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Analyzing the Inbound Logistics Flow for a Fragile Component at Volvo Buses

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Abstract

This thesis investigates the logistics flow for a long and fragile component at Volvo Buses. The focus is placed on six areas of the logistics flow for the component, namely, packaging, emballage, handling at the supplier (loading), transportation, handling at the buyer (unloading) and storage. This thesis challenges the current logistics set up for the component and looks into alternative logistics setups. Different transportation and storage options are explored and the the most favourable options are identified. For the optimal logistics setups, for all four scenarios, call off volumes at which the yearly total landed cost is minimized, are then selected. Additionally, lead time and the environmental impact for the optimal logistics setups are discussed. A combination of interviews, observations and emails is used to collect the necessary data for this thesis. General scenario process is initially used to generate the different scenarios. An extension of the EOQ model, built specifically to fit the problem in this thesis, is then used to generate all the scenarios numerically, under the different call offs and to analyze the results. Lead time and environmental impact were analyzed qualitatively. From the analysis of this thesis, under the assumptions of the model, improved transportation and storage options were suggested. The thesis also found that the third call off volumes are the most optimal under most of the scenarios. Only for Supplier A, where 4 p/ns are considered, the second call off volume is found to be the most cost efficient. Moreover, the optimal call off volumes do not change as the capital tied up is reduced. Since the results in this thesis are based on many assumptions and limitations in the scope, a further research is suggested where dynamic pricing is and optimal production batch sizes are considered for improved results that will correspond to reality better.

Key words: EOQ, Extensions of the EOQ Model, Optimal logistics flow, Optimal Call Off Volumes.

Acknowledgements

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Abbreviations

3PL- third party logistics provider
DDT- door to door transport
FTL- full truckload
FTF- face to face
FR- freight rate
GHG- greenhouse gases
JIT- Just in time
LTL- less than truckload
p/n- part number
VPI- Volvo Poland Industry

Definitions

Call off volume in this thesis, is a purchase order placed by the customer with its supplier that is set over a certain period of time, in order to allow for pre-negotiated pricing agreements. By issuing a call off volume, the customer doesn't have to keep more stock than needed, while the supplier is able to predict future orders.

Call off frequency in this thesis, is determined by the call off volume. The call off volume together with the frequency should equal more or less the expected total yearly demand, depending on how well production meets forecasts. By having smaller call off volumes, the call off frequency will be larger to ensure that the yearly demand of orders is met. And vice versa with bigger call off volumes, the call off frequency will be smaller, as less orders will need to be called off to meet the demand.

Emballage in this thesis, is a pallet, often made from wood or metal, which is used to transport and/or store goods. An emballage is also used as a way to prevent damages to goods and make it easier to keep unit loads.

Packaging in this thesis, is defined as the process of preparing goods for transport and storage, by wrapping the goods in protective materials such as plastic and carton.

Inventory holding time in this thesis, is defined as the time the inventory is kept in storage, from the time it arrives in storage up until it is consumed.

Optimal production batch size in this thesis, is the quantity of components produced at which the cost of production is minimized.

1. Introduction

In this section the background to the problem and the problem discussion was first presented. The scope and aim of the thesis was then explained together with some limitations that the study has. This section also included the two research questions that the thesis intends to answer throughout the report. Finally a structure of the thesis was presented to give the reader an overview of the whole report.

1.1 Background

Today's modern supply chains are complex systems of integrated information and resources that require constant improvement. Especially in an environment where market competition is rapidly increasing day to day, the need to maintain one's competitive advantage is becoming more challenging. Previously, distribution and logistics was viewed as processes that only added costs to the supply chain. Now they play an important role within the supply chain, bringing value to products (Rushton, Croucher and Baker, p.28, 2006).

Competing on cost or lead time, according to Harrison and Van Hoek (p.30, 2011) are the most common approaches towards gaining a competitive advantage through logistics. Some businesses even attempt to achieve both objectives although these strategies naturally contradict one another (Simchi-Levi, Simchi Levi and Kaminsky, p.30, 2007). Inventory management plays an important role within logistics, and deals with strategic decisions like where to place customer order decoupling points in the network, how much inventory should be kept as safety stock and at what point reordering should take place. All these decisions will affect the costs and lead time of the entire supply chain.

Businesses that focus on reducing costs, do so in order to attract customers who choose to buy based on the lowest price. For this to be achieved, there are several methods of cost minimization, like reducing the tied up capital by keeping low inventory and having smaller and frequent deliveries. However, the lower the inventory levels, the greater the risk of possible stockouts, therefore it is important to have a well-functioning logistics flow that will reduce this risk. On the other hand, customers who favor higher customer service over low prices, are directed towards businesses centered on ensuring that products get when and where they need to be. With this, larger stocks should be kept and less frequent distributions carrying more payloads, should be used for example. This will ultimately increase the costs of storage and the total landed costs (Rushton, Croucher and Baker., p.28, 2006).

As inventory plays such a vital role in determining the logistics set up, businesses often use inventory models to help them balance their supply chains. One of the most well-known models is the economic

order quantity (EOQ), which is used for finding the most optimal level of inventory and at what point inventory should be replenished to keep the costs and risks of inventory overstocking or stock outs, low (Hillier and Lieberman, 2000).

At some point or another, attention needs to be placed on the environmental impacts of logistics and the global supply chain. Especially when it comes to global freight transport, which accounts for 23% of greenhouse gas (GHG) emissions (IEA, 2017). It is the responsibility of businesses to do right by society and proactively make the effort to choose logistics strategies that are environmentally conscious.

When it comes to buses, the logistics flow is a rather complex one, with around 4000 part numbers needed for the completion of one bus. Moreover, as buses requires a lot customization, there is generally a low percentage of the standardized parts used in production. On top of that, large manufacturers, like Volvo Buses, source parts from all over the world, adding to the complexity of their supply chain. To ensure that they are able to produce the necessary amount of orders each year, Volvo Buses needs to make sure that their logistics flow is cost and time efficient, as well as environmentally sound. This thesis will look at a specific component, which requires careful packaging, emballage, handling, transport and storage, due to its length and fragility.

1.2 Problem Discussion

This thesis is part of a bigger project at Volvo Buses and focuses on a specific component for their new project. The component is long, fragile (thin and light) and easily damageable, and as such requires a special logistics flow (packaging, emballage, transportation, handling and storage). Furthermore, each bus, depending on its length, contains the component in its full length on each side. There are two suppliers (Supplier A and Supplier B), that are considered for the supply of the component. Supplier A is located 1057 km from the goods receiving destination (Volvo Polska Industry, VPI), while Supplier B is only located 280 km away. Both suppliers can deliver the component in long and short lengths. The component can also be cut into shorter lengths to ease transportation and handling. In this case several pieces of the commodity will be assembled on each side of the bus instead of one long piece. Whether the component will be cut will affect many other areas in the logistics flow such as packaging, emballage, storage and cost, but will also impact the lead time and will result in different environmental impacts.

When it comes to packaging, the components are covered in carton with plastic wrapping around it. Then depending on the supplier, the component can either be put in a wooden (Supplier A) or metal (Supplier B) emballage before being placed on a trailer for distribution.

Transportation is conducted through a forwarding company hired by Volvo. These trucks are either designated specifically for the transportation of these components or it can be mixed with other components. The decision of which method of transportation to take is dependent on the call-off volume.

Moreover, which supplier that is selected will affect transportation in terms of the distance traveled. Transportation affects both lead times and costs and can have a big impact on the environment.

Furthermore, handling and storage will be affected by the call off volume. Volvo can either use their own storage space at VPI or rent an external storage area. If VPI doesn't have sufficient space in their warehouse, or the cost of storing goods in their own warehouse is too costly, then the alternative option is to rent storage space from an external actor.

In summary, the choice of supplier for the component, the packaging, emballage, transportation, handling and storage, are all of high importance as they can significantly affect the total landed cost, lead time and environmental impact of the logistics flow.

1.3 Scope and Limitations

The scope of this thesis (visually presented in Figure 1) was narrowed down to the areas corresponding to the logistical flow, from loading at the supplier to storing at VPI. Moreover, this thesis's focal point is on examining how different call off frequencies (dependent on the call off volume), impact the six logistics flow areas, namely loading (handling at the supplier), packaging, emballage, transportation, unloading (handling at the goods receiver) and storage, and how this then affects the total landed cost, lead time and environmental impact. With different call off volumes, the authors expect that it will affect all the six areas mentioned above and that it will lead to different outcomes in terms of lead time, total landed cost and environmental impact.
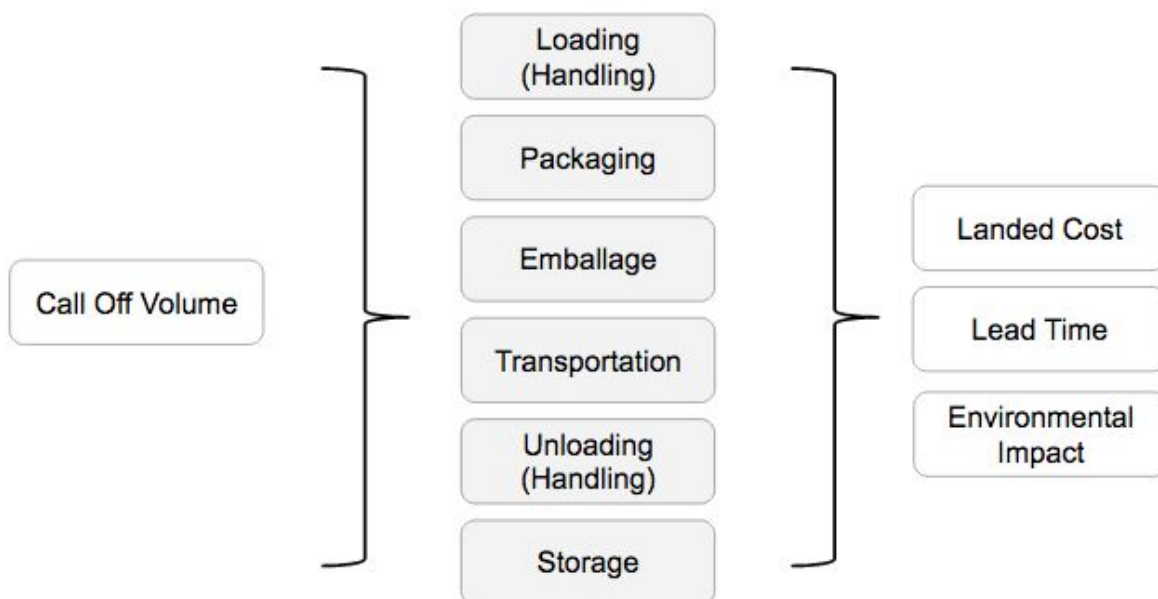
Figure 1: Scope of the Thesis

However, due to the short time frame allocated for the research, as well as the difficulty in collecting certain data, this thesis has certain limitations. As the main focus lies in finding out how different call off volumes for the six logistics areas impacts the total landed cost, lead time and the environment, the author's initial plan for this research was to look at all three areas in a quantitative manner. However, over the course of the report, it became apparent that there wasn't enough time to collect all the data for such an analysis. Therefore, the authors made the decision to focus primarily on collecting data on the total landed costs, due to its priority over lead time and environmental impact. However, in terms of the total lead time and environmental impact, the authors decided to apply a more qualitative approach in their analysis. As so, in the author's extended EOQ model (introduced in Section 4) that was used to find the most optimal call off volumes, they chose to exclude lead time and environmental impact due to the limitations previously mentioned above.

Moreover, the ordering and pricing of the component was excluded from the scope. The price of the component was assumed to be constant and the same for both suppliers and the ordering cost was found to be so minimal and outside of the scope, that it was negated from the model. Additionally, the handling and transportation process of the component after storage, was not taken into consideration for this study. Finally, this thesis rather assumes fixed order quantities and a fixed annual demand.

1.5 Research Aim and Research Questions

The aim of this thesis was to investigate different possible scenarios for the logistics setup of the component and to propose the most favourable scenarios in terms of total lead time, total landed costs and total environmental impact.

This thesis looked at answering the following research questions:

1. What is the most favorable logistics flow in terms of packaging, emballage, loading (handling) transportation, unloading (handling) and storage for the component in question?

2. How will different call off volumes minimize total landed cost, lead time and environmental impact?

Furthermore, as this is a study conducted in partnership with Volvo Buses, the objective was to implement a research where the outcomes can reliably and feasibly be used by the company for current and future projects.

Therefore some outcomes of this research was to:

- Create a framework/tool that can be used by Volvo Buses for optimizing the logistics flow of the component investigated in this thesis and for similar components in the future (as seen in Appendix 10.8).

- Propose the most optimal scenarios towards reducing landed costs, lead time and environmental impact for the logistics flow of the component.

1.6 Thesis Structure

This thesis was structured in eight sections. The introduction was meant to give a general background and introduction to the problem this thesis is investigating as well as present the aim of the thesis and the research questions the authors tried to answer. In the subsequent section, a literature review investigating similar problems was included. The literature review helped the authors in addressing the problem and building the theoretical framework. In the methodology, the research strategy that helped in the thesis design was explained. In this section the authors also explain how the data was collected and kept trustworthy and what method was used to analyze the results. In the theoretical framework the authors briefly presented the basic EOQ model and then presented an extension that was used in generating the results of this thesis. In the empirical framework the authors mapped out the current logistical flow for the component at Volvo Buses and then explained which scenarios that were generated and analyzed. In the analysis the current logistics setup was first challenged by exploring alternative transportation and storage options. The most favourable logistic setups were then identified. Optimal call off volumes were then generated for the most favourable logistics setups in terms of cost, lead time and environmental impact. A section with suggestions was added after the analysis in which the authors presented several considerations, based on the analysis, on how Volvo Buses can improve upon the logistics flow for the component in question. The conclusion sums up all the findings in this thesis and suggests further research.

2. Literature Review

In this section, an overview of the literature was presented, with the main focus placed on extensions of the EOQ model. Specifically, EOQ models that take transportation and environmental costs into account, were discussed from the literature. The section is concluded by presenting where this thesis fits in the literature and the value it may add to the logistics and operations management field.

Given the importance and role that inventory plays in the supply chain, companies are continuously evaluating their strategies in order to find the right balance between supply chain efficiency and responsiveness. With the growing complexity of the supply chain, the development of inventory decision support tools plays a vital part in a company's strategic decision making. Inventory models are used as a way to represent inventory problems and aids in facilitating rational decision making, such as determining how much inventory to buy and when to buy. In order to answer these questions with an inventory model, it is necessary to have a combination of decision variables and situational parameters. Some situational parameters that influence how much and when you buy inventory include demand, lead time, price of the goods, quantity discounts, space constraints etc. (Vrat, p. 29, 2014).

Inventory theories deal with determining the most optimal level of stock that should be kept in storage and determining the optimal order size. The most prevalent model in inventory theory is the economic order quantity model, also called the lot sizing model. This model aims to determine at what point and by how much to replenish inventory so as to minimize the total costs and avoid needless inventory build-up (Hillier and Lieberman, 2000). Although the aim of this thesis is to suggest a logistics scenario that would be the most favorable in terms of total landed cost, the problem in the thesis extends beyond inventory management into transportation planning and packaging decisions as well. Moreover, considered in the problem are also the environmental impacts of the inbound logistics flow as well as lead times. As such, literature on extensions of the basic EOQ model was mainly looked into. There have been many extensions of the EOQ model since Harris developed the basic model in 1913 (Harris, 1913). These often allow for multi-stage production, safety stock determination or incorporate other logistics decisions such as transportation within the model (Glock, Grosse and Ries, 2014).

2.1 Joint Transportation and Inventory Models

The basic version of the EOQ model aims to identify the inventory replenishment levels that would minimize the total logistics costs based on the costs related to ordering and storing inventory (Glock et al., 2014; Hillier and Lieberman, 2000, Swenseth and Godfrey, 2002). However, all relevant logistics costs need to be considered, and other relevant criteria incorporated, for more accurate and practical

solutions. The integration of all these significant parameters and criteria into the inventory replenishment decisions can be quite challenging considering that there are many trade offs, and some criterias can be difficult to quantify (Swenseth and Godfrey, 2002; De la Vega, Vieira, Toso and de Faria, 2018). Transportation costs for one, can greatly influence total logistics costs and affect other areas such as the environment. This can greatly increase the competitive standing of a company for which the minimization of costs is an important priority (Toptal, 2009). Furthermore, there is a major trade off between transportation and storage costs. More frequent, faster and dependable transportation decreases the volume of stored inventories as well as the need for large safety stocks and at the same time it reduces the tied up capital during transportation. This though comes at higher transportation costs. Whereas, transportation of larger volumes with less frequency decreases the transportation cost but increases storage costs (Kang and Kim (2010); De la Vega et al, 2018; Baumol and Vinod, 1970). Figures 2 and 3, give a visual representation of this. Figure 2 illustrates the cost structure of transportation in regards to different shipment sizes. The lower the shipment sizes (M), the higher the transport costs (c) rise, so $c_0 > c_1 > c_2$. Furthermore, Figure 3 demonstrates how with more frequent deliveries of smaller batches, the less inventory needs to be kept. Clearly, the inventory levels on the right are significantly lower (by 60%) than on the left.
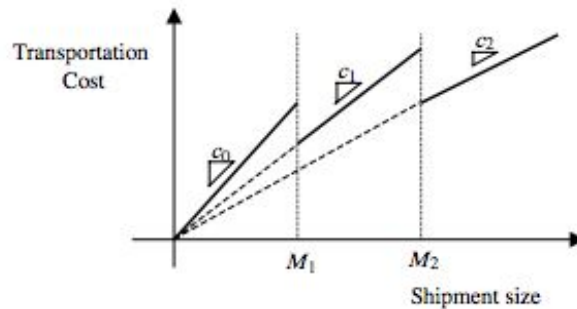
Figure 2: Transport cost as a function of the shipment lot size (Ertogral, Darwish and Ben-Daya, 2007)
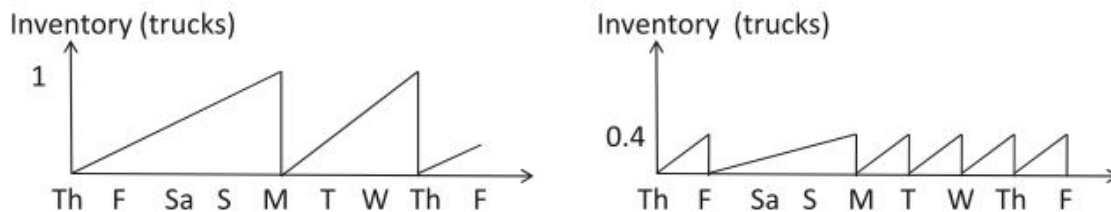
Figure 3: Reduction in inventory when the frequency of transport is increased from twice a week (left) to five times a week (right) (Yildiz, Ravi and Fairey, 2010)

As inventory and transportation choices directly affect total costs, it makes sense that a combined transport-inventory policy be established (Gupta, 1992). Previously the focus on transportation costs as a factor in determining the lot-size, had attracted very few authors. It was only in 1970, when Baumol and

Vinod (1970) became the first to suggest the inclusion of transportation costs within inventory theory. The authors proposed two models for profit maximization and inventory cost minimization, whereby they included freight rates, speed (transport lead time), variance in speed and en-route losses. However, within their model they assumed a fixed unit shipping cost that was not dependent on the size of shipment, which in later research it became a common practice to have freight discount rates based on the shipment size. Regardless, their efforts are still recognized by many (Gupta, 1992; Ertogral et al., 2007; Swenseth and Godfrey, 2002) as a pioneered effort towards advancements in this area of research.

Furthermore, before transportation costs were seen as an important factor in the overall management of inventory order lot sizes, it was merely incorporated as an implicit cost that the supplier incurred on the buyer by either adding it to the unit price of the goods or to the order costs as a fixed transportation cost per shipment. These assumptions aren't valid however, as the cost of transportation depends on the shipment size and route (Carter and Ferrin, 1995; Gupta, 1992; Ertogral et al., 2007). By oversimplifying the model this way, it limited possibile transportation cost advantages that buyers were able to incur if transportation were added as an explicit cost parameter. Adding other cost parameters in the total transportation function can make it more explicit and allows for a better illustration of reality. Kang and Kim (2010) developed an inventory replenishment model for an outbound logistics flow with dynamic demand. In the model they also included a fixed transportation cost but they further expanded this fixed vehicle cost by adding a fixed handling cost to it. Aguezzoul and Ladet (2007) added the in-transit capital costs and costs incurred at the supplier and buyer, while products waited to be shipped or used as part of the total transport costs. The authors further emphasize the importance of considering the impact of transportation already in the supplier selection process. Transportation has direct effect on lead time thus the location of the supplier can affect a company's total cycle time. Moreover, multiple sourcing indicates splitting the orders among several suppliers which leads to smaller quantities being shipped and the likelihood of greater transportation costs. Thus, the authors propose a multiobjective model for supplier selection that minimizes lead time as well as transportation, ordering and storage costs.

The focus on transportation costs have gained the attention of supply chain researchers again, due to the trend of outsourcing logistics activities to third party logistics (3PL) firms (Toptal, 2009). Hall (1985) developed a version of the EOQ model that looks at the optimal shipment size rather than the optimal order size. His total transportation cost consists of fixed shipping cost (the shipping cost per unit distance) and variable shipping cost (the shipping cost per weight). In this way he classifies less than truckload (LTL) shipments as having lower fixed costs but higher variable costs contrary to full truckload (FTL) shipments. At the same time, LTL shipments require more handling which increases the variable costs, but more shipments are loaded in each vehicle which then decreases the fixed cost. In fact, Aguezzoul and Ladet, (2007) use Hall's transportation modeling in their research. Lee's (1986) model is another of the earliest to include the discounted freight rate as an explicit cost into the EOQ model. In his research he assumed that transportation costs were fixed and increased in a stepwise format depending on the size of the order.

One of the most used transportation cost functions is the truckload discount schedule, also known as the carload discount schedule (Nahmias, 2001; Birbil, Bülbül, Frenk and Mulder, 2009). Simply explained, the transport service provider places the cost of transportation at a LTL rate, or c per unit, up until the point that the buyer pays for the cost of a FTL, or Q units, whereby there is no additional cost for the remaining units in the FTL. Once the first FTL is full, the buyer will pay a LTL rate until the second truck it filled up again. Typically the cost is lower to ship a FTL of Q units, than a LTL of Q units (Nahmias, 2001; Li, Hsu and Xiao, 2004). This process is demonstrated in figure 4.
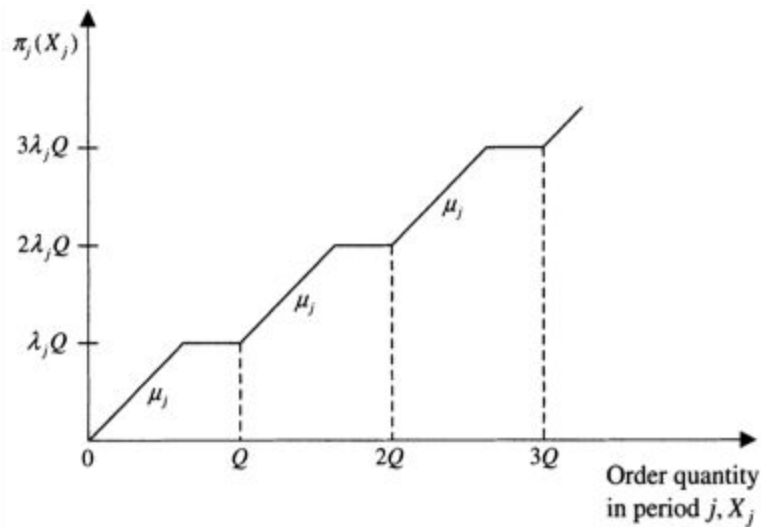
Figure 4: Transport cost with truckload discount (Yildiz, Ravi and Fairey (2010)

Similarly, Swenseth and Godfrey (2002) recognize that in practice freight rates often decrease at a diminishing rate as the weight of the shipment increases. Their model determines a minimum weight at which a LTL shipment can be over declared to a FTL shipment and further determine whether a shipment should be over-declared to FTL when it can be shipped in a LTL shipment as well. Their findings show that in some cases transportation costs can be reduced by over-declaring LTL shipments as FTL shipments and as a result reduce the total logistics costs. De la Vega et al. (2018) also consider the FTL versus LTL alternatives in making inventory replenishment decisions. However, they take a step further and include other transportation criteria despite costs. Some of these criteria are cargo security, quick response from the carrier, reliability that the orders will be on time, service level and relationship between the shipper and the carrier, flexible schedule, etc. The researchers then analyze how all these criterias and costs are affected by the change of transport policy. Adding all these criterias enables more practical solutions to be generated.

2.2 Inventory Models with Environmental Criteria

For decades, the role of inventory models have been to minimize supply chain costs. However, the growing concerns raised by scientists on the area of global warming and greenhouse gas (GHG) emissions has led to a shift of interest in incorporating environmental costs into inventory models. The logistics sector is viewed as one of the major contributing factors to CO_2 emissions, with global freight transport alone contributing to 23% of greenhouse gas emissions, while it is expected to grow by a rate of 1.9% per year from 2015-2025 (IEA, 2017). Furthermore, 93%-95% of the total GHG emissions from transportation operations is from CO_2, while 5%-7% of the remaining emissions comes from other gases like nitrogen (NO_x) and sulfur oxides (Cefic-ECTA, 2011). As businesses are being scrutinized more and more closely as an effect of society's growing concerns, the need to utilize environmentally friendly methods is taking precedence for many companies. It is the responsibility of businesses to take into consideration the environmental impact of products over its complete life cycle, from the extraction of raw materials to the reverse flow, as it makes its way throughout the supply chain. This is especially enforced in Europe where legislation requires manufacturers to take responsibility for their products even beyond its life cycle (Bonney and Jaber, 2011). In fact, in 2012, the European Commission established the European Energy Efficiency Directive, which requires companies to report their energy consumption levels on a regular basis and their plans to reduce it. In 2016, a renewed agreement was signed with a new 30% energy efficiency goal for 2030 (EED, 2018).

