, to provide an increased understanding. Finally a discussion and conclusion is performed in chapters 8 and 9, respectively.

2

Theory

As mentioned in section 1.1.2, manufacturing companies in the automotive industry are increasingly aiming for mass customization, giving rise to a large variety in assembled products (Alford, Sackett, & Nelder, 2000). The customization is further performed in the manufacturing stage since products are built-to-order (Fredriksson & Gadde, 2005). Also, product variety is related to increasing costs and complexity in the manufacturing since requiring a wide range of components, according to Alford et al. (2000). Mixed-model assembly lines are used among companies to cope with product variety and be responsive (Liker, 2004), which emphasizes the importance of efficient logistics and the availability of components (Sali & Sahin, 2016; Wänström & Medbo, 2008). Since the project aims to investigate which activities are preferred to allocate to an internal logistics center, a theoretical overview covering logistics centers and warehouses is provided below in sections 2.1 and 2.2. Furthermore, the activities that are to be performed within such a PELC facility, potentially, are elaborated upon in-depth in section 2.3, followed by the concept of a secondary feeder line in section 2.4. Finally, some logistics performance variables, including cost, flexibility, and quality, are described in section 2.5 since the framework with general recommendations must consider such performance variables.

2.1 Logistics centers

Offering end customers a wide variety of products entail some manufacturing challenges. Hanson, Medbo and Johansson (2016) mention that it is usual that space is lacking in automotive assembly plants, meaning that the components that are to be presented at the assembly stations cannot be handled within the plant. Therefore, it is typical that companies use external logistics centers, which are either commonly handled by themselves or a third-party logistics provider (Hanson et al., 2016). The main reason for outsourcing certain activities is access to expertise and specialist knowledge (Hanson et al., 2016; Richards, 2014). Other reasons often include cost reduction potential and increased flexibility since freeing up space within the own facility, according to Richards (2014). Abraham, Holt and Kathawala (1990) state that in cases where the original equipment manufacturer (OEM) pushes the inventory upstream in the supply chain, the suppliers tend to deliver smaller quantities and increase the delivery frequency. Consequently, the costs for transportation increase, which may exceed the cost for inventory reductions (Abraham et al., 1990).

2.1.1 Definition of a logistics center

As indicated in section 2.1, the literature has no consensus regarding the exact definition of which activities are performed within logistics centers since different supply chains serve different purposes and require different logistics centers. However, Yavas and Ozkan-Ozen (2020) explain that logistics centers often include warehousing activities, handling, transportation, distribution and information services. Higgins et al. (2012) add that logistics center setups can range from basic to more complex. The fundamental function includes warehousing, i.e. provide space for storage of inventory, while more complex setups may include maintenance and various value-adding activities (Higgins et al., 2012). Value-addition can further be regarded as services aimed at increasing the diversity of performed activities (Chen & Notteboom, 2012), for instance, kitting, sequencing or pre-assembly. The following definition of logistics centers is used throughout the report:

> *A logistics center ranges from performing basic warehousing activities, such as storing pallets and associated processes, to complex logistics activities, such as sequencing, kitting and pre-assembly. An external logistics center further refers to a facility located separated from the assembly plant, requiring trailer or forklift transportation.*

2.1.2 Roles of logistics centers

Besides providing points of storing inventory, Rushton et al. (2017) state that other typical roles performed in warehouses include consolidation centers, cross-docking and assembly facilities. However, such warehouses would be considered logistics centers in this study.

Consolidation centers
A consolidation center receives components from various suppliers before further delegating the parts to the manufacturing plant, according to Baudin (2004). The location of a consolidation center is optimally within an assembly plant, which would allow for transportation with tugger trains or carts (Baudin, 2004). However, it might not be feasible, and more commonly, manufacturing companies avoid setting up consolidation centers from scratch. Instead, existing companies take on the role as a consolidation center and might be located further away, which might require transportation with road trucks, according to Baudin (2004). Furthermore, companies should not need consolidation centers as plants mature (Baudin, 2004).

Adding an intermediary to the supply chain does not usually enhance the performance (Baudin, 2004). However, there might be other drivers for such logistics setups. For instance, it might be an approach to deal with the complexity of long lead times for distant suppliers or a way to manage suppliers that do not want to work with returnable containers and kanbans according to the demands of the OEM. However, these suppliers should not be viewed as long-term, but it might take time to replace the suppliers. A common reason for using a consolidation center in the automotive industry is reducing labor costs (Baudin, 2004). Baudin (2004) further explains that wages are often higher for operators than external warehouse personnel.

Consolidation centers further receive large shipments that they must break down into smaller quantities before sending the goods to the plant, which is why the consolidation center must hold substantial inventories in a warehouse, according to Baudin (2004). Also, such centers are responsible for disposing of supplier packaging, placing parts in the plant's reusable containers and delivering them. Moreover, consolidation centers should be designed to avoid multiple handling of pallets and make it error-free (Baudin, 2004).

Cross-docking

Cross-docking is a warehouse strategy with the potential of controlling logistics and distribution costs while maintaining customer service levels by moving materials directly from the receiving area to the shipping area, according to Apte and Viswanathan (2000). Thus, reductions in transportation and inventories are accomplished by minimizing the time from receiving to shipping the goods. The central principle of cross-docking is therefore moving goods through distribution centers without storing the products (Apte & Viswanathan, 2000), compared to a traditional warehouse where goods are stored in between dispatch and shipment. According to Galbreth, Hill and Handley (2008), cross-docking is, therefore, a strategy to decrease the tied-up capital in inventory.

Besides reducing the need for storing materials, cross-docking has the potential of eliminating picking, which makes up two of the most expensive operations (Galbreth et al., 2008). Apte and Viswanathan (2000) also mention that for cross-docking to work correctly, the items should be pulled out by the destination point quickly, which implies a need for a balance between incoming and outgoing goods. Therefore, a cross-dock is preferable for material with a stable and known demand rate (Galbreth et al., 2008) with low stock-out cost per unit. However, a smooth demand may not imply an increased value of having cross-docking but rather that the characteristics of the supply chain will impact the potential value of the cross-dock. Moreover, full truckload (FTL) shipments should be used when possible to enable optimizing of transportation and inventory holding costs, according to Apte and Viswanathan (2000). Furthermore, Galbreth et al. (2008) state that the demand should be considered relative to the truckload capacity.

Assembly facility

To postpone production and minimize inventories, assembly facilities might be applicable as logistics centers (Rushton et al., 2017). Such facilities can, for instance, perform activities such as kitting, testing or labeling, according to Rushton et al. (2017). However, Baudin (2004) explains that such intermediaries should not be responsible for kitting activities. One reason is the extensive information exchange needed due to the complexity of engineering changes compared to handling individual items. Moreover, picking kits should preferably be done close to the point of assembly, according to Baudin (2004). Besides allowing experienced assemblers to perform the picking, an assembly facility can replace missing or defective parts more quickly than if carried outside the plant. Also, transporting stocks of kits is not needed (Baudin, 2004), meaning an assembly facility can enhance the quality of the kits by performing picking closer to the assembly. Finally, if operating an external logistics center, such an assembly facility could perform certain pre-assembly or assembly activities.

2.1.3 Additional network node

Hanson et al. (2016) explain that external warehouses entail additional storage points and activities. However, external warehouses can reduce the handling given that transportation between the warehouse and plant can be carried out without interfering with regular traffic (Hanson et al., 2016). Increased throughput time may come with additional activities and storage could also cause reduced flexibility if the production sequence changes, according to Hanson et al. (2016). Therefore, ensuring that outsourced processes remain integrated with the business is of importance (Richards, 2014). One such example could be to operate through standard IT systems, which could support transparency between the parties, but it could also limit the potential for improvements regarding administrative processes for the external party (Hanson et al., 2016). Such aspects are essential when investigating logistics setups and which activities to perform in external logistics centers.

2.1.4 Supplier parks

Supplier parks have emerged increasingly in the automotive industry to cope with the increased demand for mass customization (Howard, Miemczyk, & Graves, 2006). A supplier park consists of clusters of suppliers located close to the production and usually carry out activities such as warehouse and inventory management, sequencing, manual assembly as well as late configuration, according to Howard et al. (2006). Thus, drivers to establish supplier parks include product mix and volume flexibility, which theoretically correspond to the concept of having an extended logistics center. Klingenberg and Boksma (2010) also discuss that supplier parks have similarities as intermediate facilities concerning material handling. Furthermore, such facilities enable just-in-time deliveries of sequential materials (Klingenberg & Boksma, 2010). Therefore, supplier parks or intermediary logistics facilities may be relevant to elaborate on in the context of extended logistics centers.

Current practices also reveal that such supplier parks usually include both commodity components, bulky parts and parts with a wide variety. However, the supplier parks may vary widely regarding location, size and the carried-out activities (Howard et al., 2006). Such setup with suppliers in close proximity further allows for just-in-time capabilities. Furthermore, Dyer (1996) explains that successive production stages should preferably be located close to economize on transport and inventory costs and improve coordination.

According to Cullen (2002), supplier parks foster long-term partnerships. However, there has also been some criticism towards supplier parks, including that it leads to a lack of supply chain flexibility (Howard et al., 2006). Dyer and Singh (1998) state that proximity also may entail knowledge sharing between different parties. Furthermore, supply chain disturbances are likely to come from disruptions in delivery (Svensson, 2000), but it is unclear if having suppliers closer to the OEM will reduce the overall disturbances (Howard et al., 2006).

2.2 Warehousing

As mentioned in the background, warehousing is associated with storing goods and a process for bridging differences in time and quantity (Hompel & Schmidt, 2007; Rushton et al., 2017) and has several other benefits that will be discussed below. The description of warehousing is in line with Ackerman (2012) stating that the warehousing functions that add value to the product and are performed in a warehouse are stockpiling to handle overflow, product mixing, consolidation and distribution, for example. However, the author also mentions that a warehouse will emphasize fast movement and facilitate change in the future instead of efficient storage, reflecting today's needs. That will practically mean that the structure in the warehouse will imitate a flow-through with employees, equipment, and layout, which prioritize flexibility (Ackerman, 2012). To implement an efficient warehouse management, a warehousing system is required, including technical structure, operational and organizational framework, and coordinating system control, according to Ackerman (2012).

2.2.1 The role of warehousing

Hompel and Schmidt (2007) states several reasons for operating warehouses in supply chains, which are brought up. The authors discuss that efficient warehouse management requires some expertise ,i.e. knowledge about the necessary processes and the optimal solutions. A benefit of warehouse management is the fact that it optimizes logistical performance by ensuring deliveries. Further, immediate fulfillment of an order can be achieved by having forecast quantities in stock. Keeping stock in a warehouse also means that distant markets become more accessible. It is also feasible for suppliers due to the variety of goods, frequent ordering, and requirements of short delivery times. If the delivery criteria are met, the company's market position will be strengthened (Hompel & Schmidt, 2007).

Further, Hompel and Schmidt (2007) mention that a warehouse can ensure productivity by keeping stocks to ensure the supply of the production level. This concept is essential for just-in-time delivery production chains, which are sensitive to disturbances due to minimized stock levels. Warehouses also provide additional services. When providing single products and various products, the assembly process is used to keep costs down, which means that the possible variants are decided as soon as possible. This activity is mainly offered at goods distribution centers (Hompel & Schmidt, 2007).

Another benefit is reducing transport costs by optimally utilizing the loading capacity and achieving fixed costs for transportation. Hompel and Schmidt (2007) state that it is less efficient to manage large amounts of small lots than the consolidated and thereby, existing capacities can be utilized more efficiently. Hompel and Schmidt (2007) further state that a warehouse can balance required and delivered quantities by enabling semi-finished products to be buffered is beneficial since companies produce in batch sizes as well, as the process times vary. This will ensure the consistent utilization of the production as well as processes. Balancing the quantities can be beneficial when there are large seasonal variations that cannot be solved by only adapting production capacity. Moreover, warehousing results in several costing problems like quantity discounts and is seen as a quantitative digression on the supplier's side and administration costs. Finally, a reason to operate warehouses is since it can include a part of the production process if the value-adding process is performed within the warehouse (Hompel & Schmidt, 2007).

2.2.2 Outsource warehousing activities

According to Skintzi, Ioannou and Prastacos (2008) and Klingenberg and Boksma (2010), companies often want to maintain control throughout operations. Despite this, companies tend not always to have the competencies required for all levels in the supply chain. Mathisson-Öjmertz and Johansson (2000) mention decreased complexity and cost efficiency as essential aspects for deciding whether to outsource the logistics function. However, the underlying assumption for cost efficiency is utilizing core competencies of the logistics provider and thereby accomplishing economies of scale (Mathisson-Öjmertz & Johansson, 2000).

Klingenberg and Boksma (2010) and Mathisson-Ojmertz and Johansson (2000) also describe the increased usage of outsourcing and explain that outsourcing often refers to relocating material handling activities. Material handling activities further indicate that an operational process occurs when performing the handling activity in the material flow and is included in the logistics function (Klingenberg & Boksma, 2010). The authors further mention that one decision approach used when outsourcing is the resource-based theory. This approach interprets the company as a set of assets and resources which must be secured and efficient to be competitive. Therefore, resource acquisitions are usually why the company decides to outsource rather than cost savings or forming relationships. Klingenberg and Boksma 2010 discuss the option to "smart source", which refers to outsourcing activities to a third party the company has a close relationship with.

Klingenberg and Boksma 2010 further mention that material handling activities, such as storing and repackaging, should be positioned pre the customer order decoupling point while kitting should be done at the point and sequencing should be positioned post or at the customer order decoupling point. However, it is stated by the authors that material handling activities can be located at the plant, at the supplier, or an external facility such as a logistics center. Based on the three cases the authors researched, it appears that companies are more likely to relocate sequencing and storing activities to an external facility than kitting (Klingenberg & Boksma, 2010). Boysen, Fliedner and Scholl (2009) also mention that the automotive industry has various ways of supplying materials. For instance, bulky parts are usually delivered near the particular line segment, whereas smaller parts are usually stacked in small load carriers (Boysen et al., 2009).

Types of warehouses
Ackerman (2012) describes three types of warehouses: private warehouse, public warehouse and contract warehouse depending on the level of user control.

The private warehouse indicates that the user is the operator and has total control over the warehouse and its processes. This type is to prefer when many goods are stored and the handling volume is constant since the private warehouse is the most economically beneficial option (Ackerman, 2012). However, in this setup, the user is responsible for all handling, management, labor disruptions and costs. Since warehousing management is required, the user is responsible to maintain the rights skills (Ackerman, 2012).

Further, the public warehouse is an independent contractor offering services to several users. This type of warehouse will mean that the public operator stores other companies' products and is, therefore, able to balance the variations as well as managing the workload (Ackerman, 2012).

Contract warehouses, on the other hand, are a combination of the previously mentioned types. Compared with the public warehouse, the difference between a contract warehouse is the long-term agreement, typically month-to-month in a public warehouse. Usually, a contract warehouse is used to perform packaging and assembly (Ackerman, 2012). The main benefit is the unique and tailored warehousing services. Besides focusing on stability and efficiency, price negotiation is required and builds on trust in the relationship, which takes time, according to Ackerman (2012).

Warehousing strategies
Warehousing is an area that companies can either manage themselves or outsource. Ackerman (2012) states that it is crucial to consider various factors when investigating which alternative to choose, i.e. whether to outsource or manage the activity by themselves. The author further states that there are advantages to carefully choosing a warehousing strategy as the strategies aim to offer different results. Further, the author states that different strategies are needed if a company wants to focus on quality or lower costs (Ackerman, 2012).

One strategy Skintzi et. al. (2008) mentions, besides outsourcing and operating themselves, is flexible outsourcing, which refers to that the manufacturer makes the investment for the warehouse and then leases it to another company. Flexible outsourcing can be a good option to outsource specific operations or gain expertise (Skintzi et al., 2008).

Parameters to consider
When deciding if the company should outsource, consideration should be given to what the company strives for and prioritizes. If the company wants to have control and improve quality, there are greater advantages in carrying out the activities in-house. On the other hand, if the company wants to become union-free, subcontracting warehousing is important. Other questions that should be considered when determining the strategy are, can suppliers exploit the company? What is the most cost-efficient alternative and would outsourcing involve less control? Is control important for these activities? (Ackerman, 2012).

Skintzi et al. (2008) further mentions other aspects to consider and describes that since managing inventories represents 20-60% of the total assets of manufacturing firms, it is essential to evaluate who will maintain the control. Most important for the manufacturing companies is to be flexible, meaning that they must have the ability to quickly respond to challenges, which is of substantial competitive advantage. One potential option to increase flexibility is to outsource the operations that are not within the company's core business. A specialized supplier in storing and managing inventories can offer cheaper and better services since they have better technology, knowledge and can take advantage of economies of scale (Skintzi et al., 2008).

Klingenberg and Boksma (2010) on the other hand, describes that cost, flexibility and delivery speed, and reliability are essential parameters to consider when outsourcing. It is crucial to consider the logistics, transport cost, personnel cost, stock holding cost, overhead, and facility costs. The second parameter is the delivery speed and reliability, which include the performance of the third party and the distance from the external facility to the company or the OEM. In contrast, a longer distance will increase the buffer size to be able to allow continuous flow. It is shown in the study by Klingenberg and Boksma (2010) that outsourcing kitting and sequencing to an external facility will increase personnel and transportation costs and will decrease the delivery speed, reliability and flexibility. While outsourcing storing activities will only affect the costs, which will increase, but no significant difference can be seen in the flexibility and reliability. Generally, an external facility located close to the factory will ensure delivery reliability due to the short distance. It will increase the logistics operating costs due to the additional non-value-adding handling at the external facility, such as unloading and loading and transportation costs.

Difficulties
If the company chooses to invest in a warehousing facility and operations, difficulties regarding determining the capacity, production, costs, the size of the production and the amount of inventory can occur. If the company instead decides to outsource some operations, the difficulties are determining the size of production and inventory released to the market and deciding the price policy. In this case, two parties want to maximize their profits (Skintzi et al., 2008).

Mathisson-Öjmertz and Johansson (2000) also explains the consequences with an intermediate facility. One consequence that could be seen in their study was the negative impact an external facility had on the efficiency of the materials handling function. Moreover, when considering the case from a packaging level, the number of activities required increased with an existing external facility and the handling operations increased. However, these parameters decreased when having an intermediate facility on a component level. Therefore, differences in efficiency are strongly related to the transportation of goods and packages rather than component handling. The result also shows that the number of non-value-adding activities and operations increases for packages when an external facility exists. It is also stated in the case study, made by Mathisson-Öjmertz and Johansson (2000), that packaging measurements such as size, number of packages, and filling degree of the material handling functions are of great importance for efficiency.

2.3 Activities to perform in logistic centres

The performance of mixed-model assemblies in the automotive industry is largely dependent on the availability of a significant number of components (Sali & Sahin, 2016; Wänström & Medbo, 2008). Johansson and Medbo (2004) also recognize the increased number of product variants constraining the space at the assembly stations, emphasizing the importance of material supply systems. The three primary modes used for feeding material to assembly lines are batch supply, continuous supply and kitting (Johansson, 1991). Johansson, Bellgran and Johansson (2006) also mention sequencing as an additional material feeding principle. However, this section elaborates on storing, kitting, sequencing and pre-assembly as potential activities that an extended logistics center can perform.

2.3.1 Storing

Inventory refers to storing items used in production to support various manufacturing activities, such as raw materials or work-in-process materials or not completed materials (Shenoy & Rosas, 2018). In this case, storing refers to, as previously mentioned in section 1.1.5, storing full pallet loads containing only one part number. These pallets are stored and later distributed to various material handling processes such as kitting, sequencing, pre-assembly or assembly line (Jonsson & Mattsson, 2016).

There are several reasons why companies choose to hold inventories in their production unit but primarily to ensure that required items are available for production at the right time and quantity. However, the quantity of items held in an inventory depends on the characteristics of the items such as demand, replenishment lead time, inventory level, lifetime and reparability (Shenoy & Rosas, 2018).

According to Roy, Carrano, Pazour and Gupta (2016), pallets are essential in handling and transporting products in the supply chain, which can be between suppliers and manufacturers. The solution with handling products in pallets has provided efficient and standardized material handling since they are most commonly used worldwide. Kulwiec (2004) further states that a full pallet load operation is seen as the easiest and cost-efficient option that involves receiving incoming loads and managing outgoing orders by re-routing the loads into outgoing trucks.

2.3.2 Kitting

Bozer and McGinnis (1992) define kits as collections of components and/or subassemblies that support the assembly processes for a given product. Thus, picking of kits means that operators must retrieve several items. The component variants are further sorted into containers and presented into single packages (Fager, 2018) and delivered to the point of consumption for a specific assembly object (Sali et al., 2015), as seen in Figure 2.1. Hence, kits commonly consist of different part numbers, picked for supporting the pre-assembly or assembly. Also, the kitting process can either be performed centrally or decentrally, which implies differing distances to the assembly stations (Brynzér & Johansson, 1995).

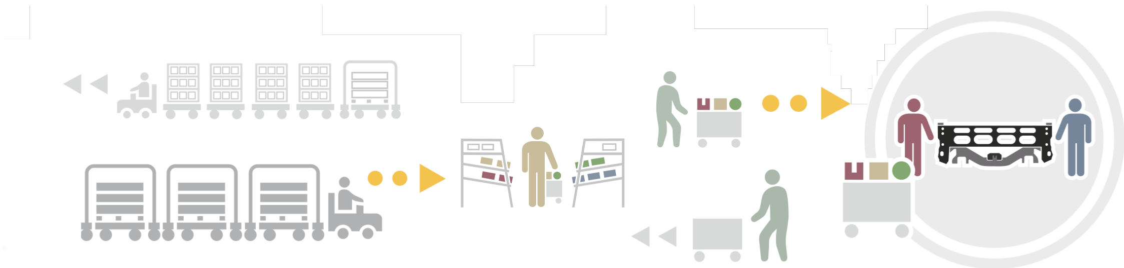

Figure 2.1: Principled kitting activity

Kitting can bring several potential advantages to a manufacturing organization. By providing only parts needed for specific assembly objects, kitting allows for space savings at the assembly line (Hanson & Brolin, 2013; Sali et al., 2015; Wänström & Medbo, 2008) and reduce work-in-process at workstations since components can be stored and pre-assembled upstream (Bozer & McGinnis, 1992). Product changeovers are also relatively easy to perform with kitting, as well as routing control and flexibility of kit containers in the assembly system, according to Bozer and McGinnis (1992). Kits are further commonly used for managing high diversity in products (Fager, 2018) for relatively small components (Sali et al., 2015). Other potential advantages with kitting include improving product quality and productivity at assembly stations due to part availability (Bozer & McGinnis, 1992). Furthermore, kitting can either be performed by pickers or assemblers (Brynzér & Johansson, 1995). However, there are several potential advantages of including kitting into the job of the assembler. Brynzér and Johansson (1995) mention higher picking accuracy and job enlargement as important reasons for such considerations. Assemblers' higher accuracy in kit picking is likely since they are familiar with which items to include in kits (Hanson & Brolin, 2013).

However, there are also multiple potential limitations with kitting. Bozer and McGinnis (1992) mention that kit assembly is relatively time-consuming with limited value-adding to the product. Fager (2018) adds that such material preparation is often performed by manual labor and might be repetitive. Despite saving space at the assembly line, kitting likely increases the overall storage requirements when kits are prepared in advance (Bozer & McGinnis, 1992), which was further found in the study by Hanson and Brolin (2013). The study also concluded that the overall man-hour consumption increased when kitting was implemented since requiring a kit assembly process before the assembly operations (Hanson & Brolin, 2013). As mentioned above, kitting has the potential of improving the quality of end-products. However, the incorrect kit content can cause production delays and poor product quality (Fager et al., 2014). Bozer and McGinnis (1992) add that temporary component shortages or defective parts could force assembly operators to use parts from other kits, which causes severe quality issues and double handling.

2.3.3 Sequencing

The basic principle of performing sequencing is the same as kitting. Fujimoto (1999) explains that sequencing means that sequenced materials are supplied in the same order as the product sequence at the assembly line, as seen in Figure 2.2. Thus, sequencing of materials includes preparing and delivering components needed for assembly processes in a predetermined order (Svensson, 2006). The arrangement of sequenced materials can either be performed by an OEM, suppliers or a third party (Johansson & Medbo, 2004), but a nearby location will shorten the lead time (Mathisson-Öjmertz & Johansson, 2000). Limited space at the assembly and insufficient service levels may drive OEMs to let suppliers be responsible for the sequencing, according to Mathisson-Öjmertz and Johansson (2000). However, Baudin (2004) explains that such a setup requires more deliveries and increased information exchange between buyer and seller.

Figure 2.2: Principled sequencing activity

Sequencing requires fewer components being displayed (Johansson & Medbo, 2004), which enables space savings at the assembly line and supports product diversity (Sali et al., 2015). Instead of sorting several part families for a specific assembly product, sequencing entails sorting one part family for assembly objects (Fager, 2018). Similarly to kitting, the material is prepared upstream and delivered to the point of consumption, which supports the assemblers at the workstations by reducing decision making and the risk of picking the incorrect item, according to Sali et al. (2015). Hence, sequencing allows for less space consumption and facilitates improved quality of end-products. Svensson (2006) adds that sequencing, therefore, supports producing customized products while maintaining economies of scale.

According to Sali et al. (2015) and Wänström and Medbo (2008), sequencing is preferred for bulky and voluminous components with high diversity, meaning a high number of variants per component. Additional material handling and preparation is further required for sequencing, which requires substantial resources, i.e. labor and space (Fager, 2018). However, Fager (2018) also mentions that errors in the material preparation process can have considerable negative impacts on the production system and the product quality it produces, in similarity with kitting. In addition, Wänström and Medbo (2008) acknowledge sequencing as having the potential to result in more handling and more problems if the production sequence is disrupted. Thus, sequencing material according to the production sequence may limit the flexibility.

2.3.4 Pre-assembly

Gibb and Isack (2003) define pre-assembly as a strategy where prefabrication of parts occurs before manufacturing the components onto the main product, i.e. the installation of various parts into one occurs before their final position. This activity was implemented to improve construction and includes modular building and volumetric and non-volumetric pre-assembly and component manufacture or subassembly (small scale sub-assemblies). Both the volumetric and non-volumetric pre-assembly items are assembled on-site before being manufactured in their final position. The main difference is that volumetric items enclose usable space.

The main drivers for performing pre-assembly are cost, productivity, quality and time benefits and reduction of duration, congestion, and improved safety (Gibb & Isack, 2003). The authors further state that these were also the most frequently mentioned categories when discussing the benefits of pre-assemblies when interviewing clients since pre-assemblies brought the construction to the factories, which is in line with Gibb (2001) statement. By having it on-site, the waste and environmental impact decrease as well. If the pre-assembly occurs off-site, it is essential to get the opportunity to be able to freeze the design in an early stage, have sufficient lead times, and give time for prototyping. However, Gibb and Isack (2003) state in their study that quality is a recurrent problem when the pre-assembly occurs off-site.