Furthermore, popular manufacturing trends like just-in-time (JIT) and lean, which views inventory as waste, favoring smaller batch sizes and frequent deliveries in order to reduce the amount of inventory held, can have serious implications on the environment. The JIT method speeds up the product's life cycle which could lead to faster obsolescence and greater waste in the end (Bonny and Jaber, 2011; Benjaafar, Li and Daskin, 2013). Moreover, while many companies tend to focus on the physical processes, like using energy efficient equipment or using less pollutant resources, they often overlook business processes and operations such as the frequency of deliveries, that are a significant source of emissions (Benjaafar, Li and Daskin., 2013; Chen, Benjaafar and Elomri, 2013). In order to reduce resource usage and waste, inventory systems should attempt to: choose locations, routes and frequencies that will reduce transportation; recycle goods rather than scrap them; design goods for repair, reuse and restore; avoid using materials that could have adverse effects on the environment; use smaller goods and packaging in order to reduce transport and packaging material etc. (Bonney and Jaber, 2011). Furthermore, the implementation of logistics environmental strategies such as the reduction in energy consumption and fuels, as well as material efficiency maximization, can lead to cost advantages for companies and can also be turned into a competitive advantage (Liotta, Stecca and Kaihara, 2014). In addition, the increase in the number of socially responsible consumers, and the pressure by different regulations and legislations, forces companies to reduce their environmental footprint. Adjustments of order quantities have in the past been shown to be an effective way to reduce emissions (Hovelaque and Bironneau, (2015); Chen, Benjaafar and Elomri, 2013; Benjaafar, Li and Daskin, 2013).

In response to the growing need for inventory models that include environmental criterias, researchers have attempted to examine the relationship between inventory and the environment and more importantly, possible ways of creating responsible inventory planning models that incorporate the environmental aspect. Most of the existing models include the environmental aspect either as a constraint in optimization models (Chen, Benjaafar and Elomri, 2013; Benjaafar, Li and Daskin, 2013), or try to quantify it (Battini, Persona and Sgarbossa, 2014; Bouchery, Ghaffari, Jemai and Dallery, 2012).

Some researchers have approached the problem by using carbon emissions as a constraint in the EOQ model. Chen, Benjaafar and Elomri, (2013) and Benjaafar, Li and Daskin, (2013) in particular have examined the extent at which adjustments in business operations could be made without greatly increasing costs. This is an important consideration, as companies are often resistant towards environmental regulations due to the high costs of implementing change. Their research underlines the possibility of reducing carbon emissions by modifying order quantities. The target would then be to have an order quantity (Q) that minimizes cost (per unit time) within the carbon emission constraint. Carbon caps are typically imposed by government regulations, or voluntarily by the company based on their environmental goals. As shown in figure 5 below, as the carbon cap (C) increases, the costs start decreasing. This implies that the outcome of reducing the emission cap initially leads to a bigger reduction in emissions relative to increases in costs. For example, a reduction of emissions by 20% only leads to an increase in costs by 4% according to Figure 5.
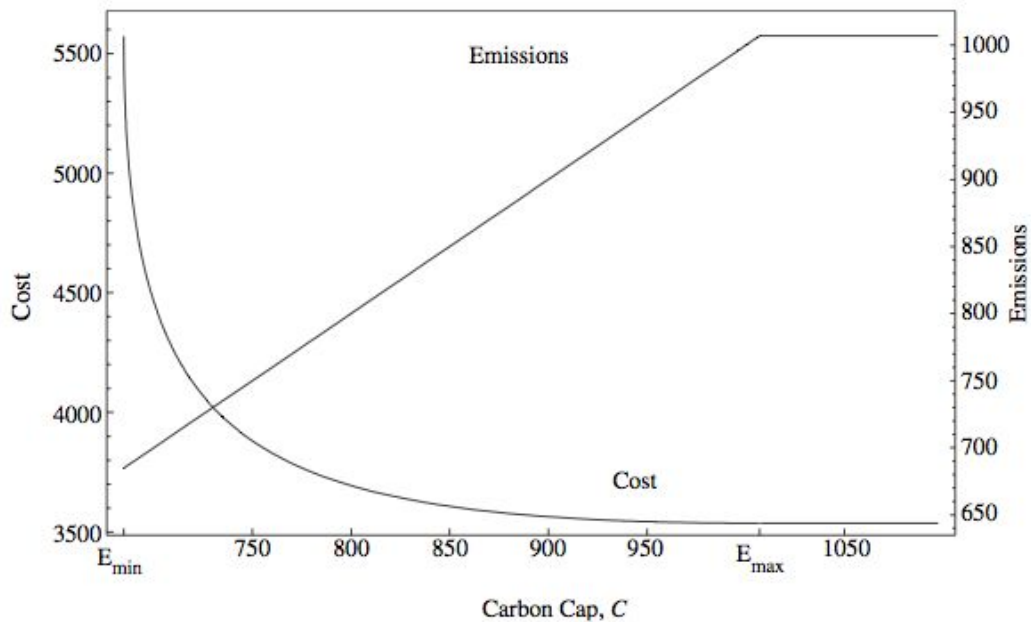

Figure 5: The impact of the carbon cap on emission and cost (Chen, Benjaafar and Elomri, 2013)

There have also been attempts to integrate CO_2 parameters into traditional inventory models by interpreting carbon emissions as an economic cost. Additionally, while some authors consider mainly

carbon emissions (Chen, Benjaafar and Elomri, 2013; Benjaafar, Li and Daskin, 2013), there have also been attempts by some authors (Bouchery et al., 2012; Arslan and Turkay, 2013; Battini, Persona and Sgarbossa., 2014) at revising the standard EOQ model to encompass also social dimensions in addition to the economic and environmental dimensions. Like cost, emissions are associated not only with transportation and handling but also with inventory ordering, holding as well as waste disposal (Chen, Benjaafar and Elomri, 2013; Battini, Persona and Sgarbossa, 2014). Battini, Persona and Sgarbossa (2014) consider the environmental impacts from all these areas in an attempt to cover the whole process from the beginning to the end of an order cycle. In their paper they try to capture the economic and environmental trade-offs of different lot sizes. This is done through expanding upon the classical EOQ model by including the environmental aspects from all areas in an order cycle. However, rather than adding the emissions as a constraint, as some authors do (Chen, Benjaafar and Elomri, 2013; Benjaafar, Li and Daskin, 2013), Battini, Persona and Sgarbossa, (2014) monetized the carbon emissions and added them as a cost through a direct accounting approach. This enabled the authors to include not only environmental, but also social aspect to the emissions parameter by considering them jointly as "external costs" in the model.

Similarly, Bouchery et al., (2012) extend the classical EOQ to account for sustainable development criteria into the inventory replenishment decisions. In addition to the economic criteria of cost minimization, Bouchery et al., (2012) consider also carbon emissions related to order processing, transportation and storage, as environmental criteria and injury rate as a social criteria. These criteria are added as additional costs in the model. Even so, their findings are similar to the findings of Chen, Benjaafar and Elomri (2013) and Benjaafar, Li and Daskin (2013), who consider carbon emissions as a constraint. Bouchery et al., (2012) propose that carbon emissions can be reduced by adjusting operational activities only for a small increase in cost. This cost will be increasing as it approaches the minimum amount of emissions, in which case the authors suggest considering more strategic adjustments such as investments in greener technologies. Bouchery et al., (2012) further suggest that scenarios where all criterias are optimized are difficult to achieve, as such companies in most cases have to choose between trade-offs. In a similar way to Bouchery et al., (2012), Arslan and Turkay (2010) consider all sustainable development (economic, environmental and social) criteria in their model. They incorporate these criteria both as constraints and as objectives, and propose five different approaches for analysing the impact of these criteria (Direct Accounting, Cap and Trade, Direct Cap, Carbon Tax and Carbon Offsets). The optimal total cost generated by all different approaches is always larger when compared to the optimal total cost of the standard EOQ model. As such, the authors pinpoint to the importance of companies to include the environmental and social criterias and improve their parameters.

Hovelaque and Bironneau (2015) propose an interesting approach to integration of environmental aspects into inventory decisions. They integrate a carbon emission function that includes carbon emission parameters related to storage and transport frequency directly in the demand function for the product, complementary to price sensitivity. With integrating emissions into the demand function, the authors

acknowledge the increased environmental awareness and that a change in inventory policy (favoring either less frequent deliveries but more storage or the opposite), will impact the amount of greenhouse emissions and consequently the demand for the product as well. Bonny and Jaber (2011), also have alternative suggestions. They propose that in order to develop models that will consider the environmental impacts, measures other than cost need to be taken into consideration when determining inventory levels. Moreso, using cost minimization as the key performance measure, does not put precedence on the underlying goal of meeting society's demands for greener ways. Therefore, Bonny and Jaber (2011) believe that the performance measures should push for environmentally good activities and so in their research, they have constructed a list of non-cost metrics that can be evaluated in the EOQ model.

2.3 Literature summary and problem fitting

Many researchers have identified the importance to include other criterias and parameters into inventory planning decisions. Transportation especially has been included by many as an area that greatly affects inventory decisions and total logistical costs (Section 2.1). More recently, researchers have further accounted for environmental criteria, mainly carbon emissions from transportation but also emissions from other areas in the supply chain such as handling and storage. This research will incorporate a holistic view of the logistical flow all the way from the supplier to storage at the manufacturer. As such it will account not only for ordering and storage costs, as seen in the classical EOQ models, but also include costs associated with packaging, emballage, loading (handling) transportation, unloading (handling) and storage. Furthermore, as the problem of the thesis is a multiobjective one, these six areas will be investigated not only from a cost perspective, but also their impact on lead time and the environment will be considered. The reviewed literature helped the authors in building the theoretical framework that was used for generating the results of this thesis. Similarly to the reviewed literature, the authors used the basic EOQ model and further expanded it to account for all the areas in the logistics flow examined in this thesis.

3. Methodology

This section begins by explaining the research philosophy that guides the thesis design, the research approach and the method that was undertaken in order to answer the research questions. Presented afterwards is a description of how the data was collected and its trustworthiness. The last subsection touches upon the anonymity and confidentiality responsibility that the authors have towards Volvo.

3.1 Research Philosophy

Collis and Hussey (2013, p.43-45) recognise positivism and interpretivism as the two main research paradigms that are most commonly used in research design. Positivism is connected to the natural sciences and provides mathematical proof or logic to the research and as such it is generally associated with quantitative methods of analysis. Interpretivism on the other hand, is related to social sciences, and unlike positivism, believes that the social reality is in fact shaped by common perceptions. This philosophy is usually associated with qualitative methods (Collis and Hussey, 2013, p.43-45). Since this paper uses a combination of quantitative and qualitative methods for data analysis, none of these purist philosophies were appropriate. Rather, the pragmatic research philosophy was found to be the most well-suited for this thesis, as it allows for methodological mixtures that would provide the best possible answers to the research questions. According to Johnson and Onwuegbuzie (2004), a mixed methods research should use a research philosophy that is more pluralistic and offers a more balanced view. The research philosophy in a paper with a mixed method approach should attempt to combine the insights that both of these methods offer and see the benefit of bringing them together. Pragmatism is a philosophy that takes a middle position between positivism and interpretivism (Collis and Hussey, 2013, p.54). This philosophy recognises the existence and importance of both natural but also social world and places high value on reality favouring practical and outcome related methodologies (Johnson and Onwuegbuzie, 2004).

3.2 Research Approach

With a deductive research approach, particular knowledge is derived from general theory or models. Conversely, in an inductive approach new general knowledge such as theory or models is developed through specific empirical observations (Collis and Hussey, 2013, p.6). In an abductive research however, theories that are constructed or applied, are grounded in everyday activities and social contexts, with the theory development and empirical research proceeding in parallel (Ong, 2012). The final results in an abductive study are not testing nor development of new theories, but instead the elaboration and adaptation of theories through extension or combination of theories (Ketokivi and Choi, 2014). Like in

inductive research, this thesis begins by first generating the empirical data. However, rather than aiming to develop a new theory from the specific information gathering, this thesis selects an existing theory and expands on it with the objective of using this extended theory to solve a specific practical problem. As such, the abductive research approach was found the most well-suited to this thesis.

3.3 Research Method

The choice of research method should be driven by the aim of the research and the questions that it seeks to answer. A mixed research method approach was found to be the most appropriate to answer the research questions of this paper. Taking a non-purist approach allows researchers to combine components of both quantitative and qualitative methods that offers a best chance of answering their own specific research question (Johnson and Onwuegbuzie, 2004). The focus in this thesis lies in challenging the planned logistics setup for the component and generation of different logistics scenarios with the aim to identify how different factors impact the total landed cost, lead time and the impact on the environment. The whole logistics flow covering several areas and different aspects and parameters related to the areas are considered in this thesis. Therefore, combining both qualitative and quantitative methods was found to give the best results. Using a mixed methods approach has the benefits of providing better answers to broader research questions as the researcher can combine the strengths of different methods to overcome the weaknesses. Moreover, a mixed methods approach can produce a more complete knowledge and more practical solutions (Johnson and Onwuegbuzie, 2004). Furthermore, having an open mind that combines different types of data and enables thinking "outside the box", is more beneficial (Mason, 2006). As in the case of this thesis, where the authors have collected a mix of qualitative data collection methods in the form of semi-structured interviews and observations, as well as quantitative methods from internal data collection and calculations.

Johnson and Onwuegbuzie (2004) suggest that the best way to design a mixed method approach is by finding the right balance between the use of the qualitative and quantitative methods in a way that will offer the best opportunity to answer the research question(s). Moreover, mixed methods can extend the logic of qualitative explanation. Quantitative research methods attempt to find patterns and changes in the social phenomena however there are limitations when it comes to thoroughly explaining what these outcomes really mean (Mason, 2006). For this thesis, a quantitative method was adopted for calculation of the total landed costs for different scenarios that were then compared and contrasted and most favourable scenarios in terms of cost were identified. Lead time and environmental impact on the other hand were analyzed more qualitatively. Since most emphasis in this research was placed on the total landed costs, the quantitative method is more dominant with the qualitative method mainly used to aid and expand the quantitative analysis.

3.4 Research Strategy

As this thesis focuses on a particular organization's logistics flow for a specific component, an action research strategy has been chosen for this study. Action research is used as a means of attempting to bring about effective change in a partially controlled environment (Collis & Hussey, 2013). In some cases, action research is quite similar to a case study approach, as they are both used to conduct research on an organization. However in this case, an action research strategy is more applicable.

With action research, there is a need for close collaboration between the researcher and the client organization, especially when it comes to understanding the organizational environment, the prerequisites and end goal of the research (Gummesson, 2000, p. 215). As in this thesis, the researchers and Volvo Buses, have been in close collaboration since before the start of the study and have continued to have the support of the company throughout the data collection, analysis and final output of the report. Furthermore, according to Gummesson (2000, p. 119), action research is typically associated with two main goals: to solve the problem of the company and to contribute to previous research. In terms of solving the problem at Volvo Buses, this thesis looks at finding the most favorable logistics flow for the component in question, and looks at which call off volumes result in the lowest cost, lead time and environmental impact. Furthermore, this report contributes to previous literature on the EOQ model, by applying theory to a real life problem.

3.5 Data Collection

3.5.1 Primary data

Primary data was mainly collected through face-to-face (FTF) interviews with relevant contacts from all areas of the thesis's scope. In addition to the FTF interviews, primary data was collected through skype interviews, weekly meetings with the steering committee, as well as from emails. Moreover, some of the primary data was also collected through observations.

Interviews

A semi-structured interview method was chosen when conducting both FTF and skype interviews (Appendix 10.6). Since many interviews had to be conducted in a limited time frame to collect all the necessary data it was decided that a semi-structured interview method was the most appropriate. Having questions prepared beforehand helped in structuring the whole interview process and ensured that all areas of interest were covered. At the same time having open-ended questions gave the interviewees some freedom to express themselves and add other insights that they thought were relevant. Moreover, semi-structured interviews are very flexible and allow for the style, pace and questions to be adapted to the interviewee during the interview process. This gives the interviewer the freedom to also address areas

that were not thought of previously, but that needed to be elaborated in more detail (Qu and Dumay, 2011). Appendix 10.7 provides an interview guide for all six areas of the logistics flow.

The purpose of conducting interviews was in order to map out the current logistics flow for the investigated component. The lack of secondary data on the case, further gave reason as to why interviews were necessary for data collection. The objective of the interviews was to gain a overall perspective of the entire logistics flow from the point the component left the suppliers, to when it reached the goods receiver. Different actors within the logistics flow were thus interviewed, due to the insightful information they brought to the investigation. A snowball sampling method is the most appropriate when the respondents have to have experience on the phenomenon being studied (Collis and Hussey, 2014, p. 132). In this thesis all respondents have expertise in at least one of the areas covered in the scope. The initial respondents were provided by the steering committee. This sample was then extended through a snowball sampling approach, where the initial respondents gave further referrals to contacts that had additional information.

The interview process, for most of the interviews, looked more or less the same. The interviewees were introduced to the thesis topic and scope and the interview questions were sent to them beforehand. By sending the interviewees the questions beforehand, it allowed them to come better prepared with the right data before the interviews. The interviews lasted approximately one hour. The skype interview process was the same as in the FTF interviews. Skype interviews were mainly conducted with contacts from the VPI office and when FTF interviews were not possible.

Observations

Observations can be defined as a systematic description of events, processes, behaviours and artifacts in the selected social setting that is being studied (Marshall and Rossman, 1989, p.79). Observations help researchers to gain a more in-depth understanding of the area they are studying, and also help with the interpretation of the data (DeWalt and DeWalt, 2002. pg.8). For this thesis, it was found of great contribution to be able to observe some of the processes that represent major parts of the scope of the research (Appendix 10.6). VPI was visited for this purpose where the process of receiving the commodity, handling and storage was observed. The observation deepened the knowledge of the authors, especially in regards to packaging, emballage, handling and storage. Furthermore, observations helped to visualise and clarify the information given during the interviews. Pictures and notes were taken during the observations as this allowed for further analysis after the observation process.

Weekly Meetings with the Steering Committee

A steering committee is defined as being a project's deciding body, and plays an important role in the various phases of a project (Tonnquist, 2016, p.80). As an action research strategy was chosen for this thesis, it was important to have a strong researcher-client organization relationship. Therefore, before the thesis work began, a steering committee consisting of four individuals from different departments (logistics and special projects) was appointed. By having meetings with the steering group (Appendix 10.6), the authors were able to communicate the current status of the project, what information was lacking or hard to find and in what ways the steering committee could aid in the research process. For instance, the steering group helped the authors get in contact with the right people and gave them access to data when it was difficult to retrieve on their own means. Furthermore, they helped form the scope and goals for the project.

Emails

Communication through emails was also used as a method of data collection (Appendix 10.6). Emails were mostly used as an initial contact point and for follow-up questions where clarification or further information was needed.

3.5.2 Secondary Data

Books and journal articles were collected and reviewed for the purpose of conducting a literature review and to help in the construction of the theoretical framework. Documentations and spreadsheets were also examined and analyzed for the purpose of mapping out the logistical flow in the empirical results and the analysis.

Literature Review and Theoretical framework

The purpose of the literature review was to identify the field of literature in which this thesis belongs, to gain some insights on how other authors have approached the problem and to support and strengthen this research with theory. The literature review mainly looked at inventory theory models as they provided insights into the behaviours of shippers and companies in making logistics decisions. Special emphasis was placed on extensions of the EOQ model that looked at other factors that impacted inventory decisions such as transportation and the environment. Looking at these models was beneficial since the scope of this paper covers several areas (packaging, emballage, handling, transport and storage) in a logistical flow. These models also helped in the writing of the theoretical framework. The literature was collected mainly through Gothenburg University's library databases like SCOPUS, Web of Science and

even Google Scholar. Some of the selected articles were a little old but were used regardless. Since the EOQ theory dates back two centuries ago, it was found relevant to include some of the first authors that contributed to this theory.

Empirical data

In addition to primary data, secondary data was also collected and used in the empirical framework. Existing internal company documentation such as purchasing agreements, excel spreadsheets and similar, were collected and used for mapping out the existing logistics set up for the component. Moreover, data from internal company excel spreadsheets and powerpoint presentations were sometimes used in the calculations.

3.6 Method for Data Analysis

One of the main aspects of this thesis was to investigate how different call off volumes would impact the six areas (Figure 1) in the logistics flow, but also to challenge the current logistics set up and explore other logistics alternatives. To answer the two research questions in this thesis two methods of data analysis were used. A general scenario process was used in combination with the extended EOQ model (Section 4.2). The extended EOQ model was built specifically for the problem of this thesis and was used to generate and analyze different scenarios for the component's logistics flow.

The general scenario process includes five phases, namely: scenario field identification, key factor identification, key factor analysis, scenario generation and scenario transfer (Kosow and GaBner, 2008, p.25). The first phase defines the purpose of the generation of the scenarios. The main objective of the scenarios was to see at what call off volume the total logistics cost, lead time and environmental impact will be minimized. Additionally the aim of the scenarios was to explore the different logistics options. Plentiful of scenarios could be generated for the logistics flow of the component as each of the areas in the logistics flow under investigation contain several possibilities. Different combinations of these possibilities would result in an endless myriad of options. As such, in the second phase of the general scenario process, the main factors that influence the scenarios were identified and scenarios only around those parameters, variables and factors were decided to be considered. In the third phase the selected key factors and parameters were analyzed and a final selection made. Then scenarios were generated. The steering committee was involved in the scenario generation and together it was decided to look at 6 call off volumes for 4 different scenarios (Figure 10) for two suppliers. The main factors that could have a potential impact were the length of the component, whether the component was ordered in 1 or 4 part numbers (p/n's) and the different transportation and storage options. After this phase the scenarios were transferred to the extended EOQ model and each scenario was generated numerically. For the lead time and environmental impact, a descriptive explanation and analysis was included. The extended EOQ

model was further used in analyzing the generated scenarios. As the scenarios were generated numerically it was possible to compare them and the EOQ values were selected.

3.7 Research Trustworthiness

3.7.1 Reliability, Validity and Generalizability

How reliable the research is, is largely dependent on whether the same results would be found if the study were to be repeated using the same or similar method (Lewis and Ritchie, 2003, p.270; Mason, 2002). In the case of this thesis, the authors attempted to tackle this problem by conducting several interviews with the same respondents at different times. Moreover, the authors made sure to introduce the scope and objective of the thesis the same way for all respondents before the interview took place. Considering that a big part of this thesis was quantitatively analyzed, the interviews were used as a method of collecting data on costs and for gaining a general understanding of the processes with respect to the six areas of the logistics flow this thesis is investigating. Thus, most of the data collected through interviews, was a factual data rather than opinions or personal perceptions. As the data was extracted from Volvo Buses' internal database as well as from interviews with several key actors in all six areas of the logistics flow, the authors were able to ensure the reliability of their data by cross-checking with different sources and having follow up meetings with interviewees.

Furthermore, reliability is concerned with showing that the author has not misinterpreted or assumed falsified information due to careless analysis and/or documentation (Mason, 2002). In order to avoid these problems, Lewis and Ritchie (2003) suggests summarizing the research procedure in a clear and transparent way and consistently and systematically collecting and analyzing the data to ensure that the study is supported by solid evidence. The fact that the research was conducted by more than one author, made the research more reliable. For instance, the authors were able to consult with one another in all matters such as the types of interview questions that were asked, that all procedures were followed in a consistent manner and that the interpretations of one author was always backed up by the other. Furthermore, most of the interviews conducted were conducted together, so the authors were able to ensure unbiased observations when it came to interpreting the raw data. One final factor that needs to be noted is that since the interview questions were semi-structured, the follow-up questions were likely to differ depending on the interviewer. However this again is offset by the fact that most of the interviews were conducted together.

Observations can increase the validity of the study, since through observations, the researcher can gain a better understanding of the context and phenomenon under study (DeWalt and DeWalt, 2002, p.92). Furthermore, observations can help researchers to check and confirm information described in interviews (Marshall and Rossman, 1989). At the same time, there is a research bias associated to observations. This

implies that there is a risk that the observation might be interpreted subjectively rather than objectively. Furthermore, the quality of observation can be affected by the researchers' skills and knowledge to grasp, document and analyze what has been observed (Kawulich, 2005). To overcome research bias the authors made sure to prepare before the observation and get accustomed with the facilities at VPI. This helped also in identifying areas that are of utmost interest which made the observations more focused to the needs of the thesis.

Pictures were taken while observing which was of great contribution especially when observing the packaging, emballages and the storage area. During an observation a lot of information is received and needs to be absorbed fast, which might become overwhelming. To avoid this, notes were taken during break points in the observation process which helped in remembering the most important points. Other tips were followed, such as writing a summary of the observations immediately after the process was finished to prevent missing details that later might be forgotten, listening carefully and following keywords in conversations (Kawulich, 2005). Moreover, since many of the interviews had been conducted before the observations, the authors already had knowledge of the processes and used the observations to deepen their knowledge or clarify any misconceptions and in that way also strengthen the knowledge received in the interviews.

Although this thesis is based on a specific company in the automotive industry and on a distinct problem within the logistics flow for a special component, the possibility of generalizing this research in other contexts, may be perceived as being difficult, given the scope of the study. However, as the focus is on a broader sense of the logistics flow from a supply chain management perspective, it is possible to generalize the study towards other organizations in the same or different industry. Additionally, one of the objectives of the thesis was to derive a tool that could be applied to other components at Volvo Buses, and therefore is applicable for a wider application. Moreover, the author's use of the basic EOQ model as a base to build upon and develop into one more suitable for the aim of their research, may be relevant to a wider body of theory. Many of the extensions of the inventory model incorporate transportation or environmental criteria, however the authors have incorporated five more aspects of the logistics flow, into their EOQ model, thereby creating their own extension of the model.