In the article by Gibb (2001), the author discusses the cost of pre-assembly and states a decrease in costs when performing pre-assembly if considering the entire manufacturing process since it will enable, for example, reduction of site labor and associated costs. However, it can be seen as very expensive to have pre-assembly in the factory, at least in the short-term, due to the overheads and setup costs. It is then essential to analyze the costs in the long-term since it will be seen that the increased productivity and quality will bring cost savings and economies of scale (Gibb, 2001).

2.4 Secondary feeder line

As previously mentioned, the desire for improved flexibility and efficiency has driven the development towards mixed-model assembly lines (Azzi, Battini, Faccio, & Persona, 2012). The automotive industry has also experienced an increase in variants. Therefore, the number of required part numbers in assembly plants has increased, which further has severe impacts on inventory levels to assure part availability (Howard, Miemczyk, & Graves, 2006), leading to multi-line systems being utilized (Azzi et al., 2012). A multi-line system implies that some components are assembled in secondary lines, referred to as feeder lines, connected to the assembly line through pull signals (Azzi et al., 2012; Boysen et al., 2009), as suggested in Figure 2.3 below.

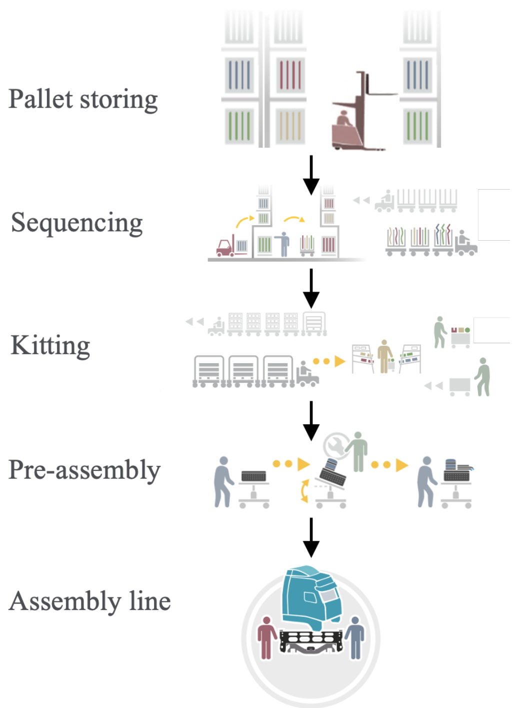

Figure 2.3: Secondary feeder line concept with logistics activities

Moreover, according to Boysen et al. (2009), components that are pre-assembled in-house usually supply the final assembly through such feeder lines. The principle of feeder lines is considered to correspond to manufacturing according to a ”manufacturing fishbone”, as stated by Volvo Trucks, which shortens the length of the final assembly line and supplies the correct materials.

2.5 Logistics performance variables

There are various aspects to take into consideration when making decisions related to logistics. In addition, it is not unusual that such decisions come with several trade-offs, meaning that optimal solutions from every point of view are nearly impossible. This study evaluates options based on cost, flexibility and quality, which are described in depth. An ergonomics perspective is also brought up briefly.

2.5.1 Cost

This section focuses on warehousing, transportation, inventory and handling costs since these can be considered when determining the preferred logistics setup. Moreover, a cost-minimization approach is described.

Warehousing costs
According to Min (2009) and Rushton et al. (2017), warehousing costs are an essential part of a company's business expenditures since it often stands for 20-30% of the logistics costs. This statement explains why many companies choose to improve their warehousing productivity and control the warehousing costs. Min (2009) argues that a warehousing decision support system will enhance productivity and visibility in the warehouse, which could be of great importance but will require a high amount of data collection. Both Min (2009) and Aminoff, Kettunen, and Pajunen-Muhonen (2002) states that warehousing costs include labor costs, material handling costs, costs for equipment like IT systems, trucks, storage equipment. Further, inventory carrying costs, costs for the building and building services and taxes, and costs for performing value-added work are included.

The primary operations Aminoff et al. (2002) mentions, carried out in a warehouse, are unloading, receiving, shelving, stocktaking, transferring, storage, picking, packaging, shipping, and loading. Rushton et al. (2017) also mentions that space releasing and efficiency in order picking are essential factors to improve to become more efficient. Moreover, the two main cost drivers are labor costs which represent 56% of total warehousing costs, and building which stands for 22%. On the other hand, the most expensive operations are stated to be picking and packaging together with shipping (Aminoff et al., 2002). Therefore, to improve cost efficiency, the first targets to improve work efficiency and space utilization in picking, packaging, and shipping. Improving cost efficiency could be done by changing the order structure, enlarging picking lot size, minimizing the picking time, for example, automation, determining the optimal working methods, and making efficient use of receiving and shipping area Aminoff et al. (2002).

Transportation and inventory costs
Burns, Hall, Blumenfeld and Daganzo (1985) describe the two strategies in the distribution phase: direct shipping and milk-runs, which are analyzed to minimize both transportation and inventory costs. Distribution can take place by truck either by direct shipping, meaning shipping separate loads directly to each customer by utilizing the concept of milk-runs, which indicates that trucks deliver goods to more than one customer per load. Transportation cost, however, considers all costs connected to transportation of goods between suppliers and factories. Further, the transportation costs includes mainly the route of the vehicle, truck operating costs, shipment frequency, truck capacity, shipment size, transportation cost per mile and

transportation distance (Burns et al., 1985).

Inventory refers to products waiting to be shipped or used. Burns et al. (1985) state that inventory costs are closely related to shipment size, carrying charge, number of items delivered and the time between production and point of use . Variables that affect both inventory costs and transportation costs are customer demand, customer density and value of items (Burns et al., 1985). Moreover, Aminoff et al. (2002) state that minimizing costs can be done by improving the work efficiency measured in minutes per in-and-outgoing material and improving space utilization changing the layout, for example.

Minimizing transportation and inventory costs

The measurements stated above for each cost aspect can be minimized by coordinating the production and transportation produced in batches. This by analyzing the optimal shipment size and evaluating the trade-off that occurs since large-item loads reduce the transportation cost but increase the inventory costs (Burns et al., 1985).

Burns et al. (1985) further state that, when producing a fixed number of items, the direct shipping costs will increase in distribution to several customers. This means that if the suppliers deliver items to many small customers, it is better to use the milk-run alternative to minimize the costs. Milk-runs is preferred when customers demand small quantities of high-value products. Another alternative could be to coordinate the transportation to reduce the number of empty returns (Burns et al., 1985).

Other authors discussing this topic are Swenseth and Godfrey (2002), who believe that approximately 50% of the total annual logistics cost of a product can be tracked to transportation. They, therefore, mean that one should consider the transportation cost when determining the purchase quantities. The authors state that the costs can be improved by negotiating acceptable freight rates (Swenseth & Godfrey, 2002). Laine (1979) also states that the transportation costs decrease with the number of suppliers, i.e. the more suppliers, the higher cost. This also describes why companies strive to minimize the distance to the suppliers.

Handling costs

When focusing on the handling costs in a warehouse, the main costs included are labor costs, operating costs, maintenance costs, services and handling equipment such as pallets and forklifts. Ashayeri and Gelders (1985) further state that using pallet racks is better in cost aspects since improved space utilization and decreases investment costs. Jeganathan and Naveenkumar (2018) also state that approximately 25% of the manufacturing costs are linked to material handling.

Jeganathan and Naveenkumar (2018) further state that material handling is defined as movement, storage, control, protection of material and distribution. This is often linked with production and manufacturing flows which indirectly means that transit time, resource usage and service levels are influential measurements to consider. Material handling is also one crucial measurement to consider when determining supply chain efficiency. Efficiency, in this case, means having the correct number of the right product to the right destination at the right time (Daehy, Krishnan, Alsaadi, & Alghamdi, 2019). Therefore, it is vital to effectively design these activities from a cost perspective and since a lack in material handling leads to an imbalance in production flows and, therefore, extra stocks and long transit times (Jeganathan & Naveenkumar, 2018).

Minimizing handling costs
Furthermore, there are huge opportunities for reducing costs by labor reduction and improving productivity if a company decides to use technology in material handling. It will enhance both speed and the throughput of material, according to Jeganathan and Naveenkumar (2018). Williams (1972) also states that it is essential to consider handling costs when performing a cost minimization since it has more potential than, for example, production processes when it comes to reducing costs. The author further describes that the materials handling costs can generally be divided into labor, equipment and space costs. However, when determining whether it will be advantageous to use a warehouse option or a third-party logistic provider, it is also essential to consider the various warehousing activities such as unloading, storage, transferring, order-assembly, order-picking, control, services, returns, as well as equipment maintenance. It is also essential to know that the performance may be measured in throughput of goods i.e. measured in weight, volume or number of packages (Williams, 1972).

Another aspect Skjoett-Larsen (2000) brings up is that material handling performed by a third-party logistic company is described to be cost-efficient and creates a competitive advantage due to the increased flexibility, service and efficient operations. However, aspects mentioned in section 2.2.2 are essential to consider when determining the location of the activity. Moreover, it is beneficial to use an external warehouse in cases where warehousing demand fluctuates since the company exclusively pays for the actual use of space and not a fixed cost. Daehy et al. (2019) also explains that time-sensitive products and products requiring specific handling methods that can be costly and time-consuming if performed externally. Also, the authors describe that outsourcing can be seen as a valuable and cost-efficient strategy due to the competitive advantages, including reduction of costs in times when disruptions occur and enable the company to focus on their core activities, product quality and customer service. Daehy et al. (2019) also encourage designing a robust design optimization method that is a method for cost-savings and will decrease uncertainties by reducing the system's variation and increasing the robustness.

2.5.2 Manufacturing flexibility

The environment in which manufacturing firms previously operated was characterized by stability, less variety in products and longer lead times, according to Beach, Muhlemann, Price, Paterson and Sharp (2000). Jain, Jain, Chan and Singh (2013) also mentions that current firms are operating in uncertain and changing environments. Moreover, increased customization, product variety and shorter life cycles and delivery times impact the industry (Jain et al., 2013). Therefore, manufacturing flexibility is becoming an increasingly important strategic objective (Beach et al., 2000) and a critical component for manufacturing companies in their attempts of achieving competitive advantages in uncertain environments (Jain et al., 2013). Therefore, flexibility is closely related to a manufacturing firm's survival (Patel, 2011). Flexibility further entails responsiveness to internal and external disturbances, according to Jain et al. (2013). Moreover, there are various definitions regarding manufacturing flexibility (Beach et al., 2000), as well as several dimensions to the concept that are used interchangeably (Jain et al., 2013), since there is no agreement regarding a general definition (Saleh et al., 2009; Upton, 1994).

The literature covers several flexibility aspects, such as mix, volume, material handling flexibility (Jain et al., 2013) and sequence flexibility (Beach et al., 2000). Jain et al. (2013) further mention demand as the largest source of uncertainty, meaning volume and product mix. Koste and Malhotra (1999) define mix flexibility as the variety of products that manufacturers can produce without changes in performance outcomes or high transition penalties. Thus, a broad product line is facilitated by mix flexibility (Upton, 1994) and the heterogeneity of the products provide insights into the range of mix flexibility (Koste & Malhotra, 1999).

Furthermore, volume flexibility implicates manufacturing systems being able to operate at different overall output levels while being profitable (Sethi & Sethi, 1990; Upton, 1994). In addition, Sethi & Sethi (1990) also describe material handling flexibility as the system's flexibility to move different part types efficiently for proper processing and positioning in the manufacturing facility. Gerwin (1987) further explains that sequence flexibility arises when dealing with uncertain delivery times of raw materials. In summary, manufacturing flexibility may be viewed as an organization's capability to responsively address internal or external uncertainties and disturbances (Jain et al., 2013) with minimal penalty regarding aspects of time, effort and performance (Upton, 1994).

Furthermore, the ability to respond to changes needed in the material preparation arising from changes in the production system corresponds to flexibility in the materials preparation process (Fager, 2018). This aspect is increasingly important as the lead time in the logistics system changes when considering an external logistics center.

2.5.3 Quality

The quality of a product is the ability to satisfy a customer's needs, expectations and requirements, implying the importance of exceeding demands (Bergman & Klefsjö, 2010; Skärvad & Olsson, 2015). Thus, high product quality primarily impacts end customers and should meet their requirements in terms of the performance, price and function of products (Bauer, Duffy, & Westcott, 2006). Satisfied customers are critical since entailing financial benefits through increased sales and long-term relationships with customers (Ax, Johansson, & Kullvén, 2015). Moreover, the quality of the production system refers both to product quality, as mentioned above, and process quality, according to Skärvad and Olsson (2015). Process quality implies the manufacturing concerning scrapping, repairs or interruptions in the production (Skärvad & Olsson, 2015). Finally, Bergman and Klefsjö (2010) state that increased market share, rapid development of products and lower internal costs are possible effects of companies' quality and quality improvement work.

As mentioned above, high product quality with few defects can imply increased customer satisfaction and loyalty (Jahanshahi, Gashti, Mirdamadi, Nawaser, & Khaksar, 2011), which likely entails fewer customer complaints (Bauer et al., 2006). However, poor product quality may have the opposite effect for companies and imply further costs. Cheah and Shah (2011) state that the cost of quality comprises two primary components; the cost of conformance and the cost of non-conformance. The cost of conformance includes prevention and appraisal costs, i.e. expenses of preventing defects from occurring and evaluating product quality. Furthermore, the cost of non-conformance includes costs related to a failure to meet customer requirements (Cheah & Shah, 2011).

Moreover, Bergman and Klefsjö (2010) state that traditional costs are relatively simple to detect and only constitute a small share of the total quality deficiency costs. Therefore, Sörqvist (2001) adds hidden costs, lost revenue and costs for customers to show the complexity of the matter. Moreover, Skärvad and Olsson (2015) state that the cost for quality deficiencies for manufacturing companies can amount to 25% of the revenue. Similarly, Cheah and Shah (2011) conclude that most quality costs are hidden and more significant than those easily measured. Even though not all quality issues reach the customer, such savings potential further highlights the importance of working with quality.

The distance and lead time from where processes are carried out to the use point plays an essential role for quality. Baudin (2004) explains that it is easier to replace missing or defective items when performing activities within the plant, which has implications of less transportation due to the proximity of the materials available nearby the assembly point. Furthermore, Fager (2018) explains that operators must resolve errors detected at the assembly line before assembly can continue. Usually, such errors require some effort to correct, which is why they can be solved and avoided if the material preparation workspace is close to the point of assembly (Fager, 2018). However, quality adjustment costs will arise when such problems cannot be solved immediately, according to Fager (2018). Thus, response times that exceed the cycle time of the process will constitute a challenge, which is vital to consider when determining the location of certain logistics activities.

2.5.4 Ergonomics

High-quality products where assembly tasks in the manufacturing are performed manually are usually characterized by highly repetitive movements, high physical demands and high work pace (Trzcielinski & Karowowski, 2012), which emphasizes the need for ensuring a healthy and safe working environment for employees. Thus, ergonomics becomes important. Furthermore, Trzcielinski and Karowowski (2012) define ergonomics as a scientific discipline trying to understand the interactions between humans and other elements of a system for optimizing human well-being and overall system performance. Hence, the design of the man-machine system should minimize stress, boredom and fatigue while maximizing physical safety (Rohmert, 1985). Falck, Örtengren and Högberg (2010) describe that biomechanical simulations are commonly used in the automotive industry for evaluating physical workload to detect ergonomics risks. In contexts of such assembly environments with shorter cycle times and continuous improvements, the design of manual work and risk preventions are handled through ergonomics (Trzcielinski & Karowowski, 2012).

Moreover, researchers have identified a correlation between ergonomics and product quality. Falck et al. (2010) explain that poor conditions regarding ergonomics may cause quality deficiencies, which implies increased production costs. There are several dimensions in the concept of ergonomics. Weight is one common ergonomics requirement which implies that lifting tools are needed when the weight of an item exceeds a threshold (Falck et al., 2010).

3 Methodology

This section aims to describe the methods used for answering the research questions of the report. The methodology section includes a description of the research strategy and data collection, including qualitative and quantitative methods, data analysis, and research quality.

3.1 Research strategy

As described by Trochim, Donnelly, and Arora (2016) and Creswell (2009), a research design is used to both structure the research and to illustrate how different parts interact to address the core problem statements. Schell (1992) and Berg (2009) state that a case study attempts to investigate an event and is perceived as flexible since researchers can retain the holistic characteristics of actual events, although empirical events are investigated which will be described in section 3.1.1. Case studies also provide researchers with opportunities to investigate an area or problem in-depth to describe the case, according to Bell and Waters (2018). The case study approach further attempts to identify standard and unique features of organizations or processes and how they interact, which affects the possible degree of generalization (Bell & Waters, 2018). According to Berg (2009), a descriptive case study requires a descriptive theory before the data collection. Therefore, the analysis and research questions are determined before the data collection, consistent with the strategy of Berg (2009).

Further, this research is abductive, which implies a combination of induction and deduction, i.e. both empirical and theoretical research is used during the study adopting a realistic perspective. This is since the study includes both interviews created to understand a particular setup with a person's observations and experiences and direct observations made by the researchers. This data was also complemented with numerical data provided by Volvo Group. The data collection was then analyzed and supplemented with a relevant theoretical framework to conclude.

Figure 3.1 below shows which methods are used for the separate research questions and what the questions include.

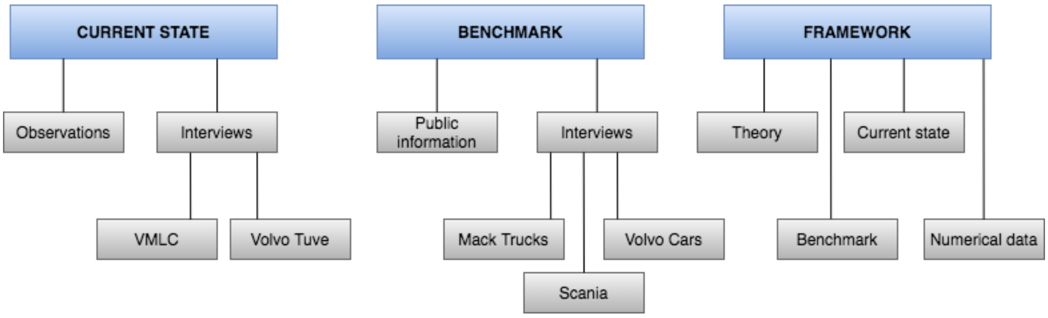

Figure 3.1: Various methods used to answer the separate research questions and the companies interviewed

Mapping the current state, as a part of answering RQ1, means that a map is conducted of the various activities performed at the Volvo Tuve plant and VMLC. This information is mainly gathered through observations and interviews.

A benchmark is carried out for answering RQ2 to compare Mack Trucks, Scania and Volvo Car Corporation logistics setup. The benchmark is performed by interviewing people from the different organizations and through public information and interviews. The benchmark will further be analysed in section 6.1.

Finally, answering RQ3 implicates giving generic recommendations for the placement of the activities based on theory, numerical data from Volvo Group, interviews, and information from the benchmark. The parameters in the decision trees are described in section 6.2. Further, the framework in section 7 is also based on the cost analysis described in section 6.3.

3.1.1 Case study at Volvo Group

The case study research design is considered applicable to the case of Volvo Group because the research questions are based on current problems at the company, which the study looks further into and investigates. As described in section 3.1, the structure of a case study includes questions defined within the scope of the organization and its boundaries. This statement is in line with the statements of Schell (1992) and Noor (2008) regarding that a case study is a strategic methodology that investigates a real-life event where the boundaries between phenomenon and context are not evident. The description of a case study agrees well with the format and structure of this study as an investigation will be made at a real-life event, i.e. at a realistic company and where questions are defined within the scope the organization. However, this research is relevant and partly applicable to other automotive industry businesses since generic recommendations are presented.

The main locations of the case study are Volvo Groups' headquarter in Gothenburg and the Volvo Tuve Plant for investigating Volvo Group's current state and suggest potential improvements. The Tuve factory is the primary location because the suggestions are mainly based on the Tuve factory. This case study provides the opportunity to work closely with relevant employees to provide them the opportunity to share their expertise and participate in interviews. Also, this gives the researchers the ability to observe the investigated environment. Information about the material flow through the logistics centers and the Volvo Tuve plant, i.e. the current setup, what types of processes are performed at the separate locations, information about possible improvements and suggestions on the location for various material and activities, are collected through interviews, observations and retrieved data from Volvo Group.

3.1.2 The four steps of the research

The research was conducted in four steps: investigating the area through literature, mapping the current state at the Volvo Tuve Plant and the VMLC, performing a benchmark with companies in the same industry (Mack Trucks, Scania and Volvo Car Corporation) to investigate their logistics setup, strategies and challenges. Finally the last step was to give guidelines and recommendations for future setup.

The first step included getting a better knowledge of the company and understanding the aim and background of this project. A planning report was performed to decide the structure, aim, research questions and methodology of the study, which brings up the importance of conceptualization to ensure that everyone has the same vision (Berg, 2009). It is essential to get an overview of the current state and problems to state a scope and research questions. The research questions were based on the company's request and adapted to the university format requirements and the interest of the researchers. The next step was to investigate the theory and literature of the topic which included logistics centers, warehousing, activities (e.g. kitting, sequencing and storing), performance variables and the suggested location of the activities. The execution of the literature review is described in section 3.2.3 below.

The next step was to make some observations and prepare interview questions. Further, interview questions were formed to map the current state at the Volvo Tuve plant to understand the location of the various activities. Furthermore, the next step was to find companies in the same industry to benchmark, contact them and prepare interview questions regarding their logistics setup, what activities they have internally in the plant and what they have in their logistics center and discuss their challenges, while in parallel start looking into the public information available about the companies.

After performing the interviews, which were the basis for the benchmark, the final step was to, concerning flexibility, quality, cost and characteristics of the material, provide a framework containing a prioritization of the location for the logistics activities. The development of the framework required perspectives and opinions from experts within the Volvo Group and cost data. Then a period of analysis and discussion was performed to be able to come to the conclusions.

3.2 Data collection

This part further explains the process of the data collection and the various methods used to gather scientific data. The described methods are complementary to each other to get an insightful and realistic picture of the setting. Qualitative and quantitative data are discussed, followed by the literature review, interviews, observation, and the benchmark process.

3.2.1 Quantitative research method

In this study, numerical data was provided through Excel and was further analyzed to reach the final stage, i.e. the recommendations. Bell and Waters (2018) also bring up some advantages with quantitative research methods, including objectivity and generalizability and the possibility of performing statistical tests. According to Bryman and Bell (2015), this type of research method is seen as a distinctive strategy and is including numerical data. A quantitative method is rarely found in a pure form but is often complimented. The authors also mention that this type of method often contains concepts like variables and related measurements. However, disadvantages include the research being highly dependent on the chosen tool, which makes it difficult to establish causality (Bell & Waters, 2018). Therefore the case study is complemented with interviews to include personal experiences.

3.2.2 Qualitative research method

Unlike the previous method, a qualitative method is expressed in words rather than numbers which in this case is interviews and observations. This method often has an inductive view of the relationship between research and theory and stresses the understanding of the social world by examining the participants' interpretation. Finally, the fact that social properties are a result of interactions between people (Bryman & Bell, 2015). There are several advantages and disadvantages with qualitative research methods. Some advantages, mentioned by Bell and Waters (2018), including limiting the research to few participants, allowing for using an 'insider' perspective and that the focus of the study can be adjusted if needed.

3.2.3 Literature review

A literature review was performed to increase the understanding of the research topic to be able to answer the research questions and provide recommendations. The literature study was the basis for the theoretical framework in section 2 which includes information about the different flows and processes (e.g. kitting, sequencing and storing), logistics centers, warehousing and the parameters flexibility, quality and cost, as well as definitions of the performance measures. Other topics to investigate were information and methods about how to prioritize when process positioning. A vast majority of the data collection in the literature study was done at the beginning of the project to get a fundamental understanding, despite continuing during the project since other areas needed to be addressed later in the process.

The data collection was mainly done through databases including the online library provided by the Chalmers University of Technology and "Google Scholar" to find relevant articles. Also, material from courses at the Technology Management and Economics department was used. Another information source used is Volvo Group's internal database, which provided information about the current logistics setup and various activities.

3.2.4 Interviews

For this project, semi-structured interviews were used for gathering detailed information about the VMLC, other companies' logistics setups and Volvo Tuve's current logistics setup. According to Bryman and Bell (2015), a case study like this often favors a qualitative data collection and research method like, for example, interviews and observations since being effective when collecting detailed data and getting a deep understanding. However, interviews provide essential information but only by revealing the interviewee's perception (Bell & Waters, 2018). Moreover, semi-structured interviews, as used in this case, includes guiding questions that can be supplemented with additional questions to get a deeper understanding of the problem or the case, enhancing the flexibility of the interview (Wilson, 2012). The interviews were held with different relevant actors with knowledge about the current and future logistics setup.

The first interview was held with a global logistics specialist at Volvo Group to understand the current state and the storage processes. The duration of the interview was about 30 min. The duration of the second interview with a logistics manager from Volvo Group was also approximately 30 min. The aim was to further understand the logistics processes internally at Volvo Group. Finally, the last interview, connected to the current state, was held with an employee working at a third-party logistics company operating the VMLC and the duration was approximately 30 min as well.

Other companies were also interviewed to understand their logistics setup. Moreover, interviews were held when conducting the benchmark. The roles of the interviewees and duration of the meetings are further described in section 3.2.6.

3.2.5 Observations

Observations were used to create a better understanding of activities performed in the Volvo Tuve plant and VMLC, including storing, kitting and sequencing, and gaining an understanding that should form the basis for the recommendations about the optimal location for the activities. Bell and Waters (2018) states that observations are a widely used as a research method to collect data by observing the surroundings. An approach for structured observations could be adopted, meaning that certain potentially relevant variables for the study are determined beforehand (Bell & Waters, 2018).

However, observations were mainly used to investigate the current state and determine what types of kitting and sequencing areas the data analysis in Excel can be based on. The considered material was determined together with engineers from Volvo Group and by observing various areas to find large and bulky parts that demand significant space. The observations are performed to complement the interviews to identify current problems and non-optimal solutions at the Volvo Tuve plant. Moreover, by observing the environment, improvement solutions could be identified, as described by Bell and Waters (2018), arguing that observations can reveal information that otherwise would have been impossible to discover. Therefore, observations can confirm detailed data e.g. from interviews. Other benefits mentioned with observations are direct access, the possibility to deeply understand the environment and flexibility (Dudovskiy, 2018). However, there are important ethical issues to consider, such as fully informed consent of research participants (Dudovskiy, 2018). Also, people tend to filter information gotten from observations, making it essential to consider possible biases (Bell & Waters, 2018). Biases or misinterpretations in this study are further minimized involving multiple observers.