3.8 Anonymity and Confidentiality

As this thesis is an in depth study on Volvo Buses, the researchers are aware of the anonymity and confidentiality responsibility they have. The reason for this was to reduce the risk of sharing classified information that could jeopardize the competitive advantage of the company. Therefore, no information should be traced back to the suppliers or the specific component. As such certain information was hidden or different names were used. Therefore, within the thesis, the suppliers are referred to as "Supplier A" and "Supplier B" and the component in focus is referred to as merely "the component", with its description kept brief. It is important to note, that by doing so, this has in no way affected the outcome of

the thesis. Rather, it has enabled the authors to gain access to all necessary information without concern that the thesis would be foreclosing too much. Before the publication of the thesis, the client-organization was allowed to review the work to ensure that all material was acceptable. Although this may bring up the issue of participant bias, this issue is minimized by determining beforehand the extent of what information can be publicized in the thesis and how it can be reworded to accommodate for new opinions on the matter without jeopardizing the work.

4. Theoretical Framework

In this section the basic Economic Order Quantity (EOQ) is briefly introduced, followed by the author's own extensions to the model that was built for the purpose of solving the problem of this thesis.

4.1 Basic Economic Order Quantity Model

The basic EOQ model assumes that all parameters are constant and deterministic. As such, the product units are always assumed to be withdrawn from the inventory on known continuous basis. This implies that the demand, *a* for the product is constant at x units per unit time, *t*. The inventory holding cost per unit and time, C*h*, the order/setup cost, *Co*, as well as interest and depreciation, are also assumed to be constant and are given in the model. As for inventory replenishment, the EOQ model assumes that inventory is replenished when needed, at a predetermined reorder point, usually when the inventory level drops to 0. The inventory is replenished through producing or purchasing a fixed batch size (*Q* units). Furthermore, these *Q* units are assumed to arrive simultaneously at the same time (figure 6). The time from when an order is placed to when it arrives, is referred as the lead time, and as all other parameters in the basic model, it is assumed to be known and constant. Furthermore, the time between two consecutive inventory replenishments, is known in the model as a cycle. How long a cycle will last can be determined by the average consumption time per batch size, Q/a. The last assumption of the model is that shortages are not allowed (Glock, Grosse and Ries, 2014; Hillier and Lieberman, 2000).
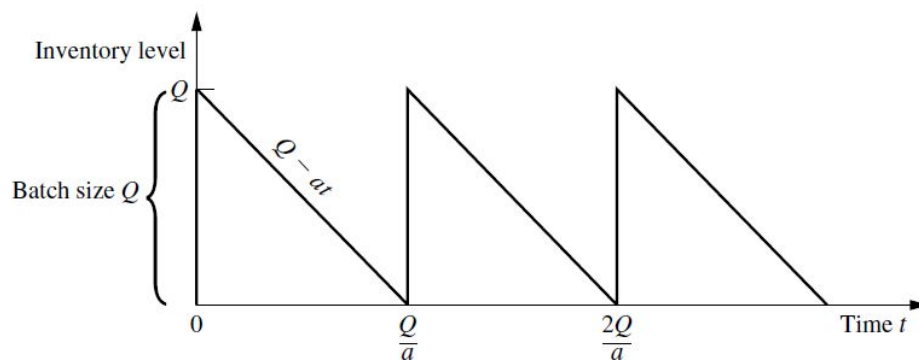

Figure 6: Inventory level as a function of time for the basic EOQ model. Source: Hillier and Lieberman, (2000).

Given an average inventory level of $Q/2$, the order or set up cost $Co + PQ$ and the holding cost $ChQ^2/2a$, the total cost *TC* function can be written as:

$$TC = Co + PQ + \frac{ChQ^2}{2a}$$

To find the total cost per unit time of the total cost *TC* formula above, it needs to be divided by cycle length, Q/a.

$$TC = \frac{Co + PQ + \frac{ChQ^2}{2a}}{\frac{Q}{a}}$$

This can be further simplified to:

$$TC = \frac{DCo}{Q} + DP + \frac{ChQ}{2}$$

By getting the first derivative of the TC function and setting it to zero, the optimal quantity Q^* can be derived. This equation is known as the EOQ formula, or sometimes as the square root formula, and gives the amount of inventory level that minimizes the total cost (Glock, Grosse and Ries, 2014; Hillier and Lieberman, 2000, p.942).

$$\frac{\delta TC}{\delta Q} = -\frac{aCo}{Q^2} + \frac{Ch}{2} = 0$$

By setting the derivative above, equal to zero and solving for Q^*, the optimal order quantity is derived.

$$Q^* = \sqrt{\frac{2Coa}{Ch}}$$

The figure below demonstrates that the cost of holding inventory increases as the order quantity increases. However, the order cost decreases with the increase of the order quantity. The total cost is minimized at the intersection of the holding cost and order cost curves. This intersection is the goal of the optimal order quantity.
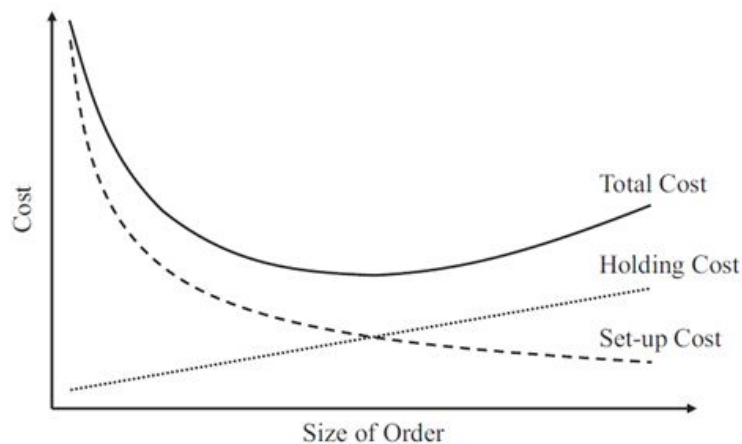
Figure 7: Cost curves of the basic EOQ model. Source: Glock, Grosse and Ries(2014).

4.2 Extended EOQ

An extension of the EOQ model was built to fit the problem that this thesis is investigating. The model is extended to include packaging (Cp), handling at the supplier(Chs), transportation (Ct) and handling at the buyer (Chb), in addition to the inventory ordering (Co) and inventory holding (Ch) costs that are included in the traditional EOQ model.

The input parameters of the model are presented below:
Q - order quantity (call off volume)
Qe - quantity of emballages
a - annual demand
P -price of the component
Co - cost of ordering
Ch - cost of holding inventory
Cp -cost of packaging
$Cp(c)$ - cost of carton packaging
$Cp(p)$ - cost of plastic packaging

Handling at the supplier parameters
Chs-cost of handling at the supplier
$Chs(A)$ - cost of handling at Supplier A
$Chs(B)$ - cost of handling at Supplier B
$LT(h)$ - lead time for handling at the supplier per emballage
$LT(a)$ - lead time for administration at the supplier per emballage

$Sb(A)$ - blue collar salary at Supplier A

$Sb(B)$ - blue collar salary at Supplier B

$Sw(A)$ - white collar salary at Supplier A

$Sw(B)$ - white collar salary at Supplier B

Transport parameters

Ct - transportation cost

$Ct(A)ltl$ - direct, LTL transportation cost for Supplier A

$Ct(A)tl$ - direct, TL transportation cost for Supplier A

$Ct(A)cons$ - consolidated, LTL transportation cost for Supplier A

$Ct(B)ltl$ - direct, LTL transportation cost for Supplier B

$Ct(B)tl$ - direct, TL transportation cost for Supplier B

$FRltl(A)$ -freight rate for direct, LTL transport for Supplier A

$FRtl(A)$ - freight rate for direct, TL transport for Supplier A

$FRltl(B)$ -freight rate for direct, LTL transport for Supplier B

$FRtl(B)$ -freight rate for direct, TL transport for Supplier B

$PCT(A)$ - freight rate from supplier A to xDock

$OCT(A)$ - freight rate from xDock to warehouse for Supplier A

$Chxu$ - unloading cost at xDock

$Chxl$ - loading cost at xDock

Handling parameters

Chb - cost of handling at the buyer

$Chb(i)$ - cost of handling at the buyer at internal warehouse

$Chb(c)$ - cost of handling at the buyer at external warehouse

$LT(u)$ - lead time for unloading at the internal warehouse per emballage

$LT(ua)$ - lead time for administration at internal warehouse per emballage

$Sb(i)$ - blue collar salary at internal warehouse

$Sw(i)$ - white collar salary at internal warehouse

$Chb(u)$ - cost for unloading per emballage at the external warehouse

$Chb(a)$ - administration cost for unloading at the external warehouse

Inventory holding parameters

$Ch(c)$ - external warehouse holding cost

$Ch(is)$ - internal holding cost, shelter roof

$Ch(iw)$ - internal holding cost, warehouse in production hall

$Css(c)$ - cost of storage space at external warehouse

$Css(is)$ - cost for storage space at VPI, shelter roof

Css(iw) - cost for storage space at VPI, warehouse in production hall

Q/2 - average stock level

Qe/2- average emballage level

H- inventory holding time (in weeks)

d- demand for the component per week

The model is built upon the following assumptions:

1. The annual demand for the component is known and constant.
2. A fixed number of buses is assumed to be produced weekly.
3. Call off frequencies are given.
4. The purchase price is constant for every commodity length and is the same regardless of the supplier.
5. No safety stock is kept.
6. The buyer is responsible for the transportation cost.
7. The buyer is not responsible for the return flow (no return flow).
8. The cost of ordering remains constant (equal to 0).
9. The internal storage space has limitless capacity.

The extended total cost function can be seen below:

$$TC = Co + PQ + Cp + Chs + Ct + Chb + Ch\frac{Q^2}{2a}$$

Due to restrictions in the type of data collected from certain sources, the authors had to make assumptions and estimations for some of the data that was missing. Described below are how each of the parameters were calculated.

Cost of Ordering

Due to the fact that the ordering process is outside the scope of this thesis, the ordering cost *Co* was assumed as a fixed cost equal to zero for both Suppliers. Furthermore, the choice to exclude the ordering cost was also because the lead time and cost associated with the ordering process was believed to be very minimal regardless of the size of the call off volume, and therefore ignorable in the model.

Price

The price for the components was given and is assumed to be fixed and the same for both suppliers. The price only differs for when the component is long and short. This assumption is far from reality. The given fixed prices for the long and short components reflect price levels that are more stable which happens only when minimum order quantity production batch sizes are ordered from the suppliers. In

reality the price level will increase dramatically when the component is ordered in quantities that do not correspond to an optimal production batch size from the suppliers.

Cost of Handling at the Supplier

The handling at the supplier *Chs,* was calculated as a sum of the packing, loading and administrative costs. Furthermore, the handling and administration costs were calculated based on the lead time for packaging, loading and administration per component and employee salary at each supplier. Two employees are needed for packaging and loading per component and one employee for administration. Since data on the exact lead time for handling and administration was missing from the Supplier B it was assumed that it was the same as for Supplier A. The equations for *Chs* at both suppliers are presented below:

$$Chs(A) = [2(LT(h) * Sb(A)) + LT(a) * Sw(A)] * Q$$

$$Chs(B) = [2(LT(h) * Sb(B)) + LT(a) * Sw(B)] * Q$$

Cost of Packaging

The cost for packaging was calculated as a sum of the cost for the carton packaging, $Cp(c)$ and the cost for the plastic wrapping, $Cp(p)$ as shown below:

$$Cp = [Cp(c) + Cp(p)] * Qe$$

The costs for both the carton and plastic packaging were given per square meter and as such, they depended on the dimensions of the emballages as the packages correspond to the size of the emballages. As so, the cost of packaging $[Cp(c) + Cp(p)]$ was multiplied by the number of emballages Qe to find the total cost of packaging Cp. Data on the cost of packaging was collected only from Supplier A, and was assumed to be the same for Supplier B. However since the dimensions of the emballages differ between the suppliers, the cost for packaging per emballage also differs between the suppliers.

Cost of Emballage

As the cost of the emballages was not possible to collect from either supplier, it was not included in the total cost *TC* equation.

Cost of Transportation

The freight rate charge is based on the volumetric weight of the emballages. Thus first the volumetric weights were calculated based on the dimensions of the different emballage types. A corresponding freight rate (FR) was then determined from the given freight rates. The freight rates are different for the two suppliers since they are located different distances. The freight rates also differ depending on the type of transportation (LTL or FTL) and whether the transportation is direct or involves consolidation. A handling cost was added to the transportation cost when consolidation is considered. After a corresponding freight rate was determined for each transport option. The transport costs were calculated as follows:

Direct, LTL cost for Supplier A:
$$Ct(A)ltl = FRltl(A) * Qe$$

Direct, FTL cost for Supplier A:
$$Ct(A)tl = FRtl(A) * Qe$$

Consolidated, LTL cost for Supplier A:
$$Ct(A)con = PCT(A) * Qe + (Chxu + Chxl) * Qe + OCT(A)$$

Direct, LTL transportation cost for Supplier B:
$$Ct(B)ltl = FRltl(B) * Qe$$

Direct, FTL transportation cost for Supplier B:
$$Ct(B)tl = FRtl(B) * Qe$$

Cost of Handling (Unloading)

Two handling options were considered and calculated. Handling at the external warehouse and handling at VPI's warehouse. Similarly to the handling costs at the supplier, the handling cost for unloading at VPI was calculated as a sum of the cost for unloading and the administrative cost. Furthermore, the unloading cost and the administrative cost was calculated by considering the lead time for unloading and administration per emballage and the salary of the blue and white collar employees at VPI respectively. Only one employee is needed for unloading and one for administration. The formula used is as follows:

$$Chb(i) = [LT(u) * Sb(i) + LT(ua) * Sw(i)] * Qe$$

The handling cost for the external warehouse was calculated as follows:

$$Chb(c) = [Chb(u) + Chb(a)] * Qe$$

The cost for unloading per emballage $Chb(u)$, and the administrative cost per emballage $Chb(a)$, were readily provided by the external warehouse and as shown in the formula above just added and then multiplied by the number of emballages in an order to get the total handling cost at the warehouse for that call off volume.

Cost of Holding Inventory

Three storage options were investigated in this thesis, namely storage at an external warehouse, $Ch(c)$ and two internal storage options (shelter roof, $Ch(is)$ and warehouse at the production hall, $Ch(iw)$). For all storage options the costs were calculated using the same principle. A storage space cost per square meter was collected for all three storage options. Besides the cost for the storage space itself the storage space costs for all three storage options incorporate also costs related to storage space infrastructure, equipment and storage space investments. Taking these costs a storage space cost was then calculated for the space occupied by the average number of emballages, $\frac{Qe}{2}$ and multiplied by the inventory holding time, H depending on the call off volume, Q and the weekly demand for the component, d. A capital tied up cost was then added to the storage space cost. The capital tied up was calculated as 15% of the value of the average inventory level, $(P * \frac{Q}{2} * 15\%)$. A percentage of 15 was chosen for the capital tied up as this is the standard percentage used at Volvo Buses for calculating cost of capital in Poland for the first quarter of year 2018. The equation used in calculating the inventory holding costs can be seen in below:

$$H = \frac{Q}{d}$$

Cost of holding inventory at the external warehouse, *Ch(c)*:

$$Ch(c) = (Css(c) * \frac{Qe}{2} * H) + (P * \frac{Q}{2} * 15\%)$$

Cost of holding inventory at VPI, shelter roof, *Ch(is)* and warehouse, *Ch(iw)*:

$$Ch(i1) = Css(i1) * \frac{Qe}{2} * H + (P * \frac{Q}{2} * 15\%)$$
$$Ch(i2) = Css(i2) * \frac{Qe}{2} * H + (P * \frac{Q}{2} * 15\%)$$

The environmental impact was not incorporated into the model, but instead was examined qualitatively both for the current leogistics set up for the component and for the presented alternative logistics scenarios. Furthermore, it was not possible to find the theoretical derivation for the additional add ons, due to the type of data that was collected. Therefore the authors opted for a numerical optimization of the extended EOQ model instead, using Excel to derive the economic order quantity (Q^*).

5. Empirical Findings: Volvo Buses

In this section, a brief introduction of Volvo Buses is presented, in order to gain some background on the complexity of bus production and the importance when it comes to the logistics flow design. This is followed by a presentation of Volvo Buses' current logistics flow for the component at interest. And lastly the section is concluded with possible alternative scenarios that challenge the current logistics flow.

5.1 Volvo Buses

Volvo Buses is part of Volvo Group and focuses on the manufacturing of buses and coaches. With production facilities located in Europe, Asia, North and South America (see figure 8) and market presence in 85 countries, Volvo Buses is a world leading bus and coach producer. The full brand portfolio consists of Volvo, Prevost, Nova, UD and Sunwin that produce complete busses, chassis, intercity buses and coaches as well as many services related to their products. For a global company such as Volvo Buses, it is of utmost importance to have a well designed and functioning supply chain (Volvo Buses, 2018).

Figure 8: Bus Manufacturing Facilities. Source: Volvo Buses, 2018.

Buses are complex to manufacture. There are approximately 4000 parts in one bus that are sourced from different suppliers and the logistical flows for all these parts need to be carefully designed. Differently from other vehicle manufacturing, the manufacturing of buses and coaches is more difficult to standardize. This is because buses are very customised to the needs of the customer. Thus this often requires parts that differ in different bus or coach models for which a new logistics flow needs to be

designed. The component considered in this thesis is just one example of a special part as it requires special packaging, emballage and is more difficult to transport, handle and store.

5.2 Current Logistics Flow

In this thesis, two suppliers that can provide the component were considered, Suppliers A and B. Supplier A is located approximately 1057 km and Supplier B is located 280 km, from the production and storage facilities. Besides their different locations, the suppliers also have different lead times, packaging options, handling and production capabilities that will affect their total landed cost. For simplification purposes, it was assumed that both suppliers have the same production capabilities (both can produce short and long components). The total lead time from Supplier A, from point of production to final storage, is 21 working days. This lead time can be reduced to 11 working days if larger orders are placed and stored at the supplier's site. For Supplier B, the lead time is 42 working days. Since the scope of this thesis excludes the ordering process, the focus is placed on the lead time starting with handling (loading) at the supplier, up until the component is delivered and stored in the warehouse. In order to ensure that certain information and actors are kept confidential, the logistics flow was not presented in depth. However, what is necessary for the readers to know, has been presented in this section and should not affect their understanding of the current logistics flow for the component in focus.

5.2.1 Packaging and Emballage

It is the supplier's responsibility to ensure that the packaging and emballages used, are according to Volvo Buses packaging instructions. Since the component is a visual part (no dents or scratches are allowed) and made from a thin and fragile material, the packaging and emballage used to transport and store the components in, should protect the goods from any risk of damages during transportation and handling. Furthermore, only 1 p/n per package is assumed to be allowed. Thus, whenever the component is ordered in 4 p/n's, they will have to be packaged in 4 separate packages and emballages. Since Supplier A is located 1057 km away, they use a non-returnable emballage for this component. The component is first packed in a carton box that is wrapped in plastic and then it is placed within a wooden emballage or frame. Approximately 34 components fit within one of the packagings from Supplier A. Similarly, Supplier B packs the component in carton boxes, which are then wrapped in plastic. Their boxes are slightly larger, with 40 components fitting within one carton box. Supplier B though, uses metal emballages in which the carton box is placed. These metal emballages are reusable and owned by Supplier B.

5.2.2 Loading (Handling) Process

Once the components have been packaged and placed on an emballage, they are loaded onto the transportation using a four-way forklift. Both packaging options allow for stackability. The handling at Supplier A takes approximately 115 minutes per emballage with the short component, and 119 minutes per emballage with the long component. At Supplier B, handling takes 136 minutes per emballage with the short component and 140 minutes per emballage with the long component. The handling at the suppliers includes packaging and loading on the trailer. The lead time for handling at the suppliers differs per emballage between Supplier A and Supplier B is because the packaging at Supplier B contains more units of the component. However from a total packaging, emballage, and loading lead time perspective, it takes between 1 to 9 working days for both Supplier A and B, depending on the call off volume. If the call off volumes are small, the packaging, emballage and loading lead time will be smaller. On the contrast, if the call off volumes are large, the lead time will be bigger.

Supplier	Packaging and Loading Lead Time per Emballage	Total Packaging, Emballage and Loading Lead Time per Call Off Volume	Emballage	Packaging
Supplier A	Long component: 119 min Short component: 115 min	1-9 days	Wooden (unit load:34)	Carton and plastic
Supplier B	Long component: 140 min Short component: 136 min	1-9 days	Metal (unit load:40)	Carton and plastic

Table 1: Packaging, emballage and loading

5.2.3 Transport Process

Volvo Buses arranges and pays for the transportation for both suppliers, with the exception of the return flow of the metal crates, which Supplier B arranges and pays for themselves. Rather than owning their owns vehicles though, Volvo Buses uses a third party logistics provider to do the actual transporting. However, it is still Volvo Buses who takes the responsibility and risk for the components during the transportation leg and not the carriers or the suppliers. Once the orders have been produced, packaged and placed on emballages, the suppliers order transportation through Volvo Buses' transportation ordering system. Through this system, the suppliers can select how many trucks they need and, based on the goods receiving date, when the components should be picked up by the carrier. A standard trailer (length=13.6m, width=2.45-2.48m and height=2.7m), is used for both suppliers, and can hold 12 long or 24 short metal crates and 30 long or 60 short wooden crates.

Due to the significant differences in distance between the two suppliers, they have different transportation flows. Supplier A uses a less than truckload with consolidation at a cross dock located approximately 267 km away from Supplier A, before arriving at VPI. The total transportation lead time from Supplier A to VPI is approximately 5 days with 3 days allocated for the consolidation. Supplier B on the other hand, uses a LTL with direct transport and a transport lead time of only 1 day. This data is presented in Table 2.

Due to past contracts between Supplier B and Volvo Buses, the return flow of the reusable metal emballages is the responsibility of Supplier B. Therefore, Supplier B pays for the transport and takes the risk once they are loaded onto the trailer. When enough metal crates are collected (usually enough to fill a truckload), VPI informs Supplier B to send transportation for the return flow.

Supplier	Transport Distance (km)	Transport Flow	Transport Lead Time (days)	Trailer Type
Supplier A	1057 km	LTL + Consolidation	5 working days	Standard
Supplier B	280 km	LTL DDT	1 working days	Standard

Table 2: Transportation

5.2.4 Unloading and Storing Process

Due to the length of the components and the limited storage space at VPI, the goods are delivered at an external storage facility only 15 minutes from the production site. Once the transportation arrives at the goods receiving location, the components are unloaded from the trailer using a four-way forklift. The components are either immediately unloaded or they can wait up to 30-40 minutes before being unloaded. When unloading, it only takes approximately 5 minutes per emballage. However the entire handling (physical and administration) can take up to 24 hours, until it's placed in the storage, regardless of the call off size. The handling lead time depends on how many packages were delivered, how long it takes before the components are unloaded from the truck and due to administrative handling and updating in the system. However, since there is no general rule on how long handling should take, the authors chose to quantify the handling lead time as less than or equal to 1 working day.

Once all administration steps and updates to the system are made, the components are placed in the external warehouse in a designated area. The components are stored in their original packaging and emballage that they were transported in. Furthermore, each p/n is stored on separate shelves. Although

there are no thorough quality checks after the goods are received, the packaging is checked to ensure that it is according to Volvo packaging standards and that there were no signs of damage during transportation.
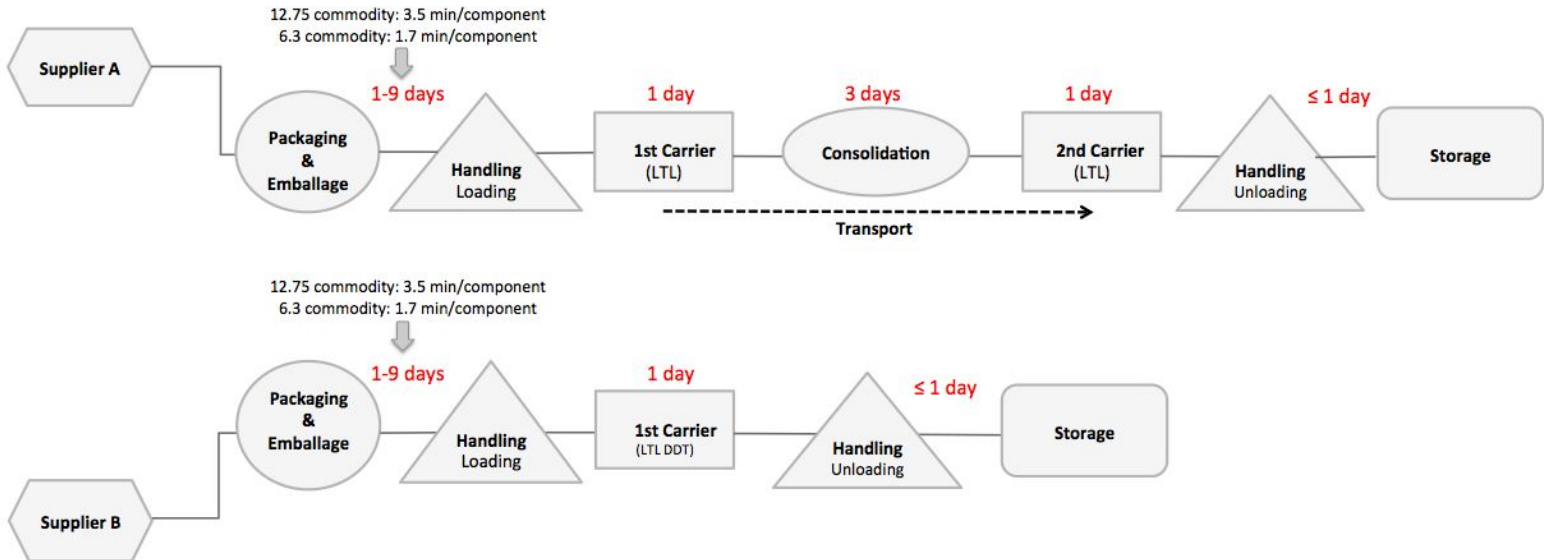

Figure 9: Map of Supplier A and B's Logistics Flow Lead Time

5.2.5 Scenario Generation Based on Different Call Off Volumes

The total logistics costs for the current logistics set up for both Suppliers A and B were calculated for six given call off volumes. Since suppliers A and B have different emballages with different unit loads, the call off volumes that were chosen are slightly different. The call off volumes for Supplier A and Supplier B for both the long and short components, can be seen in Table 3. The call off volumes for the short components are merely double the call off volumes of the long components, since two short are equal to one long. Furthermore, these call off volumes apply to both 1 p/n and 4 p/n.