3.2.6 Benchmarking

The benchmark was conducted by comparing the logistics setup of Volvo Group and other similar companies within the industry, in this case, Mack Trucks, Scania and Volvo Car Corporation. A benchmark was performed since it is described in the literature as an essential approach for improving processes within companies (Bergman & Klefsjö, 2010). As stated by the authors, the basic idea is to carefully compare the internal processes with other processes to find possible improvements and the best working method, according to Bergman and Klefsjö (2010).

Furthermore, the benchmark was performed through online interviews to understand other companies' logistics setup and the reason behind the locations of various activities. Therefore, the questions addressed the background of the logistics setups, activities performed in the logistics centers, advantages and disadvantages with the companies current setup, performance measurements and learnings. Bergman and Klefsjö (2010) state that process improvements can either be incremental or radical, implying small adjustments or complete changes. Understanding the particular processes is highly critical and mapping the activities in terms of flow charts is a suggested working method (Bergman & Klefsjö, 2010). It is essential to understand that benchmarking is not performed to copy another company and their setup but rather to reflect on why the solutions worked and gave good results in the compared business or context and benefit from reflecting on how to use it in their own business.

The first benchmark was conducted with Mack Trucks (Lehigh Valley Operations, LVO), which is considered an internal benchmark since being a part of Volvo Group. The initial interview was held with a business process developer at Volvo Group and later, a follow-up interview was held. The duration was approximately 60 min respectively 30 min. The second benchmark was held with two employees from Scania, responsible for the logistics center in Södertälje, respectively Oskarshamn, with the roles of manager logistics engineers. The interview was held for 60 min. Finally, the Volvo Car Corporation benchmark was held with a material handling engineer with a global role for about 60 min.

3.2.7 Secondary data

Secondary data refers to data collected by someone that is not the primary user, i.e. if the data is collected with another purpose than for the specific analysis and therefore collected through primary sources (Church, 2002). In this study, secondary data refers to data provided by Volvo Group, such as their internal databases and former projects related to this study. Also, numerical data provided by Volvo Group was used as a basis for the recommendations. This data complemented the interviews and observations and gave information including weight, volume, and size of a part, the number of part number in a part family, frequency, and information about the pallet area. By using Excel, the researchers tested the numbers and parts to draw conclusions based on the data. Further, as stated by Church (2002), secondary data makes it possible for other individuals to use the available and already existing data for other research projects where the data is essential. Secondary data is mainly associated with published data but can also refer to primary archived data (Church, 2002).

3.3 Data analysis

Various information-gathering methods were carried out including interviews, observations, and data analysis, as previously mentioned. The differentiation was done to answer all research questions and strengthen the credibility of the recommendations. However, different methods were applied for different questions depending on the type and extent of the answer. The first interview, for example, only focused on understanding the current state of the Volvo Tuve plant while the benchmarking interviews focused on gathering information about the comparison company's setup. Observations were further used for the current state map to determine relevant kitting and sequencing areas to analyze. Finally, the data analysis through Excel was used as a basis for the recommendation and data from the interviews and the theoretical framework to give a generic framework. An overview of the methods that was used for the various questions is illustrated in Figure 3.1.

3.4 Research quality

This section reflects the quality of the study, including the data collection. According to Heale and Twycross (2015), the quality of a research can be measured based on validity and reliability. These measurements refer to the extent to which the researchers worked to strengthen the quality. These two measurements will be described in this section.

3.4.1 Reliability

Reliability is a measure that indicates the extent to which the outcome of the study would be the same if the study would be repeated in the same situation, i.e. the consistency of a study. There is no exact calculation of reliability. However, reliability can be measured based on the following attributes: homogeneity, referring to the extent to which all the items measure one construct, stability, referring to how the measure is affected over time, and equivalence, which indicates the consistency among responses of multiple users of an instrument (Heale & Twycross, 2015). Since this study used a qualitative research method, external reliability was challenging to achieve since it is impossible to stop a social setting that is constantly changing (Bryman & Bell, 2015). However, Bryman and Bell (2015) suggest that a researcher replicating the study should adopt a similar social role as the original researcher to achieve external reliability. The reliability is, however, strengthen by using quantitative methods such as data for parts. High reliability increases the probability that the result will be the same in a repeated study.

3.4.2 Validity

Heale and Twycross (2015) state that validity is a concept measuring the accuracy of a study. Validity indicates that the measure or result must be associated with the concept and accurate for the research topic. If this is not fulfilled, the study will become inconsequential.

For qualitative research, Bryman and Bell (2015) argue that internal validity is seen as strength due to social life participation, allowing the researchers to ensure the congruence between concepts and observations. However, external validity is seen as more problematic since using case studies. The authors further suggest trustworthiness and authenticity as possible criteria to evaluate qualitative research (Bryman & Bell, 2015).

The credibility of this study increased since the study was performed at a case company, meaning that it was based on reality which also assured that the study could be performed in reality. A case study also means that actual data was used for the recommendations and not data based on assumptions and template numbers. Also, the benchmark and interviews were based on several sources, increasing the credibility. Both reliability and validity were considered when the collected data was evaluated from the study. However, the consistency could be affected since the data, for this study, will be collected through interviews.

4
Current state

This chapter describes the current state at Volvo Tuve and VMLC. Hence, chapter 4 aims to answer RQ1. Section 4.1 describes the processes from Volvo Group's point of view, followed by a description of the processes at the Volvo Tuve plant and VMLC in sections 4.2 and 4.3. Moreover, section 4.4 presents Volvo Group's current views on a PELC. Information for the current state was gathered through interviews and observations. Further, a sample of interview questions is presented in appendix A.

4.1 Process definitions

This section defines the processes of storing, kitting, sequencing and pre-assembly according to Volvo Group's perception.

4.1.1 Storing

Volvo Group considers the storing activity to be when a full pallet is delivered to the factory and most commonly placed in an inventory within the plant. The inventories are located in various storage points throughout the plant. After the storage points, the pallets are delivered directly to the assembly line, sequencing, kitting, or a pre-assembly, i.e. the point of consumption. This is further initiated when there is a need downstream in the material flow. It is stated to be relatively easy to handle storing of full pallets since the material is delivered in pallets that require less space and contain more material. Pallets further bring parts in a dense way since the package is designed to be efficient in terms of quality and density, and protects the parts. Pallets are also made to be handled several times with a forklift, i.e. easy to load and unload. The pallets can be differentiated based on the usage frequency in the assembly, either high-, medium- and low-runners. The frequency will further be discussed in section 6.2.

4.1.2 Kitting

Volvo Group considers kitting as a process where a mix of small and medium-sized parts are put together into kits for specific chassis. Furthermore, the activity follows the sequence of the chassis assembled at the assembly line when delivering kits to the pre-assembly or assembly. Kitting assures quality and facilitates work at the assembly line by decreasing material handling and presented components. Volvo Group strives after having kitting closely to the use point since small and medium-sized parts can easily be delivered by pallet trains. Thus, allowing for forklift-free areas which enhance the safety near the point of use when delivering the items. Moreover, kitting is usually either be performed by assembly or pre-assembly operators, which largely depends on the balancing and workload. Despite this, most often, the same operator performs the kitting and the pre-assembly activity.

4.1.3 Sequencing

Sequencing is mainly performed for large parts of multiple chassis by placing the items in a sequence corresponding to the chassis sequence at the assembly line. Usually, the sequencing includes one or a few components within the same part commodity. The plant should preferably locate the activity closer to the goods receiving area since larger parts are more challenging to deliver with pallet trains. Furthermore, sequencing typically requires changing packing, which motivates locating such activities closer to the receiving area. Moreover, Volvo Group does not principally differentiate between sequencing and kitting. The part size usually determines whether the parts are to be sequenced or kitted.

4.1.4 Pre-assembly

Pre-assembly is an area where different parts are assembled in advance into modules and delivered to the assembly line to be assembled onto the chassi. Hence, the pre-assembly often is performed close to the assembly line and is done to decrease the workload on the line, ensure quality and enable a higher pace. Pre-assembly is commonly done in connection to other activities such as kitting and sequencing. Therefore, it is not always easy to distinguish between activities since they might overlap, for example, kitting can become a pre-assembly work. By definition, pre-assembly is being performed when assembly activities or assembly of modules occur, i.e. when the work performed is value-adding instead of picking activities. Pre-assembly could also include very light assembly activities, further elaborated upon in section 4.4. Finally, the operator at the assembly line often performs the work since they rotate between the pre-assembly and assembly line.

4.2 Activities performed in Volvo Tuve

In Volvo Tuve, the various activities mentioned in section 4.1 are performed to achieve effective material supply. This section describes how these activities are currently performed at Volvo Tuve.

4.2.1 Current storing activities in Volvo Tuve

The majority of materials used at Volvo Tuve are delivered in pallet loads, referred to as storing. The pallets are further stored in multiple locations within the factory. The location varies from automatic inventory, regular inventories or close to the point of consumption. The storage point is primarily decided based on downstream activity where the pallet is to be consumed. For instance, pallets used for items that are to be kitted are usually stored above the kitting area, saving floor area but which requires handling when there is a need for replenishment. On some occasions, a full pallet can be placed directly at the assembly line. This is, however, relatively rare since requiring line space. Moreover, this is only the case for parts with less than three part numbers per part commodity. Such a concept aims to minimize the number of handlings while assuring quality at the assembly stations.

4.2.2 Current kitting activities in Volvo Tuve

Kitting is most suitable for handling small parts in the factory, while larger parts are preferred outside the plant due to limited space. Compared to sequencing, kitting is more common inside the factory and as Volvo Group strives for a ”fishbone” structure, as mentioned in section 2.4, kitting is performed close to the pre-assembly and assembly line. The vision of a fishbone structure in the factory indicates achieving the following structure: assembly line, pre-assembly, kitting, sequencing and storing. However, storage can also be located in the kitting area. The secondary feeder line concept is a type of network which provides parts to the primary use point, often the assembly line and indicates that value-adding activities should be performed close to the assembly line. With this strategy, the transportation of material will decrease. It is essential to keep in mind that the fishbone structure is a strategy and not the reality and therefore, kitting may also be performed further away and not close to the assembly line. Kitting follows the same frequency differentiation as storing, i.e. high-, medium- and low-runners and their respective classification.

4.2.3 Current sequencing activities in Volvo Tuve

Sequencing is often performed further away from the assembly line at Volvo Tuve compared to kitting since it often involves larger parts taking up more space. However, kitting and sequencing can often be performed in the same areas. Sequenced items can consist of one part for one specific chassi or several parts belonging to the same chassi. However, sequencing one part for a chassi is more common when it is delivered to Volvo Tuve from suppliers. Even if one part is delivered to the assembly line, it can be considered in sequence since being delivered in a sequence from suppliers, external warehouses or performed internally and delivered to the line one by one due to limited space. In cases of disturbances where particular chassis cannot be built, they must be temporarily removed from the production sequence, which may entail additional handling.

4.3 VMLC

The 3PL operating the VMLC facility is located approximately 10 km from the Volvo Tuve plant and delivers mainly sequenced and kitted goods to the plant. Therefore, the price is set according to the number of picks and value-added activities performed. Currently, the items delivered from VMLC are mainly related to the cab assembly, which tends to consist of large parts with many variants. The background to this setup is since Volvo Tuve previously had its entire cab assembly in Umeå, which was partly relocated to Tuve. However, not all processes and parts could fit into the Tuve plant. Therefore, Volvo Group kept the setup with a VMLC when moving the processes related to the cab assembly. Hence, Volvo Group is the only customer for the VMLC. Furthermore, having a VMLC supplying some material to the plant was not a strategic decision but rather a legacy setup.

4.3.1 Activities and processes

A typical process at the VMLC includes filling a sequence rack with the material needed at the Volvo Tuve plant. The materials are usually large and bulky, making them difficult to handle, and line stopping to some extent. Further, the materials usually also consist of several part numbers per part commodity, which implies the need for considerable use of storage space. Moreover, the racks often consist of materials from several suppliers, meaning that VMLC creates value by merging different flows onto one rack. When picking the items, operators work by pick to voice and scan items before placing them onto racks. After that, filled racks are placed in a buffer zone until receiving a signal from Volvo Tuve. The used IT system at the VMLC is based on the picks needed for the assembly sequence, which is sent by Volvo Tuve two days in advance, making the IT system somewhat rigid.

The Volvo Tuve plant receives mainly large sequenced or kitted items or product families in racks from VMLC, which are adapted and intended primarily for the material flows from VMLC. Moreover, VMLC does not distinguish between kitting and sequencing since activities are usually combined. Also, VMLC is responsible for performing some relatively basic pre-assemblies. Storing is another activity required at the VMLC for coping with differences in quantity and time gaps when receiving materials from suppliers. Furthermore, a logistics service provider is responsible for the transportation between VMLC and the Tuve factory. Volvo Tuve further receives 16 daily deliveries from VMLC, highly dependent on the assembly since it is a pull flow from VMLC and racks must be used to transport the material.

4.3.2 Suppliers and ABC-classification of suppliers

In some cases, the VMLC setup entails limited transparency regarding stock balances. Parts sent from suppliers to VMLC are classified into A-, B- or C-parts. A-parts are owned by Volvo Group themselves while suppliers own B- and C-parts. Furthermore, A-parts become Volvo Group's possession as soon as received at the VMLC, meaning they appear in Volvo's MRP system and access the available quantities. Additionally, this means that Volvo Group can follow up with suppliers in cases where the goods have not been received.

A-suppliers are also required to have 24 hours of storage available at the VMLC. Furthermore, suppliers are responsible for the stock levels for B and C-parts, and the VMLC is responsible for follow-up in cases where the stock does not correspond to approximately three days of stock. For certain long-distance suppliers, the stock can correspond to 12 days of production. Thus, the stored quantities at the VMLC depend on the structure that a particular supplier has toward Volvo Tuve. Furthermore, Volvo Tuve does not have access to stock levels for B- and C-items. The ownership of B-pallets is further transferred to Volvo Tuve when a pallet is opened, which can be advantageous if the demand for the parts decreases over some time. Lastly, C-parts are pre-assembled to some extent and Volvo Group only purchases the individual items that are picked and processed. Such agreements, as well as division of responsibility, are further stated in contracts between the parties.

4.3.3 Performance of VMLC

VMLC performs approximately 10 000 picks per day. In 2020, the logistics provider had 50 incorrect picks, which corresponds to one faulty delivered item per week. However, there may be additional incorrect picks that Volvo Tuve did not report to VMLC. Either way, the picking accuracy is relatively high and VMLC aims for 99,9% delivery precision on the racks. To achieve this, the VMLC works actively with certain measures to assure high quality. For instance, VMLC is not loading certain sensitive materials onto trailers that Volvo Tuve will not be unloaded until after the weekend to avoid water dripping from condensation. Racks are also washed from dirt to minimize the risk of quality deficiencies. However, the responsibility differs depending on what is reasonable for the VMLC or suppliers to discover and the ownership of materials. Volvo Group is responsible for defects on material from A-suppliers since owning the material while suppliers are responsible for B-suppliers. Finally, VMLC has more responsibility for materials from C-suppliers due to having greater responsibility for stock balances and quality since performing some pre-assemblies on such materials.

As for flexibility, VMLC picks the items in sequence approximately 4 hours ahead of building the trucks at the assembly line, which corresponds to 2-hour buffers at VMLC, respectively Volvo Tuve. Thus, VMLC must receive information about changes in the assembly sequence at least 4 hours ahead to not pick the particular rack. However, as mentioned above, it might be challenging to make changes despite notifying on time due to the somewhat inflexible IT system, which entails that the VMLC must carry out changes manually. Thus, if changes are to be made, they must be performed manually regardless of when VMLC was informed of a potential change in the truck assembly sequence at the line. Despite the issues with the inflexible system, the logistics provider is not hesitant to do such manual changes if needed.

4.3.4 Challenges with VMLC

As previously mentioned, Volvo Tuve has limited visibility into the IT system used at the VMLC, which limits the transparency between the parties. Instead, if the external logistics center operates through the internal logistics operating system, Volvo Group can monitor inventory levels, the exact location of pallets and estimate delivery lead times. Transparency is not possible when the VMLC operates a separate IT system and such information is instead shared when requests are made through e-mail. However, this setup does not assure accuracy regarding information since Volvo Tuve cannot verify the information.

Furthermore, a common internal IT system used at an external logistics center and Volvo Tuve can also support certain flows by, for instance, consolidating picks into one trailer for transportation. This entails fewer scans when the delivery reaches the plant since the goods have already been goods received, which simplifies the process when goods are delivered from the external warehouse, such as a VMLC facility. However, this process is not currently performed in the VMLC.

Other challenges related to the VMLC setup include the complexity of the ownership and costs. There is no transparency within the supply chain costs, making it hard to keep track of all costs and understand what Volvo Tuve is paying for. By having a shared responsibility for costs inside the VMLC, where suppliers own the inventory and Volvo Tuve the processes, it becomes difficult to add logistics activities and it increases the complexity regarding payments and responsibility.

4.4 Current perception of the PELC concept

This section describes Volvo Group's perception of the PELC concept and future implementation since Volvo Tuve does not currently have a PELC facility. The paragraphs in this sub-section are mainly based on the PELC definition provided by internal process guides from Volvo Group.

4.4.1 What is a PELC?

The basic idea of a plant extension logistics center (PELC) is to perform internal logistics activities in a facility outside the plant, serving as an extension of the factory. The main driver for establishing a PELC is the lack of space for certain activities within the plant. Thus, such plant extension aims to support internal logistics processes for individual Volvo Group sites by using Volvo's internal IT systems. The PELC concept will include direct management by the particular Volvo Group site to increase flexibility and control to try to solve current problems that exist within VMLCs. Such difficulties include tracking activities, negotiating with suppliers and not always supporting specific logistics needs due to limited access to information about stock balances. Moreover, a PELC allows for having long-distance suppliers delivering goods that Volvo Group owns upon arrival. Furthermore, it is stated not to be essential which actor owns the PELC facility itself and operating employees as long as Volvo Group owns the materials and there is transparency. One option includes Volvo Group owning the facility and having their employees managing the inventory flowing through the PELC. Another option is having a third-party logistics firm manage the PELC operations, which Volvo Group might prefer since it increases flexibility. It is also stated that the operations could be performed by Volvo Group employees as well. Lastly, the Volvo Group plant and logistics department would be responsible for ensuring the PELC operates as expected.

4.4.2 Activities in a PELC

Various activities could be performed in a PELC, some examples of such activities include trailer unloading or loading, goods receiving and downsizing (optimize the packaging to the minimum possible), warehousing, sequencing and kitting. However, Volvo Group generally suggests placing value-added activities in proximity to the assembly line and basic activities further away. Furthermore, kitting, sequencing and pre-assembly should not be done in a PELC if possible due to limited time to respond to potential faulty or missing components. This mainly since kitting is prepared each takt time, meaning it should be done close to the point of use so that parts can be easily replaced if needed. The same reasoning with limited time to solve potential issues applies for sequencing. Despite sequencing for 3-6 chassis at once, the time for solving quality issues is limited. The main argument for not including such activities in a PELC is since problems with externally performed value-adding activities could stop the assembly line. Thus, it is essential to avoiding including critical parts that could stop the line if not available when needed. Instead, warehousing activities could be assigned outside the plant, for instance, storing pallets or holding safety stocks. Either way, it is essential to make an overall analysis to carefully consider the optimal location for a particular activity and making strategic decisions regarding what to include in the PELC. Such analysis should comprise part consumption levels and the volume of boxes to understand the total space consumption.

4.4.3 Differences between the VMLC and a PELC

The PELC concept entails a plant extension of the internal logistics activities by relocating certain activities and flows from the main plant to an external logistics center. Such activities are managed in the PELC the same way as if they were performed within the plant. A PELC will therefore entail that Volvo Group owns and manages the inventories. However, it is preferred that third-party logistics perform the operations.

Furthermore, utilizing Volvo Group's IT systems within a PELC will enable the seamless extension by providing control and information regarding, for example, operations and inventory levels. Thus, more transparency is possible with PELCs compared to VMLCs. As third parties may operate VMLCs and Volvo Group has limited control, there might be a desire to minimize inventory levels at the VMLC. This could impact the ability to deliver materials in cases of disturbances upstream in the supply chain resulting in stockouts. However, this is less likely to occur with a PELC since Volvo Group has more control.

4.4.4 High level value stream mapping

Four value stream maps are presented in Figures 4.1-4.4 to visualize the different flows of material when going through either the Tuve plant only or a PELC facility.

Pallet storage

Figure 4.1 shows the material flow of pallet material delivered to the Volvo Tuve factory. The suppliers send material to the plant, regulated by a pull signal. The material is transported with a logistic service provider to Volvo Tuve's gate, where incoming material and transports are registered before the material is unloaded using a forklift. An ID scanning process is performed to register the goods into the Volvo Group IT system. The material can then be handled in two ways depending on where the point of consumption is.

A forklift can transport the material directly to the automated storage area located close to the goods receiving. When the material is needed, it is loaded on a pallet train that transports material to the use point. The alternative material handling process is selected when the material's use point is further away in the factory. This because Volvo Tuve has a centralized goods-receiving area, which does not consider the use point of the material. The process means that a trolley transports the material to a local store, where the material is loaded on a pallet train and transported to the use point when needed.

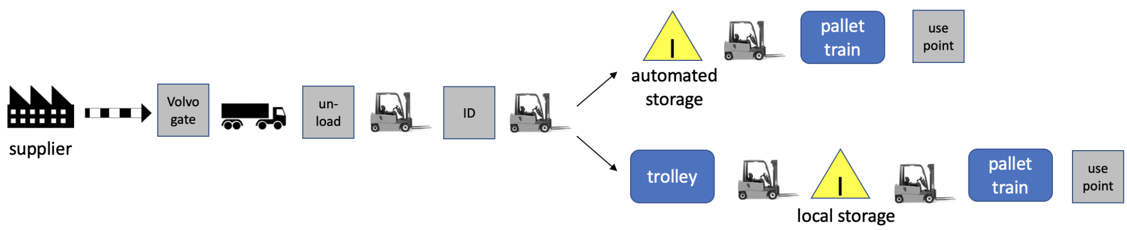

Figure 4.1: Material flow at Volvo Tuve of pallets

Figure 4.2 visualizes the material flow for pallets which goes through a PELC before being delivered to the Volvo Tuve plant. Pallets are sent from the suppliers by a pull signal that triggers the delivery. The material is then transported to a PELC gate and unloaded by a forklift to be ID scanned and reported into the IT system used in the PELC. The forklift transports the pallets to the main storage area inside the PELC facility. When the material is needed, a forklift loads the trailer and a logistics service provider transports the material to the Volvo Tuve plant, bypassing the Volvo Tuve gate before going to the direct gates. These gates should be implemented and used to make the goods receiving area more decentralized and closer to the use point to minimize the internal traffic. When the material receives to the Volvo Tuve plant, the material is unloaded, transported and loaded on a pallet train that transports the material to the use point.

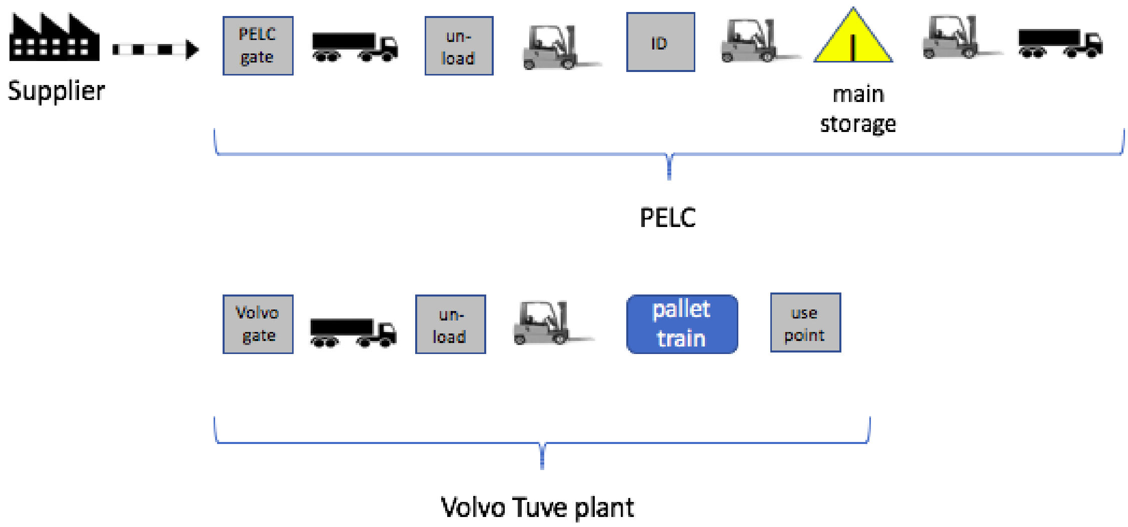

Figure 4.2: Material flow at a PELC and Volvo Tuve of pallets

Sequenced and kitted materials

As for the material flows of sequenced and kitted material, Figure 4.3 shows the overall flow from the supplier to the point of use when the material arrives directly at the Volvo Tuve plant. The goods receiving process from the Volvo Tuve gate to the identification process follows the same process steps as for the pallet storage material described above. The pallets are further transported to their storage location before transported, by tugger train, to the sequence or kitting area where the picking is performed. The components are then usually placed onto sequence racks or kit trolleys. Finally, the materials are transported, preferably pushed by operators to the point of use. Thus, the final transportation is preferably not done with forklifts for safety purposes, but rather by a tugger train.

Figure 4.3: Material flow at Volvo Tuve of sequenced and kitted material

Figure 4.4 shows the material flow of sequenced or kitted material when going through a PELC facility before arriving at the Volvo Tuve plant. Firstly, the material arrives in pallets to the PELC from suppliers before being unloaded from the trailer, identified and transported to the main storage area in the PELC. The sequencing or kitting is then performed when receiving a pull signal from the plant. A truck trailer is then loaded with the particular sequence racks and kit trolleys and transported through the main gate of the Volvo Tuve plant. Moreover, a PELC setup allows receiving goods more decentralized, i.e. a direct gate closer to the actual point of use. The sequences and kits are further loaded on a tugger train and transported to the use point in similarity with the previous case.

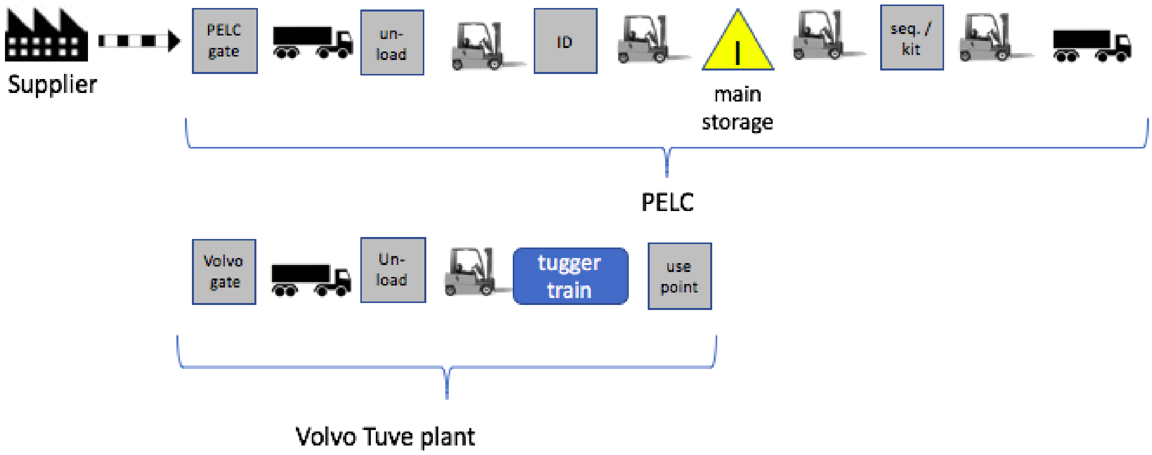

Figure 4.4: Material flow at a PELC and Volvo Tuve of sequenced and kitted material

A final remark is that the high-level value stream maps involving the PELC represent an assumption of how the concept would most likely affect the process setup when implemented. As seen, the total number of activities would increase by adding an intermediary to the supply chain. However, fewer process steps would generally be performed at the Volvo Tuve plant since receiving the goods from suppliers at the PELC.

5
Benchmark

Sections 5.1-5.3 below present the findings from the performed benchmark. The companies include Mack Trucks, Scania and Volvo Car Corporation (VCC). Furthermore, the benchmarks bring up a general background and perspectives of the different setups, the implementation and which suppliers, materials, and activities are affected by having a logistics center. Also, the perceived advantages and disadvantages, performance of the logistics setups and main learnings are presented below. Furthermore, a sample of benchmark interview questions are presented in appendix B.

5.1 Mack Trucks

Mack Trucks in the US, referred to as Lehigh Valley Operations (LVO), constitutes an internal benchmark performed since belonging to the Volvo Group. The interview was carried out with a Volvo Group business process developer and an engineer from LVO. Furthermore, the interview brings up perspectives on Mack Truck's logistics center.

5.1.1 Background of the logistics center at Mack Trucks

Currently, the logistics center at Mack Trucks, located less than 1 km from the plant, has several inbound flows where most materials delivered and handled are pallet materials from suppliers. This since all pallet flows goes through the logistics center together with alternative flows like sequenced material from suppliers. Even if the primary activity performed in the logistics center is storing and handling of pallet materials, some kitting and sequencing activities are also carried out in the logistic center. Such activities are performed externally since Mack Trucks logistics center is considered an extension of the LVO plant. Furthermore, the facility supports the two separate assembly lines located inside the factory that builds two different trucks, one vocational truck and one for trash collection, by providing the lines with material. Differentiation is seen in the takt-time between the two lines and the material needed. One is a very low volume product, around 18 trucks per day, and the other line, the mainline, builds around 110 trucks per day. The interview reveals that Mack Trucks logistics center is located approximately 1 kilometer of driving from the plant, which was the plan to minimize the lead times. However, the goods need to be transported by regular traffic. Therefore a logistics service provider is performing the transportation between the facilities. The logistics center is further supported with a third-party managed supplier pick-up point (PuP) to support long-distance flows from suppliers. Therefore, a supplier pick-up point allows for a shortened lead time from long-distance suppliers.

Even if the logistics center originally was a temporary setup about seven years ago, it is today a part of the master plan and way of working. A third-party owns the logistics center and LVO leases the space. Furthermore, LVO is responsible for all equipment and, since a few years back, the operations are performed by LVO employees. However, a more flexible setup would be to have a third-party performing the operations since allowing for adjustment of the volumes. Moreover, it is stated that the logistics center holds around five days of inventory for domestic suppliers to secure deliveries and about 20 days of inventory for international suppliers. However, this depends on the lead times, transportation, and safety stock. LVO further has high inventories because of the volatile processes, production backlogs, and supplier disturbances due to the long distance of the supply base.

5.1.2 Suppliers and material in the logistics center

The interview reveals that many materials and suppliers can be affected by having a logistics center, possibly all of them, not least long-distance suppliers and material defined as low runners. The Mack Trucks logistics center concept is a suitable application for long-distance suppliers since a logistics center can keep inventories for longer time frames to secure deliveries that otherwise could be affected due to long lead times and disturbances. Thus, inventories are carried to cover the transportation lead time and safety stock is therefore needed, which would not have been able inside the plant due to space limitations. Therefore, much valuable space would be taken from value-adding activities. This makes the space in the plant more efficient and flexible since the material needed and activities that are important to have close to the mainline will fit into the plant, while other material and activities that are not as prioritized could be kept outside and not take valuable space. However, this setup depends on the ability to call off the parts in time to get them to production to meet the need, which can be done if operating in the same IT systems.

A relocation of the infrequent and space requiring materials, also applies to materials from domestic suppliers like low-runners. The materials that take much space but are infrequently used are located outside the plant to utilize the space more efficiently and not tie up space inside the valuable factory. These materials are defined as very low-runners, low-runners and high-runners or bulky materials.

Originally, LVO started to move out all pallet storing materials to the logistics center to get more flexible space and then started to relocate and reorganize the logistics activities. However, according to the interviewee, it is essential to focus on pallet storing materials that can bypass the logistics center and be delivered directly to the plant to minimize handling processes. This since multiple handling activities imply longer lead time, space needs, resources and time needs and quality risks. Mainly, this is about frequently used parts for example, that are delivered daily to the plant or the logistics center. LVO had plans to relocate activities of high-runners' suppliers to the plant, which was not accomplished since other insourced materials consumed more space in the plant than expected.

5.1.3 Activities in the logistics center

From the interview, it also becomes evident that LVO has a master plan to which they try to relate the principles of the logistics center. The placement of the logistics processes is prioritized by having takt driven processes closest to the production line. Furthermore, basing the placement on takt time represents comprehensive guidelines for describing were to perform logistics activities. However, most processes have initially been relocated to the logistics center, which has later been re-evaluated. Thus, processes, such as value-adding activities, have been moved back to the LVO plant. It is revealed in the interview that Mack Trucks still perform activities such as storing, sequencing, and kitting in their logistics center despite there being some re-location in progress.

Kitting
One example of a takt-driven process is kitting since kits are usually prepared for individual chassis each cycle time and must be completed within the takt time at the assembly line. Therefore, the theoretical principles used at LVO suggest placing kitting within the plant. Moreover, in theory, kits should be picked, transported and delivered within the takt. However, in reality, kits are prepared a few takt times in advance but each kit must be available at the assembly line for each chassi, i.e. each takt time. LVO recognizes the potential issues of placing kit preparation in an external logistics center. The criticality of transportation and quality is further mentioned as essential drivers for the principle. Also, longer distances between the kit preparation and point of use require more kits in a loop, increasing the complexity and adding work-in-progress.

Sequencing
Sequencing is the second most critical process in terms of time since only one type of item is prepared for multiple chassis, allowing to delivery of parts corresponding to several takt times. Thus, an operator can sequence one rack with items representing equally as many takt times as the number of pieces in the rack. Therefore the lead time allows for placing sequencing further away from the assembly. LVO, therefore, considers sequencing as the second most prioritized process to have within the plant.

Storing
Pallets usually represent more cycle times at the assembly stations since normally carrying a large number of pieces. Therefore, storing pallets corresponds to more coverage in time, requiring a lower prioritization of holding within the LVO plant. Another aspect mentioned in the interview is that goods receiving is preferably performed further away from the assembly. Hence, pallets are usually stored at the logistics center, especially from long-distance suppliers. It is the case since such material usually requires more safety stocks to cover for potential risks associated with

increased lead time, leading to savings in space at the assembly plant. Furthermore, high-volume and high-frequency deliveries of materials from nearby suppliers are not preferred to flow through the logistics center since mainly introducing waste in terms of additional handling.

Considerations when relocating activities

Despite established guidelines of the location of logistics activities mentioned above, there may be a need to relocate particular processes to external logistics centers, such as kitting. Concerning this, LVO has determined certain aspects to consider, such as the number of parts handled at a kit preparation station, needed space and if parts require a lifting tool. According to the interviewee, a lifting tool should preferably not be used twice in the material flow since lifting a component is seen as waste due to additional time, equipment, quality risks and decreased flexibility.

Furthermore, since it is common for LVO to have changes in the production schedule, kits supplying the early stations cannot be located in the logistics center. The reason is due to the uncertainty and extended response time in cases of disturbances in the production sequence. Therefore, LVO has investigated the possibility of using a physical trigger, i.e. chassis entering the assembly, to initiate a particular kit preparation process. In cases where kits have such a physical trigger and the distance to the point of use exceeds the lead time from the logistics center to the plant, they constitute a possible kit to relocate to the logistics center. Otherwise, kits are prioritized to keep inside the plant and kit preparation is then based on the production schedule, which allows for a shorter response lead time if changes occur at LVO and fewer kits in the material flow. Such reasoning has given LVO candidates for which kits to relocate to the plant extension. Other aspects to consider when space limitations in the plant include part diversity, meaning storing of such parts takes up significant space. Furthermore, LVO considers it is essential to adapt the placement of logistics activities to the particular context where the plant is operating since the optimal utilization is dependent on various variables.

The interview also reveals that some commodities come in large racks made of steel designed to optimize trailer loading. LVO has decided to kit and sequence materials that come in large packages and require forklifts in the logistics center. This decision is taken to reduce the need for forklifts inside the plant and facilitate handling since the material will come in smaller fixtures when arriving at the plant from the logistics center.

Activities to avoid locating in the logistics center

LVO also mentions that putting different processes in a logistics center may require new IT systems, different operator competencies, supervision or new risks for parts. As for activities that are not preferred to place in a external logistics center, assembly-related activities are avoided in the LVO setup, especially assembly activities impacting a critical or particular characteristic. Critical or special characteristics mean a process may create warranty risks for suppliers or quality risks for customers. Such considerations have eliminated many processes from being placed in the logistics center. However, LVO recognizes the opportunity to locate light pre-assembly activities in the logistics center, assuming that they may decrease expenses downstream in the material flows. Also, such activities cannot require documentation or special tools needing special maintenance or expertise, for instance, pre-placing bolts into a fastening position or putting parts in the orientations to be assembled.

5.1.4 Advantages of operating the logistics center

The interview also reveals several advantages of operating the logistics center at LVO. Even if a logistics center can mean a decrease in transparency, transparency can be achieved by a integration of IT systems. Having integrated systems provides LVO with more visibility and allows access to information about available quantities in the logistics center. This integration also allows for greater control over KPIs and more influence over designing, developing and improving processes at the logistics center.

Another aspect is the leveling of inbound goods received, meaning that the logistics center absorbs the time variability in arriving goods. This since most goods receiving is carried out in the logistics center, which implies that the material flow between the facility and the plant are more leveled. Further, Mack Truck's logistic center constitutes a buffer to the plant. In times of high assembly delay, the logistic center is affected by higher inventories on-hand. Moreover, the plant pulls parts from the logistics center, meaning that the material flow into the plant is predictable and linear to the production. Besides creating an even physical flow, it also helps estimate the labor needed to handle the material flow.

In addition, a logistics center can also be utilized as a cross-dock operation and deliver goods to any entrance of the plant instead of all goods receiving taking place at one area in the main plant. Also, the LVO setup allows for delivering goods closer to the point of use since the material has already been goods received at the logistics center, allowing to eliminate some internal transports by reducing the distance between the point of arrival and point of use. However, this requires balancing the number of entry gates with means of transport of the goods to assure a reasonable fill rate of the transportation. Moreover, LVO uses four different inbound locations at the plant instead of carrying out all goods receiving in one area of the plant.

Another advantage of operating the logistics center, mentioned in the interview, is that the logistics center can manage and return potential packaging directly to suppliers. LVO further considers this an advantage when performing some sequencing in the logistics center, since special packaging does not reach the plant.

5.1.5 Disadvantages related to the logistics center

The main complaint that the LVO setup receives from operators is for suppliers that deliver material relatively frequently. This implies that the pallets are within the logistics center for a limited time, which entails that the logistics center processes adds additional lead time. Particular process steps must be performed in a certain order in the facility due to the rigidity of the IT system. For instance, for a pallet to be goods received, the system requires certain steps to take place before the delivery is completed. Hence, LVO does not consider it valuable to have high-runner pallets going through the logistics center.

Therefore, one disadvantage is the inflexibility of the IT system used in the logistics center when handling pallets with high frequency. This process leads to additional lead time being added into the processes, which could potentially cause downtime in the plant if parts are not available on time. Thus, many issues and additional risks with the material flow arise for nearby suppliers, delivering materials frequently to the logistics center. High-runners require additional touchpoints and lead time. Therefore, the logistics center handling high-running materials could be seen as a bottleneck to material availability in cases of backlog and low inventories.

5.1.6 The performance of the logistics center

The interview reveals a trade-off between the additional handlings and process steps that a logistics center entails and the potential advantages for the plant. Thus, a decision must be made based on potential advantages with a plant extension against the consequences of additional process steps. Therefore, the Mack Truck logistics center setup affects several performance variables such as flexibility, quality and cost.

Flexibility
The Mack Truck logistics center creates space flexibility within the LVO plant, which is especially advantageous when, for instance, changing the product variants that are being assembled. Then additional space is required to relocate some processes to make room for others strategically. Therefore, due to the space flexibility that the logistics center at Mack Truck entails, LVO can decide which processes are the most cost-efficient and least complex to relocate. Furthermore, the logistics center provides opportunities of absorbing fluctuations in space needs due to the flexibility in space utilization. This further decreases the need for outsourcing processes to 3PLs. Also, flexibility regarding the location of activities increases if the activities are performed based on a stable production schedule, which Mack Trucks does not have.

Furthermore, as mentioned in section 5.1.5, the rigidity of the IT system might influence the flexibility for materials with frequent deliveries to the logistics center due to being stored there for a relatively short amount of time. In long-term, such issues may influence the quality of the end-product if materials are not available at the assembly line in time due to poor placement of certain materials combined with the rigid IT system.

Quality
The logistics center setup adds wastes in handling since the materials are handled

several times due to performing extra unloading and loading activities. Furthermore, potential quality risks could be introduced due to additional transportation or handling when picking individual components i.e. kitting or sequencing is carried out in the logistics center. Therefore, LVO may choose to keep high-quality sensitive items with critical characteristics within the plant facility to reduce additional handling and quality risks. Similarly, assembly-related activities should not be placed in the logistics center. This entails that quality may be affected negatively for some activities, such as sequencing or kitting, and unchanged for other activities, such as storing. An explanation is since the packaging is expected to protect the goods until the packaging is opened.

Cost
As previously mentioned, additional transportation and handling are added by implementing a logistics center, which increases the lead time and costs. Therefore, it is essential to determine which materials to keep in the logistics center with lead-time and cost in mind. However, there is a trade-off between the additional waste introduced in the supply chain and the potential benefits that an logistics center can accomplish in terms of, for instance, flexibility. From a cost perspective, high-runners of pallet material from nearby suppliers should be avoided in the logistics center due to additional handling, as suggested above. However, time and cost-saving can be achieved by performing some activities in the logistics center, such as storing pallets of low-runners or long-distance suppliers.

The logistics center also allows for backsourcing activities to the LVO plant, such as pre-assembly, that third parties have previously performed. This can further reduce costs and quality risks when assembling components closer to the assembly line than at suppliers or the logistics center.

5.1.7 Learnings from Mack Trucks

There are also many lessons learned from the implementation of Mack Trucks logistics center and considerations for establishing future logistics centers. One consideration mentioned in the interview is to have a clear strategy on which types of flow to include before the actual establishment of the logistics center. Establishing such a strategy requires evaluating the trade-off between the potential advantages of placing flows in an external logistics center and additional lead time and costs. The background to this is since LVO moved a large number of materials to the logistics center rather blindly and without strategic consideration due to the urgent need for space in the plant. Instead, LVO has worked backward to establish a strategy and tie the logistics center to their master plan, meaning that some flows were returned to the plant. This has resulted in reasonably large investments for reorganizing the space utilization and layout in their logistics center. However, initially developing a strategy for using a logistics center entails a more cost-efficient solution since it reduces the trial and error when blindly moving materials and activities to an external logistics center. Hence, by establishing a planned approach beforehand, a logistics center will entail the most optimal utilization of the facility.

Another critical consideration includes the geographical location of the logistics center. A logistics center located nearby the plant implies shorter lead times, increases the flexibility and thus quicker, more reliable and predictable transports between the sites. Furthermore, having an extended logistics center close to the plant will mean fewer materials are in the material flow loops, i.e. work-in-progress.

System integration and its actual cost are also aspects to consider. LVO advocates evaluating the actual costs of setting up the IT system into the external site. Furthermore, striving towards using the Volvo Group IT system is preferable since it allows for accomplishing an extension of the plant, which is desirable in this context. This means that integrating with a third-party system is not preferable since adding complexity and costs. Moreover, by using a third-party system, Mack Trucks would still have limited control, access to information, and the possibility of making adjustments.

The interview also reveals that LVO will investigate automation and technology options in the near future to improve operations further. This is motivated by the fact that logistics center manages low-runner pallets manually which is intensive in terms of handling. Automating the handling of low-runner pallets at LVO can entail decreased lead time from picking to delivery and reduce the space needed.

5.2 Scania

In this section, the benchmark with Scania is presented which was carried out with two managers of logistics engineering at Scania, responsible for different logistics centers. The company has three logistics centers, two in Södertälje and one in Oskarshamn.

5.2.1 Background of the logistics centers at Scania

The interview revealed that Scania has their production for the European market located in Södertälje and Oskarshamn and subsidiary factories located in South America in Brazil and Argentina and factories performing the final assembly of chassis in Holland and France as well. Scania has both processing plants focusing on transmission and engines and delivering items such as gears and assembly with processes such as engine assembly, gearbox assembly, axle assembly, and chassis located in Södertälje. The cabin production is instead located in Oskarshamn. The company has two logistics centers located in Södertälje, one providing the engine assembly with parts located at the factory area, next to the factory. This logistics center performs engine assembly and storing activities. The second logistics center is for chassis and transmission located 100 meters from the factory. The property is owned and operated by Scania. The logistics center in Oskarshamn, aimed for cab production, is located three kilometers from the factory and has approximately 90 minutes lead time from the time an order is received. The facility is rented on a long-term contract and the property is thereby not owned by Scania. However, Scania employees perform the processes. The material, to and from both logistics centers located more than 100 meters away, is transported by trucks in standard trailers while for the logistics centers located at the factory area, the transportation is made by logistic trains with wagons. Furthermore, Scania uses its own IT system in both the logistics center in Södertälje and Oskarshamn. Using the own IT system means that they have a reasonably transparent system allowing them to control the inventories.

Since Scania offers the customers to build or design their trucks based on a modular system, the company has many variations. The choices are many and include the number of axels, type of engine and gearbox, and color decisions. Due to the many combinations, Scania has many variants of trucks and a high degree of customer adaptation.

The background for implementing this setup and the logistics centers was the space limitations due to the high number of variants which made it impossible for the material to fit in the factory area and at the assembly line. The logistics center in Oskarshamn were previously outsourced to an external party. However, since 5-6 years back, Scania decided to insource the facility and run the logistics center business in-house, explaining why the logistics center's geographical setup. Further, they decided to build the new facility 3 km away from the factory since the vacant industrial land controlled the location of the logistics center. The logistics center for the engine assembly in Södertälje was built close to the factory since Scania had some available land where they got permission to build their logistics center. Having a logistics center in the factory area was Scania's ambition to avoid long transportations. The logistics center for assembly has been around for about 8-10 years.

5.2.2 Suppliers and materials in the logistics centers

A logistics center performing various activities linked to production affects multiple materials, including stored, sequenced, and kitted materials. It is stated in the interview that Scania has some difficulties with space limitations, forcing them to have an external facility operating some activities. One of the logistics centers in Södertälje has decided to keep inventories of mainly low-runners and, in some cases, also medium-runners while the most frequent items are delivered directly to the factory. This since Scania wants as few touches as possible on the high-runners. The affected suppliers are then suppliers for the low-and medium-runners since these are mainly stored and material with low frequency which often is sequenced in the logistics center before being delivered. One difference between Södertälje and Oskarshamn is that the logistics center in Södertälje handles all large and bulky materials that require large packages in the plant and have standard packaging such as boxes and pallets in the logistics center.

This is not the case in Oskarshamn and their setup. The logistics center in Oskarshamn stores and handles mainly large pallets, pallets larger than E-pallets, regardless of frequency and large and bulky materials that are sequenced. This decision was made to release as much space as possible in the factory. Moreover, the factory in Oskarshamn has a warehouse in-house, where E-pallets and H-pallets are received and stored, which differs from the setup in Södertälje. However, since all material on large pallets goes through Oskarshamn's logistics center, it affects both local and long-distance suppliers. The same goes for the logistics centers in Södertälje, since they differentiate the location of material based on the frequency and size, all suppliers can be affected by having a logistics center. It can also be revealed from the interview that a logistics center enables flexibility in the transportation planning phase for long-distance suppliers that Scania purchase many materials from which indicated that long-distance suppliers would be affected.

However, it is stated in the interview with the logistic managers that the setups are not optimal for every situation. It is essential to consider the context when determining the position of the activities, such as the location of the logistics center. If the logistics center is far away, the transport costs will be very high which may change the location of materials. It is advantageous to have material that varies closer to the factory as well as bulky materials. The factory's ability to receive and hold high-frequency materials in inventory can determine the location also. This implies that frequency and size are crucial parameters.

5.2.3 Activities in the logistics centers

The interviewee describes that the logistics center in Oskarshamn performs various activities such as goods receiving, storage of large pallets, i.e. pallets with larger dimensions than E-pallets, sequencing, and kitting to the factory where they pick parts in the sequence the product is to be produced on the line. Since the main driver for the implementation is space limitations, Oskarshamn has decided to relocate both storing, sequencing, and kitting of large materials to the logistics center. The facility also handles the return flow of empty packaging. After packages being released in the assembly, they are transported to the logistics center and separated before sent back to the suppliers.

The same activities are performed at the logistics center in Södertälje besides sequencing. This means that they perform goods receiving, storing, kitting, handles the return flow of empty packages and have a unit supply of pallets. However, as stated in section 5.2.3, Oskarshamn handles large and bulky materials in the logistics center. In contrast, Södertälje handles smaller and standard packages in the logistics center and delivers the large material directly to the factory.

In the decision-making regarding the location of activities, in Södertälje, the decisions are made at the interface between logistics and the assembly function to see what is best from a holistic perspective since the circumstances change over time and new materials are introduced. The logistics center has a close dialogue with the assembly plants to determine the location of activities depending on the consumption of the part. They also have some discussions with people on a higher managerial level before relocating an activity. However, Scania has a general principle that pre-assembly and kitting should be performed as close to the use point as possible. Despite this, there are some exceptions, such as the pre-assembly of the driver's seats performed in the logistics center in Oskarshamn. This exception has to do with the characteristics of the materials as they are bulky and require much space in the factory. Thus, Scania always works with the principle that assembly, pre-assembly, kitting, and sequencing should be done close to the assembly while storing can be located further away. Both cases reveal that the size of the packaging, the number of variants, and the frequency of the material are other parameters to consider.

5.2.4 Advantages of operating the logistics centers

The logistics centers allow for handling and storing materials that otherwise would not have been able to fit into the assembly plants. Furthermore, this supports the customer in getting products customized to their particular needs since having more space for material available. The logistics center in Södertälje further points out that there is no need for having the same process multiple times in the flow. For instance, the logistics center has one large location for box storage, allowing Scania to develop and improve one process to make it very efficient. Thus, box storage is not carried out in the plants. Instead, the logistics center can supply parts to different assembly plants.

Furthermore, the logistics center in Oskarshamn points out the flexibility as an advantage of operating an external logistics center. This is explained by the ability of the logistics center to manage fluctuations as demanded volumes increase or decrease and variants change. Therefore, Scania does not need to expand its plant when introducing new products.

Another benefit mentioned during the interview is that all logistics centers operate in the same IT system as Scania's main plant, meaning larger transparency within the supply chain. It further allows the logistics centers and plants to have better knowledge of stock balances, for example. This is supported by having insourced the logistics activities, which Scania employees perform.

5.2.5 Disadvantages related to the logistics centers

Scania admits that having all activities within the plant would be an optimal setup. However, the current setup implies more handling and transports between the facilities, which is an undesirable consequence of the logistics centers. The logistics center in Oskarshamn and the plant also have two separate unloading locations since the logistics center manages the unloading of large pallets while the plant manages E-pallets. Therefore, the truck delivering the goods must unload at two locations, which is viewed as a disadvantage. However, the Södertälje engine assembly logistics center, located next to the main assembly, has only one goods reception for all material. Despite this, Scania considers it disadvantageous to have multiple goods receptions and handling when the plants have space limitations.

Moreover, the logistics center in Oskarshamn carries out some kitting and pre-assembly, which arguably should not be performed in the logistics center, according to Scania's guidelines. Scania has assigned the logistics center some pre-assembly since already handling the parts, including lighter assembly tasks, such as screwing or putting clips onto some component, and more difficult assemblies, such as attaching adapters onto chairs. Therefore, the logistics centers does some assembly which translates to the principle of facilitating less assembly downstream in the flow. However, there is no doubt that the logistics centers would prefer to handle more storage operations instead of the assemblies.

Another challenging aspect is delivering faulty parts from the logistics centers, which implies no spare parts are available at the assembly. Delivering incorrect parts may trigger emergency transports to replace faulty or defective items. Scania further reveals that the logistics centers might not always be responsible for incorrectly delivered material. Instead, deficiencies might occur in the assembly plant. This principally implies prolonged lead time due to the location of the logistics centers, especially the facility in Oskarshamn.

5.2.6 The performance of the logistics centers

Scania also reveals multiple perspectives on the impact of the logistics centers regarding performance, including flexibility, quality and cost.

Flexibility
As mentioned in section 5.2.4, flexibility is considered an advantage of operating logistics centers since it allows for absorbing changes in volumes and variants as the demand for different parts changes. Thus, the logistics centers handles fluctuations meaning Scania does not continuously have to rebuild the assembly plants. A logistics center further enables flexibility in the planning of transports when shipping material to Scania. This is especially important for long-distance suppliers, allowing Scania to order larger quantities to accomplish economies of scale. Another important consequence of shipping larger quantities is less CO_2 emissions from transports and decreased cost.