Supplier A		Supplier B	
Long	*Short*	*Long*	*Short*
34	68	40	80
102	204	80	160
170	340	160	320
306	612	320	640
612	1224	600	1200
1224	2448	1200	2400

The total costs under these call off volumes were then calculated for 4 scenarios (Figure 10). Scenario 1 assumes that all components are long and have only 1 p/n. Scenario 2 assumes that the components are long with slight variance in the lengths and therefore 4 p/n's. Scenarios 3 and 4 are similar to Scenarios 1 and 2, but instead they assume that the component is short.
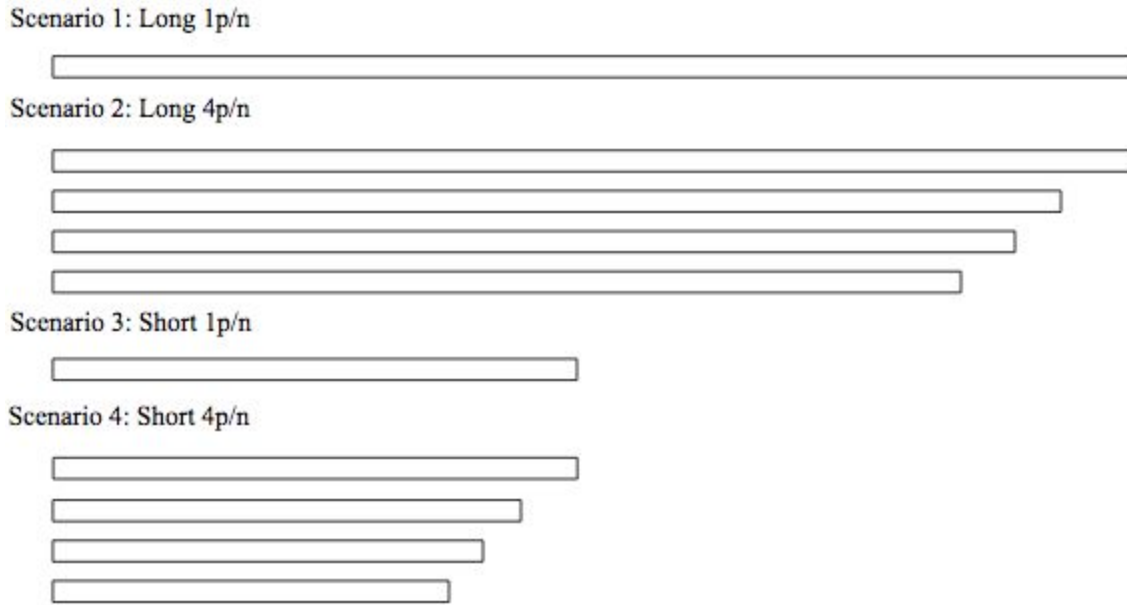

Figure 10: The 4 scenarios

Together with these 4 scenarios and 6 call off volumes, the current logistics setup and alternative logistics setups were generated and discussed in the analysis. Such as scenarios for various transportation options for both suppliers were generated as well as scenarios for the alternative options of storing.

6. Analysis

In this section, the analysis is presented with the aim of answering the two research questions.: 1. *What is the most favorable logistics flow in terms of packaging, emballage, loading (handling) transportation, unloading (handling) and storage for the component in question? 2. How will different call off volumes minimize total landed cost, lead time and environmental impact?* As such the most favourable logistics options are first identified with focus placed on different storage and transport alternatives. For the most favourable logistics setup the optimal call off volumes are then determined first with respect to cost and then with respect to lead time and environmental impact.

6.1 Investigating Alternative Logistics Setups

To be able to answer the first research question, the authors looked into the main cost factors in the current logistics flow in order to determine which areas to focus the analysis on.

6.1.1 Areas with greatest impact

Looking at Chart 1 (logistics flow costs for Supplier A for scenario 1), it is obvious that the price of the component has a large impact on the total logistics flow costs, dominating 92% of the total cost. As previously mentioned (Section 4.2), the price of the component is assumed to be fixed and constant for both suppliers regardless of the size of the orders, and therefore does not give an accurate representation of real life circumstances. Moreover, as the focus of this thesis is on the six areas of the logistics flow, the authors will focus their attention towards those costs areas instead. That being said, the three main cost drivers in the logistics flow are storage (holding cost) (4.24%), transport (1.95%) and handling at the supplier (1.29%). As the logistics flow costs for the remaining scenarios looked approximately the same as in chart 1, there was no value in presenting it for the other scenarios as well.
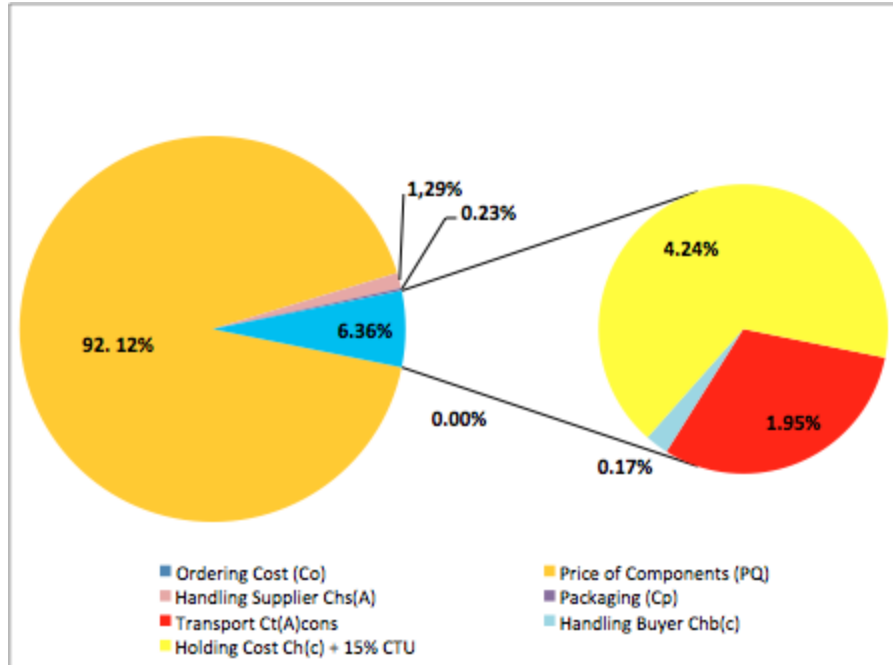
Chart 1: Logistics Flow Costs for Supplier A, Scenario 1

According to the literature (Section 2), when trying to reduce the total landed costs, lead time and environmental impact, there will always be tradeoffs when it comes to risk, especially between transportation and storage. If the focus is placed on reducing the amount of goods placed in storage, as many companies tend to do because they believe it will reduce the cost of storage and tied up capital, there is the potential risk of damage or problems with the reliability of delivery of the components. The risk of stock outs could result in higher costs and lead time if the production had to stand still, and a higher environmental impact if last minute transportation is needed. On the other hand, choosing to store more goods also brings the risk of obsolescence, as the consumption of the different lengthed components will depend on which lengthed buses have a greater demand for production. This risk is even greater when it comes to storing 4 p/ns, as the components are pre-cut to specific lengths already, whereas with 1 p/n, they can be cut to any length and therefore can be easily adjusted towards the production demand. Therefore the risk of storing more, may save on certain costs such as transportation, whereby larger quantities are shipped less frequently, as well as result in lower lead time and environmental impact. However, the risks are equally present whether the decision is to store more and transport less, or to store less and transport more.

In deciding which area (transport or storage) to reduce the total landed cost, the choice should realistically affect the handling at the supplier too. For instance, if large quantities are shipped less frequently, the cost of handling will decrease as the number of handling per year will fall. And vice versa, if small quantities are shipped more frequently, the cost of handling will increase, as more handling throughout the year is necessary. However, as the calculations for handling costs in this thesis are

calculated in a way that the handling costs are shown as being constant, it does not represent real life accurately. Therefore, the authors decided to focus on transport and storage when looking at alternative options for reducing the total landed costs, lead time and environmental impact, to ultimately find the most favorable logistics flow. In the following sections, the authors will look into the current and alternative storage and transport options for all four scenarios.

6.1.2 Investigating Alternative Transport Solutions

As transportation has one of the greatest effects on the total landed costs, lead time and environmental impact, the authors decided to look closer into the different possible transportation options. As the current transport option for Supplier A is LTL with consolidation and a transport lead time of 5 days, the alternative transport options that the authors looked into were FTL and LTL with direct transportation. The current transportation option for Supplier B on the other hand is LTL with direct transportation to VPI and a lead time of 1 day. The authors decided to look only at direct FTL as an alternative transport option since Supplier B is located only 280 km from the goods receiving location. Therefore, consolidation was not considered as a likely option. Although all four scenarios were derived with these transport options, some of the scenarios were placed in Appendix (10.3), as similar results were found.

Graphs 1 (scenario 1) and 2 (scenario 2) below, looks at the transport costs for Supplier A, and Graphs 3 (scenario 3) and 4 (scenario 4), looks at the transport costs for Supplier B. It can be seen in all four graphs, and for all transport options, the transport costs start to decrease as the call off volumes increase. This is due to the lower freight rates that are given when the chargeable weight of the payload is higher. In other words, the higher the call off volume, the higher the chargeable weight of the payload and therefore, the price per weight drops regardless of how many orders per year are made. Furthermore, this also explains why all the curves do not pass through the origin (0), but rather begin at a higher cost and then descend when bigger call off volumes are ordered.
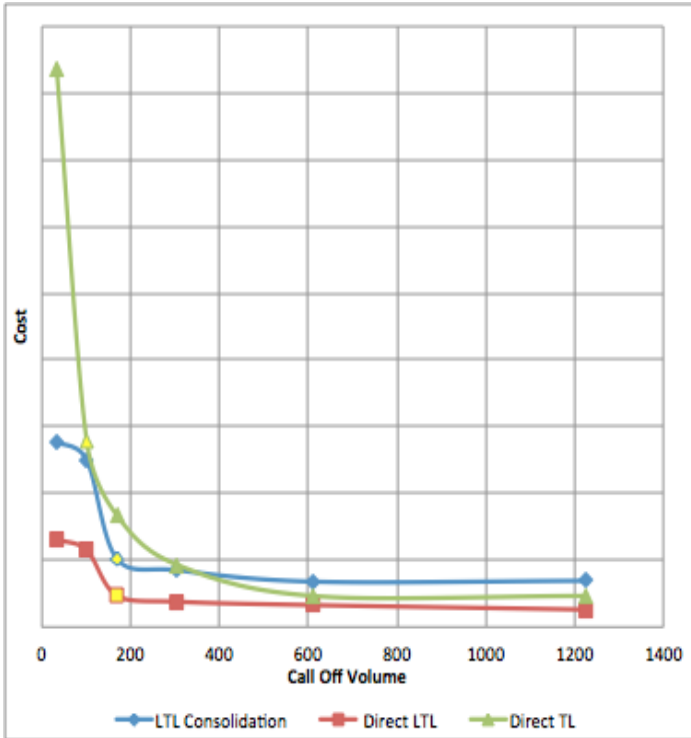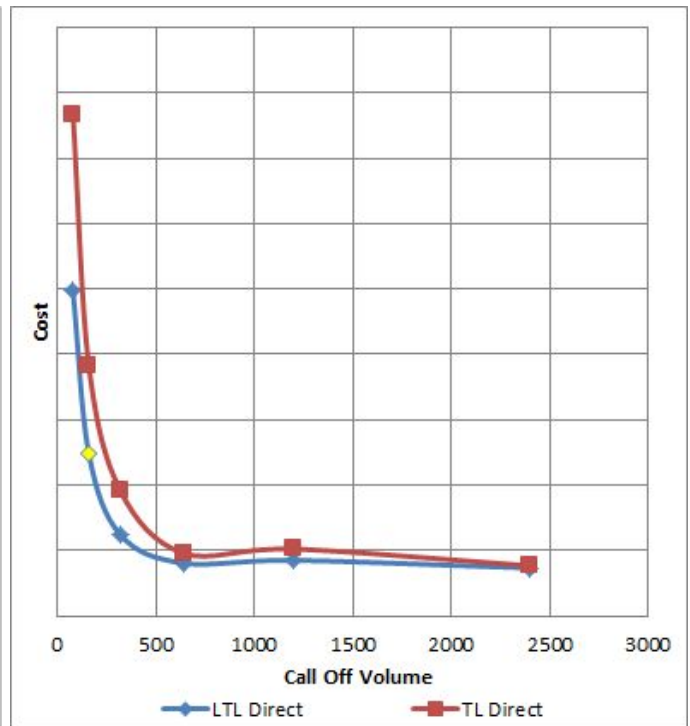
Graph 1: Transport Costs for Supplier A, Long for 1 p/n
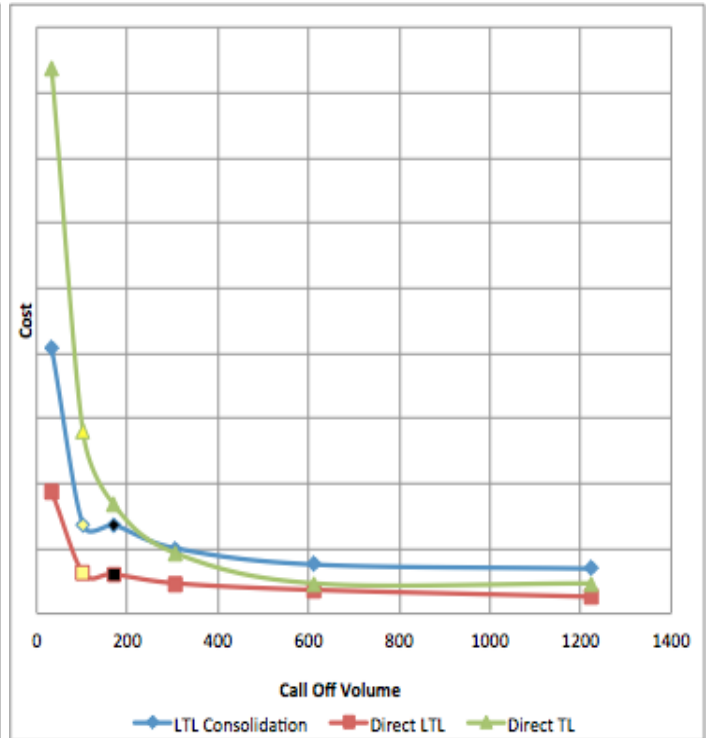
Graph 2: Transport Costs for Supplier A, Long for 4 p/n's
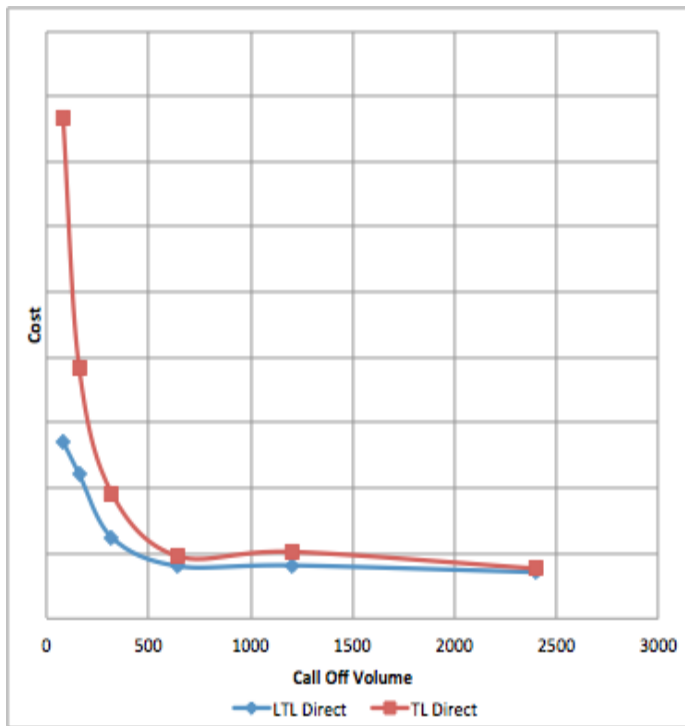
Graph 3: Transport Costs for Supplier B, Short for 1 p/n

Graph 4: Transport Costs for Supplier B, Short for 4 p/n's

6.1.2.1 Landed Cost

Transport Costs for 1p/n and 4p/n's

Supplier A

In graphs 1 and 2, the LTL with consolidation and direct LTL curve, drops significantly when the call off changes from 102 to 170 (marked in yellow). Whereas the direct FTL curve drops suddenly when the call off changes from 34 to 102 (marked in yellow). The reason for this sudden drop is due to the freight rates which decrease by a large amount in the beginning as the chargeable weight increases. Eventually the decreasing freight rates start to slow down as it reaches a certain chargeable weight, and the difference in the cost of transport becomes less as greater volumes are called off (hence why the curves at larger call off volumes start to look flat). Eventually when the truck reaches maximum capacity, a new truck will need to be allocated to ship the rest of the components, and the same process is repeated until that truck is filled up and so on. These results are equivalent to what has been found in the literature (Section 2.1).

Looking closer at Graph 2, there is a slight difference in how the curves look compared to Graph 1. Although the LTL with consolidation and direct LTL curves seems to be going up when the call off volume goes from 102 (marked in yellow) to 170 (marked in black), they are actually decreasing. The reason why the curve decreases so little between those two points, is because of the chosen call off volumes. The first three call off volumes for Supplier A for the long component (which can be found in Table 3) are 34, 102 and 170. The difference between these call off volumes is always 68, however when the call off goes from 170 to 306, the difference is much greater (136) and thus the curve looks the way it does.
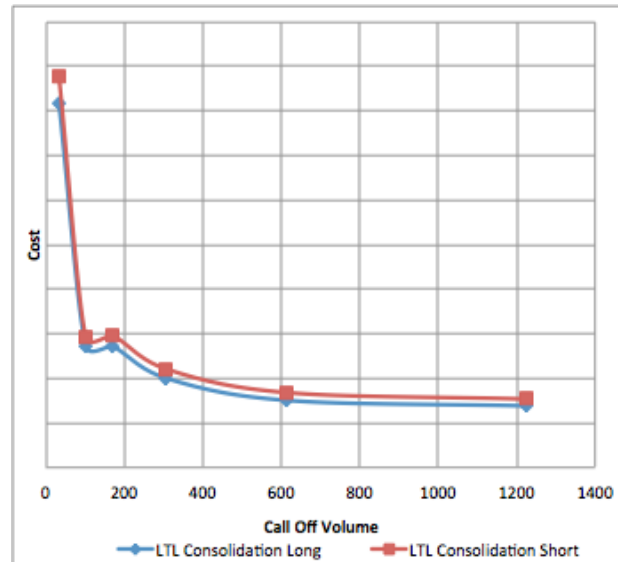
Supplier B

What's interesting about Graphs 3 and 4, which was not as strongly present in Graphs 1 and 2, is how much the same transport options differ for 1 p/n and 4 p/n's. For instance, in Graph 4 the direct LTL curve begins at a higher cost, and has a greater drop when the call off volume changes from 40 to 80 (marked in yellow). The reason that the direct LTL curve starts at a higher cost in graph 4, is because of the extra emballages that 4 p/ns requires (as this thesis does not assume mixed packaging within the same emballage). As the call off volumes are the same for 1 p/n and 4 p/n's, the same amount of components are ordered, only that with 4 p/n's, these components are split evenly into different lengths and therefore emballages. For smaller call off volumes, the difference in the number of emballages is much greater, since with 4 p/ns, the number of components don't completely fill up an emballage. For instance, with the first call off volume (80), for 1 p/n (Graph 3), only two emballages are needed for every shipment. However with 4 p/ns (Graph 4), eight emballages are needed. Eventually with larger call off volumes, the

difference between the number of emballages used for 1 p/n and 4 p/n's, starts to decrease (as can be seen in the graphs as they follow the same curvature).
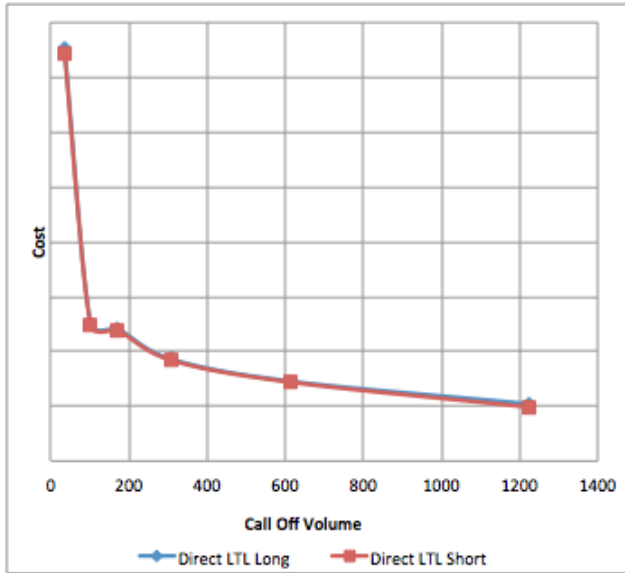
Transport Costs for Long and Short Components

In terms of comparing the transport costs of long and short components, there was not much of a difference for both suppliers. Graphs 5 (LTL with consolidation), 6 (direct LTL) and 7 (direct FTL) below, compares the long and short components for Supplier A. As the graphs showed the same results for Supplier B when comparing the two transport options (direct LTL and FTL), they were placed in Appendix 10.4. Furthermore, since the authors don't look into a LTL with consolidation option for Supplier B, they decided to focus instead on Supplier A for the analysis of long and short components.

Graph 5: Transport Costs for Supplier A, LTL Consolidation for 4 p/n's

As Graph 5 shows, there is a slight difference between long and short components for LTL with consolidation. Previously mentioned in Section 4.2, handling at the cross dock was included in the calculations of the transport costs for consolidation. Since short components have double the number of emballages than long components, it makes sense as to why the LTL with consolidation curve for short components is slightly higher than for long components.

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Graph 6: Transport Costs for Supplier A, Direct LTL for 4 p/n's   Graph 7: Transport Costs for Supplier A, Direct TL for 4 p/n's
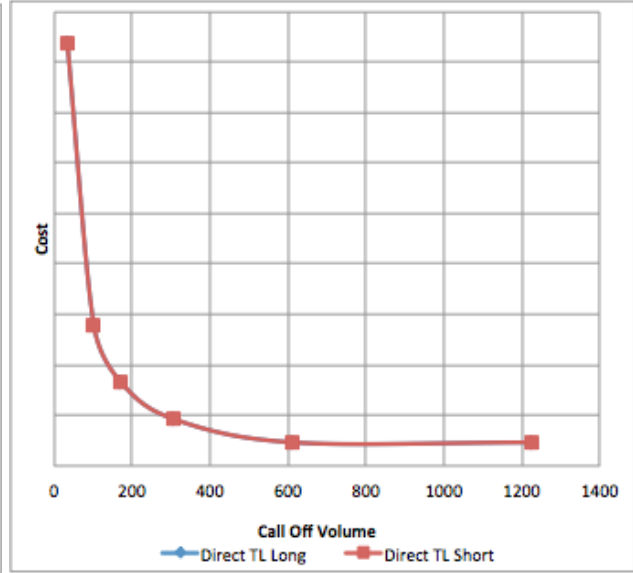
Graphs 6 and 7, on the other hand, show even less of a deviation between the short and long components when looking at direct LTL and TL. The only differences between the short and long components is the number of components that need to be ordered and the number of emballages. Even though double the amount of short components and emballages should be ordered compared to the large components, the short emballages are half the size of the long emballages, and therefore the same amount of emballages can fit in a trailer. Therefore, the direct LTL and FTL curves for long and short components are pictured as so.

6.2.2.2 The Most Optimal Transport Solution

Supplier A

Landed Cost

When comparing the different transportation options in graphs 1 and 2 for all call off volumes, the best option in terms of costs was clearly direct LTL, as it was well below both LTL with consolidation (current transport flow) and direct FTL. When looking at the difference between 1 p/n and 4 p/n's, direct LTL was still found to be the best case for both. However, when it comes to 4 p/n's, the cost of transporting at small call off volumes is slightly higher in the beginning, as more emballages need to be shipped.

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Lead Time

When analyzing lead time, LTL with consolidation had the greatest lead time with 5 days compared to both direct LTL and FTL, which have a lead time of 2 days. The reason for this is because with consolidation, the component needs to stay at the cross dock for 3 days. This delays the lead time substantially, making direct LTL and FTL the best option time wise.

Environmental Impact

In terms of environmental impact, LTL with consolidation has a greater impact, since it cannot take the shortest route like direct LTL and FTL can take. Moreover, the route taken with LTL with consolidation, is a mix of rural and urban roads, with transportation in urban areas having a greater impact on the environment. Direct LTL and FTL on the other hand is mostly rural roads, and thus will require less stopping and constant speeds. Although, direct FTL has a shorter route than LTL with consolidation, if the call off volumes are too low that they don't fill up the trailer, there will be a lot of wasted space.

Supplier B

Landed Cost

From what can be seen in Graphs 3 and 4, direct FTL is more expensive than direct LTL, and therefore the current scenario with direct LTL is the most optimal transport solution for Supplier B. The reason for direct FTL being so expensive, is because the cost of hiring the entire space of the FTL will always stay the same, no matter the volume being called off. Perhaps if the authors looked at transporting even bigger call off volumes, the direct FTL and LTL curves would intersect at some point. However, there is no need to transport bigger volumes, as the maximum call off volume is equal to the total yearly demand.

Lead Time

Regardless of the transport option, the lead time will remain the same, since the distance and route doesn't change. Although handling at the supplier was not considered together with the transportation lead time, in reality, the lead time would be higher with 4 p/n's when smaller call offs are made. This is because more emballages will need to be handled initially. Therefore, the optimal call off volume, should determine whether to transport 1 p/n or 4 p/n's.

Environmental Impact

The environmental impact may differ between the two options depending on the call off volume. For instance, having direct TL with a low payload will result in limited space utilization, which is an inefficient way of transporting goods and negatively affects the environment. However, if larger call offs are made, and fill up a TL, the environmental impact will be the same as for direct LTL. In most cases however, direct LTL would be the most environmentally friendly option.

6.1.3 Investigating Alternative Storage Options

Storage was another main area that the authors decided to take a closer into. Storing the component internally, at VPI rather than externally (current logistics setup, Section 5.3.2) was an appealing option to consider as it offered a possibility for a potential reduction in the holding costs. Two internal storage options were considered, namely storage under a shelter roof and storing at the internal warehouse in the production hall. The costs for these storage options were then generated in comparison to the cost of storing externally for both suppliers under all scenarios and for all call off volumes. Only some of the scenarios were presented in the analysis and the rest were placed in Appendix 10.3, as they were found to be very similar. The lead time and environmental impact of the different storage options were discussed qualitatively.

As explained in Section 4.2, the holding cost consist of a storage space cost and a cost for capital tied up. Since the cost of tied up capital is not affected by the choice of storage space, it was removed from this section of the analysis and it was discussed in more detail in the Section 6.2.2. Removing the tied up capital enabled a clearer focus on the storage space cost for the three storage options investigated.

6.1.3.1 Cost

As it can be observed in all graphs below (Graphs 8, 9, 10, 11), and in Appendix 10.3, the yearly storage cost curves are continuously increasing with larger call off volumes. This is because with larger call off volumes there will be a greater number of emballages that will have to be stored, thus occupying more storage space. On the other hand, with smaller call off volumes the storage space cost declines and so if no order is placed the storage space cost will decrease to 0 as there will be nothing to store. This can be seen in the Graphs 5 and 6, if the curves are extended further down they would cross through the origin, (0).
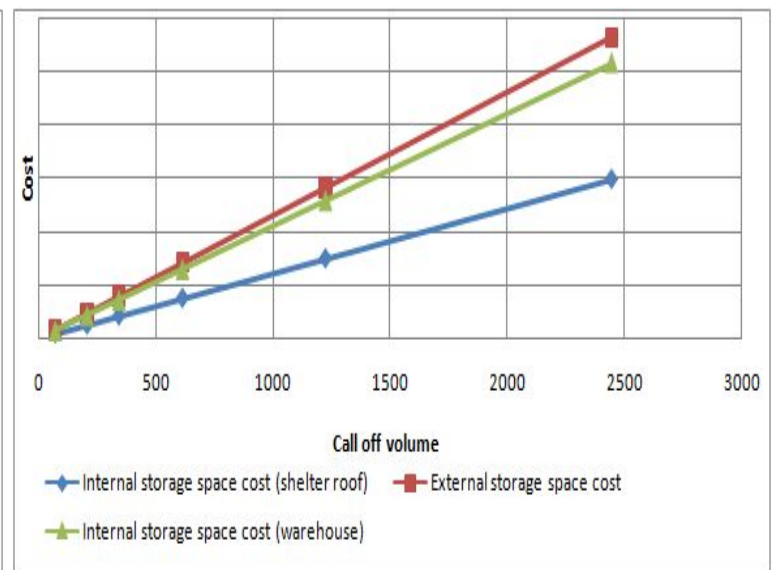
Storage space costs for long and short components

Graphs 8 and 9 below demonstrate the yearly storage space costs for the three storage options for Supplier A under scenario 1 (long, 1p/n) and scenario 3 (short, 1p/n) when the component is shorter. As it can be observed, the storage space costs are almost the same regardless of the length of the component. The storage space costs are only slightly lower when the component is short for all storage options and the difference is very small, approximately 0.012%. When illustrated with a graph the curves almost overlap (Appendix. 10.3) This difference is because the short components will occupy slightly less storage space. For Supplier B same results were observed (Appendix 10.3).
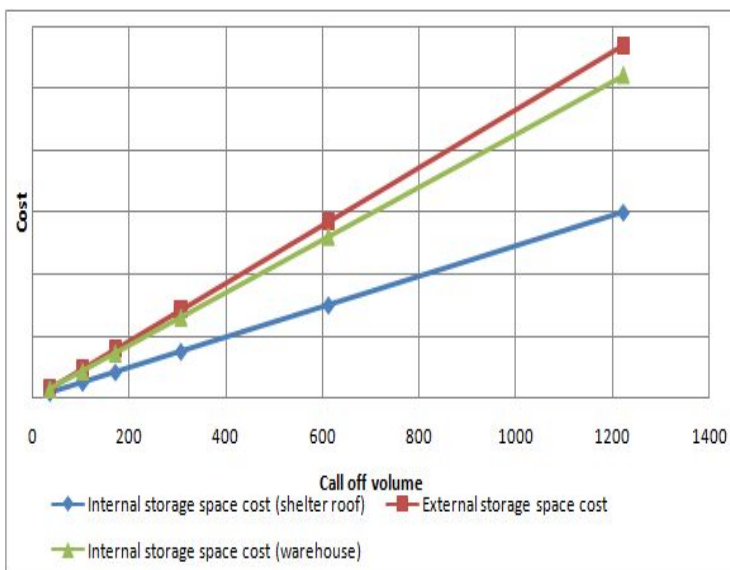
Graph 8:Yearly storage space costs, Supplier A, Long, 1 P/N   Graph 9: Yearly storage space costs, Supplier A, Short, 1 P/N

Storage costs for 1p/n and 4 p/n' s

A difference can be observed in the storage space costs for all storage options when the scenarios with 1 p/n (Graphs 8 and 9) were compared to the scenarios where the component is in 4 p/n's (Graphs 10 and 11). Furthermore there is a difference when the two suppliers are compared as well (Graphs 10 and 11).
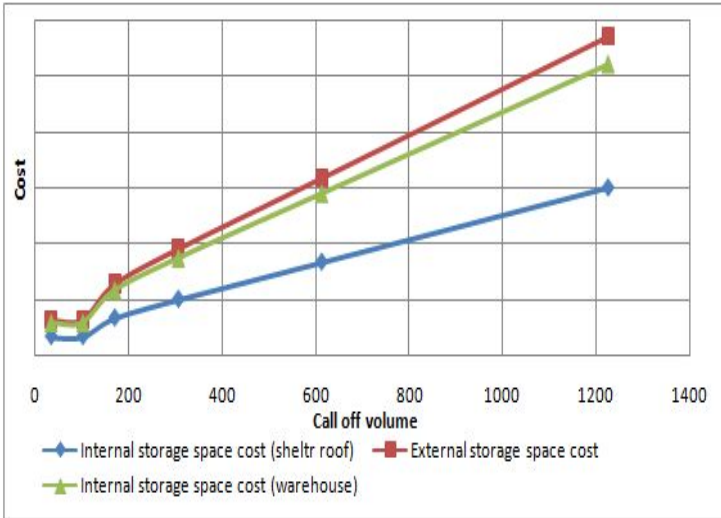
Graph 10:Yearly storage space costs, Supplier A, Long, 4 P/N's
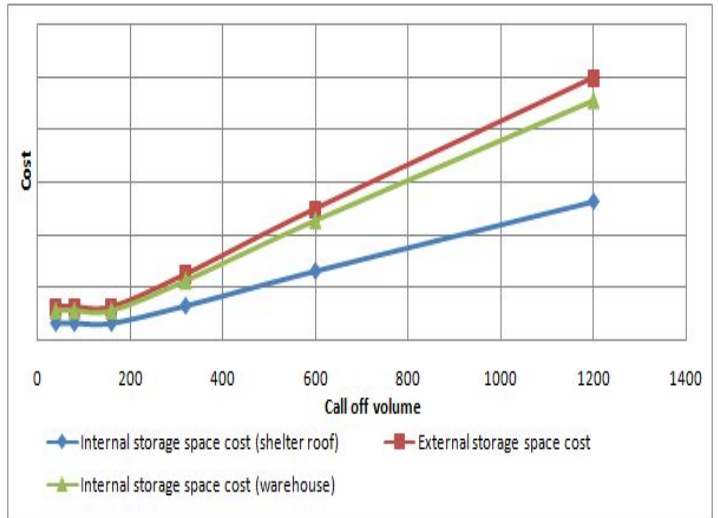
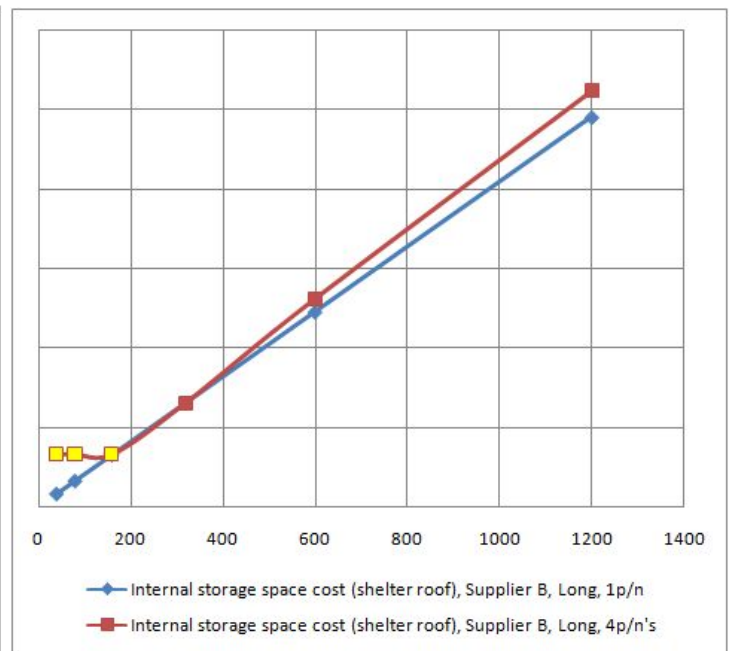Graph 11: Yearly storage space costs, Supplier B, Long, 4 P/N's

Graphs 12 and 13 look into more detail and compare the storage space costs when the component is ordered as 1 p/n and 4 p/n's for Supplier A and Supplier B respectively for the storage option storing under shelter roof. Same results were observed for the other storage options and thus placed in Appendix 10.3. As can be seen in Graph 12, differently from when the component is ordered in 1 p/n, when the component is ordered in 4 p/n's (red line) the storage space cost is the same for the first two call off volumes (34 and 102) corresponding to Supplier A (Table 3) (points marked in yellow). This is because in this thesis it is considered that different part numbers cannot be mixed in the same packaging and emballage. Thus, although only 34 components will be called off at a time in scenario 2 (long, 4 p/n's), they will have to be placed in four emballages and packages, whereas in scenario 1 (long, 1 p/n), only one emballage will be needed as the unit load for supplier A is 34 (section 5.2.1). For the second call off volume of 102, still four emballages will be needed when the component is ordered in 4 p/n's for Supplier A and thus, the storage space cost is the same for these call off volumes. Under scenario 1 (long, 1p/n), for the second call off volume (102), three emballages will be sufficient and the storage space cost is lower. In Graph 12 it can be seen that for scenario 2 (long, 4p/n's), the yearly storage space cost is always higher when compared to scenario 1 (long, 1p/n). This is because of the extra emballages that will be required when the component is ordered in 4 p/n's, occupying more space. For the last call off volume (1224) the cost will be the same regardless of the part numbers because in both cases, 36 emballages will be needed. Similar results were seen under scenarios 3 (short, 1 p/n) and 4 (short, 4 p/n's) for Supplier A (Appendix 10.3).

Graph 13 illustrates similar results for Supplier B. In the case of Supplier B, the storage space cost will be the same for the first three call off volumes corresponding to this supplier (Table 3) and the reasoning is the same as for Supplier A. In the case when 4 p/n's are ordered, they will require additional packaging and emballages that will occupy more storage space. For Supplier B since the unit load differs from

Supplier A (unit load is 40, section 5.2.1), for the first three call off volumes under scenario 2 (long, 4 p/n's), four emballages will be needed. Under scenario 1 (long, 1 p/n), the number of emballages reaches four only at the third call off volume of 160. At this call off volume, (160) and at the call off volume 320, since the same amount of emballages will be required over the year regardless of the part numbers, the storage space cost is the same. Then at a call off volume of 600, again the yearly storage space cost becomes more expensive under scenario 2 (long, 4 p/n's) because of the additional emballages that will be needed. Similar results were observed under scenarios 3 (short, 1 p/n) and 4 (short, 4 p/n's), and thus were placed in Appendix 10.3. This observation emphasises the importance of the emballage and packaging size and their unit load as it affects how much space will be occupied, and as such has a great impact on the storage space cost.
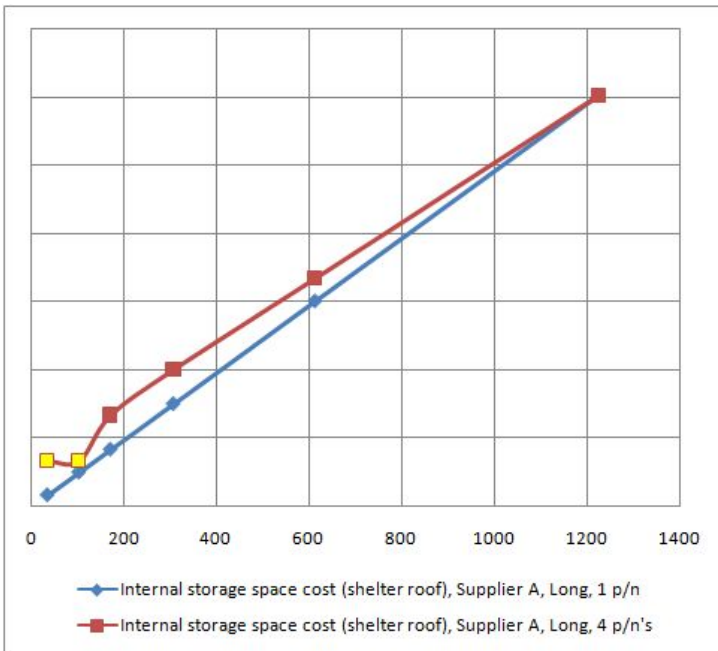
Graph 12: Yearly storage costs for Supplier A 1 p/n and 4p/n's   Graph 13: Yearly storage costs for Supplier B 1 p/n and 4p/n's

Most cost efficient storage option

For both Suppliers in all 4 scenarios (Figure 10), it is always cheaper to store internally with the shelter roof option being the cheapest option (Graphs 8, 9, 10, 11 and Appendix 10.3). Having the internal storage option cheaper than the external option was expected, especially the shelter roof option which was confirmed to be the cheapest option. However, it should be kept in mind that the model in this thesis assumes unlimited storage space internally. In practice, if the internal storage space option (shelter roof) is considered, a further evaluation of the internal storage capacity needs to be done.

Furthermore, it was found that with regards to storage space cost, for most call off volumes, it is cheaper to have the component delivered in 1 p/n rather than in 4 p/n's. However, this is very dependant on the

number of emballages and the unit loads at the different suppliers as previously described. Thus, for example in the case of Supplier B at the call off volume 160, the cost for storage space will be the same regardless of whether the component is ordered in 1 or 4 p/n's since the same amount of emballages will be required in both cases (Graph 13). It was also found that the storage space cost will be slightly lower when the component is ordered with the shorter length. However, this difference is very small.

6.1.3.2 Lead time

When it comes to lead time, it was observed that regardless of which storage option will be selected, the lead time will not be affected. This is because the external storage is located only 10 minutes away from the internal storage space and the assembly line. The overall lead time will be influenced when the component is stored externally, because in that case additional handling and transportation will be required to deliver the component to the assembly line. However, since the scope of this thesis ends with storage and does not include delivery to the assembly line, the authors did not look further into that aspect.

6.1.3.3 Environmental impact of the different storage options

Since data on the environmental impact of the external storage space was not obtained, it was difficult to determine what storage option would have greater environmental impact. At the internal storage the handling equipment used to unload the component would be a four-way forklift. The internal storage space has 4 four-way forklifts, out of which 3 are electric. Additionally, all packaging materials are sorted and recycled at the internal storage space. Knowing that storing the component internally will also occupy a very small portion of the internal storage space, it can be said that the environmental impact form storing the component internally will be negligible. Storing the component at the external warehouse occupies approximately 10%, also a very small portion of the external storage space. Thus, the authors believe that the energy consumption and the emissions from the handling equipment for this component will be minimal at the external storage as well.

6.2 Optimal Call Off Volumes

In order to answer the second research question, the authors will use their extension of the EOQ model to find the most optimal call off volume and at which frequency Volvo Buses should order the components. In finding the EOQ, it shows at which call off volume will result in the lowest yearly total landed costs. As the authors looked into many different scenarios, they decided to focus only on the most optimal ones when evaluating what call off volume to order over the timespan of a year. Furthermore, the authors analyzed lead time and environmental impact descriptively.

From the findings in Section 6.1, where the authors analyzed alternative logistics setups in order to find the most optimal scenarios, they found that direct LTL transportation and storage at VPI under shelter roof was the most optimal setup for both Supplier A and B for all scenarios. Therefore, the final stage was to find the optimal call off volume at which to optimize cost, lead time and environmental impact in the logistics flow.

6.2.1 Economic Order Quantities

When analyzing the most optimal logistics flow for scenarios 1 (long 1 p/n) and 3 (short 1 p/n) for both Supplier A and B, the authors always found similar conclusions. The third call off volume (labeled with a yellow point on Graphs 14 and 16), was always found to be the most optimal. As the graphs look the same for scenario 3, they were placed in Appendix 10.4. The reason for always getting the third call off volume as the most optimal, is due to the transport and storage (holding cost) curve, as they are the only curves that are not flat. As has been explained in Section 6.1.2 (investigating alternative transport options), the reason that the transport curve is decreasing with larger call off volumes, is because the freight rates start to decrease as the chargeable weight of the payload gets higher. In terms of storage costs, which are increasing in a linear manner with larger call offs, it was found to be due to the increasing number of emballages as more components were ordered (Section 6.1.3). Therefore, with the decreasing transport curve and the increasing storage curve, the author's extended EOQ model found the lowest cost to be located at the third call off volume.

Looking at Graphs 15 and 17, which include all the costs for all the six areas in the logistics flow (excluding the annual cost of the component), one can see how the transport and storage curves are the main cost factors. The third call off volume was labeled with a yellow point on the transport and storage curves, to make it easier to visual at which points on both curves, the most optimal solution was found.
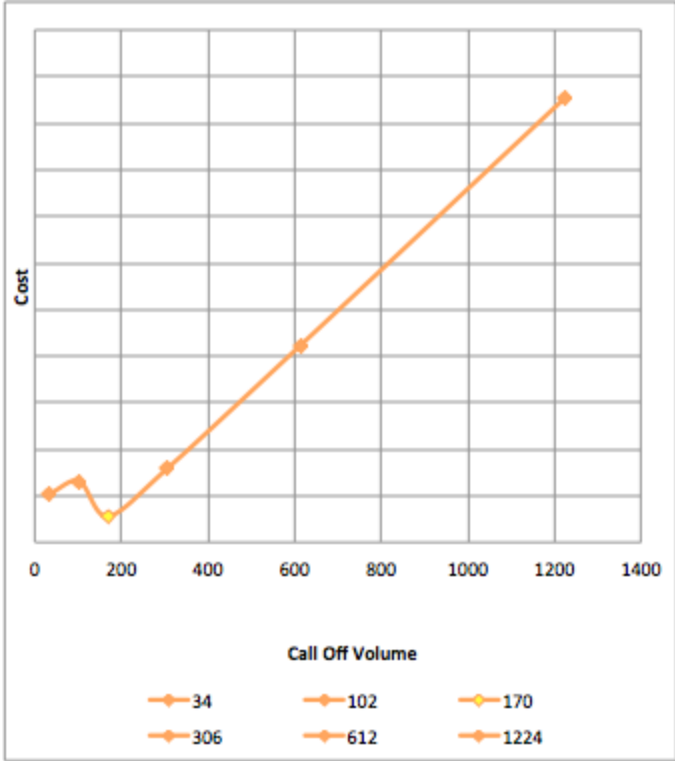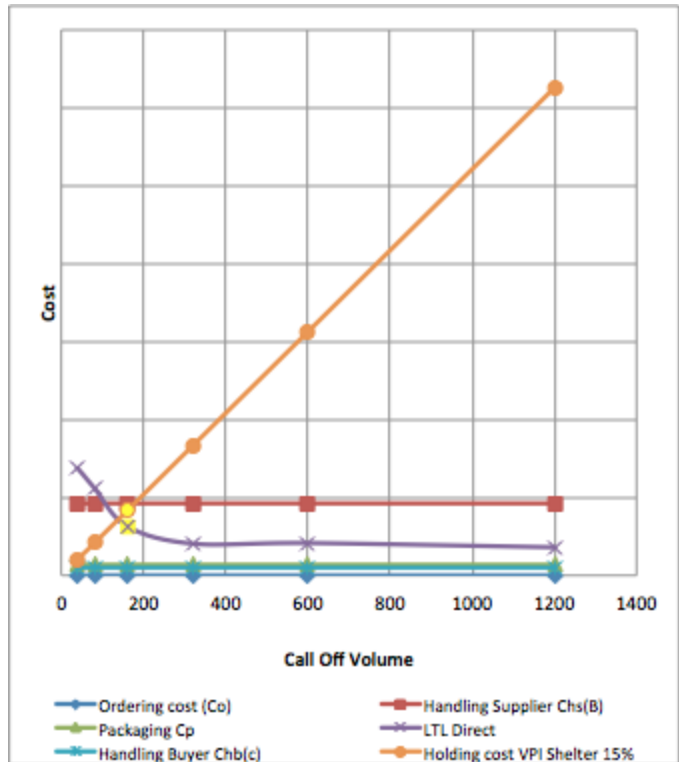
Graph 14: Total Yearly landed cost curve, Supplier A, Long for 1 p/n
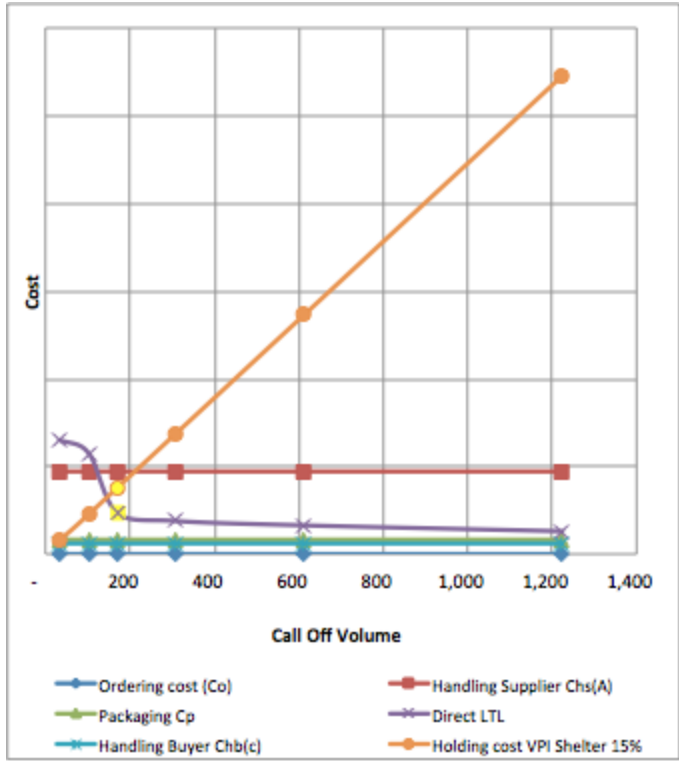
Graph 15: EOQ points, Supplier A, Long for 1 p/n
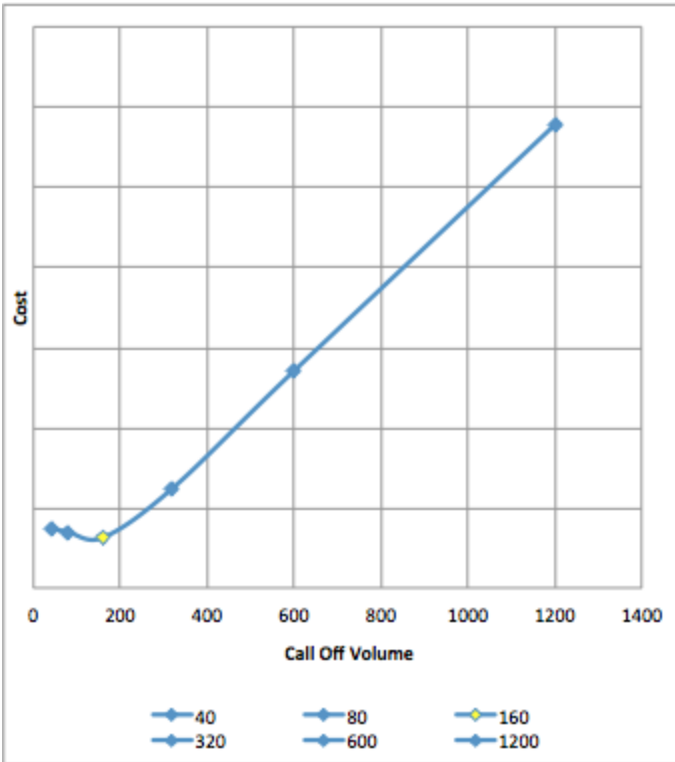
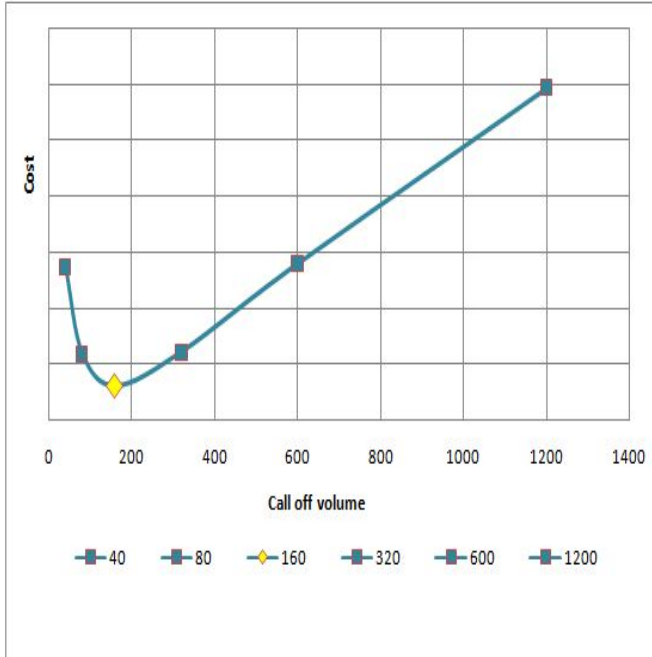Graph 16: Total Yearly landed cost curve, Supplier B, Long for 1p/n

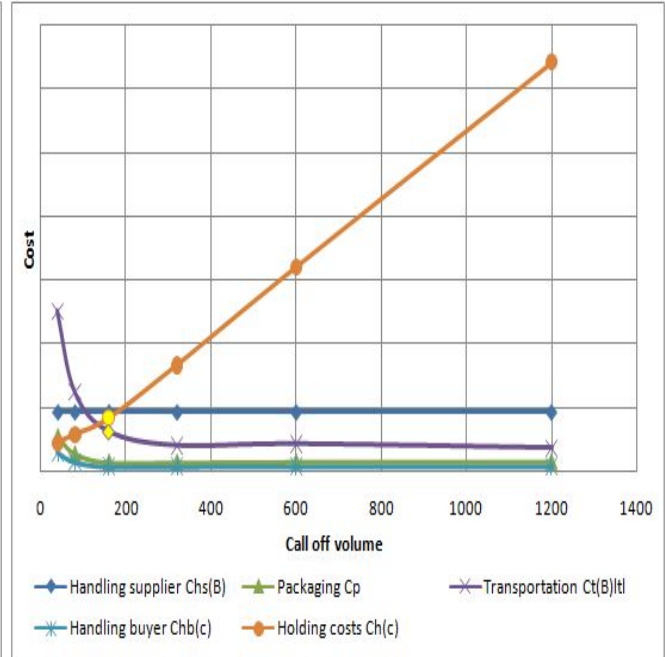Graph 17: EOQ points, Supplier B, Long for 1p/n

Although there is a slight variance between Supplier A and B's EOQ curves, which in some part is due to the fact that the Suppliers have different transport distances and unit loads per emballage, the reason for the slight increase at the second call off volume, (102) in Graph 14 compared to the decrease in Graph 16, is because of the transport curve. In Graph 15, the transport curve looks slightly different than Supplier B's transport curve in Graph 17. This is because of the different freight rates that each supplier has. Percentage-wise, the drop in freight rates from the second call off to the third call off (marked in yellow) in Graph 15, is 59%, whereas in Graph 17, the freight rate drops only 33% from the second call off to the third call off (marked in yellow). Therefore, the curvature of Graph 17's transport curve varies much less in the beginning.