Quality
The Scania logistics centers further work with quality by consistently delivering the right parts at the right time to the assembly plant. Moreover, to assure quality, the logistics centers monitor the KPIs closely and work with continuous improvements. Another mentioned aspect is that the logistics centers have the same IT system as the Scania assembly plants, which implies transparency regarding stock balances etc. Therefore, it allows the logistics centers and plants to seamlessly manage the material flows to assure high-quality parts are delivered on time to the assembly.

Scania further admits that the complexity may increase if outsourcing the logistics centers activities to a third party.

The interview also reveals that if the logistics center in Oskarshamn happens to deliver the wrong item to the plant, emergency transport is set to deliver the correct component. However, it is rather unusual that the logistics center delivers the incorrect parts. Instead, it is more common that kit items are damaged in the assembly and must be replaced by emergency transport from the logistics center since no spare items are kept in the plant.

Cost
As brought up in section 5.2.5, having an external logistics center setup will require more handling and transports, making it more expensive by driving the costs up. This is especially when the transport between the logistics centers and plant is done by trailer transportation instead of transportation by pallet train between the facilities, as for the logistics center in Södertälje. However, the land on which the logistics center is established might be less expensive than the factory land, which can decrease costs. Furthermore, the logistics centers may not require complex assembly space with special equipment, assuming that logistics centers mostly perform pallet storage, picking or simpler operations.

5.2.7 Learnings from Scania

The learnings from Scania include establishing a clear interface between the plant and the logistics center, meaning having clear requirements and division of responsibility which requires clear guidelines. However, both the Oskarshamn and Södertälje logistics centers admit that the plant can be considered the customer of the logistics centers, implying that the facility should meet the plant's needs. Therefore, it is essential to work closely to understand the needs to find optimal and effective solutions for both parties that consider, for instance, quality and cost. Thus, setting clear guidelines is becoming increasingly important.

Furthermore, the purpose of an logistics center is to contribute with greater flexibility to the entire supply chain, which makes it essential to collaborate closely and communicate in cases of more significant fluctuations of ordered volumes or changes in the supplier base. This makes it important to have a close dialogue with the departments with insights into material flows to prepare the logistics center for changes.

Scania also mentions the importance of considering return flows that such logistics centers facilitate. This, therefore, implies the consideration of having reverse flows of empty packaging to accomplish a higher fill rate in both directions. Besides this, the Scania logistics centers break down the packaging by removing collars to make it more compact and stacking the packaging. According to Scania, this has the potential of decreasing transportation costs.

The final mentioned learning was that insourcing the logistics center processes, instead of having a third-party logistics provider, implies visibility in the entire flow. An external party is assumed to require additional negotiations and contractual agreements. Thus, transparent interface is needed with a 3PL compared to having the activities insourced. In addition, the flexibility is assumed to increase with an insourced logistics center setup since it allows for moving activities between the plant and logistics center.

5.3 Volvo Car Corporation

The final benchmark was performed at Volvo Car Corporation (VCC), focusing on the logistics setup concerning the Torslanda plant and their logistics center, located in Gothenburg. The interview was carried out with a material handling engineer from VCC with knowledge about global logistics.

5.3.1 Background of the logistics center at VCC

VCC has six different sites located in China, the USA, Belgium, and Sweden. The interview reveals that all factories have activities connected to a logistics center and a cross-dock via inbound operations. Linked to the Torslanda factory, there is a logistics center in place since 2010, operated by a 3PL that only performs storing activities. There is also a cross-dock connected to the factory, operated by Volvo Cars staff, where factory-related activities are performed, such as the sequencing of fuel tanks and storage of engines, etc. This corresponds to the general rule of having Volvo Cars' employees handling factory-related activities, such as value-adding activities or storing highly valuable components located outside of the factory. The areas outside the factory area have been implemented due to lack of space. Furthermore, all factory-related processes outside the factory are generally located close to the factory, approximately 10 minutes from the factory.

The reason for the existence of the logistics center was the lack of space in the factory. Therefore it was most logical to locate the center near the factory to support the factory as a factory extension, which also became possible when VCC chose to implement the same IT system internally in the factory. Another reason for the location of the logistics center is the vulnerability parameter which implies that the closer the logistics center is, the shorter the lead time and the faster problems can be solved.

5.3.2 Suppliers and materials in VCC

Suppliers that can be affected by implementing a logistics center are long-distance suppliers or overseas suppliers, as VCC generally has more in stock from these suppliers, and related materials from these suppliers will be located here. However, there are no high safety stocks in the Torslanda factory or related logistics centers due to the location of their supplier base which is in Europe and therefore has a short lead time making high safety stock unnecessary. There will not be any significant difference for the suppliers since the delivery point is not essential, i.e whether the material goes to the logistics center or directly to the factory. However, it can be important to keep track of which suppliers historically had quality issues.

The activities that are performed in the logistics center in Torslanda are mainly storing all types of pallets and large sequenced materials. As previously stated, the location of activities is situation-based, meaning the characteristics of the materials in the logistics center vary. However, size, supplier base, and frequency are parameters that are often considered. The interviewee also states that fill rate in trailers can be affected by the item size and packaging, which should be consider when moving materials out from the factory area to a logistics center.

5.3.3 Activities in the logistics center

In this case, with a lack of space in the factory, VCC must move out some processes. The activities the company choose to place outside the factory have varied over the years. It has went from outsourcing many assemblies and sequencing activities to relocating these activities back into the factory and instead outsource pallet materials. According to the interview, VCC prioritizes moving out the least value-adding activities to the logistics center, i.e pallet storage first, followed by sequencing, kitting and pre-assembly. Thus, activities are moved out according to a guideline or standard. However, according to the interview, the location of activity depends on the situation. For example, the interviewee mentions that the Torslanda factory has a 98% of its supplier base located within Europe with a lead time of 10 days to the factory while the factory in Charlestown has a higher proportion of flows coming from another continent, i.e. a higher number of overseas flows and therefore another type of setup is needed. In Charlestown, they have decided to hold a higher safety stock in inventory due to their distant supplier base compared with Torslanda. Therefore, the interview refers to a setup based on the situation where VCC must analyze every unique situation to identify what type of material can be placed outside the factory, how much, and what type of space is needed. In general, size and frequency are parameters that VCC are evaluating during a relocation.

As stated before, value-adding activities such as sequencing and kitting should generally be kept inside the factory. Space limitations can increase either due to new launches, volume changes, supplier changes, or other reasons and can therefore be planned or unplanned. In general, if a problem occurs close in time and needs to be solved fast, the planning time is reduced, which can lead to the wrong things being placed outside the factory. However, VCC often start from the area where they want to create space and investigate to identify the best potential solution and location for materials.

5.3.4 Advantages of operating the logistics center

The best scenario would be if the factory could manage to have all activities within the factory area. However, this is not the case at VCC and it is generally difficult to achieve such a state. However, it is stated that the main benefit of operating according to VCC's setup, given space limitations, is advantages in quality since the material is not handled more than necessary. This is also why pallet material is prioritized to be moved out to a logistics center before sequencing since sequenced materials are more sensitive. It is also a benefit to keep the involvement of other parties low since it becomes more difficult to get to the root cause of the problem if several people touch the material.

Another advantage is that the cost is theoretically lower with a logistics center since there is no need for a more extensive circulation of packaging in sequence or assembly flows than if shipped directly from suppliers. Several different types of parts in the same part commodity mean different material characteristics. Therefore, different types of packaging are designed to protect the material, meaning that the fill rate decreases if all sequenced parts are included. A third advantage is that pallet storing is considered a simple activity that VCC can relocate to an external logistics center, compared to more complex activities, such as sequencing. Other advantages are that logistics center uses the same IT system as used in the factory, which increases transparency, increases flexibility, and support. In summary, parameters such as quality, number of cubic meters shipped, investment costs, and access to the same IT systems are the main advantages for this setup.

5.3.5 Disadvantages related to the logistics center

One general disadvantage that VCC identifies with their setup is that adding another node to the supply chain by involving a third party affects the risk of materials getting lost. This is due to the increased complexity of involving several actors, despite potentially having control and insight into stock balances. Furthermore, if pallets get lost or damaged, a risk could be decreased quality, highlighting the importance of having close contact with the 3PL. Hence, VCC also points out the importance of documentation when goods receiving material and of reporting broken material. Despite the increased complexity, VCC admit that the problem with lost packages is relatively small due to a close relationship with the logistics center and good communication.

Moreover, using the IT system of VCC at the logistics center allows for minimizing stock balances, making the system increasingly sensitive for disturbances, which becomes an issue in severe disruptions in the supply chain. Thus, VCC mention flow optimization as a potential improvement and continuous improvement for removing process steps and increase the understanding of the activities performed by the logistics center.

5.3.6 The performance of the logistics center

As for performance measures related to the logistics center, VCC consider flexibility a crucial measure. It is also vital to ensure that the material arrives just-in-time at the appointed time without material shortages if disturbances occur along the transportation route. Furthermore, the quality and cost of having a third party performing activities externally are important compared to doing activities themselves at VCC.

Flexibility
The available space in the VCC factory in Torslanda is inflexible due to a fixed number of square meters, meaning that it is essential to evaluate how future space requirements may change when outsourcing warehousing activities to increase flexibility. Generally, however, changes in volume are difficult to manage and find appropriate solutions as the product mix and space requirement fluctuate. Despite this, VCC have managed variations in space requirements by having close contact with the logistics center, which has enabled a quick response to changes in space requirements regarding warehousing. However, in cases where the space requirements have exceeded the available space in logistics center, VCC have been forced to rent additional storage space.

Moreover, flexibility regarding volume and variant are generally difficult to manage independently of the location of the logistics activities. Furthermore, the location of the logistics center also impacts the flexibility since the proximity allows for rapid replacement in cases of deviations or missing components. The response time to retrieve and deliver an item is further estimated to 15 minutes, given availability at the logistics center. However, it might be difficult to prepare if larger disturbances occur regardless of the flexibility and resilience of a supply chain. Thus, VCC consider flexibility an important performance measure due to rapid changes in the industry.

Quality
As for quality, there is an area in the logistics center dedicated to assuring the quality by reviewing the materials before arriving to the plant by Volvo Car employees, which is particularly advantageous in cases of potential issues with some suppliers. However, the logistics center may decrease insight and understanding of quality issues and why they occur in specific processes.

Cost
VCC consider the cost of utilizing a logistics center higher than if operating the warehouse themselves or having the activities internally. However, the cost is mainly dependent upon, for instance, the geographical location of the concerned plants, unions and wage levels. Thus, the generated costs are dependent upon the context. Moreover, overhead costs are associated with outsourcing processes to external actors. Despite this, the logistics center is considered to operate more efficiently even though potentially generating higher costs. The current logistics setup with the logistics center generates costs associated with the square meter usage, operation costs, the needed equipment and staffing for VCC.

Moreover, a logistics center deviates from an ideal state of storing all material and performing all activities in-house. Therefore, according to VCC, companies should strive towards backsourcing activities to the factory by reviewing opportunities to take back space to minimize the outsourced space usage.

5.3.7 Learnings from VCC

The importance of communication with the third-party logistics provider is brought up as extremely important. Communication is further stated to be important regardless of the responsibility or ownership division of the used facility, manpower etc. Volvo Cars has several departments involved in communication with the logistics center, such as purchasing, logistics engineers working with material flows, and the ones responsible for the plant's operational reliability. Moreover, joint communication is also crucial for different departments and functions.

Furthermore, a comprehensive understanding of why certain activities are outsourced is critical. VCC suggest investigating and mapping the activities in a process to understand how the process works to determine its optimal placement. Such investigations tend to be on a higher level which may trigger the desire to understand and map the particular processes in detail. Moreover, such initiatives may reveal hidden process steps and costs that can be eliminated if appropriately understood. Thus, understanding processes is critical to decide which activities to relocate.

Another aspect, according to VCC, is the importance of understanding the actual costs associated with an external setup and looking for potential measures to minimize costs instead of implementing expensive and unnecessary solutions. This especially the case for problems or related symptoms of which the organization has limited knowledge, making it increasingly important to identify root causes. Furthermore, VCC point out the ease of getting used to the 3PL setup and related costs, as mentioned above. This is primarily since outsourcing activities may be associated with many costs, making it essential to understand why certain processes are outsourced.

Furthermore, VCC mention the desire to develop general guidelines when trying to determine which activities to potentially outsource and relocate to another actor. However, such general guidelines with specific steps are difficult to accomplish since plants operate in different contexts. On the other hand, if one plant were to operate in a static setup, it would be easier to follow general instructions. However, this is rarely the case. Instead, it is preferable to focus on understanding the drivers and reasons for relocating some processes.

Finally, as another learning, VCC points out the importance of understanding the division of responsibilities when outsourcing logistics activities to perform continuous improvements to improve processes and solve problems.

6

Data analysis

The first part of this section, 6.1, includes a benchmark analysis and answers RQ2. The second section describes the parameters to determine cost, identified to be affected by handling frequency, space requirement, and transportation frequency. Further, a cost analysis is performed and is a basis for the framework. Finally, other parameters to consider are described in section 6.4.

6.1 Benchmark analysis

This section analyzes the following parameters: the background of the logistics setups, suppliers and materials, activities and perceived advantages and disadvantages. Further, the performance, including cost, quality, and flexibility, are analyzed and the parameters to consider for other companies. Moreover, the benchmark is mainly analyzed based on the literature review summarized in section 2.

6.1.1 Overall setup of the logistics centers

Table 6.1 summarizes the different setups of external logistics centers, which includes background to the implementation of a logistics center and general information about their logistics setup.

Table 6.1: Overall setup of benchmark companies´ external logistic centers

Mack Trucks	Scania	Volvo Car Corporation
• Implementation is driven by space limitations in the plant • Less than 1 km from the plant • 3PL owns rented facility • LVO employees perform logistics activities in the LCs • 3PL carries out transports with regular traffic • LC supports two separate assembly lines in LVO plant some sequencing and kitting • Supported by supplier PuP to support long-distance flows	• Implementation of LCs driven by space limitations in plant and a high number of variants • 2 LCs in Södertälje, each LC located 100 m from the plant • 1 LC in Oskarshamn located 3 km from the plant, rented • Scania employees perform logistics activities in the LCs • LCs use internal IT system	• Implementation is driven by space limitations in the plant • 6 different sites connected to the LC or the cross-dock • LC is operated by the 3PL, performing storing activities • LC located 10 min from plant • VCC employees in cross-dock performing pallet storing and sequencing activities • LC uses the same IT system as internally in VCC Torslanda

Drivers of the implementation

It can be stated from the benchmarks that the main driver for implementing an external logistics center is the lack of space. Meaning that an external facility is needed to manage all material as they have a high number of variants. This is described by all companies in this study, i.e. Mack trucks, Scania, and VCC. The authors Hanson et al. (2016) also mention the lack of space as a common problem due to a wide variety of products which they explain can lead to manufacturing challenges. Therefore companies that cannot handle all materials within the plant usually investigate a logistics center as an option. Klingenberg & Boksma (2010) also mention that the driver for implementing supplier parks, similar as for a logistics center, is high product mix and volume flexibility. Other benefits are stated by (Baudin, 2004) mentioning that a consolidation center can be preferable in the automotive industry to reduce labor costs, postpone production, and minimize inventories. Klingenberg and Boksma (2010) however state that resource acquisition is the main reason for outsourcing activities rather than cost savings or establishing relationships, which is in line with the statements in the benchmarks.

Location of the logistics center

It can also be stated from the benchmark that each company has a logistics center located near the factory within 10 minutes' distance. Mack Trucks logistics center is located less than 1 km from the factory. Scania has one logistics center next to the factory, one 100 meters from the plant, and one 3 km from the plant. Further, VCC's logistics center is located about 10 minutes from the factory. A close distance between the logistics center and plant is considered necessary in the literature as well. Baudin (2004) states that the distance and time it takes to the external warehouse play a significant role in the quality aspect. Baudin (2004) also explains that it is easier to replace missing or defective items when activities are performed within the plant or close to the plant. Therefore, as stated in the benchmark, it is preferable to have the logistics center close to the factory. Also, having the facility close to the plant will require fewer transportations. Klingenberg and Boksma (2010) on the other hand, consider the reliability and state that longer distances between the logistics center and the plant will affect the reliability negatively. Therefore the material must be secured with a safety stock to allow continuous flow.

Integrated systems

Another similarity is that two out of three companies in the benchmark use their internal IT systems, enabling the transparency of the inventories. Richards (2014) explain that ensuring that outsourced processes remain integrated with the business is of importance by, for example, operate through the same IT systems. As stated in the benchmark, using the same IT system will support transparency between the parties. Moreover, it could also limit the potential for improvements regarding administrative processes for the external party, which is also mentioned by Hanson et al. (2016).

Operator of the logistics center

There are also some differences in the companies logistics setup, for example, regarding the facility's operator. In most cases, employees from the company are operating the logistics center and performing the activities. The only exception is the VCC logistics center, which has a third party operating the logistics center. However, VCC's cross-dock, performing sequencing and kitting, is performed by Volvo Cars employees. Moreover, when looking at the ownership of the facility, most of the companies have decided to rent the facility from a 3PL besides the logistics center in Södertälje, where Scania owns the facility. Another difference is activities performed in the logistics center and the number of flows the logistics centers' support, which is discussed further in section 6.1.3. The different setups are discussed in the literature as well. Hanson et al. (2016) explains that an external logistics center can be operated by the OEM themselves or a 3PL if there is a need to access expertise and specialist knowledge. However, Richards (2014) also mentions that cost reduction potential and increased flexibility, since freeing up space within the own facility, are reasons to outsource. Usually, companies avoid setting up a new consolidation center but instead utilizes existing companies within the industry. This can, however, mean that a consolidation center can be located further away.

Different logistic setups are also discussed by (Ackerman, 2012). The author explains that a private warehouse, meaning that the user is the operator and has total control over the warehouse and processes, is to prefer when a huge number of goods are stored and the handling volume is constant. However, the setup enables renting free space and be flexible for variations. This is the case for most companies in the benchmark, even if the handling volume is not constant. The reason for VCC's logistics center being operated by a third-party logistics provider is not mentioned but could be explained by being able to balance the variations and handling the workload. This is possible by having an independent contractor offering services, according to Ackerman (2012).

6.1.2 Suppliers and materials

Table 6.2 below summarizes the main suppliers and materials impacted by the chosen logistics setup. The respective company in the benchmark brings up different perspectives. Table 6.2 is further based on sections 5.1.2, 5.2.2 and 5.3.2.

Table 6.2: Main suppliers and materials concerned by the chosen logistic setup

Mack Trucks	Scania	Volvo Car Corporation
• Long-distance suppliers and low runners of batch material are mainly affected by the LC • The LC allows for holding of inventory to secure deliveries if disturbances occur and frees space for value-addition • Domestic suppliers delivering low-runner materials kept in LC if requiring a lot of space • Nearby suppliers frequently delivering high-runners and should not go through the LC	• LCs affect large materials for both storing, kitting and sequencing activities from both local suppliers and from long-distance suppliers • Södertälje LC stores low and medium-runner pallet material • Oskarshamn LC stores all frequencies of large materials • Long-distance suppliers that Scania buy a lot from in LC due to economies of scale	• Long-distance suppliers and overseas suppliers are mainly affected, for have more in stock • VCC Torslanda has most of its suppliers based in Europe, meaning a shorter lead time • Mainly pallet storing materials and large materials held in LC • Parameters to consider when relocating activities are size, supplier location and frequency

Long-distance suppliers and domestic supplies that deliver materials to the logistics centers are mainly affected by having an external facility. This can be connected to (Baudin, 2004) claiming that a newly implemented intermediary can be preferable when dealing with the complexity of long lead times for distant suppliers or a way to manage suppliers. However, what type of material is handled in the logistics centers differs. Mack Trucks logistic center stores mainly low runners of batch material, Scania's logistics center in Oskarshamn stores and handle large materials, while the logistics center in Södertälje stores and handle low and medium runners. Moreover, VCC's logistics center handles mainly pallets and large materials. A big difference from the logistics centers in Oskarshamn, Mack Trucks, and Volvo Cars logistics centers is that the logistics center in Södertälje chooses to deliver large material to the factory and instead handle smaller material in logistics center. This is in line with Boysen et al. (2009) claiming that bulky parts are usually delivered near the particular line segment. Despite this, most companies agree that large materials should go through a logistics center to save space but have a slightly different setup or guidelines depending on the frequency of the material. Mack Trucks and Scania in Södertälje, for instance, mention that high-runners should not go through the logistic center while VCC's logistic center handles all frequencies of pallet materials. The fact that logistics centers often handle bulky parts, as described in the benchmark, is also described by Howard et al. (2006) mentioning that logistics centers and supplier parks often handle bulky parts and parts with a wide variety.

VCC have their supplier base mainly in Europe, which means that not many suppliers are seen as long-distance suppliers. However, the location of suppliers is not mentioned in the other cases. As stated in the benchmark, having long-distance suppliers can imply that safety stocks are required, which is also confirmed by Hompel and Schmidt (2007). The authors mention that it could be feasible for suppliers due to the variety of goods, frequent ordering, and requirements of short delivery times. The authors further state that a warehouse can ensure productivity by keeping stocks to ensure the supply of the production level, which is confirmed in the benchmark. Finally, all companies agree that size, location of the suppliers and frequency are important parameters to consider when relocating logistics activities.

6.1.3 Activities performed in the logistics centers

Table 6.3 below summarizes the main activities performed in the logistics center for the respective company. Table 6.3 is further based on sections 5.1.3 5.2.3 and 5.3.3.

Table 6.3: Activities performed in the logistics centers

Mack Trucks	Scania	Volvo Car Corporation
• Takt driven processes closer to the assembly line stations • Most logistics activities are currently performed in LC • Kitting for initial assembly stations is avoided due to poor production precision • Storing can be performed outside the assembly plant • Avoid lifting tool twice • Avoid placing assembly-related activities in the LC • Large part diversity drives the relocation of the material	• Oskarshamn performs storing of all large materials, also sequencing, kitting and manages package return flows • Södertälje performs storing of small materials, some kitting and manage return flows • General principle that value adding activities should be performed close to use point • Parameters to consider are frequency, size and variants • Avoid touching high-runners twice in Södertälje LC	• Pallet storing is located in LC and prioritized to be moved • Kitting, sequencing, pre-assembly performed in plant • Location of the activities is situation based • Value-adding activities should be performed in plant, not LC • If space limitations occur, VCC starts by relocating activities from a required area

Location of the activities

Based on Table 6.3 it can be stated that different activities are located in the logistics centers depending on which company that is analyzed. However, most of the companies are performing storing activities in the logistics center. Mack Trucks has decided to locate most activities, i.e. storing, kitting, and sequencing, in their logistics center, and then strategically relocate the most value-adding activities to the factory. This strategy differs from the other companies' strategies as they use the an opposite strategy. Moreover, it is stated that storing represents several cycle times and is therefore preferred to have in Mack Truck's logistics center. Scania's logistics center in Oskarshamn has decided to perform storing activities of large materials regardless of the frequency and perform some sequencing and kitting activities of large materials. They also handle the return flow of packaging materials. The logistics center in Södertälje, on the other hand, performs storing and handling of smaller materials and low- and medium-runners and handle large material and high-runners in the factory. This since they want as few touches on the high-runners as possible. They also perform some kitting and have a return flow of packaging materials. VCC's logistics center performs storing activities of all items regardless of frequency and has value-adding activities such as kitting, sequencing, and pre-assembly in the plant.

The summarized activities are in line with Yavas and Ozkan-Ozen (2020) and (Rushton et al., 2017) statement, explaining that logistics centers often include warehousing activities, such as handling and storing to provide space in the own facility. It can also, in more complex setups, include various value-adding activities. This is also in line with the theory regarding secondary feeder lines expressing the optimal location for activities. However, Baudin (2004) states that assembly facilities should not be responsible for kitting activities due to the extensive information exchange needed since the complexity in cases of engineering changes compared to only handling individual items, which correspond to the results in the benchmark. Moreover, according to Klingenberg and Boksma (2010), logistics centers enable just-in-time deliveries of sequential materials, which could be why companies tend to relocate sequencing before kitting activities. The authors also explain that companies are more likely to relocate sequencing and storing activities to an external logistics center than kitting. The same perception is obtained in the benchmark.

Further, Baudin (2004) also explains that kit picking should preferably be done close to the use-point. This corresponds with the benchmark, showing that most companies avoid having value-adding activities in the logistics centers, unless the item is bulky. This is in line with Klingenberg and Boksma (2010) statement that storing and repackaging should be positioned before the customer order decoupling point, while kitting and sequencing should be done at the customer order decoupling point or after.

The reason why many companies have decided to operate the activities by themselves can potentially be described by Skintzi et al. (2008) statement that companies want to control and improve quality. The authors further describes that managing inventories represents 20-60% of the total assets of manufacturing firms, making it essential to evaluate who will maintain the control. However, to stay flexible and respond quickly to changes, a good solution is to outsource operations outside the company's core business. This is a good decision since it can potentially result in cheaper and better services and give economies of scale, which Volvo Cars Corporation did. Klingenberg and Boksma (2010), also state that delivery reliability can still be ensured by having an external logistics center by locating it close to the plant as even if the logistics operating costs will increase.

Parameters to consider when relocating

Further, all companies mention that the location of the activities depends on each specific situation. However, all companies have general guidelines indicating that takt-driven or value-adding processes should be placed closer to the use point. They also mention different parameters to consider when relocating activities. Most companies consider size and frequency when determining the position of the process and are trying to have value-adding activities closer to the use point. However, Mack Trucks also mentions that production precision is essential and avoid using lifting tools twice. The logistics centers connected to Scania also consider variants as well as avoiding touching high-runners twice.

To conclude, most companies have storing activities in their logistics centers, either of all pallets or large materials. Some of the logistics centers also perform some value-adding activities for large materials. However, the companies agree that value-adding activities should be performed as close to the use point as possible.

6.1.4 Perceived advantages of the respective logistics setup

Table 6.4 below summarizes the main perceived advantages brought up by respective company in the benchmark. Sections 5.1.4, 5.2.4 and 5.3.4 further provide the basis for Table 6.4.