As seen in Graph 18, in the case of Supplier B, for scenario 2 (long, 4p/n's), the third call off volume, (160, marked in yellow) remained the optimal call off volume at which the yearly total landed cost was kept the lowest. The result was the same for Supplier B even under scenario 4 (short, 4p/n's) (Appendix 10.4). If Graph 19 is compared to Graph 17 it can be seen that while the handling at the byer and the packaging cost curves are constant under scenario 1 (long, 1p/n), they are decreasing under scenario 2 (long, 4p/n's). This is because initially, at smaller call off volumes, more emballages will be required within the year when the component is ordered in 4p/n's. However, at larger call off volumes, starting with the call off volume 160, the yearly number of emballages ordered will be the same as when the component comes in 1 p/n, with only two extra emballages needed for the last call off volumes for when the component comes as 4 p/n's. Thus, the handling at the buyer and packaging cost curves are a bit higher initially and then becomes almost constant.

However, as it can be seen from Graph 19, handling at the buyer and the packaging cost curves have minimal influence in determining the optimal call off volume, and as in scenarios 1 and 3, the main reason for the third call off volume being the optimal under scenarios 2 and 4 for Supplier B is the interaction between the transport and storage cost curves. At the third call off volume, the largest number of components will be stored in the lowest possible number of emballages when the component comes in 4 p/n's, thus minimizing the storage space cost. At the same time the transport freight rate drops significantly for the chargeable weight corresponding to the call off volume 160.
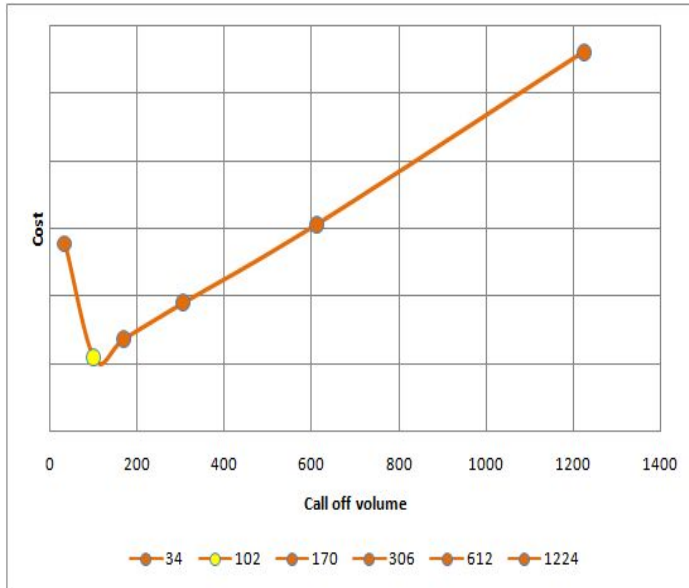
Graph 18: Total Yearly landed cost curve, Supplier B, Long for 4p/n   Graph 19: EOQ points, Supplier B, Long for 4p/n

Only for Supplier A under scenarios 2 (long, 4p/n's) and 4 (short, 4 p/n's) it was the second call off that was found to be the most cost efficient. Graphs 20 and 21 below, demonstrate this (points marked in yellow). The reason why the optimal call off volume for Supplier A under scenario 2 differs than that for Supplier B under scenario 2, is because of the difference in unit loads and thus the different number of emballages that will need to be transported and stored. Differently from Supplier B, for Supplier A under scenario 2, the largest amount of components will be stored in the lowest number of emballages at the second call off volume, (102) thus minimizing the storage space cost. At the same time the transport freight rate for Supplier A drops the most significantly with the chargeable weight that corresponds to the second call off volume.
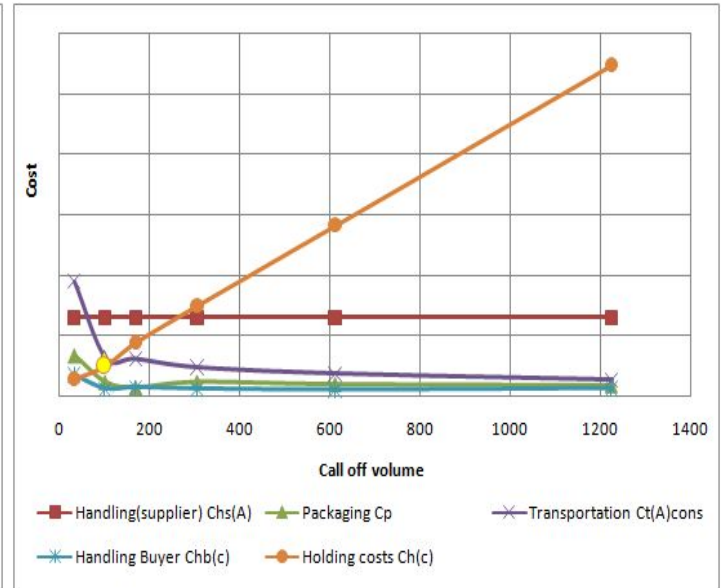
Graph 20: Total Yearly landed cost curve, Supplier A, Long for 4p/n   Graph 21: EOQ points, Supplier A, Long for 4p/n

As similar results are observed for scenario 4 for Supplier A and B, these graphs were excluded from the analysis but were presented in Appendix 10.4.

6.2.2 Capital tied up

As capital tied up makes up a large proportion of the inventory holding cost the authors decided to look further into this area. Therefore a section on capital tied up was added in order to see how lowering the percentage of capital tied up from 15% to 3% would affect the storage costs. Furthermore, since the authors found storage and transport to be the greatest cost factors in the logistics flow, this section will also look into how changing the percentage of capital tied up will affect the storage costs in relation to transport costs.

As previously explained in section 4.2, the inventory holding costs in this thesis include a cost for capital tied up which is calculated by using a cost of capital of 15% of the value of the average inventory level. This method of calculating capital tied up is a standard method used at Volvo Buses and the percentage applied is country specific and calculated quarterly. The 15% used in thesis corresponds to Poland (where the components are stored) for year 2018, quarter 1. Within this thesis, certain assumptions and limitations have been set throughout this study in order to narrow the scope and realistically match the time frame that the authors were given. For instance, the scope of this thesis starts from the point the components are at the suppliers being packaged and placed in an emballage for transporting, to when they are unloaded into storage at the customer. Therefore the scope of the thesis does not take into consideration the manufacturing process at the suppliers' production facility and what batch sizes are the

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most optimal. In reality, the supplier will produce a batch size that will result in lowering their production costs. Therefore, if the supplier were to produce less than the optimal batch size, the costs would increase dramatically for both the suppliers, and ultimately the customer, who will pay for it in the price of the component.

Without looking too closely at batches sizes, this thesis assumes call off volumes that are within the optimal batch size and therefore the price for the different lengthed components are fixed. However, in assuming a fixed price, and without analysing batch sizes in more detail, the true effects of tying up capital are lost. Regardless of the amount of components being called off, the batch size at which the supplier will produce the components, will still be at a certain level that will be optimal for them to produce at. That optimal batch size, whether it is shipped immediately to the customer or left in the supplier's warehouse until the customer calls off the rest of the components, will be tied up capital that the customer will have to pay at the end of the day. Simply put, once the goods are produced, the capital starts getting tied up.

Comparing 15% and 3% Capital Tied Up

Using the standard Volvo cost of capital when calculating the cost of capital tied up has it advantages. The cost of capital provides Volvo with the minimum rate of return that is required on its investments that will satisfy the company's shareholders and investors. Incorporating the cost of capital in the capital tied up can help in decisions with regards to inventories. At the same time, using this standard Volvo cost of capital when calculating the cost of capital tied up, investments in inventories can also be prevented and these investments might have resulted in higher returns. For instance, a capital tied up of 15% of the value of the average inventory level results in quite high holding costs. Having very high holding costs creates a preference for smaller call off volumes that are shipped more frequently. If the capital tied up is reduced storing the components will not be as expensive anymore and there might be potential savings if larger volumes of the component were called off and in turn higher returns might be achieved.

The authors decided to take a closer look into this and challenged Volvo's standard percentage of 15% for calculating tied up capital in Poland, by reducing it to only 3% so as to investigate whether the lower capital tied up will result in different optimal call off volumes. The authors based their choice of percentage on the Polish 10-year government bond (Trading Economics, 2018), as this value seemed the most consistent to look at.

When adjusting the capital tied up from 15% to 3% (as seen in Graphs 22 and 24), the same optimal call off volume was found. This was the case for all 1 p/n and 4 p/n scenarios. However, reducing the capital tied up did bring a big reduction in the storage costs, as can be seen in all graphs (22, 23, 24 and 25). Graphs 22 and 23, show the relationship between the two storage curves, with the 3% capital tied up curve falling much lower than the 15% curve. Moreover, Graphs 23 and 25 shows how the reduction in

the storage costs interacts with the transport costs. At the most optimal call off volume (marked in yellow), the 3% capital tied up curve actually moves below the transport curve. Previously with 15% capital tied up, the curve laid above the transport curve. As so, it is quite a drop in the costs of storage, however, not big enough to change the optimal call off volume.
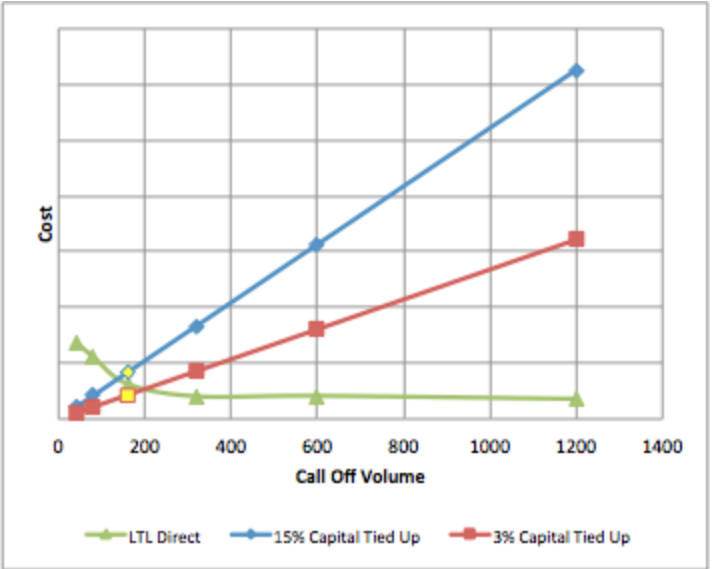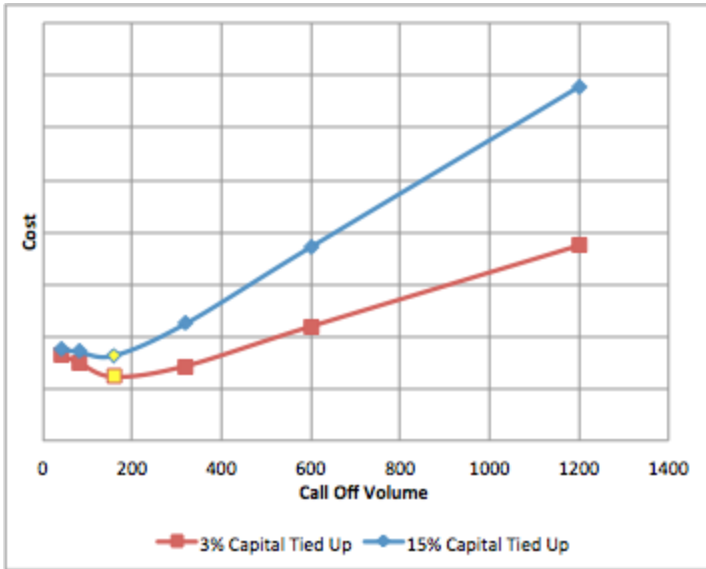
Graph 22: Total Yearly Landed Cost Curve (3% & 15%), Supplier B, Long, 1 p/n

Graph 23: Transport and Storage (3% and 5%), Supplier B, Long, 1 p/n
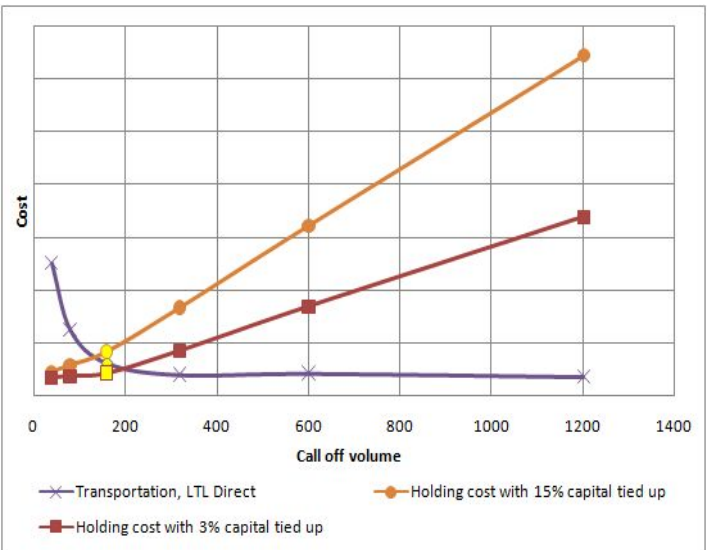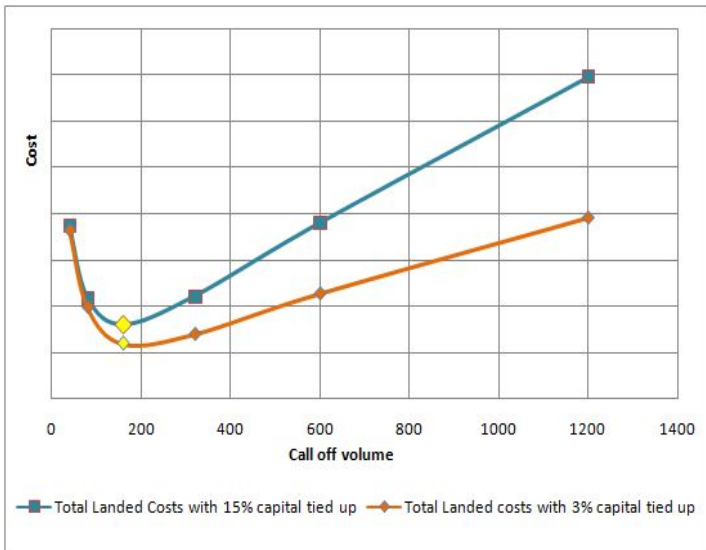
Graph 24: Total Yearly Landed Cost Curve (3% & 15%), Supplier B, Long, 4 p/n

Graph 25: Transport and Storage (3% and 5%), Supplier B, Long, 4 p/n

6.2.3 Summary of the Optimal Call Off Volumes

Here a summary of the most optimal call off volumes for every scenario is presented in Table 4. For a more visual representation of the optimal call offs, the EOQ graphs for all scenarios can be found in the Appendix (10.4).

	Supplier	Length	P/N	Optimal Call Off Volume (with 3% Tied Up Capital)	Optimal Call Off Volume (with 15% Tied Up Capital)
Scenario 1	A	Long	1	170	170
Scenario 2	A	Long	4	102	102
Scenario 3	A	Short	1	304	304
Scenario 4	A	Short	4	204	204
Scenario 1	B	Long	1	160	160
Scenario 2	B	Long	4	160	160
Scenario 3	B	Short	1	320	320
Scenario 4	B	Short	4	320	320

Table 4: Summary of the Optimal Call Off Volumes

6.2.4 Lead Time

An analysis on the most optimal call off volumes that will result in the lowest lead time will be analysed descriptively, rather than quantitatively, in this section. From what has been found when analysing the most optimal call off volumes on a total landed cost perspective, the third call of volume was always seen as the best choice, except for Supplier A in scenarios 3 and 4. However, when it comes to finding the most optimal call off volume for lead time, a closer look at each area of the logistics flow needs to be considered.

As previously found in Section 5.2, when analysing the current logistics flow, transportation was found to be the most influential area for lead time. In contrast to what was found for total landed costs, larger call off volumes in terms of transportation, would be the most optimal when lead time is concerned. This is because, with the highest call off volumes for the different scenarios and suppliers (1224 for scenarios 1 and 2 and 2448 for scenarios 3 and 4 from Supplier A, or 1200 for scenarios 1 and 2 and 2400 for scenarios 3 and 4 from Supplier B), the number of orders, and therefore number of trucks transporting goods, will only be once a year. If smaller volumes were called off however, the frequency of shipments would be 36 times bigger for Supplier A and 30 times bigger for Supplier B. Therefore, by having larger call off volumes, the frequency of transport, and thus time spent on transporting goods throughout the year, will be the most optimal.

In terms of handling at the Supplier, the lead time was found to vary substantially based on the call off volumes. For instance, with the smallest call off volume (34 and 68 for Supplier A and 40 and 80 for Supplier B), it only takes 1 day. However, with the largest call off, it can take up to 9 days. The reason for these large differences in the lead time, is because of the way the physical handling was calculated in this report. The lead time for the physical handling at the supplier is calculated from when the components are placed one by one in its packaging till it fills the unit load of that emballage, and is loaded onto the trailer. Since the handling lead time is calculated based on a per component basis, the call off volume will not matter so much when looked at annually. However, the administrative handling time will differ based on the called off volume, as it is calculated by the number of orders per year (which decreases with larger call offs). In this case, it would make more sense to have larger call off orders, since the administrative lead time will be the determining factor in handling lead time at the Supplier.

When it comes to comparing short components and long components, it would take more time to handle short components. This is because when ordering shorter components, the call off volume is double the call off volume for longer components. With that being said, double the number of components will need to be packaged, placed in an emballage and loaded onto the trailer at the supplier. With double the number of components and emballages, it will take double the time. Moreover, there are also slight differences when it comes to packaging and handling 1 p/n versus 4 p/ns when smaller call off volumes are used. For 1 p/n, a call off volume of 34 for Supplier A or 40 for Supplier B, is placed in one emballage. However, for 4 p/n's, with the same call off volume, the components are split into four different emballages since different lengthed components cannot be placed in the same packaging. But as the call off volumes start to increase, the difference in the number of emballages is reduced. Furthermore, there is also a slight difference when it comes to the handling and packaging lead time of the different suppliers. The reason for this is because Supplier B has a bigger unit load (40) than Supplier A (34), and so more components will need to be packaged and handled at Supplier B.

Lastly, handling at the goods receiving also adds to the overall logistics flow lead time. However, the way that the unloading process was calculated was based on the number of emballages. Therefore, like handling at the supplier, the call off volume will not affect the lead time from a yearly point of view. Also like handling at the supplier, handling at VPI slightly differs when it comes to short and long components and also 1 p/n and 4 p/n's. With short components, double the emballages need to be handled at all call off volumes. But with 4 p/n's, only with small call off volumes, does the difference in handling lead time differ compared to 1 p/n.

In conclusion, as transport is the greatest factor influencing lead time, choosing the shortest transport option for each supplier, would be the best choice for Volvo Buses. This would mean having to change Supplier A's transport flow from LTL with consolidation to direct LTL, and to keep Supplier B's transport flow as is.

6.2.5 Environmental Impact

Since the authors did not collect enough data on environmental impact to incorporate it into the model quantitatively, a more descriptive analysis was included with regards to environmental impact. In Section 6.2.1 the authors look into the most optimal call off volumes in terms of total yearly landed cost. In this section the most cost efficient call off frequency will be analyzed from an environmental perspective and then a discussion will be presented on what call off frequency will be the most environmentally friendly.

In almost all scenarios the third call off volume (170 for Supplier A and 160 for Supplier B) was the most cost efficient. Looking from an environmental perspective this call off volume will not be the most optimal. This is because the greatest environmental impact in the logistics flow for the component in focus comes from transportation. With the third call off volume, approximately 8 orders will have to be placed within a year, which implies quite a lot of transportation involved. For Supplier A under scenarios 3 (long, 4p/n's) and 4 (short, 4 p/n's), the most cost efficient option was an even smaller call off volume, 102. This would require 12 shipments within the year and especially since Supplier A is located further away, this option will definitely not be the one that is the most environmentally friendly. The call off volume at which the environmental impact from transportation will be minimized, is in fact the largest call off volumes for both suppliers. In this case only one order within the year will be placed and all components will be shipped in two trucks and delivered for storage. Ordering and storing large quantities of the components though, carries a risk of the components becoming obsolete or getting damaged in which case they will have to be scrapped thus producing waste.

When it comes to minimizing the packaging and emballage materials used, call off volumes that require the lowest number of emballages and packaging will be the best. In the case when the component is ordered in 1 p/n yearly the number of emballages and packaging used will always be the same (30 emballages for Supplier B and 36 for Supplier A). Furthermore, since the unit loads between suppliers differ it seems that Supplier A will require more emballages and packaging yearly than Supplier B. However, the packaging and emballage used by Supplier A are smaller than the ones used by Supplier B and since more detailed information in exactly how much plastic wrap and carton packaging will be used yearly under the different call off volumes the authors could not draw any conclusions on whether Supplier A or Supplier B will use less packaging materials. Regarding the emballages used the authors consulted with packaging engineers on whether metal or wooden emballage is more environmentally friendly. Since the metal emballages are reusable they were considered to be more environmentally friendly than the wooden emballages that are used only once. However, this does not account for the

emissions that will be generated from the return transport flow for the metal emballages. A more detailed investigation is required to determine what emballage material is more environmentally friendly.

As for the environmental impact from storing the components ordering smaller quantities will have less environmental impact. This is because with smaller quantities ordered less storage space will be occupied and less energy, equipment and materials will be required to heat and maintain the storage space. Moreover, since data on the environmental impact from the external storage space was not collected the authors could not go into further analysis on comparing the different storage options.

In conclusion, as transportation is considered to have the greatest influence when it comes to environmental impact, if Volvo Buses wants to minimize the environmental impact then they should strive toward ordering larger volumes and storing the components instead of having more frequent shipments.

7. Suggestions

This section discusses several suggestions that Volvo Buses may be able to take into consideration, based on the results found in the analysis.

Based on the analysis, the authors came up with several suggestions that Volvo Buses could take into consideration in the future. It is important to note however, that the findings in this thesis pertains only to the logistics flow and does not include other areas that are crucial for the final decision making. Therefore it is important to keep a bigger picture in mind when considering the suggestions given below.

7.1 Transport

In terms of transportation, the authors found that for all scenarios associated with Supplier A, direct LTL was the cheapest, fastest and most environmental option. Rather than taking 5 days to transport the goods from Supplier A to VPI, the transport lead time could be reduced to 2 days. With the current transportation option (LTL with consolidation), it takes upto 3 days at the cross dock alone. Furthermore, the costs of direct LTL are lower compared to LTL with consolidation, which is due in part to the extra handling and administration costs, but also because of the higher freight rates. Additionally, it is believed that the environmental impact of direct LTL transport is lower than LTL with consolidation, due to a more optimal distance and route. Therefore for Supplier A, the authors recommend that Volvo Buses consider the option of direct LTL to save on costs, lead time and environmental impact.

Supplier B on the other hand, the current scenario (direct LTL) was found to be the best transport option in terms of cost, for all scenarios. In terms of lead time, there wasn't much deviance between the two transport options, as the distance and route will stay the same. Furthermore the environmental impact is seen as being the lowest for direct LTL, since with lower call off volumes, direct FTL would be carrying half empty trucks all the time. Therefore, the authors recommend that the current scenario is kept for all the scenarios.

7.2 Storage

When it comes to storage space cost, storing the components internally, under shelter roof was found to be the cheapest option and it can be recommended to Volvo Buses. However, as in this thesis it was assumed that there is limitless internal storage capacity, if the internal storage option under shelter roof is to be considered, Volvo Buses should further investigate the space capacity of this storage option. In terms of lead time and environmental impact, all there storage space options are believed to have minimal

differences, and therefore the authors have chosen not to go further in depth on the matter in their analysis.

As already mentioned, the analysis in this thesis is based on many assumptions as well as the scope is limited to only six areas of the logistics flow for the component (Figure 1), thus excluding other relevant areas. This is especially true when it comes to the cost of capital tied up. As explained in Section 6.2.2, this thesis excludes the manufacturing process at the supplier from the scope and at the same time assumes a fixed price for the component regardless of the size of the order. In reality the suppliers will produce optimal batch sizes that will minimize the cost of production. Any ordered quantity that is less than the optimal batch size will in fact have dramatically higher price level. Assuming a fixed price level will not reflect the true value of the capital tied up. Additionally, rather than looking at optimal batch size this thesis considers call off volumes in which case the cost for capital tied up is only added once the component is stored at Volvo Buses internal or external storage. In fact, the capital will get tied up once the components are produced regardless of whether they are stored at the supplier's premises or at Volvo Buses. As such, the authors suggest incorporating the actual price level and consideration of the optimal batch size of the supplier when final decision on optimal call off volumes is being made. Moreover, Volvo Buses uses a standard method for calculating cost of capital tied up based on the company's cost of capital. Although this method has advantages the authors suggest that the limitations and disadvantages of this method should also be considered when final decisions are being made.

Using the standard Volvo cost of capital when calculating the cost of capital tied up has it advantages. The cost of capital provides Volvo with the minimum rate of return that is required on its investments that will satisfy the company's shareholders and investors. Incorporating the cost of capital in the capital tied up can help in decisions with regards to inventories.

7.3 1 p/n and 4 p/n

Throughout the analysis, the authors looked at how 1 p/n and 4 p/n's affected the total landed costs, lead time and environmental impact for the different logistics flow areas. As transport and storage are the two main cost drivers, the authors decided to focus on comparing how different part numbers affected these two areas for different call off volumes.

When focusing on transport, the authors found that with the first two call off volumes for all scenarios, the cost of transport for 4 p/n's was much higher than for 1 p/n. The reason for this, is because of the extra emballages that 4 p/n's requires for smaller call off volumes. Eventually with bigger call off volumes, such as the third call off volume for Supplier B, the number of emballages will not vary much. In terms of lead time, bigger call off volumes were found to be the most optimal, as the frequency of transport decreases throughout the year, meaning less shipments in total. This also holds true for environmental impact, as shipping larger call off volumes will reduce the need for so many trucks. For

example, having a call off volume of 40 components will result in 30 orders per year, compared calling off an entire yearly demand of 1200 components, which will take only 1 trip per year.

With regards to storage space cost, for most of the call off volumes it was found to be cheaper to have the component delivered in 1 p/n rather than in 4 p/n's. However, this is very dependant on the number of emballages that will be required throughout the year as well as on the unit loads at the different suppliers. In the case of Supplier B for instance, for the optimal call off volumes, 160 and 320, the storage space costs are the same regardless of whether the component is delivered in 1 or 4 p/n's. This is because under these call off volumes the same amount of emballages will be stored under all scenarios. Thus, if the optimal call off volumes are selected for Supplier B, whether the component is in 1 or 4 p/n's, will not affect the storage cost. For Supplier A for all call off volumes, it is cheaper to have the component delivered in 1 p/n. Only for the last call off volume, the storage space cost will be the same regardless if the component comes in 1 or 4 p/n's.

7.4 Comparison of Suppliers A and B

Supplier B was found to have the lowest total landed costs, lead time and environmental impact, due to its close proximity to VPI, and therefore was viewed as the best choice of supplier. The analysis found that the handling at Supplier B is cheaper due to the lower handling wages and the fact that the goods are only handled once compared to three times for Supplier A. Even if Supplier A were to change to direct LTL transport, the handling costs would still be slightly greater than at Supplier B due to the handling wages.

Furthermore, if such a case occurred where unexpected damages to the components resulted in a stock out, Supplier B would be the best choice to replenish the stock, due to their close proximity to VPI's production facility.

8. Conclusion

This section presents the final conclusions of this report, summarizing the problem and aim of the thesis before discussing the results from the analysis and suggestions for future improvements to the current logistics flow for the component in focus. Furthermore, a section on possibilities for future research on the topic are considered.

This thesis was part of a current on going project at Volvo Buses, with the focus of this study placed on measuring the logistics flow of a long and fragile component. The scope was limited to six areas within the logistics flow (packaging, emballage, loading at the supplier (handling), transport, unloading at the warehouse (handling) and storage), however, due to the length and fragility of the component, the logistics flow had to be customized with special packaging and emballages and ways of handling, transporting and storing. The main aim of the thesis was to examine which areas within the logistics flow had the greatest effects on total landed cost, lead time and environmental impact, based on four different scenarios. To examine this, the authors looked at six different call off volumes every time, to see how cost, lead time and environmental impact would change given smaller or larger call off volumes per year. As this thesis was conducted on Volvo Buses, the overall goal of this investigation was to present findings that could potentially challenge the current logistics flow set up for this and similar components in the future. Additionally, an extension of the EOQ model was built to include all areas of the logistics flow and used to generate and analyse the different scenarios. The purpose of using the extended EOQ model was to find the optimal order quantity that would result in the lowest total landed cost.

The thesis aimed to answer these two research questions:

1. *What is the most favorable logistics flow in terms of packaging, emballage, loading (handling) transportation, unloading (handling) and storage for the component in question?*

2. *How will different call off volumes minimize total landed cost, lead time and environmental impact?*

In terms of finding the most favorable logistics flow for the component in question, the authors looked at several alternative scenarios when trying to answer the first research question. Since transport and storage was found to be the two main cost factors from the total landed cost, the choice to focus on optimising those two areas made the most sense. For transportation, the authors found direct LTL to be the cheapest, least time consuming and most environmentally friendly option for both suppliers. As Supplier B already implements a direct LTL transport option, only Supplier A was suggested by the authors to change.

Furthermore, the most cost optimal storage option for both suppliers was if they stored the components internally under sheltered roofs. If Volvo is to consider this option, a further evaluation on whether there is enough internal storage space capacity needs to be done.

To answer the second research question, the authors looked into six different call off volumes for each of the four scenarios for both suppliers. As landed costs was the main focus in this thesis, a thorough investigation into the most optimal call off volumes in regards to cost, was analyzed. The authors found for almost all scenarios, the third call off volume to be the most optimal. However for Supplier A for scenarios 2 and 4 (where 4 p/n's is concerned), the optimal call off volume happened to be the second call off. When adjusting for a lower tied up capital the results still found the same call off volumes to be the most optimal. Although the moving from a capital tied up of 15% to 3%, did not affect the optimal call off volumes, they did however affect the storage cost curve by greatly reducing the cost of storage. The storage cost curve at the optimal call off volume actually ended up lower than the transport cost curve, meaning that at that call off volume, storage costs were cheaper than the cost of transporting.

The most optimal call off volume for lead time and environmental impact was analyzed descriptively on the other hand. Since limited data was collected on these areas, they were not analyzed in a quantitative manner like costs were. Again transport was found to be the greatest contributing factor to lead time and brought the biggest impact on the environment. In terms of lead time and environment, it was found that calling off larger volumes, was the most optimal. This is because with smaller call offs, the number of orders per year are bigger, meaning that more trucks are needed per year to transport the same volume of goods. If Volvo Buses were to order all the components at once (1200 or 1224 for long and 2400 or 2448 for short), then there would only be need for one order per year, compared to 30 or 36 times per year depending on the supplier. This would be the most environmentally friendly option, as there will be less congestion on the roads and less CO_2 emissions.

Further Research

On a closing note, due to the many areas in the logistics flow that this thesis attempted to look into, but with a limited time frame and resources, it was not able to look at all areas with the same level of detail.This does however leave room for further research possibilities. For instance, the author's own extension of the EOQ model, that was used for calculating the total landed costs to find the cost-optimal call off volume for all scenarios, made several assumptions. Such as having a fixed component price for both suppliers and also assuming call off volumes that match the minimum order quantity production batch size. These assumptions do not hold in real life, as price levels will increase substantially when the component is ordered in quantities that do not fall in the optimal batch size. Therefore, it would be beneficial for this study to expand the scope to include production at the supplier, so that the research can take fluctuating prices and sub-optimal batch sizes into consideration. Furthermore, by extending the scope to include production at the supplier, the research can also look at the real effects of tied up capital from the moment the goods are produced. By focusing more on the supplier side, it would even create an

opportunity to examine with more thought, on which supplier is the best choice for Volvo Buses beyond just the logistics flow. As this thesis looked at the two suppliers on a separate basis, there is an opportunity for future research to really compare the two suppliers from the point of production to the point of the component's consumption.

Moreover, as the authors mainly concentrated on collecting data for analysing total landed cost, it would be interesting to continue the research on the logistics flow at Volvo Buses for the component in focus, but from a lead time and environmental perspective. Especially since the initial goal of the thesis was to include environmental impact into the author's extended EOQ model, more focus on these two areas would be very beneficial for the study.

Another area of interest that could also be looked into with more detail, is the flexibility and quality of the logistics flow, as the component is a fragile good that is more prone to risk than other goods at Volvo Buses. Additionally it is a valuable component for the production of buses, and therefore the logistics flow requires the right amount of flexibility to ensure quick and risk free deliverance.

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10. Appendix

10.1 Investigating Alternative Transport Solutions
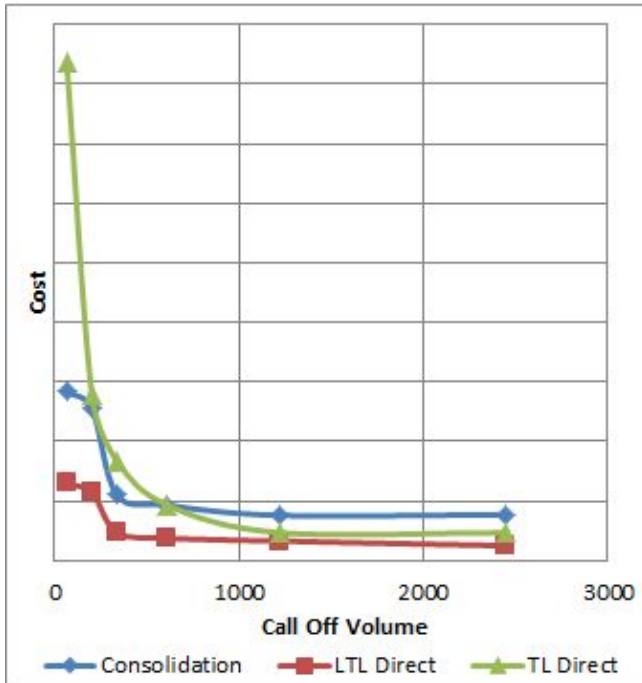
Graph 1: Transport Costs for Supplier A, Short for 1 p/n
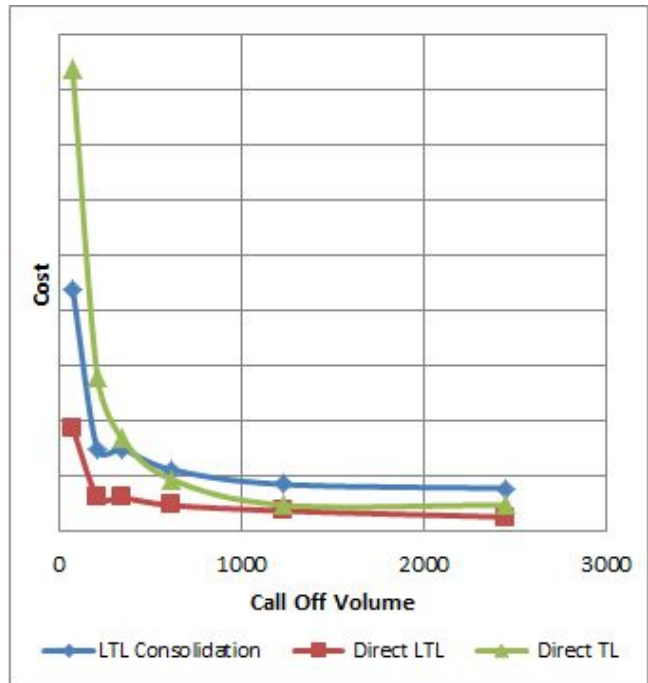
Graph 2: Transport Costs for Supplier A, Short for 4 p/n's
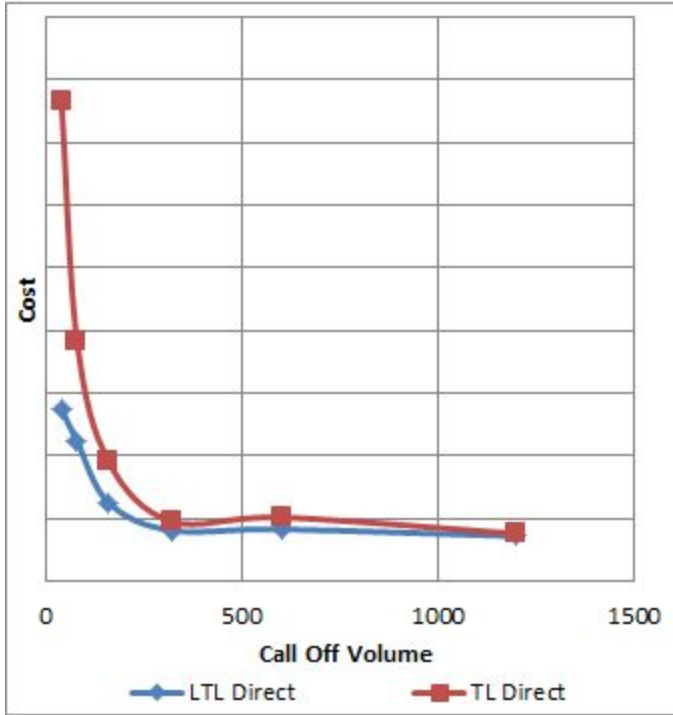
Graph 3: Transport Costs for Supplier B, Long for 1 p/n
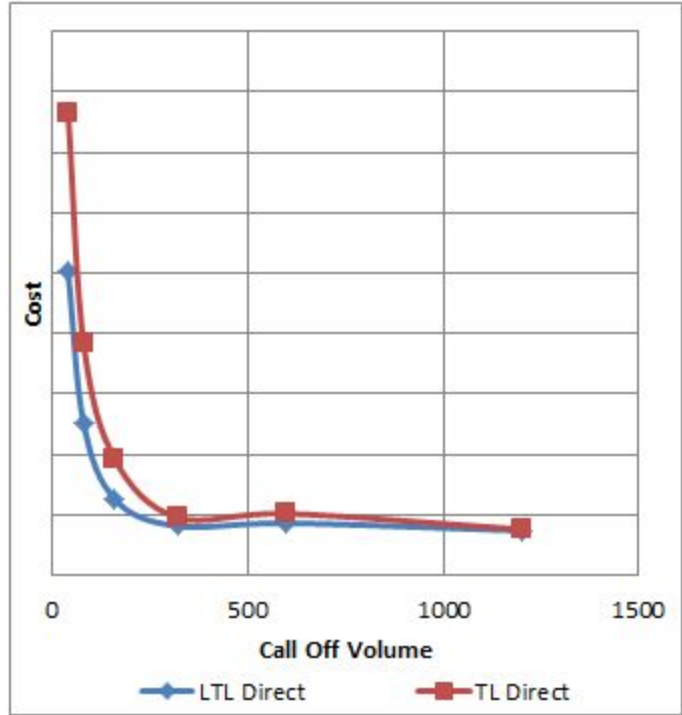
Graph 4: Transport Costs for Supplier B, Long for 1 p/n

10.2 Transport Costs for Long and Short Components
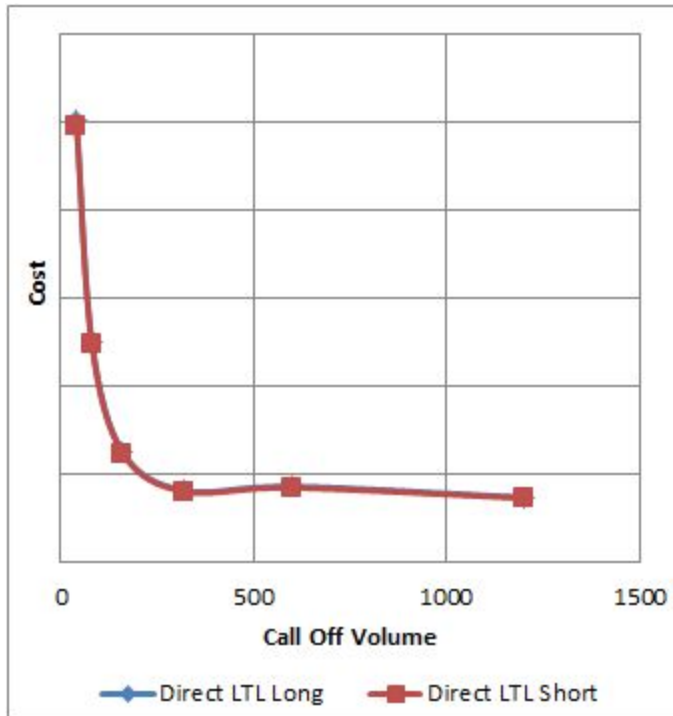
Graph 5: Transport Costs for Supplier B, 4 p/ns
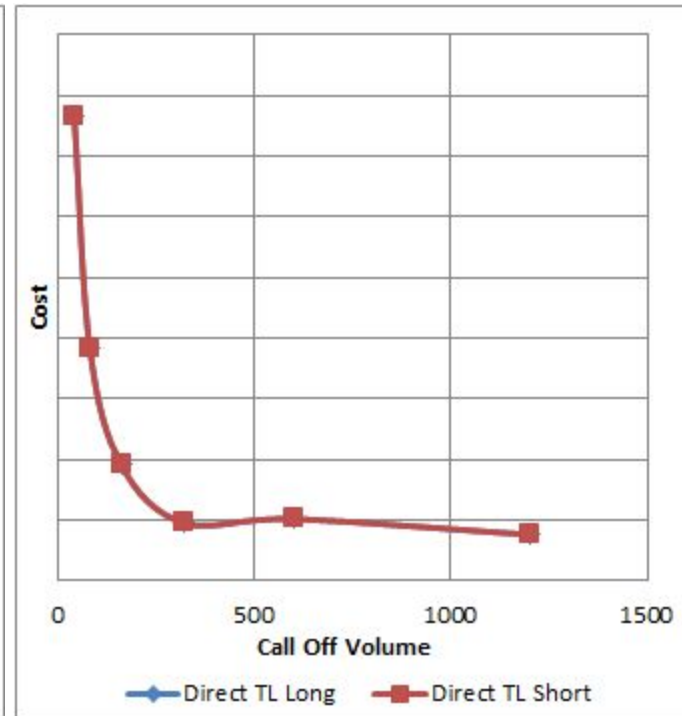
Graph 6: Transport Costs for Supplier B, 4 p/ns

10.3 Alternative Storage Solutions
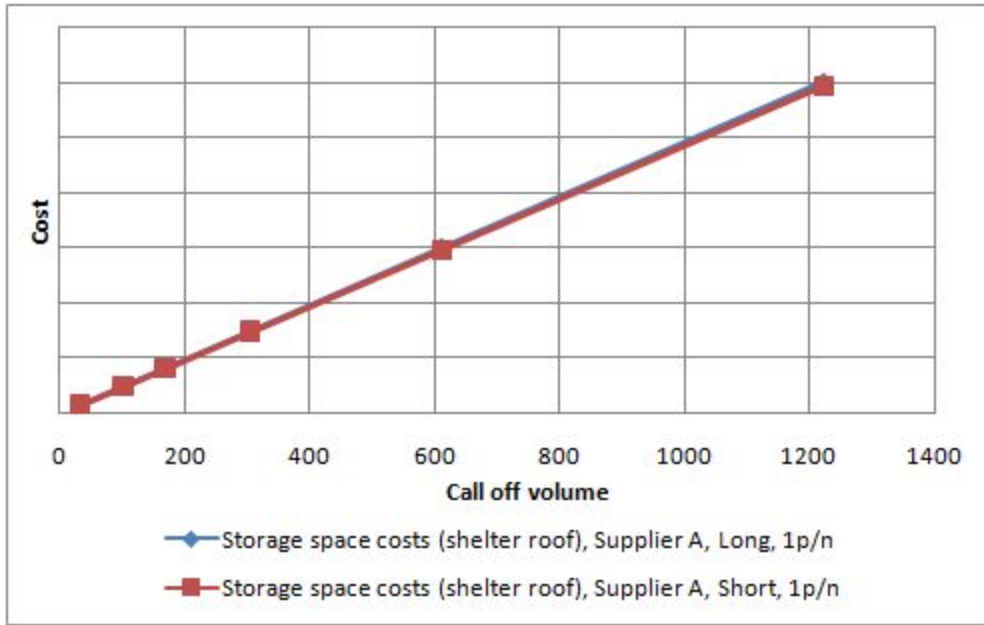
Graph 7:Yearly storage space cost s for Supplier A, Long and Short component, 1p/n
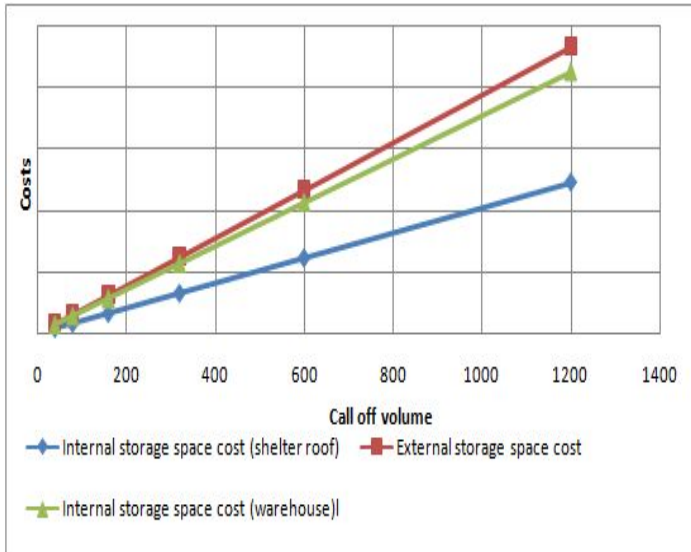
Graph 8:Yearly storage space costs for Supplier B, Long, 1p/n
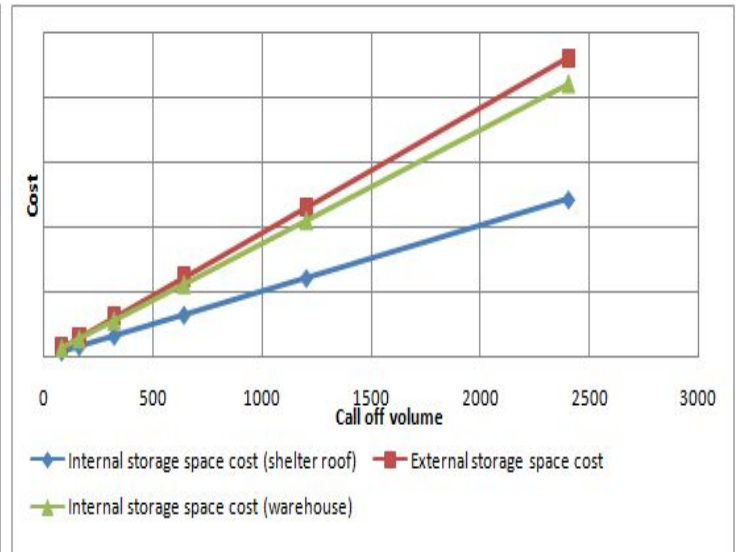
Graph 9:Yearly storage space costs for Supplier B, Short, 1p/n
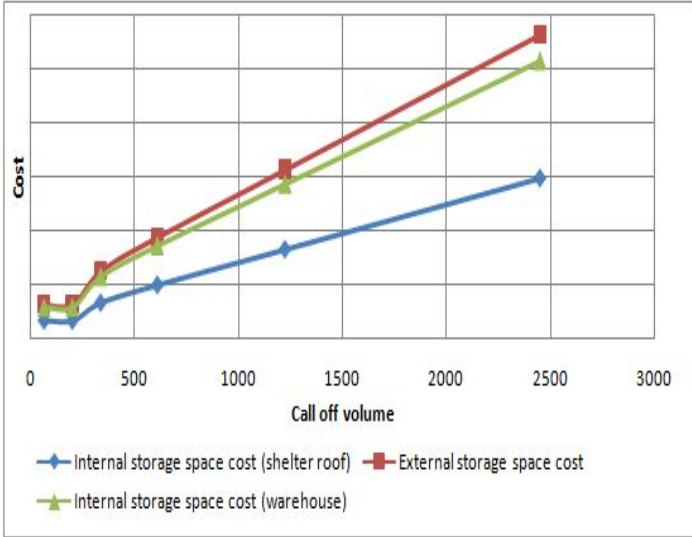
Graph 10: Yearly storage space costs for Supplier A, Short**,** 4p/n's
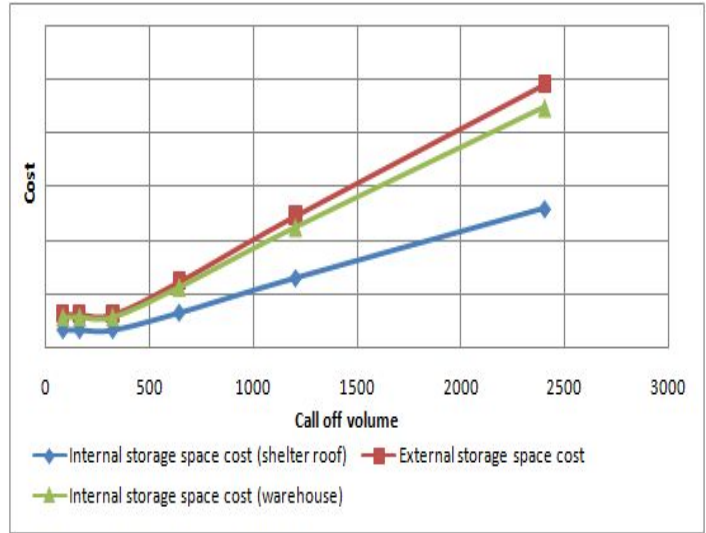
Graph 11: Yearly storage space costs for Supplier B, Short**,** 4p/n's
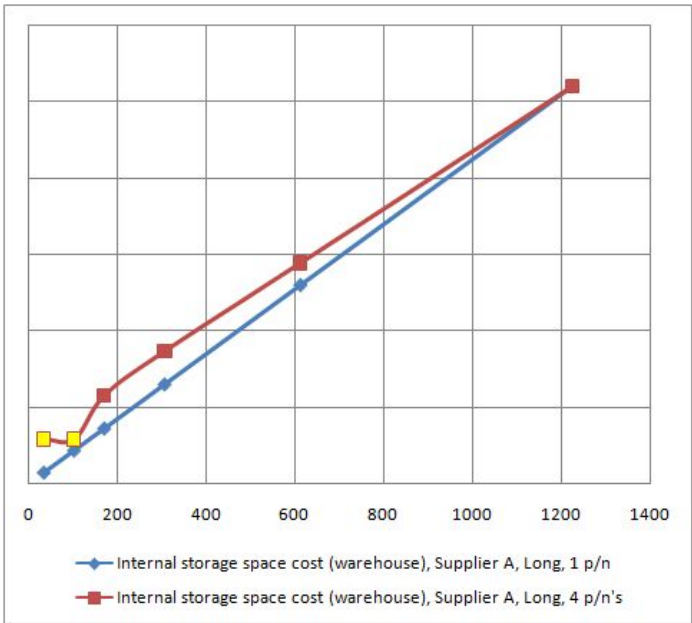
Graph 12: Yearly storage costs for Supplier A, Long, 1 p/n and 4p/n's