Table 6.4: Perceived advantages of operating according to each logistics setup

Mack Trucks	Scania	Volvo Car Corporation
• IT system integration with LC enables transparency, information access, visibility and control over KPIs • Absorbs the variability of arriving goods to inbound • Allows for direct delivery to any entrance at LVO plant, reduces internal transports • LC can return packaging directly to suppliers	• Supports customers in getting the variant they demand by having material available • Limits need for redundant processes at LCs and plants • LCs providing flexibility in managing volume fluctuations • IT system integration with LCs enable transparency	• Good quality since material is not handled many times • Few responsibility issues since few parties involved • Lower cost and circulation of packaging not needed • Lower cost for performing storing of pallets in a LC • Integration of IT systems with LC provides advantages • The number of cubic meters shipped increases due to packaging optimization

Mack Trucks and Scania mention the flexibility of an logistics center as an advantage since allowing for absorbing fluctuations in material arriving at goods receptions and allowing customers to receive customized products corresponding to their needs and desires. Howard et al. (2006) explain that the main drivers for implementing supplier parks are coping with product mix and volume flexibility, which likely applies to external logistics centers as well. Skjoett-Larsen (2000) agrees that it is beneficial to utilize logistics centers when the demand fluctuates. Increased flexibility also allows for customization to a larger extent (Jain et al., 2013). Moreover, the benchmark reveals that external logistics centers support delivering goods closer to the point of use instead of a central goods receiving area.

The companies involved in the benchmark also point out that an external logistics center can decrease the need for redundant processes, i.e. several corresponding processes in the assembly plant and the logistics center, which is considered a significant advantage from such a setup. Mathisson-Öjmertz and Johansson (2000) also mention decreased complexity as an important consideration for external logistics centers. However, Baudin (2004) argues that adding intermediaries to the supply chain has limited positive impacts on enhancing the performance. According to the companies in the benchmark, a logistics center also allows for returning packaging directly from the logistics center, which is brought up by Baudin (2004) as well since consolidation centers may be disposing supplier packaging. Furthermore, using the same IT system in the logistics center as the assembly plant is further viewed as an advantage since enabling transparency in the supply chains. Ensuring that outsourced processes remain integrated also becomes evident in Richards (2014), which may be achieved through a common IT system. Therefore, the literature seem to correspond to the companies' views.

VCC also mentions increased efficiency, in terms of lower cost and improved quality, since their logistics setup mainly involves handling pallets, which is viewed as an advantage. Daehy et al. (2019) agree that outsourcing certain activities may be a cost-efficient strategy since it allows the OEM to focus on core competencies. Kulwiec (2004) and Daehy et al. (2019) further elaborate that handling full pallet loads is considered the most straightforward and cost-efficient operation. Therefore, it is reasonable to relocate such a process to an external logistics center, as the case of VCC shows, which is further supported by Klingenberg and Boksma (2010) since companies are generally more likely to relocate storing and sequencing to an external logistics center. Baudin (2004) also adds that kitting should preferably be placed close to the assembly point for quality purposes. However, Mathisson-Öjmertz and Johansson (2000) explain that adding an intermediary facility will have a negative impact on packaging level and increase the number of non-value-adding activities, which challenges the view of VCC. Furthermore, VCC states that packaging optimization allows for more efficient space utilization when transporting pallets. Lastly, Ashayeri and Gelders (1985) state that improved space utilization is an advantage of having pallet racks, which implies that pallets can be stored on top of each other. Thus, having an external logistics center can prove several advantages if designed and appropriately utilized.

6.1.5 Perceived disadvantages of the respective logistics setup

Table 6.5 summarizes the main disadvantages brought up by the companies in the benchmark. Sections 5.1.5, 5.2.5 and 5.3.5 further provide the basis for Table 6.5.

Table 6.5: Perceived disadvantages of operating according to each logistics setup

Mack Trucks	**Scania**	**Volvo Car Corporation**
• Additional handling and lead time needed for high-runner material delivered frequently • The rigidity of the IT system	• Additional lead time through handling and transportations • Separate goods receptions and unloading areas for trailers • Some kitting and assembly carried out in Oskarshamn LC • Delivering incorrect items or deficiencies to assembly plant implies additional lead time to correct quality issues	• Higher probability of losing material with a 3PL involved • Responsibility issues between LC and plant if the material gets damaged • Same IT systems make it sensitive to disturbances • Improvements could be flow optimization and relocating activities and processes

Additional handling and transportation are mentioned as downsides of external logistics centers. Hanson et al. (2016) also mention additional activities as a consequence of utilizing external logistics centers. Negative impacts on material handling efficiency are further brought up by Mathisson-Öjmertz and Johansson (2000). According to the benchmark, logistics centers may further imply longer lead times for deliveries from the logistics centers than having all material delivered from inside the assembly plant. The companies also mention that longer lead times also constitute a disadvantage if delivering incorrect items since replacing the components becomes more difficult with an external logistics center. The literature, including Fager et al. (2014) and Bozer and McGinnis (1992), mentions that a possible downside of kitting is that it more difficult to replace components in cases of missing components. Hence, the longer lead times that external logistics centers entail may severely impact product quality, according to the literature, as mentioned by the companies.

Despite recognizing certain advantages of working in integrated IT systems, as mentioned in section 6.1.4, the companies also brought up potential downsides that IT systems can bring. For instance, sensitivity if disturbances occur or the IT system only allowing for operations to be performed in a specific order, causing rigidity, are mentioned as disadvantages. However, the literature review does not primarily consider the impacts of IT systems in the manufacturing industry.

Besides this, Scania also points out two goods receptions and unloading areas as downsides, despite stating that such setup allows for removing redundant activities. Furthermore, it might be problematic to have certain activities located in an logistics center, for instance, kitting and assembly, as in Scania's logistics center in Oskarshamn. As mentioned above, the literature agrees that some activities are not preferred to place externally. For instance, Klingenberg and Boksma (2010) mention storing and sequencing, as opposed to kitting, may be located externally to a greater extent. However, Wänström and Medbo (2008) explain that sequencing activities may result in additional handling if the production sequence changes. Boysen et al. (2009) also suggest that the material characteristic, such as size, may influence the location. Therefore, based on the benchmark and literature, one might state that storing may be preferable to relocate before considering moving sequencing and kitting to external logistics centers.

VCC also mentions the difficulty of determining responsibility between the logistics center and the plant in cases of damaged material due to having a third party carrying out the logistics operations. However, they also state that such difficulties are expected when involving a 3PL to manage the logistics center. Klingenberg and Boksma (2010) suggest outsourcing activities to third parties with which the OEM has a close relationship. However, establishing trust in a business relationship requires time (Ackerman, 2012). Therefore, establishing a close working relationship may facilitate improved daily operations with fewer conflicts.

6.1.6 Affected performance variables by the logistics setups

Besides the perceived advantages and disadvantages the companies mentioned, this section goes into depth regarding how flexibility, quality and cost are affected by the logistics setups. Tables 6.6-6.8 summarizes the logistics performance variables that were mentioned by the companies in the benchmark. Sections 5.1.6, 5.2.6 and 5.3.6 further provide the basis for Table 6.6-6.8.

Flexibility
As mentioned in section 6.1.4, one of the main drivers of implementing an external logistics center is its flexibility in, for instance, creating a space that manages changes in article volumes or variants. Moreover, a logistics center may imply a decreased need for outsourcing activities to 3PLs, given that OEM employees perform activities. Limitations in space as a common disadvantage in the automotive industry which drives the need to use external logistics centers to manage product mix and volume flexibility (Hanson et al., 2016; Howard et al., 2006).

The benchmark further reveals that improved and more flexible planning is possible when determining transportation and shipping, allowing for economies of scale for long-distance suppliers. Baudin (2004) agrees that intermediaries, such as consolidation centers, in the supply chain may be used to manage long-distance suppliers and long lead times. Apte and Viswanathan (2000) also mention that companies should use full truckload shipments to accomplish efficient transports for cross-docking processes. This likely also applies to external logistics centers to accomplish efficient transports.

Table 6.6: Flexibility performance of external logistics centers

Mack Trucks	**Scania**	**Volvo Car Corporation**
• Space flexibility is created through LC to manage fluctuations in variants • LC reduces the need for outsourcing activities to 3PL • Increased flexibility with a reliable production schedule • Less flexibility due to the rigidity of the IT system at LC, may affect end-product	• LCs absorbs fluctuations in variants and volumes • Allows for economies of scale for long-distance suppliers in planning transport deliveries, thus potential CO2 reductions	• Inflexible space utilization • Close communication with LC enables variation in space requirements • VCC rents space in the LC • Proximity to the LC enables volume and variant flexibility

A reliable production schedule will further promote flexibility, according to Mack Trucks, since the logistics center can take on more logistics activities compared to having poor production precision. Wänström and Medbo (2008) also mention that certain processes, such as sequencing, can be negatively affected by changes in the production schedule, which highlights the importance of considering the reliability of the production schedule when evaluating the location to ensure flexibility. Beach et al. (2000) and Jain et al. (2013) further points out the importance of flexibility.

Quality

A logistics center may entail negative consequences for quality if items are picked individually or in cases of performing assembly-related processes. Therefore, such activities should preferably be performed within the main plant, according to Mack Trucks, which seems to correspond to the literature to a certain extent. Klingenberg and Boksma (2010) explain that storing and sequencing activities are more likely to be performed externally while kitting should be placed internally. Baudin (2004) adds that the overall quality of kits may be improved when performed close to the assembly. This is since logistics centers will imply difficulties to replace items if kits are incomplete (Bozer & McGinnis, 1992; Fager et al., 2014). Ackerman (2012) further mentions improved quality as an advantage by carrying out activities internally instead of outsourcing processes. However, storing pallets is not considered critical for quality since the packaging itself should protect the components in the pallet, according to the benchmark. Kulwiec (2004) also mentions that pallet operations are considered the least complex handling operation. Hence, the perceptions of the companies seem to correspond to the literature.

Table 6.7: Quality performance of external logistics centers

Mack Trucks	Scania	Volvo Car Corporation
• LC adds waste, may entail negative quality risks when items are picked individually • Quality sensitive materials, assembly-processes should be kept in the LVO plant • Pallet packaging is expected to protect storing materials from potential damages	• Same IT system allows for seamlessly managing flows for assuring high quality • Emergency transports from LC Oskarshamn to plant if material is not available	• Inspections done at plant assure material quality • LC entails a decreased insight into quality issues

Scania mentions that integrating the IT system seamlessly between the sites allows for managing the flows of goods to accomplish high quality. Richards (2014) also mentions the importance of having outsourced activities integrated with the business. Integrated IT systems may support transparency, but Hanson et al. (2016) state that it may also limit the potential for improvements. Moreover, in cases of material deficiencies or missing material, Scania carries out emergency transports from the external logistics center to the plant. VCC also admit to having decreased insight into quality issues when having a 3PL managing their logistics activities. Thus, inspections are required to ensure the materials are intact to fulfill the quality requirements. However, having a close relationship with the logistics center may minimize such matters due to better communication.

Cost

Lastly, the companies agree that the cost for utilizing space from an external logistics center increases due to the need for additional handling and transportation. This is especially the case if trailer transportations is needed instead of pallet trains. Baudin (2004) agrees that transporting materials with tugger trains is preferable instead of truck transportation. Therefore, a longer distance between the OEM and the logistics center will negatively impact the transportation cost. Mack Trucks also mentions that high-running materials, constitute a cost driver. Hence, it is preferable to store low-runners or goods from long-distance suppliers in a logistics center. The delivery frequency further tends to increase with smaller deliveries (Abraham et al., 1990), meaning that infrequent deliveries from long-distance suppliers will constitute a larger inventory. This leads to a large inventory and when space is limited within the assembly plant, an external logistics center holding goods from long-distance suppliers has positive implications for inventory levels at the plant. Also, VCC mention that the logistics center operates more efficiently while generating increased costs. Therefore, there is a trade-off to consider when deciding the logistics setup. It is further reasonable that the companies view an intermediary facility as creating costs in the supply chain, but by utilizing the right competencies, the literature suggests that such setup might be cost-efficient. Daehy et al. (2019) add that outsourcing might be a cost-efficient strategy since allowing the OEM to work on their core activities. Mathisson-Öjmertz and Johansson (2000) further state that the underlying assumption for cost-efficiency is that both parties focus on their core competencies.

Table 6.8: Cost performance of external logistics centers

Mack Trucks	Scania	Volvo Car Corporation
• Increases due to additional handling and transportation • High-runner pallets in the LC considered cost-driver • Positive storing low-runner materials or long-distance supplier goods in LC • LC allows for backsouring of logistics activities	• More handling and transports drive up costs, especially for Oskarshamn LC since truck transport instead of trains • Land might be inexpensive compared to plant land area, may decrease facility costs • Less complex assembly space needed in LC, compared to plant, may decrease costs	• Higher cost when utilizing an external logistics center • Overhead costs associated with outsourcing processes • LC may operate efficiently despite likely higher costs • LC associated with cost for used space, equipment, operations and manpower

Furthermore, Scania states that the land of a logistics facility might be less expensive than the land of the main plant. Also, the space needed might not be as complex as the space of an assembly, which may further decrease the cost. Galbreth et al. (2008) explain that picking is viewed as one of the most expensive operations and Kulwiec (2004) claim that pallet storing is a rather simple activity. This supports the view of Scania that space externally might not have to be as complex as an assembly space given that simpler operations are outsourced, such as storing. Klingenberg and Boksma (2010) add that storing activities only affect the cost while outsourcing sequencing and kitting processes decreases delivery speed, flexibility and reliability. In summary, despite entailing higher costs in certain areas, logistics centers may lead to decreased costs in other areas.

6.1.7 Considerations for external logistics centers

This section highlights what the benchmark companies brought up as important aspects to consider for other companies intending to implement external logistics centers. Table 6.9 below further summarizes the main points that the companies shared during the benchmark interviews. The basis for Table 6.1.7 are sections 5.1.7, 5.2.7 and 5.3.7.

Table 6.9: Other considerations for companies when to considering to implement external logistics centers

Mack Trucks	Scania	Volvo Car Corporation
• Clear strategy from the beginning when deciding relocation to avoid large investments later • Considerations to location (geographically) of a LC • Investigating true cost of IT system integration and strive towards common IT system • Potential to implement automation into the LC	• Establishing a clear interface of requirements, division of responsibility and guidelines between LC and plant • Work closely with plant and communicate if fluctuations • Importance of considering LCs handling return flows • Insourcing the LC activities instead of having third party	• Strong relationship and communication with 3PL • Understand the processes and location of activities • Understanding the actual costs linked to the LC • Have guidelines for types of materials to relocate • Understanding the division of responsibilities

Mack Trucks mentions having a clear strategy of which activities to relocate from the beginning to avoid considerable investments later on as well as considering the geographical location of the logistics center and its implications. As previously mentioned, the literature agrees that the geographical location of an external logistics center is critical and proximity is favorable. Moreover, the importance of understanding the reason for locating a specific process is brought up by VCC. It is further desirable to have clear guidelines for the re-arrangement of logistics processes. Moreover, section 7 attempts at establishing such general guidelines for the location of logistics activities.

Scania and Volvo Car Corporation further bring up an established and clear interface between the actors involved and the division of responsibilities. Another point is to work closely to communicate potential information concerning fluctuations. Communication and having a good relationship between the logistics center and plant is also mentioned as crucial by VCC. As already elaborated upon, the literature also points out the importance of the relationship between the parties.

Furthermore, investigating the actual costs of, for instance, integrating IT systems or the actual setup is viewed as highly critical before implementing an external logistics center. Such an extension may also allow for insourcing certain activities instead of having a 3PL carrying out the processes. As stated above, the need to consider costs and the potential benefits from focusing on core competencies when outsourcing activities are also evident in the literature. Thus, investigating possibilities, having a strategic direction and understanding the drivers behind outsourcing certain activities is essential before establishing an external logistics center.

6.2 Description of parameters to determine cost

From the current practices at Volvo Tuve and VMLC, described in sections 4.2-4.3, and the benchmark performed at Mack Trucks, Scania and Volvo Car Corporation, described in sections 5.1-5.3, some parameters were identified to be essential to consider for the placement of logistics processes. This section will include an in-depth description of the parameters, including handling frequency, space requirement and transportation frequency, which are seen as relevant to determine costs. These parameters will further be used in the cost analysis, section 6.3.

The data used for the analysis was provided by Volvo Group and is based on historical data for selected kitting and sequencing materials. The material selection was made in consultation with logistics engineers at Volvo Group and was selected since considered suitable materials to potentially be moved out due to their size or packaging. These specific materials are assumed to represent all kit and sequence materials in the factory and thus reliable as a basis for the general recommendation.

Importance of cost for process positioning
As stated in theory 2.5.1, cost is a parameter of high importance when determining process position. The cost that is considered relevant and comparable in this study

is handling cost, transport cost, and cost for the space. It is stated by Klingenberg and Boksma (2010) that outsourcing of value-adding activities to an external logistics center will increase personnel and transportation costs. The data is based on handling frequency, transportation frequency, and square meter space. These can be indirectly translated into a cost.

Classification of materials based on frequency
The cost analysis differentiates between the activities storing of pallets, sequencing and kitting. The activities are analyzed and compared to provide the basis for the guideline that indicates what should be prioritized to relocate. The activities are then separated and classified based on the frequency, i.e. requirement of the material on the assembly line, which was viewed as a relevant classification based on sections 4.2.1-4.2.2. The frequency is further divided into very low-, low-, medium- and high-runners differentiated on a percentage level, describing the requirement of articles. This classification by frequency is used by Volvo Group to differentiate materials in a particular activity. However, the limits were not as obvious and have been chosen in consultation with logistics engineers at Volvo Group. The percent intervals shows the share of assembled trucks in which the part is included:

- <2 % very low runners
- 2-5 % low runners
- 5-20 % medium runners and
- >20 % high runners

6.2.1 Handling frequency

One of the parameters that are considered crucial when determining the location of activities is handling frequency. This parameter is based on the demand per day, where 203 working days are assumed. The unit of the demand differs between storing and kitting and sequencing. The demand for storing pallets is described in pallets per day. In comparison, the demand is presented in picks per day for kitting and sequencing. As stated in theory, handling cost is a part of the total cost, which is essential to consider when relocating activities. Actually, 25% of the manufacturing costs are linked to material handling, according to Jeganathan and Naveenkumar (2018), and is why this parameter is chosen to be analyzed. As stated by Ashayeri and Gelders (1985) the handling costs include labor costs, operating costs, maintenance costs, services, handling rates and handling equipment. This indicates that the cost becomes higher the higher frequency that is required. Hompel and Schmidt (2007) explain that it is less efficient to manage large amounts of small quantities than the consolidated and thereby existing capacities can be utilized more efficiently and the deliveries can be balanced.

6.2.2 Space requirement

Relocating the logistics processes will enable using the released space in different ways. For instance, relocating pallet storing will mainly provide storage space, while relocating sequencing and kitting will mainly release floor space in the plant. Thus, different parameters are used when determining the space usage.

The pallet area and the number of pallets in storage were multiplied to determine the amount of storage space that could be released by relocating storing of pallets. The pallet area is based on the packaging size. Moreover, pallets are usually stored above each other to utilize the facility's height, which principally saves floor space. However, storing a pallet requires additional space besides the pallet area, such as truck aisles, which companies should consider which is why the numbers are multiplied by 1.

As for determining the space that relocating sequencing or kitting could provide, the number of affected part numbers, pallet area and bins were taken into account. The affected part numbers for sequencing include the part family, i.e. the entire sequence. In similar, kitting implies that the affected parts are the chosen parts that are to be relocated. Furthermore, the pallet area of the parts will require the floor space of the pallets but also takes the needed space for kitting aisles, truck aisles, extra surface and storage space for the pallet into account. Thus, the pallet area is multiplied with a factor of 5. This number is estimated based on a previous project carried out at Volvo Tuve and the reason is to provide a more accurate representation of the reality. Finally, it is assumed that high-runners require an additional bin per packaging, meaning that the high-running materials for sequences and kits are multiplied by 2.

6.2.3 Transportation frequency

When relocating activities, it is essential to consider how the transportation frequency will be affected and if it pays off to relocate a particular activity to an external logistics center. This is in line with Swenseth and Godfrey (2002), which describes that transportation is a big part of the total costs when handling the material. It is described in the theory that consolidation is preferred to optimize transportation and that reducing transport costs can be achieved by optimally utilizing the loading capacity as well as achieving fixed costs for transportation. The logistics engineers at Volvo Group also stated that transportation cost is vital to consider. Further, it is assumed that transportation frequency is based on when the pallet, trolley, or rack needs to be refilled. However, the transportation frequency is difficult to determine based on specific materials alone since shipping pallets, trolleys and racks in the same trailer.

For the storing activities, the demand of pallets per day is taken into account and the unit load, which indirectly depends on the part size. The bigger the article, the lower the unit load. By taking the demand per day divided by the unit load, it can be stated how many times the material needs to be refilled. The transportation frequency is stated in every x days. The demand is instead stated in trolleys or racks per day regarding the transportation frequency for the kitting and sequencing materials. It also depends on the number of chassis the kit covers.

6.3 Cost analysis

A cost analysis is performed to determine the differences in costs to perform storing or sequencing activities in the plant or a logistics center, i.e. Volvo Tuve or the VMLC. Kitting activities are not included in the cost analysis because neither the literature or benchmark advocate relocating such activities. The costs at the VMLC are assumed to represent the costs of a potential PELC setup. The analysis is intended to form a complement to the benchmark when establishing a general framework in section 7, as the location of the activities will be based on a cost, among other parameters. Further, compiled information and calculations for the cost analysis can be found in appendix C.

The cost analysis is, as previously stated, based on handling frequency, space requirement and transportation frequency which are assumed to generate the costs. These are further provided in appendix C (Table C.1-C.3) and the cost difference is presented in percentages. Moreover, the data collected from Volvo Group considers the standard costs per square meter, picks, and the cost for handling one pallet in the different locations. Further, the differences in needed handling for the various setups are considered, which are described in section 4.4.4. To be able to compare the different activities, a starting point is to determine an equally large area to release, which in this case was decided to correspond to approximately 160 square meters. In appendix C (Table C.5), it can be seen that the difference in cost for performing the activities is lowest for storing pallets. The reason why all pallets are not prioritized has to do with a assumed larger difference in transportation costs because the transportation frequency will be significantly higher for more frequent materials (as seen in Table C.1-C.3). The actual transportation cost is not taken into account in the cost analysis. Instead, it is assumed that a higher frequency of the pallets, trolleys or racks will lead to a higher transportation frequency, which increases the transportation cost. Moreover, there is a significant difference in the price between sequence material and medium-runners of pallets. The reason why sequencing material is prioritized before medium- and high-runners, despite generating significantly higher costs if placed in a logistics center, is because materials with higher frequency are desirable to hold in the factory. Moreover, the transportation cost will be higher since more pallets must be shipped in total.

Based on this, it is assumed that the handling and space cost is not decisive parameters in this case as no significant difference is visible for the different storing frequencies. Besides the cost analysis, the framework in chapter 7 will also be based on flexibility and quality.

6.4 Parameters to consider in the decision trees

Besides considering cost when determining the location for a process, it is essential to consider other important aspects as well. The parameters used in the decision trees are presented in chapter 7. These aspects are further described below and are determined to be important in consultation with logistics engineers at Volvo Tuve. The described parameters in the following section are important aspects since different materials require different setups. Also, the framework should result in a general guideline. Therefore several parameters must be analyzed before a relocation.

6.4.1 Line stopping material

Line stopping material includes critical material. If this particular material is missing, the production stops, and the operators cannot continue building the vehicle. The line stops since critical materials cannot be adjusted later, unlike other materials. The material should therefore be easily assembled and preferably inside the factory. This is an essential parameter after discussions with logistics engineers and the parameter is relevant for all materials i.e. for pallet material, sequence and kit materials.

6.4.2 Long-distance suppliers

Long-distance suppliers have, through interviews and the benchmark, been discovered to be a important parameter to take into account when relocating activities. Because it is relatively common for the supplier base to be located in other countries or continents, which affects the lead time. In this case, a supplier with a lead time of more than five days is seen as a long-distance supplier. The distance has been verified with logistics engineers and by analyzing and comparing Volvo Group's supplier base data with specified locations and lead times. With an increased lead time, safety stocks can be of great importance, making a logistics center relevant. This statement is in line with Klingenberg and Boksma (2010) and Baudin (2004) stating that long-distance suppliers should be taken into account as these have increased lead times which can implicate that large quantities of goods are being transported at once. Therefore it would be advantageous to place material from long-distance suppliers in an external logistics center. It is described that an intermediary can be an approach to deal with the complexity of long lead times for distant suppliers. By locating materials from long-distance suppliers in a logistics center, consolidation can optimize logistical performance. It is not uncommon that safety stocks are required for these suppliers and by having a logistic center that can handle these stocks, distant markets become accessible.

6.4.3 Pick up days

When it comes to pick-up days, it is an essential parameter since the number of pick-up days will affect the number of required transportations. Pick-up days are in this study referred to as the number of shippings of goods from suppliers. If the pick-up days are many, smaller quantities are probably shipped to balance the flows to the factory, while few pick-up days implies that large quantities are delivered and need to be stored. With an external logistics center, goods can be transported in full truckloads and proportioned out in smaller quantities to the factory to balance the flow. This is in line with Abraham et al. (1990) describing that in cases where the

OEM pushes the inventory upstream, the suppliers tend to deliver smaller quantities and increase the delivery frequency and cost. In this case, under two pick-up days per week might require a logistics center since higher quantities will be shipped. However, these parameters are essential to consider only for pallet materials.

6.4.4 Frequent replenishments

Replenishment frequency estimates how many times a material needs to be replaced. This depends on the unit load and material frequency i.e. how many trucks have such an item. If frequent replenishment is required, which is more than two times per day, it may be preferable to place the material in the factory instead of in an external logistics center. This makes the parameter essential to consider since handling frequency and transportation frequency are affected. Moreover, the importance of the parameter is verified with logistic engineers and is discussed briefly in chapter 4. However, it is assumed that this parameter is only important for pallet material.

6.4.5 Production precision in plant

As mentioned in 5.1.3, the benchmark with Mack Trucks revealed that the production precision of the plant is crucial when determining the location of logistics processes since the process positioning is mainly takt driven. Production precision further indicates to what extent the assembly plant manufactures according to the production schedule. Moreover, the benchmark brought up that LVO does not know whether truck will be built until the chassis is assembled at the first assembly station. Therefore, the location of logistics processes, mainly kitting and sequencing, depends on to which extent the products are assembled according to the production schedule and the lead time from the external logistics center. This implies that the location of the activities mainly affects the initial assembly stations regarding production precision.

6.4.6 Quality sensitive materials

The importance of quality becomes evident in the benchmarks as well as the literature including Baudin (2004) and Fager (2018). The benchmarks reveal that quality is critical when picking individual items, for instance, in sequencing and kitting. This corresponds to the literature since replacing missing or defective items is more convenient when materials are held within the plant, allowing for solving and avoiding issues before the assembly can continue (Baudin, 2004; Fager, 2018). Thus, the quality of more value-adding processes, such as sequencing, kitting or pre-assembly, may be negatively affected by having an external logistics center. Furthermore, few defects on products can entail customer satisfaction (Jahanshahi et al., 2011) and poor quality will imply various costs (Bergman & Klefsjö, 2010; Cheah & Shah, 2011). Therefore, material sensitivity and visibility to customers should be considered, for instance, when determining the process location. Moreover, as mentioned by Mack Trucks in section 5.1.6, the quality is not considered to be essential when storing pallets since the packaging is assumed to protect the goods. VCC also store pallets in their logistics center while keeping sequencing and kitting within the assembly plant, as seen in section 5.3.1.

As a consequence, the sensitivity or fragility of materials, visibility to customer and special handling requirements should be considered for the particular material before being relocated from the manufacturing plant. The criteria have been discussed with Volvo Group employees to determine appropriate considerations. However, it is important to evaluate the individual material when deciding on a potential relocation. Examples of material sensitivity include sensitive to dust, vibrations, pressure or electronics. Fragility is also viewed as of high importance to not deliver defect products to the use point. Moreover, if the particular item is visible to customers impacts the quality as well. For instance, materials that are sensitive to scratches, such as painted plastic or lacquered details, impacts the perceived quality. Thus, visible materials to customers might require careful handling and avoiding multiple handlings may decrease the risk for quality deficiencies. Finally, materials with special handling requirements, such as safety requirements or special storage, might not be preferable to hold and handle in an external logistics center.

6.4.7 Lifting tool requirement

In section 5.1.3, Mack Trucks also mentions that it is not preferable to use lifting tools multiple times in a material flow since adding waste. Besides adding time and equipment, the risk of damaging the item increase. Also, the use of lifting tools might further be required due to ergonomic requirements to support employees health and safety, as mentioned by Rohmert (1985). Therefore, as discussed by Falck et al. (2010), lifting tools should be used for individual items that exceed a certain weight to support employees and to avoid fatigue. Thus, the weight of the material might drive the need for using lifting tools. This reasoning is mainly applicable for sequencing or kitting materials that must be handled or picked individually. Instead, storing of pallets most often require using forklifts which is not considered a lifting tool in this context.

7 Framework

This chapter presents the established framework for determining the location of logistics activities, including storing, sequencing and kitting, of a manufacturing company. The chapter thus provides an answer to RQ3. The framework was further developed to suit other production sites besides Volvo Tuve by considering the theoretical framework, benchmarks, the performed analysis and cost analysis.

The framework consists of two main parts, including guidelines for process position and two decision trees. The process positioning guidelines, described in section 7.1 below, are rather high-level and does not consider the specific materials. Decision trees, presented in section 7.2, were further developed for considering the particular materials on an item level. Hence, the decision trees are used to complement the overall priority list. Figure 7.1 below illustrates how the framework is intended to be used.

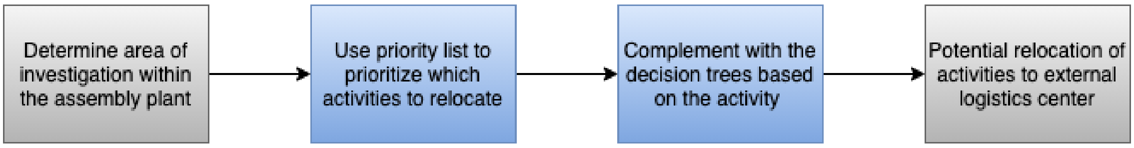

Figure 7.1: Suggested process steps for how to use the framework

As seen in Figure 7.1 above, a need to release space in the assembly plant should start by selecting a delimited area to determine what to relocate, which is followed by using the priority list in section 7.1 to decide which activities are prioritized to be relocated. Since the classification is rather high-level and does not consider particular material characteristics, the decision trees in section 7.2 should be used in addition to the priority list. The final process step is a potential relocation of the materials that constitute the activities that are to be relocated to an external logistics center.

7.1 Guidelines for process positioning

A priority list was developed to support decisions regarding the process positioning when companies have limited space in their assembly plant. The priority list presented below is further arranged based on which activities should primarily be relocated to an external logistics center. The activities are differentiated according to frequency, as described in section 6.2, for pallet storing and kitting processes.

However, sequencing processes take the materials included in the particular sequence into consideration regardless of frequency.

Priority list for process positioning

1. Pallet storing of very low and low frequency materials
2. Internal sequences of bulky materials with high variety
3. Pallet storing of medium and high frequency materials
4. Kit material of very low and low frequency
5. Other internal sequences
6. Other kit materials

The parameters considered when determining the priority for the process positioning, including handling frequency, space requirement and transportation frequency, are described in section 6.2.

The priority list for process positioning is further explained in general in section 7.1.1 and section 7.1.2 elaborates more in-depth on the activity arrangement.

7.1.1 General explanation of priority list

As seen above, the general guidelines for the process positioning follow the general principle of secondary feeder line, which is described in section 2.4. This implies that storing pallets can be performed further away from the assembly, while sequencing and kitting are preferred closer to the assembly. Moreover, kitting processes should preferably be carried out closer to the assembly or pre-assembly to minimize the time of replacing parts in cases of missing or defective material. Thus, in general, kitting has the lowest priority of relocation to an external logistics center.

There are, however, some exemptions from the principle described above. For instance, sequencing of bulky high variety materials are recommended to be relocated before pallet storing of medium- and high-frequency materials. This is since such sequence materials require large amount of space and are challenging to handle. Furthermore, pallets with higher frequency will increase transportation costs. Another exemption is the prioritization of relocating kit materials with very low- and low-frequency before some sequences. This is motivated by the fact that most very low- and low-frequency kit materials consume considerable floor space while rarely being used. Such kit materials are further assumed to be picked externally according to the manufacturing sequence and delivered to the particular kitting aisle, releasing considerable space in the plant.

7.1.2 In-depth explanation of priority list

This section elaborates more in-depth for pallet storing, sequencing and kitting materials respectively.

Pallet storing

The cost analysis in section 6.3 (appendix C) clearly shows that the least expensive activity to relocate is pallet storing if taking the handling cost and cost for space into consideration. This was especially the case for very low- and low-running pallet material, which justifies a high prioritization in the priority list in section 7.1. Furthermore, medium- and high-running material costs did not show a significant difference when considering costs for handling and space rent. However, due to their higher frequency, they would generate higher trailer and internal transportation costs. Another aspect is that pallet storing material does not primarily release floor space, which is why medium and high-running pallet storing material are not prioritized higher despite the cost analysis. Additionally, the benchmark and literature agree that the risk of quality issues when managing pallets is not viewed as critical since the packaging is expected to protect the goods. Also, handling pallets is considered a relatively simple operation, which generally motivates relocating pallet storing activities initially.

Sequencing

As for sequencing materials, the benchmark showed that most companies seems to relocate sequenced materials, especially if the items are bulky and have a large variety since it primarily constitutes larger coherent areas of floor space. The cost analysis in section 6.3 (appendix C) further shows that the costs of relocating sequencing activities to external logistics centers are significantly higher than holding the material and performing the activity in-house. Thus, the cost analysis does not motivate relocating sequencing activities. However, large and bulky materials with many different variants will release large coherent areas of floor space which motivates a potential relocation. Moreover, other sequences that do not require large floor spaces are less desirable to perform externally due to the large difference in cost, which is reflected in the priority list. Furthermore, the literature also points out potential difficulties with sequencing, such as negative production and quality consequences of potential errors in the material preparation. Also, changes in the production schedule will constitute more handling.

Kitting

Finally, kitting materials are generally the least favorable to relocate to an external logistics center, as mentioned in section 7.1.1. The companies commonly brought this up in the benchmark despite some exemptions. The literature also explains this by pointing towards potential severe quality issues if kit components are damaged or missing at the assembly since the items will be difficult to replace if the kitting is carried out externally. Furthermore, the trailer transport constitutes a significant risk of damaging the kit components since the items might not be fully protected in the kit container. Thus, it is not recommended to relocate entire kits to external logistics centers, as reflected in the priority list. However, it might be favorable to relocate a proportion of kits to release floor space in the assembly plant. Therefore, kit materials that are very low- or low-runners are suggested to be relocated since commonly requiring significant amounts of space. Moreover, if relocated, such materials are further recommended to be sequenced from the external logistics center.

Furthermore, moving out parts of different kits will entail vacancies of released space in the plant. Instead, larger coherent areas of floor space might be more desirable, as reflected in the priority list.

7.2 Decision tree

As mentioned above, the guidelines on process positioning are relatively high-level recommendations, which may not be enough to determine whether a particular activity and related material should be relocated. Therefore, two decision trees are included in the framework which considers additional aspects. Despite this, it is essential that the company using the framework, evaluates decisions while considering the particular context of the plant.

7.2.1 Pallet storage material

Figure 7.2 below represents the decision tree for pallet storing materials. The tree considers line-stopping material, long-distance suppliers, pick-up days, and the need for frequent replenishment which are parameters that have been determined to be essential to take into account by logistics engineers at Volvo Group. These are further explained in section 6.4.

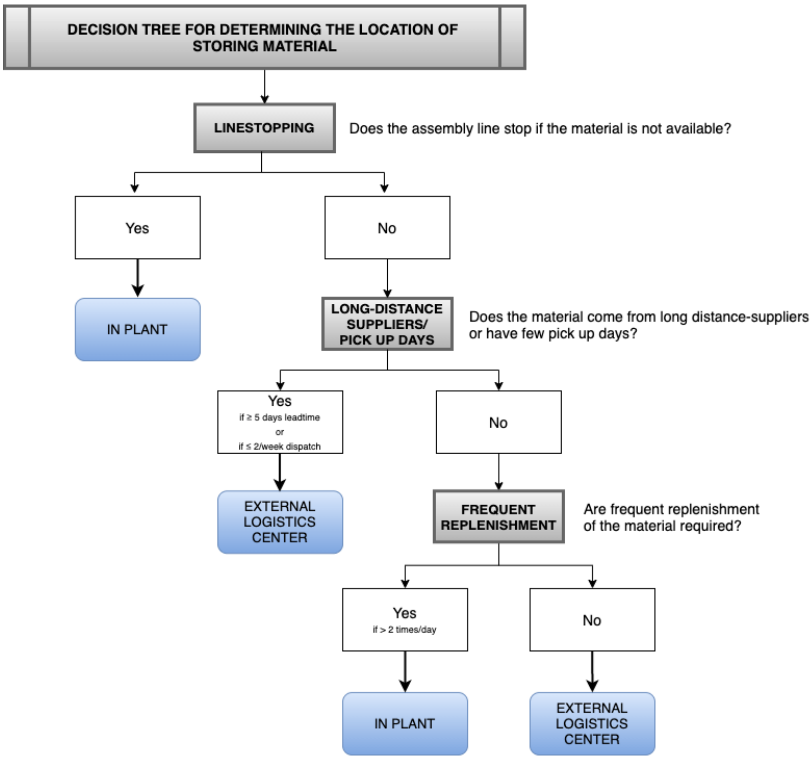

Figure 7.2: Decision tree with additional consideration when determining the location of pallet storage material

The decision tree firstly evaluates whether material is line stopping, described in section 6.4.1. Line stopping materials are recommended to be held within the plant. If the absence of the particular material does not stop the assembly line, the material is evaluated based on the distance to the supplier and pick-up days. If the lead time to the supplier is five or more days, alternatively, if the number of dispatch days is two or less, it is recommended to hold the material in the external logistics center which is described in section 6.4.2 and 6.4.3. This is done to level the arriving goods to the plant by having the extended logistics center manage the larger volumes of goods from long-distance suppliers or the large quantities that few dispatch days will imply.

Finally, the decision tree considers whether the particular pallet material must be replenished often. It is recommended to have materials that must be replenished more than two times per day in the plant. Otherwise, it is recommended to store the pallets in the external logistics center. This parameter is described in section 6.4.4.

7.2.2 Sequence and kit materials

Figure 7.3 below shows the decision tree for kitting and sequencing materials, containing parameters such as production precision, line stopping material, quality and lifting tools. The parameters have been determined to be essential to take into account by logistics engineers at Volvo Group and are explained in section 6.4.

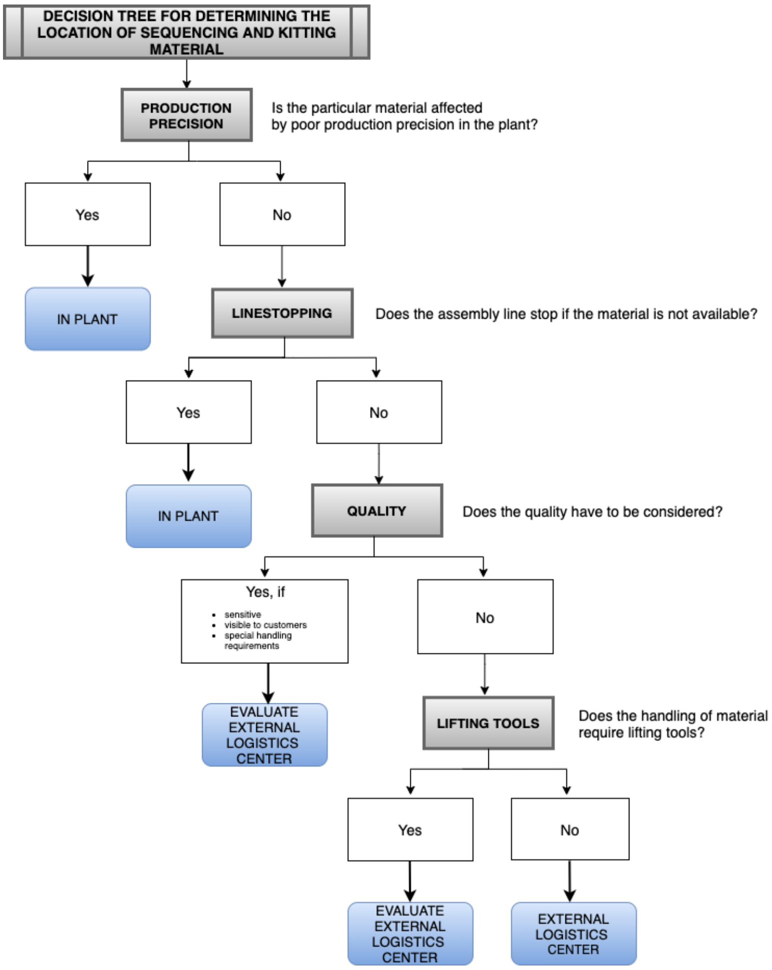

Figure 7.3: The decision tree shows which parameters that are important to consider when determining the location for kit and sequence material

As mentioned earlier, the process positioning list does not consider all the parameters, therefore the decision tree is available as a complementary part. First and foremost, it is important to take into account production precision, described in section 6.4.5. If the production precision is poor and the factory does not know which chassi to build shortly before the production starts, the material needs available and able to be handled efficiently. Therefore, the recommendation is that the material belonging to the first stations should be in the plant.

If the production precision is good, the following parameter is analyzed, which is line-stopping material, described in 6.4.1. If the material is considered as line-stopping, the material should be located in the plant. This, since the production, will stop if the material is not available which is more likely with a longer lead time. The following parameter to consider is quality, described in section 6.4.6, because this has been shown to be very important in the benchmark and interviews with logistics engineers at Volvo Group. It is preferable to evaluate an external logistics center if the material is sensitive, visible to customers, or requires special handling requirements. Furthermore, if the material is not quality sensitive, consideration should be given to whether lifting tools are necessary as it is advantageous to avoid handling material that requires tools twice as described in section 6.4.7. If lifting tools are needed, it is advantageous to consider an external logistics center. If lifting tools are not needed, the material can be placed in an external logistics center.

8
Discussion

This section contains a discussion regarding reliability and validity, followed by a framework discussion of how different locations and ownership will affect the logistics setup. Moreover, the performance measurements cost, flexibility, quality, and space will be reviewed by having an external logistics center. Finally, sustainability considerations, limitations, and ideas for future research will be discussed.

8.1 Research quality

An essential aspect for the research quality to discuss is reliability. To increase reliability, results from the current state and the benchmark are validated using factual and concrete data provided by the Volvo Tuve plant. Reliability also increases as the framework is developed including several aspects such as cost, flexibility, and quality. Furthermore, the assumptions and method used in the study are described, and by following the description, repeated studies will probably give the same results. However, if the study is performed without following the descriptions and the same assumptions, the results may differ.

One assumption that can affect the study's outcome is the frequency limits of the parts, i.e. which parts are considered low-, medium-, and high-runners. Changing the limit to a higher number probably means different materials will be included in low-runners and need to be relocated. In addition, the assumption of two bins for high-runners and one bin for the remaining items will change as probably fewer items are included in high-runners. However, more parts than just high-runners are likely to be included in the two-bin system according to Volvo Group's master process guide. Moreover, it is worth mentioning that all assumptions were made in consultation with Volvo Tuve employees, which increases credibility and means that the same results are more likely to be achieved in a repeated study.

As for validity, the thesis project considered materials viewed as a good representation when investigating the different logistics activities. These materials were determined together with logistics engineers, as mentioned above, to ensure that the materials and their specific data were applied to the project. However, a more comprehensive set of parts and numerical data, including various plant segments, could have provided a better and more holistic representation of the assembly plant. Furthermore, when analyzing the numerical data, materials for sequencing and kitting were the same as pallet storing materials since most pallets are not displayed at the assembly line, meaning that most materials are included in kits or sequences.

Moreover, the questions asked during the benchmarks were ensured with employees at Volvo Group to enhance the possibility of receiving relevant responses from the interviewees, strengthening the validity of the benchmark data. Lastly, the assumption that a PELC is a VMLC with some modifications also strengthens the project's validity by having a basis for which consequences an external logistics center could entail and applicable numerical data.

8.2 Framework discussion

The framework in section 7 was developed to support decisions regarding the process positioning when companies have limited space in their assembly plant. Although the framework was developed concerning cost, quality and flexibility, the design is not infallible and should be intended as a guideline for companies in a similar situation rather than a rule. It can be explained that the priority order for the material is situation-based and depends on several parameters. Since the framework is not adapted to all situations, it should be reviewed and adapted to each organization before relocating. Two different scenarios will be discussed below to illustrate how the prioritization will change depending on the situation.

8.2.1 Different distances

Despite the knowledge that most companies strive to place an external logistics center as close to the plant as possible, it is assumed that land is not always available nearby. Therefore, the first situation discussed is how the distance to the external logistics center will affect the prioritization and performance measurements. Most likely, companies will not be as likely to relocate value-adding activities such as kitting and sequencing at an external logistics centers located more than two hours away due to decreased flexibility that might occur. The same applies to storing frequent materials such as medium- and high-runners of pallet materials as this will mean a significant increase in the number of costly transports. A distant external logistics center would mean that more trucks would be in circulation to meet daily needs.

In addition, this setup would mean a longer lead time, which indicates that the handling in the external logistics center takes place earlier, which makes the process less flexible because the freeze fence is earlier, meaning that changes cannot be made. It should also be added that this setup has a greater chance of success in companies that have good production precision. Another problematic aspect that should be discussed is that an external logistics center further away would mean that existing Volvo employees can not be easily redirected, but instead new staff would need to be hired. This would not have been necessary for an external logistics center located within, for instance, one hour since employees may consider changing work location. On the other hand, the quality could be affected for material transported on racks as longer transports involve more vibrations that could damage the material. Therefore, the quality of racks and ensuring these should be a priority in the first place.

8.2.2 Ownership and responsibility of handlings

The framework is also assumed to change depending on the ownership of the facility and who operates the facility, a 3PL or Volvo Group employees. It is recommended that Volvo Group owns the building as there are benefits in terms of cost and space utilization. This, since the company can choose to rent out the space that is not currently used but may potentially change if the demand changes. However, the space needed can easily be adjusted if a 3PL owns the facility as well.

If Volvo Group owns the facility, the company is assumed to be more likely to place pallet materials in the external logistics center than if owned and operated by a third party. The fact that pallet materials, especially low-runners, are not given priority to be placed externally when having a third party is due to the high total cost for only storing the product, especially if stored for a long time. A usually inexpensive product would have become very expensive in the long-term if being stored in an external logistics center for a long time. Further, the total cost for the activity will be higher if being performed by a third-party than by Volvo Group employees since the profit is included in the price paid by Volvo Group. Therefore, value-adding activities are prioritized higher in the priority list if a 3PL performs the handling. The recommendation for the prioritization is also based on the secondary feeder line concept, i.e. pre-assembly, kitting and sequencing should be in proximity to the assembly line. Despite this, low-frequency kit materials can be given a higher priority to be outsourced to an external logistics center since such materials will release large amounts of space in the assembly plant.

Moreover, if a 3PL performs the activities, there is a risk that safety is not as strict as at an OEM and that they do not have as strict rules regarding ergonomics, as observed throughout the study. However, by locating certain activities externally, the OEM can utilize the 3PL's expertise and the quality can potentially increase, as seen in the literature. As mentioned in theory, one option is to "smart source" which refers to outsourcing activities to a third party the company has a close relationship with which is a good option. Further, these different setups depending on the ownership have no difference in the number of shipments or transportation costs.

8.3 Performance of an external logistics center

This section elaborates on the performance measures including cost, flexibility and quality, of having an external logistics center. The consequences for space when having external logistics centers are also discussed below since limitations in space in the assembly plant generate a need for implementing external logistics centers.

8.3.1 Cost

As illustrated in Appendix C (Table C.4), having an external logistics center will indicate an increase in handling costs. The cost increases since the cost for handling pallets, pick small and bulky items, and the cost for space will be significantly higher in an external logistics center compared to performing the handlings in-house. These costs are collected from current data that Volvo Group pays an external party operating the VMLC, which means that the cost probably will be similar if another 3PL handles the activities in an external logistics center. The costs will be slightly lower if Volvo Group employees perform the activities since no profit is included in the cost. However, neither option will be lower than performing the activities in the plant.

By relocating kitting activities to the external logistics center, additional handlings will occur. This since the kit material will be delivered in a sequence to a kitting area. However, it can be profitable to have two handlings of kit materials, even for low-frequency material because this setup will save valuable space inside the factory and in the kitting area, which is, according the concept of secondary feeder line, as described in 2.4, most likely close to the production line. Although the pallet area in Tuve is estimated per square meter, the square meter price per pallet is assumed to be lower as pallets can be stacked on top of each other in an external logistics center and require significantly less space. Therefore, it can be more expensive to relocate pallet storage to an external logistics center compared to store pallets in-house. However, this can be a good option since it creates space inside the factory.

As mentioned earlier in section 6.3, handlings do not play a significant role in costs. The cost that probably matters the most is the transport cost which is driven by the transport frequency. However, an external logistics center enables full truckloads which becomes cheaper and can enable just-in-time deliveries if the facility is close.

8.3.2 Flexibility

The effects on flexibility by using an external logistics center can be addressed with the given background information about external logistics centers and the utilization. An external logistics center will enable and support volume, variation, and to some extent deviation flexibility if located close to the plant. Volume flexibility will be positively affected as more space will be available for pallet storing and picking activities if the demand increases. If the demand instead decreases, there are opportunities to rent out parts of the facility to other parties. This is an option if Volvo Group owns the facility, which will increase the flexibility. The same applies to variant flexibility. In addition, flexibility in which activities to perform externally is positively affected if certain activities are transferred to a 3PL that performs the activities within their core business.

When it comes to deviation, the parameter is negatively affected by an external logistics center. This because the additional lead time between the facility and plant will increase the response time. The response time will further play a crucial role and will be extended even if the same IT system is applied. However, the deviation can be positively affected for kit and sequence material as the distance will probably be shorter from the external logistics center than from a supplier.

Moreover, an external logistics center enables several delivery points in the factory. The delivery is planned and loaded more appropriately and therefore the material can be delivered closer to the use point. Waste, in the form of internal transports, can thereby be reduced. An external logistics center also enables consolidation, downsizing activities, and transport optimization. Such a facility can also enable managing of return flows of packaging to suppliers. These activities mean that a higher transportation fill rate and return flows can be achieved in the trailers, as mentioned above, compared to direct shipping from suppliers. However, it is difficult to achieve a full truckload with sequence material delivered on racks since these cannot be stacked. Furthermore, if the production stops due to, for instance, a national holiday, materials from overseas suppliers can still be delivered. An external logistics enter can manage this overcapacity and the incoming material to be stored, which is a sign of high volume flexibility.

8.3.3 Quality

As seen in the value stream mapping in section 4.4.4, having an external logistics center will imply additional handlings in total, which might increase the risk of a quality issue occurring. This is especially the case for sequencing and kitting of material since the items are picked individually. However, the packaging is expected to protect pallets from possible damages, minimizing possible quality issues of damaged items. Furthermore, the transportation between the facilities might damage sequence or kit materials if transporting materials from the external logistics center requires trailer transport since racks and trolleys might not be designed optimally to protect individual components. Moreover, the quality might further be facilitated by having kit materials of very low and low runners sequenced to the kitting aisles instead of being entirely kitted in the assembly plant by improving the picking accuracy. Despite picking the items twice, the quality is not expected to decrease since only displaying the right components in the assembly kit aisle. Finally, an external logistics center further facilitates the holding of safety stocks that may impact the delivery quality by receiving goods to the plant despite potential disturbances in the incoming material flow.

8.3.4 Space

Considerations of establishing an external logistics center are mainly triggered by space limitations within the assembly plant due to requirements on highly customized products, as mentioned in section 1.1.2. Thus, introducing such external facilities for performing certain logistics activities will therefore release additional space within the plant if relocating materials. Moreover, relocating different logistics will entail either storage or floor space. Relocating pallet storing will provide storage space, whereas sequence and kit materials will provide floor space. Both types of space are likely desirable within assembly plants. Another aspect is that releasing storage space in racks might be necessary before releasing floor space, especially in kitting aisles where firms might store pallets above to utilize facility's height.

Furthermore, if relocating kitting of very low and low frequent materials, as suggested in the priority list in section 7.1, it is important to note that the trolley of sequenced kit materials will require floor space in the kitting aisles. Hence, the sequence of very low and low-runners will not release equally as much space as the materials correspond to. Further, re-positioning of low running kit materials usually corresponds to large areas of space since consisting of many part numbers. However, only relocating such kit materials will entail vacancies in the plant, which might not be desirable since there is a need for larger coherent areas. Therefore, the framework and process description in section 7 suggests choosing an area in the assembly. Companies should then evaluate the particular area of investigation before deciding which activities to relocate to an external logistics center.

An external logistics center will further allow for storing of safety stocks. Also, if production stops occur, an external logistics center will entail that storing materials received from suppliers can be managed in the external logistics center. This is especially important when the plant does not manage to stop the incoming goods from suppliers when severe production stops occur. Finally, having high and medium-runners in an automated storage location would further benefit from utilizing the automatization in the plant instead of having low and very low runners in such storage, i.e. tied-up capital.

8.4 Sustainability considerations

Introducing an external logistics center will also impact sustainability in various ways. The sections below discuss the economic, ecological and social aspects of sustainability of having an external logistics center.

8.4.1 Economic

Concerning the financial aspect of implementing an external logistics center, the cost is assumed to increase due to higher costs for space, handling, and transport activities compared with performing them in-house. There would mainly be a significant increase in costs if the handling of activities were done by a 3PL, as this is an external company that must make profit, which is not the case if Volvo Group employees perform the handling. However, an external logistics center enables consolidation, which will mean that full truckload (FTL) transports are achieved from suppliers to the external logistics center as more material can be stored. Moreover, an FTL is cheaper than less than truckload (LTL) shipping which will reduce the costs.

8.4.2 Ecological

Despite allowing for FTL transports which is beneficial from an economic perspective, as mentioned above, an external logistics center would increase the number of trailer transports to the plant to have a just-in-time flow of goods. The increased number of trailer transports would further imply emitting more airborne emissions. However, an intermediate facility would also allow for transporting FTLs from the suppliers, which potentially could have a positive impact on emissions. Additionally, an external logistics center supports FTL from long-distance suppliers, enabling shipping larger quantities, i.e. fewer transportations, since such a facility can hold more inventory, which could positively impact emissions. Moreover, the propulsion of the used transportation mode, i.e. combustion or electric vehicles, will play a crucial role in ecological sustainability. In a way, a driver for implementing a logistics center externally for Volvo Group is to be able to provide the truck market with electric vehicle solutions, meaning that an external logistics center itself could be advantageous if considering ecological sustainability. However, the source of the used electricity will determine the impact on environmental sustainability.

8.4.3 Social

A social consideration concerning social sustainability is that having Volvo Group employees performing the activities in an external logistics center may imply improved ergonomic conditions compared to having a 3PL perform the operations. For instance, Volvo Group might be particularly careful of having lifting tools used for certain picks, whereas a 3PL might not find it as important to have available, as observed. Therefore, ergonomic conditions may be worsened, possibly leading to injuries or absence due to illness. Furthermore, a setup with an external logistics center could provide new work opportunities, such as truck drivers or operators. Another social aspect could be that an external logistics center allows for a more leveled distribution of incoming goods to the goods reception. This implies that Volvo Tuve can estimate the needed manpower and eliminate peaks in arriving goods, which will entail an even workload for operators.

8.5 Limitations

The thesis project had some limitations in the data used. To differentiate between sequencing and kitting activities in the data and practically in the plant was relatively challenging, making it difficult to evaluate sequencing and kitting activities separately. Moreover, the data used could not be grouped based on the part commodity, meaning that sequencing materials were assumed to belong to the same part commodity. Similarly, kitting materials were also not possible to differentiate based on the part commodities, which entailed a differentiation based on demand frequency, i.e. very low, low, medium and high-runners. Furthermore, the study did not consider small boxes since containing small materials and thus not significant for the project.

Furthermore, the project did not consider how relocating certain materials belonging to the respective activity would impact the entire flow of materials. For instance, when optimizing transports, the entire flow is considered instead of individual or groups of materials. The project further does not consider the number of transports needed to fulfill the need when transporting goods from the external logistics center to the plant, meaning that the fill rate was not considered. Such considerations would have been valuable to consider in the cost analysis to determine and suggest the location of the logistics activities.

8.6 Future research

The thesis project provides strategic advice on the preferable location of logistics activities, including pallet storing, sequencing and kitting, when the assembly plant lacks space availability and must consider utilizing an external logistics center. However, future research in the area could include considerations to how the flow of materials would be affected by relocating the materials to an external logistics center. Future investigations at the Tuve plant could also consider more materials to verify the recommendations provided in section 7. Volvo Tuve could also investigate the transportation cost and fill rate of the transports to support the findings in the thesis. Lastly, performing benchmarks on companies within other industries and evaluating the applicability of the provided framework and strategic recommendations would have provided a broader perspective of the location on logistics activities in general.

9
Conclusion

The thesis work has provided a structured framework with strategic advice on the process positioning of certain logistics activities, including pallet storing, sequencing, and kitting when there are space limitations in the assembly plant. This was carried out by investigating current practices at Volvo Tuve by benchmarking other companies within the automotive industry and analyzing Volvo Group's numerical data. The project's premise was to investigate, evaluate, and prioritize which logistics activities may be relocated to external logistics centers and which activities should be carried out within the assembly plant.

The current state practices at Volvo Tuve show that a 3PL is responsible for some sequencing and kitting, whereas pallet storing is widely performed within the assembly plant. However, current general guidelines reveal that rather value-adding activities are preferred to have close to the assembly line, such as pre-assembly or kitting. Aligned with this, the benchmark, performed with Mack Trucks, Scania and Volvo Cars Corporation, shows that pallet storing may generally be performed externally, whereas kitting and sequencing may be preferable to have within the plant. Along with this, a cost analysis was carried out to evaluate the consequences of re-positioning storing and sequencing activities in monetary terms. A general framework was provided based on the data, flexibility and quality aspects, which suggests that processes should be prioritized according to the following order; pallet storing of very low and low-frequency materials, bulky and high variety material sequences, pallet storing of medium and high-frequency materials, very low and low-frequency kit materials, other sequences and, lastly, other kit materials. Moreover, the priority list is complemented with decision trees to consider more context and material-specific attributes since the priority list is limited to a classification of the logistics processes.

Finally, the thesis project thus presents general guidelines for the process positioning of logistics activities for companies within the automotive manufacturing industry. However, it is critical to evaluate and consider the particular context of the firm before adopting the framework. Furthermore, the complexity of various aspects for determining the process positioning of logistics activities drives the need to consider certain parameters. The study further recommends that each company examine the frequency of the materials, size of parts, pallet area, number of pallets and the unit load before applying the framework and guidelines.

References

Abraham, Y. T., Holt, T., & Kathawala, Y. (1990). Just-in-time: Supplier-side strategic implications. *Industrial Management Data Systems*, *90*(3), 12–17.

Ackerman, K. B. (2012). *Practical handbook of warehousing.* Springer Science Business Media.

Alford, D., Sackett, P., & Nelder, G. (2000). Mass customisation—an automotive perspective. *International Journal of production economics*, *65*(1), 99–110.

Aminoff, A., Kettunen, O., & Pajunen-Muhonen, H. (2002). Research on factors affecting warehousing efficiency. *International Journal of Logistics*, *5*(1), 45–57.

Apte, U. M., & Viswanathan, S. (2000). Effective cross docking for improving distribution efficiencies. *International Journal of Logistics*, *3*(3), 291–302.

Ashayeri, J., & Gelders, L. F. (1985). Warehouse design optimization. *European Journal of Operational Research*, *21*(3), 285–294.

Ax, C., Johansson, C., & Kullvén, H. (2015). *Den nya ekonomistyrningen.* Liber AB. (in Swedish)

Azzi, A., Battini, D., Faccio, M., & Persona, A. (2012). Mixed model assembly system with multiple secondary feeder lines: layout design and balancing procedure for ato environment. *International Journal of Production Research*, *50*(18), 5132–5151.

Baudin, M. (2004). *Lean logistics: the nuts and bolts of delivering materials and goods.* Productivity Press.

Bauer, J. E., Duffy, G. L., & Westcott, R. T. (2006). *The quality improvement handbook.* American Society for Quality.

Beach, R., Muhlemann, A. P., Price, D. H., Paterson, A., & Sharp, J. A. (2000). A review of manufacturing flexibility. *European journal of operational research*, *122*(1), 41–57.

Bell, J., & Waters, S. (2018). *Doing your research project: A guide for first-time researchers (7th ed.).* McGraw-Hill Education.

Bennett, D. (2014). Future challenges of manufacturing. *Journal of Manufacturing technology*, *25*(1), 2–6.

Berg, B. L. (2009). *Qualitative research methods: For the social sciences (7th ed.).* Pearson.

Bergman, B., & Klefsjö, B. (2010). *Quality from customers needs to customer satisfaction.* Studentlitteratur AB.

Blecker, T., & Abdelkafi, N. (2006). Mass customization: state-of-the-art and challenges. *International Series in Operations Research Management Science*, *87*, 1–25.

Boysen, N., Fliedner, M., & Scholl, A. (2009). Level scheduling for batched jit supply. *Flexible Services and Manufacturing Journal*, *21*(1), 31–50.

Bozer, Y., & McGinnis, L. F. (1992). Kitting versus line stocking: A conceptual framework and and a descriptive model. *International Journal of Production Economics*, *28*(1), 1–19.

Bryman, A., & Bell, E. (2015). *Business research methods (4th ed.).* Oxford University Press.

Brynzér, H., & Johansson, M. I. (1995). Design and performance of kitting and order picking systems. *International Journal of production economics*, *41*(1), 115–125.

Burns, L. D., Hall, R. W., Blumenfeld, D. E., & Daganzo, C. F. (1985). Distribution strategies that minimize transportation and inventory costs. *Operations research*, *33*(3), 469–490.

Cheah, S. J., & Shah, A. (2011). Tracking hidden quality costs in a manufacturing company: an action research. *International Journal of Quality Reliability Management*, *28*(4), 405–425.

Chen, L., & Notteboom, T. (2012). Determinants for assigning value-added logistics services to logistics centers within a supply chain configuration. *Journal of International Logistics and Trade*, *10*(1), 3–41.

Church, R. M. (2002). The effective use of secondary data. *Learning and motivation*, *33*(1), 32–45.

Creswell, J. W. (2009). *Research design: qualitative, quantitative, and mixed methods approaches (3rd ed.).* Sage.

Cullen, T. (2002). Carmakers split on supplier parks. *Automotive News Europe*, *7*(26), –.

Daehy, Y., Krishnan, K., Alsaadi, A., & Alghamdi, S. (2019). Effective cost minimization strategy and an optimization model of a reliable global supply chain system. *Uncertain Supply Chain Management*, *7*(3), 381–398.

Dede, B., & Çengel, (2020). Efficient warehouse management analysis in logistics services. *İstanbul Ticaret Üniversitesi Sosyal Bilimler Dergisi*, *19*(37), 341–352.

Dudovskiy, J. (2018). *Business research methodology.* Retrieved from `https://research-methodology.net/research-methods/qualitative-research/observation/`

Dyer, J. H. (1996). Specialized supplier networks as a source of competitive advantage: evidence from the auto industry. *Strategic Management Journal*, *17*(4), 271–291.

Dyer, J. H., & Singh, H. (1998). The relational view: cooperative strategy and sources of interorganizational competitive advantage. *Academy of Management Review*, *24*(4), 660–679.

ElMaraghy, H., Azab, A., Schuh, G., & Pulz, C. (2009). Managing variations in products, processes and manufacturing systems. *CIRP annals*, *58*(1), 441–446.

Fager, P. (2018). *Materials preparation handbook: Guidelines for choice of materials preparation design.* Chalmers University of Technology.

Fager, P., Johansson, M. I., & Medbo, L. (2014). *Quality problems in materials kit preparation.* In Proceedings of the 6th Swedish Production Symposium.

Falck, A. C., Örtengren, R., & Högberg, D. (2010). The impact of poor assembly ergonomics on product quality: A cost–benefit analysis in car manufacturing. *Human Factors and Ergonomics in Manufacturing Service Industries*, *20*(1), 24–41.

Fogliatto, F. S., Silveira, G. J., & Borenstein, D. (2012). The mass customization decade: An updated review of the literature. *International Journal of production economics*, *138*(1), 14–25.

Fredriksson, P., & Gadde, L. E. (2005). Flexibility and rigidity in customization and build-to-order production. *Industrial Marketing Management*, *34*(7), 695–705.

Fujimoto, T. (1999). *The evolution of a manufacturing system at toyota.* Oxford University Press.

Galbreth, M. R., Hill, J. A., & Handley, S. (2008). An investigation of the value of cross-docking for supply chain management. *Journal of Business Logistics*, *29*(1), 225–239.

Gerwin, D. (1987). An agenda for research on the flexibility of manufacturing processes. *International Journal of Operations Production Management*, *7*(1), 39–49.

Gibb, A. (2001). Standardization and pre-assembly-distinguishing myth from reality using case study research. *Construction Management Economics*, *19*(3), 307–315.

Gibb, A., & Isack, F. (2003). Re-engineering through pre-assembly: client expectations and drivers. *Building research information*, *31*(2), 146–160.

Hanson, R., & Brolin, A. (2013). A comparison of kitting and continuous supply in in-plant material supply. *International Journal of Production Research*, *51*(4), 979–992.

Hanson, R., Medbo, L., & Johansson, M. I. (2016). *Performance effects of using external warehouses in materials supply to assembly.* In: Proceedings of the 20th EurOMA conference, Trondheim.

Heale, R., & Twycross, A. (2015). Validity and reliability in quantitative studies. *Evidence-based nursing*, *18*(3), 66–67.

Higgins, C. D., Ferguson, M., & Kanaroglou, P. S. (2012). Varieties of logistics centers: Developing standardized typology and hierarchy. *Transportation research record*, *2288*(1), 9–18.

Hompel, M., & Schmidt, T. (2007). *Warehouse management: Automation and organization of warehouse and order picking systems.* Springer.

Howard, M., Miemczyk, J., & Graves, A. (2006). Automotive supplier parks: An imperative for build-to-order? *Journal of purchasing and supply management*, *12*(2), 91–104.

Jahanshahi, A. A., Gashti, M. A. H., Mirdamadi, S. A., Nawaser, K., & Khaksar, S. M. S. (2011). Study the effects of customer service and product quality on customer satisfaction and loyalty. *International Journal of Humanities and Social Science*, *1*(7), 253–260.

Jain, A., Jain, P. K., Chan, F. T., & Singh, S. (2013). A review on manufacturing flexibility. *International Journal of Production Research*, *51*(19), 5946–5970.

Jeganathan, G., & Naveenkumar, K. (2018). Material handling management in third party logistics warehouse. *International Journal for Research in Engineering Application Management*, *4*(8), 1–3.

Johansson, E., Bellgran, M., & Johansson, M. I. (2006). Evaluation of materials supply systems during product development projects. *International Journal of Production Research*, *44*(5), 903–917.

Johansson, E., & Medbo, L. (2004). On the use of product data in the design of the materials supply system. *Journal of Manufacturing Technology Management*, –.

Johansson, M. I. (1991). *Kitting systems for small size parts in manual assembly systems.* In: Pridham, M. and O'Brien, C. (eds.) Production research - approaching the 21st century.

Jonsson, P., & Mattsson, S. A. (2016). *Logistik: läran om effektiva materialflöden (3rd ed.).* Studentlitteratur AB. (in Swedish)

Khan, A., & Turowski, K. (2016). A survey of current challenges in manufacturing industry and preparation for industry 4.0. *In: Advances in intelligent systems and computing*, *450*, 15–26.

Klingenberg, W., & Boksma, J. (2010). A conceptual framework for outsourcing of materials handling activities in automotive: differentiation and implementation. *International Journal of Production Research,*, *48*, 4877–4899.

Koste, L. L., & Malhotra, M. K. (1999). A theoretical framework for analyzing the dimensions of manufacturing flexibility. *Journal of operations management*, *18*(1), 75–93.

Koster, R. B. M., Johnson, A. L., & Roy, D. (2017). Warehouse design and management. *International Journal of Production Research*, *55*(21), 6327–6330.

Kulwiec, R. (2004). Crossdocking as a supply chain strategy. *Target*, *20*(3), 28–35.

Laine, M. M. (1979). he north american truck manufacturing industry. *Theses and Dissertations (Comprehensive)*, *1525*, –.

Liker, J. K. (2004). *The toyota way*. McGraw-Hill.

Lin, R. J., Chen, R. H., & Nguyen, T. H. (2011). Green supply chain management performance in automobile manufacturing industry under uncertainty. *Procedia-Social and Behavioral Sciences*, *25*, 233–245.

Mathisson-Öjmertz, B., & Johansson, M. I. (2000). Influences of process location on materials handling: cases from the automotive industry. *International Journal of Logistics*, *3*(1), 25–39.

Min, H. (2009). Application of a decision support system to strategic warehousing decisions. *International Journal of Physical Distribution Logistics Management*, *39*(4), 270–281.

Netland, T. H., & Aspelund, A. (2013). Company-specific production systems and competitive advantage: a resource-based view on the volvo production system. *International Journal of Operations Production Management*, *33*(11), 1511–1531.

Nieuwenhuis, P., & Wells, P. (2015). *The global automotive industry (1st ed.)*. John Wiley Sons.

Nikolic, B., Ignjatic, J., Suzic, N., Stevanov, B., & Rikalovic, A. (2017). Predictive manufacturing systems in industry 4.0: Trends, benefits and challenges. *Annals of DAAAM Proceedings*, *28*, –.

Noor, K. B. M. (2008). Case study: A strategic research methodology. *American journal of applied sciences*, *5*(11), 1602–1604.

Patel, P. C. (2011). Role of manufacturing flexibility in managing duality of formalization and environmental uncertainty in emerging firms. *Journal of Operations Management*, *29*(1), 143–162.

Richards, G. (2014). *Warehouse management: A complete guide to improving efficiency and minimizing costs in the modern warehouse (2nd ed.)*. Kogan Page.

Rohmert, W. (1985). Ergonomics and manufacturing industry. *Ergonomics*, *28*(8), 1115–1134.

Roy, D., Carrano, A. L., Pazour, J. A., & Gupta, A. (2016). Cost-effective pallet management strategies. *Transportation Research Part E: Logistics and Transportation Review*, *93*, 358–371.

Rushton, A., Croucher, P., & Baker, P. (2017). *The handbook of logistics and distribution management: Understanding the supply chain (6th ed.).* Kogan Page Ltd.

Saleh, J. H., Mark, G., & Jordan, N. C. (2009). Flexibility: a multi-disciplinary literature review and a research agenda for designing flexible engineering systems. *Journal of engineering design*, *20*(3), 307–323.

Sali, M., & Sahin, E. (2016). Line feeding optimization for just in time assembly lines: An application to the automotive industry. *International Journal of Production Economics*, *174*(1), 54–67.

Sali, M., Sahin, E., & Patchong, A. (2015). An empirical assessment of three line feeding modes used on the automotive sector: line-stocking vs. kitting vs. sequencing. *International Journal of Production Research*, *53*(5), 1439–1459.

Schell, C. (1992). The value of the case study as a research strategy. *Manchester Business School*, *2*(1), 1–15.

Sethi, A. K., & Sethi, S. P. (1990). Flexibility in manufacturing: a survey. *International journal of flexible manufacturing systems*, *2*(4), 289–328.

Shenoy, D., & Rosas, R. (2018). *Problems solutions in inventory management (1st ed.).* Springer International Publishing.

Skintzi, G., Ioannou, G., & Prastacos, G. (2008). Investigating warehousing policies. *International Journal of Production Economics*, *112*(2), 955–970.

Skjoett-Larsen, T. (2000). Third party logistics–from an interorganizational point of view. *International journal of physical distribution logistics management*, *30*(2), 112–127.

Skärvad, P. H., & Olsson, J. (2015). *Företagsekonomi 100 (17th ed.).* Liber. (in Swedish)

Svensson, G. (2000). A conceptual framework for the analysis of vulnerability in supply chains. *International Journal of Physical Distribution and Logistics Management*, *30*(9), 731–749.

Svensson, G. (2006). Sequential service quality in service encounter chains: case studies. *Journal of Services Marketing*, *20*(1), 51–58.

Swenseth, S. R., & Godfrey, M. R. (2002). Incorporating transportation costs into inventory replenishment decisions. *International Journal of Production Economics*, *77*(2), 113–130.

Sörqvist, L. (2001). *Kvalitetsbristkostnader: Ett hjälpmedel för verksamhetsutveckling.* Studentlitteratur. (in Swedish)

Tracey, M. (1998). The importance of logistics efficiency to customer service and firm performance. *The International Journal of Logistics Management*, *9*(2), 65–81.

Trochim, W. M., Donnelly, J. P., & Arora, K. (2016). *Research methods: The essential knowledge base (2nd ed.).* Cengage.

Trzcielinski, S., & Karowowski, W. (2012). *Advances in ergonomics in manufacturing (1st ed.).* CRC Press.

Upton, D. M. (1994). The management of manufacturing flexibility. *California management review*, *36*(2), 72–89.

Vivid, R. P., Selvakumar, N., & Ruvankumar, M. (2020). Determination of hazard in truck manufacturing industry using hazard identification risk assessment technique. *Materials Today: Proceedings*, *27*(2), 1858–1862.

Volvo Group. (2019). *Annual and sustainability report 2019.* Retrieved from `https://www.volvogroup.com/en-en/events/2020/mar/annual-and-sustainability-report-2019.html`

Volvo Group. (2020a). *Tuve plant.* Retrieved from `https://www.volvogroup.com/en-en/about-us/organization/our-production-facilities/tuve.html`

Volvo Group. (2020b). *Volvo lastvagnar lanserar ett komplett program med eldrivna lastbilar i europa under 2021.* Retrieved from `https://www.volvogroup.se/sv-se/news/2020/nov/news-3820369.html?sc_cid=semb-5918775143&gclid=CjwKCAiAgJWABhArEiwAmNVTB1Ewx4AEo8M4t5_xYWr1AP5DMbRtwas4Q3mWrJwmCWOdNNlD9LoKuBoCNAcQAvD_BwE`

Williams, C. E. (1972). *The costing of handling and storage in warehouses.* Her Majesty's Stationery Office.

Wilson, V. (2012). Research methods: interviews. *Evidence Based Library and Information Practice*, *7*(2), 96–98.

Wänström, C., & Medbo, L. (2008). The impact of material feeding design on assembly process performance. *Journal of Manufacturing Technology Management*, *20*(1), 30–51.

Yavas, V., & Ozkan-Ozen, Y. D. (2020). Logistics centers in the new industrial era: A proposed framework for logistics center 4.0. *Transportation Research Part E*, *135*(3), 2–18.

A

Appendix - Selection of current state interview questions

Processes

- Could you describe the activities kitting, sequencing and storing?
- How they processes currently performed in the Volvo Tuve plant?
- How can the activities be categorized?
- What do you think is important to consider when implementing a PELC regarding processes?

VMLC

- What does a typical process look like at VMLC?
- What value-added activities are performed?
- What articles are handled at VMLC and what characterizes the articles?
- How does VMLC work with quality and flexibility?
- Who will take the responsibility if a problem occurs?

PELC

- What is the current perception of what a PELC setup would entail?
- Which activities could be performed in a PELC?
- Which are the main differences between a VMLC and a PELC setup?
- Which are the main differences between performing activities in Volvo Tuve and a PELC on a process level?

B

Appendix - Selection of benchmark interview questions

Background

- What does the current logistics setup look like?
- Why is this particular setup used?
- What is the distance between the plant and the logistic center and why is it located there?
- What does the division of responsibility and ownership look like?

Activities and suppliers

- Which activities are performed within your logistics center and how is this decided?
- What are the characteristics of the activities performed or material in the logistic center?
- Which material and/or suppliers are affected by your logistics setup?
- Do you perform any activities within the plant or logistic center that you think should be relocated?

Advantages and disadvantages

- Which are the main perceived advantages of operating according to your setup?
- Are there any potential perceived disadvantages with the logistics setup?
- Are there any frequent issues between the logistics center and the plant?

Performance

- Which performance measurements are important to consider when relocating logistics activities?
- How is flexibility (in terms of volume/variant/deviation flexibility), quality and cost affected by this logistics setup?

Learnings

- Are there any considerations or recommendations for companies considering relocating some logistics activities?
- Which are the main learnings from operating according to this setup?

C

Appendix - Cost analysis

Table C.1: Data for pallet storing materials

Activity	Frequency	Number of articles	Handling frequency [pallets/day]	Space [m2]	Transportation frequency
Pallet storing	Very low	43	4,67	160,82	lower
Pallet storing	Low	22	7,53	165,52	low
Pallet storing	Medium	18	21,43	171,46	high
Pallet storing	High	16	34,90	160,86	higher

Table C.1 shows the number of articles, handling frequency, space, and transportation frequency for every frequency category, i.e. very low- to high runners of pallet storing material. This table will further be used when calculating the actual costs for relocating the different activities and is based on collected data from Volvo Tuve.

Table C.2: Data for kitting materials

Activity	Frequency	Number of articles	Handling frequency [pallets/day]	Space [m2]	Transportation frequency
Kitting	Very low	33	25,60	131,90	lower
Kitting	Low	7	20,84	28,07	low
Kitting	Medium	20	213,60	63,82	high
Kitting	High	8	410,83	53,54	higher

Table C.2 shows the number of articles, handling frequency, space, and transportation frequency for every frequency category i.e. very low- to high runners of kitting material. This table will further be used when calculating the actual costs for relocating the different activities and is based on collected data from Volvo Tuve.

Table C.3: Data for sequencing materials

Activity	Kit ID	Number of articles	Handling frequency [pallets/day]	Space [m2]	Transportation frequency
Sequencing	1	7	30,96	61,56	20
Sequencing	2	8	130,08	54,89	15
Sequencing	3	2	26,71	29,52	20
Sequencing	4	10	30,13	40,20	15
Sequencing	5	8	23,02	78,72	11

Table C.3 shows the number of articles, handling frequency, space, and transportation frequency for the various frequency categories of sequencing material. The frequency categories are very low, low, medium, and high runners and include both small and bulky materials. This table will further be used when calculating the actual costs for relocating the different activities and is based on collected data from Volvo Tuve.

Cost data for pallet handling, picks for small and bulky parts, and costs per square meter space for the different handling activities will be the basis for table C.4. The cost data is differentiated between the locations VMLC and Volvo Tuve and are based on data provided by Volvo. The reason why VMLC is used, in cost calculations, is because it is considered to correspond to the actual cost of a potential external logistics center. Further, these costs are used to calculate the actual costs when releasing 160 square meters of the various activities which are described below.

Table C.4: Comparison and cost differences between VMLC and Volvo Tuve

Releasing approx. 160 m2	**Volvo Tuve [SEK]**	**VMLC [%]**
Storing of very low runners	X1	+ 71 %
Storing of low runners	X2	+ 71 %
Storing of medium runners	X3	+ 70 %
Storing of high runners	X4	+ 68 %
Sequence	X5	+ 135 %
Sequence bulky material	X6	+ 186 %

Table C.4 shows the difference for the total cost in percentages for releasing 160 square meters by relocating the various activities. This calculation differentiates based on the location, i.e. VMLC, and Volvo Tuve, and shows the difference between the different locations. The activities that are included in the calculations are very low, low, medium, and high runners of pallet storing material and sequencing of small and bulky parts. These have been selected because these are considered reasonable to relocate and compare. The reason why 160 square meters are used is to be able to fairly compare the activities since they will be based on an equally large area to release.

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