Graph 13: Yearly storage costs for Supplier B, Long, 1 p/n and 4p/n's

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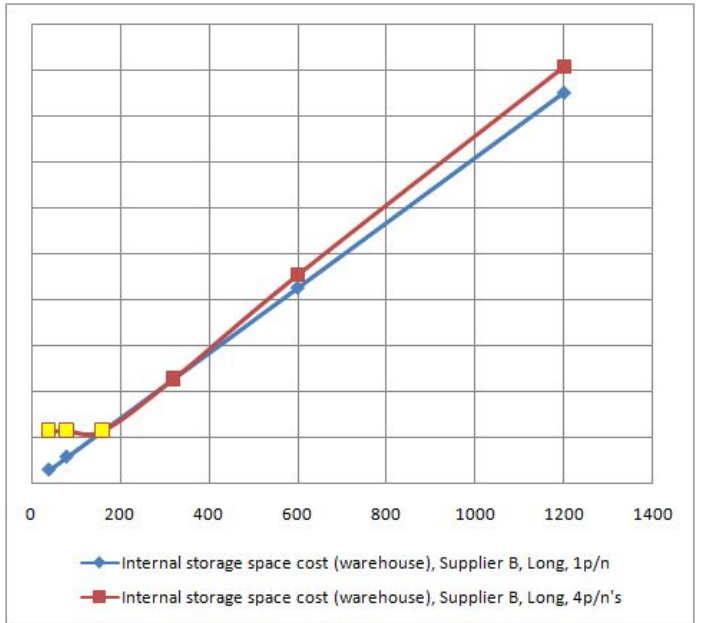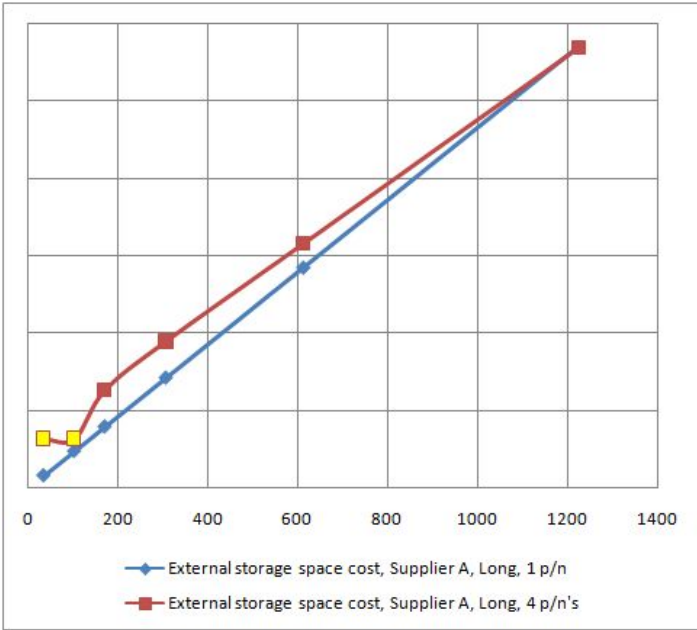
Graph 14: Yearly storage costs for Supplier A, Long, 1 p/n and 4p/n's
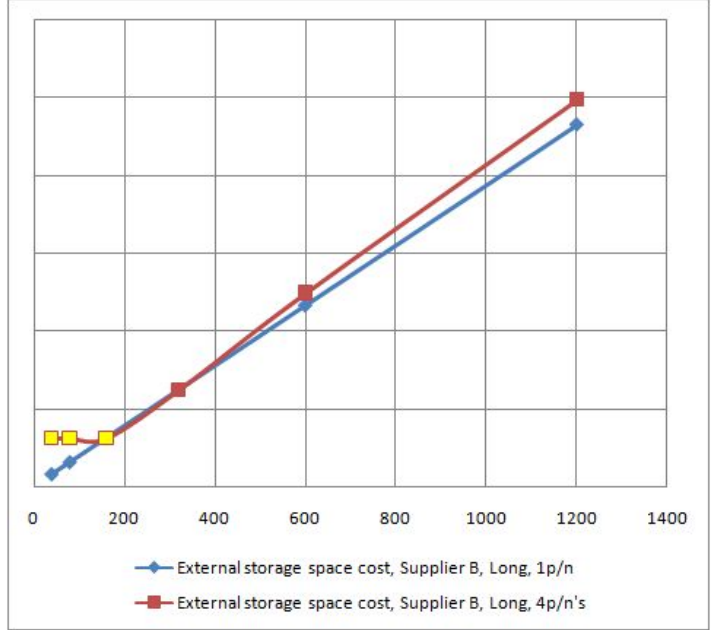
Graph 15: Yearly storage costs for Supplier B, Long; 1 p/n and 4p/n's
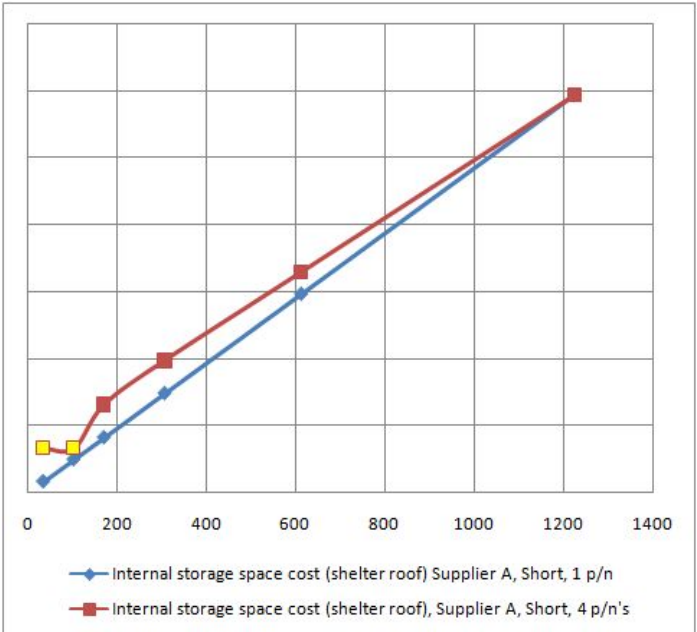
Graph 16: Yearly storage costs for Supplier A, Short, 1 p/n and 4p/n's
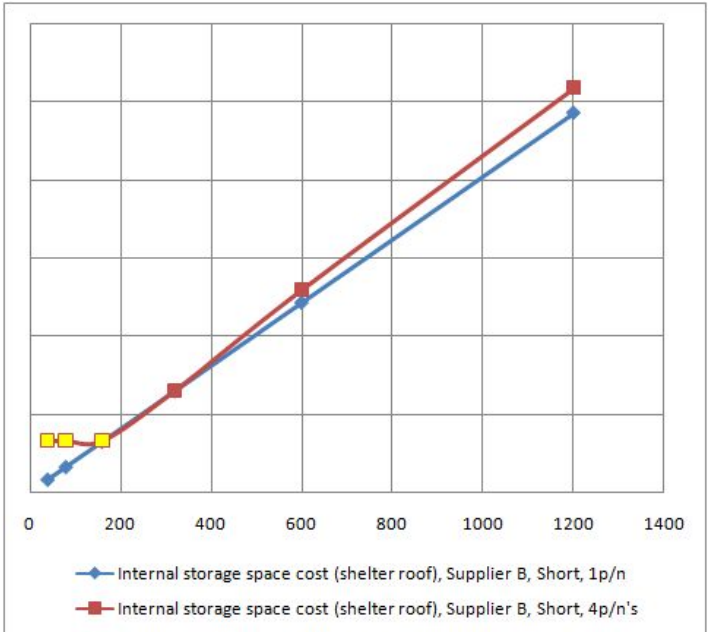
Graph 17: Yearly storage costs for Supplier B,Short, 1 p/n and 4p/n's

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10.4 Economic Order Quantities (with 15% Capital Tied up)
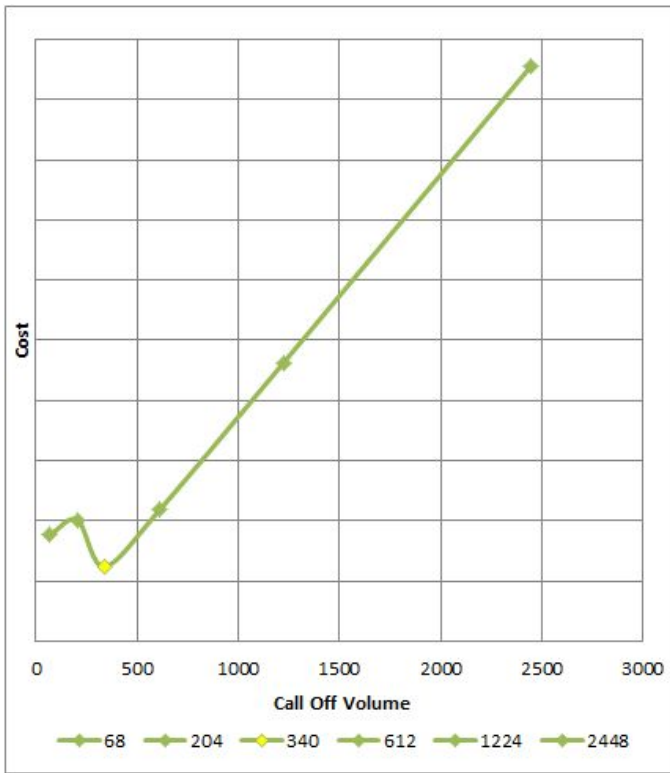
Graph 18: Total Yearly Landed Cost Curve, Supplier A, Short 1 p/n
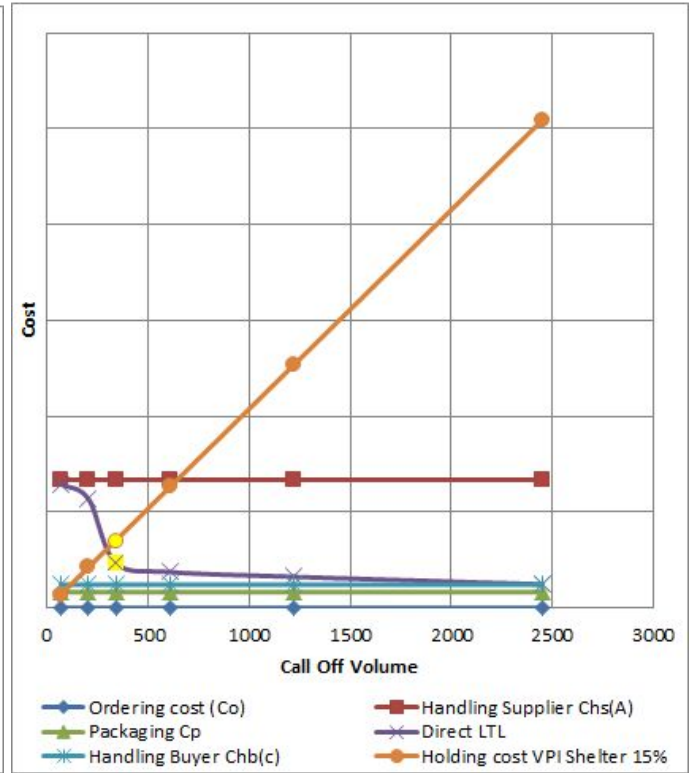
Graph 19: EOQ points, Supplier A, Short for 1 p/n
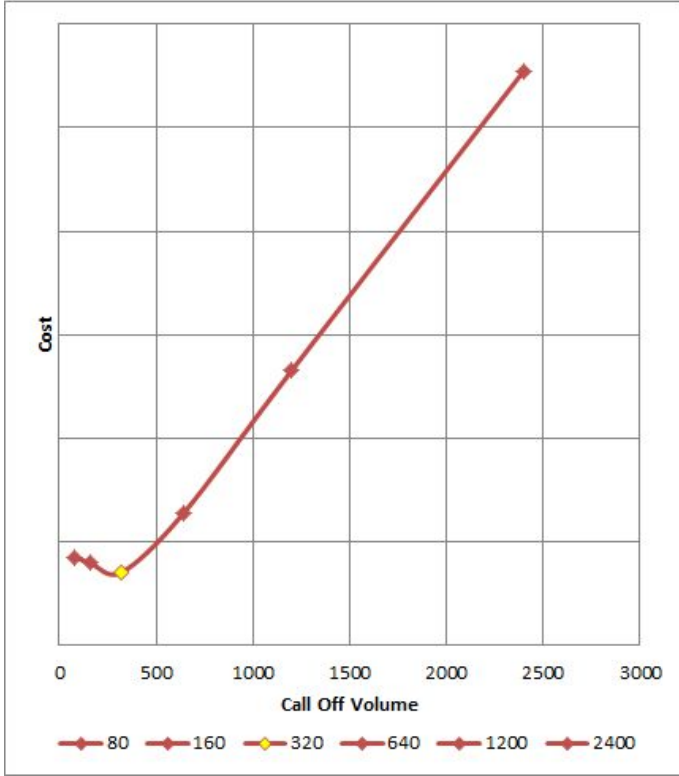
Graph 20: Total Yearly Landed Cost Curve, Supplier B, Short 1 p/n
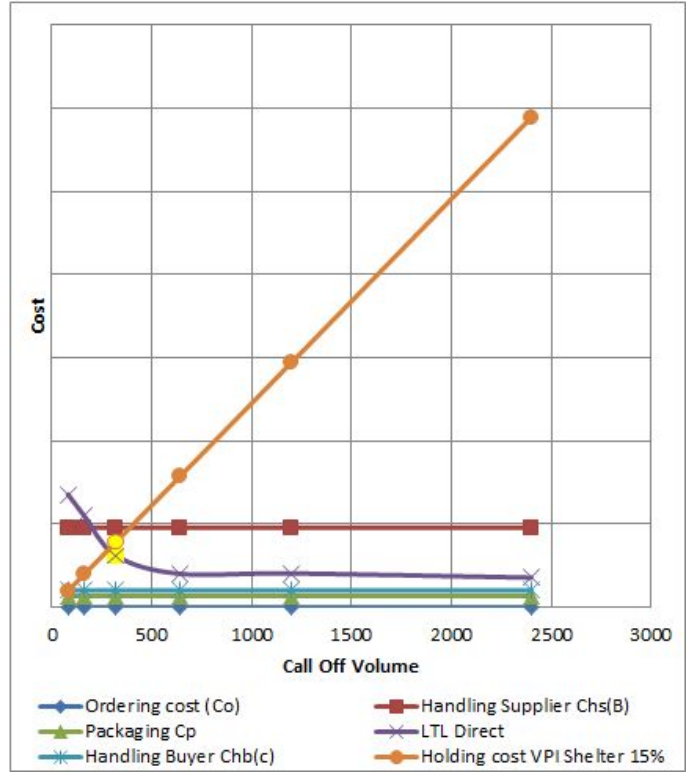
Graph 21: EOQ points, Supplier B, Short for 1 p/n
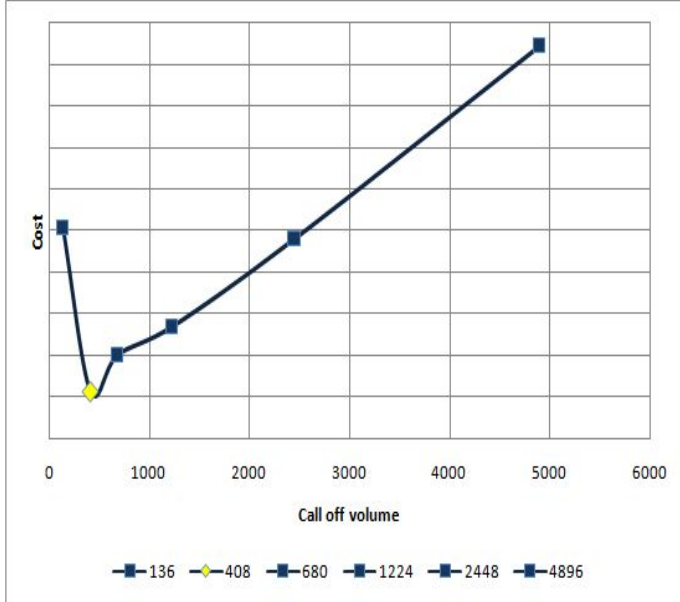
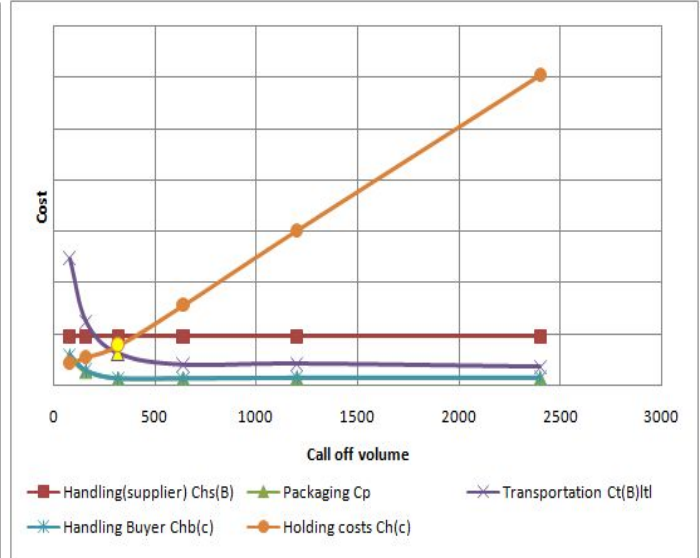Graph 22: Total Yearly Landed Cost Curve, Supplier A, Short, 4 p/n's
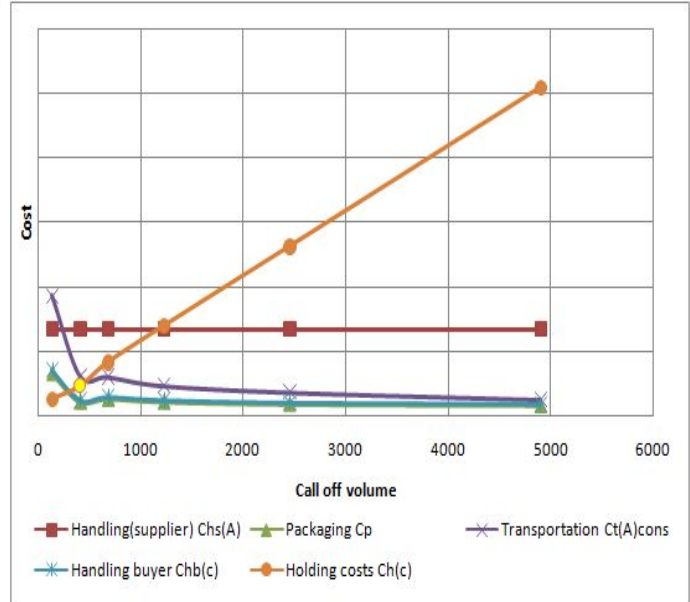
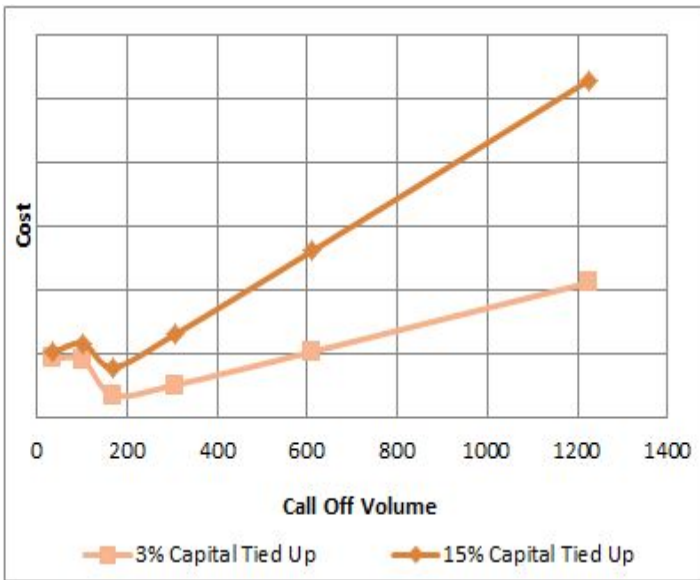Graph 23: EOQ points, Supplier A, Short for 4 p/n's
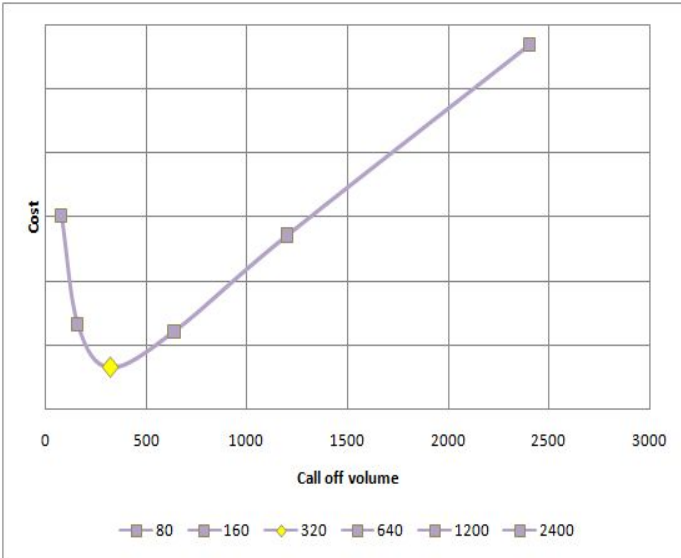
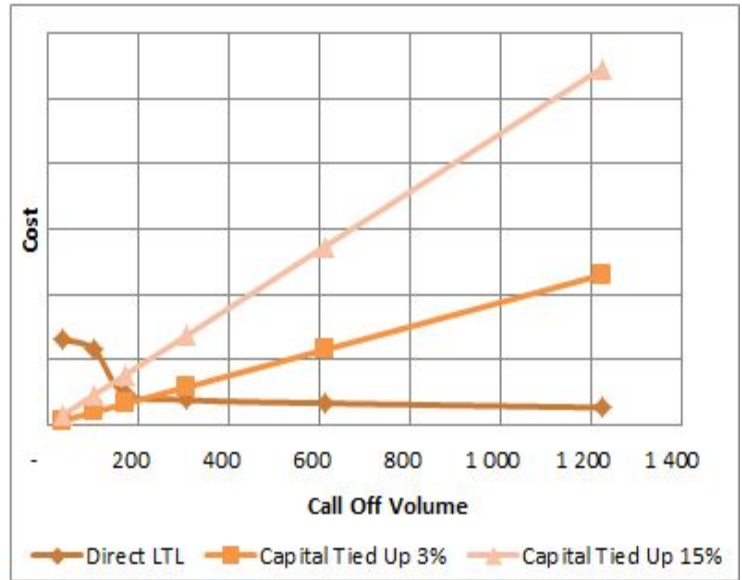Graph 24: Total Yearly Landed Cost Curve, Supplier B, Short, 4 p/n's

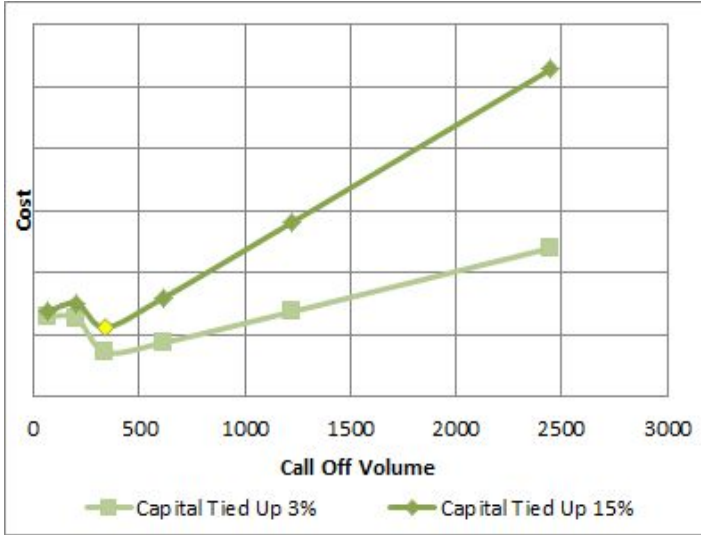Graph 25: EOQ points, Supplier B, Short for 4 p/n's

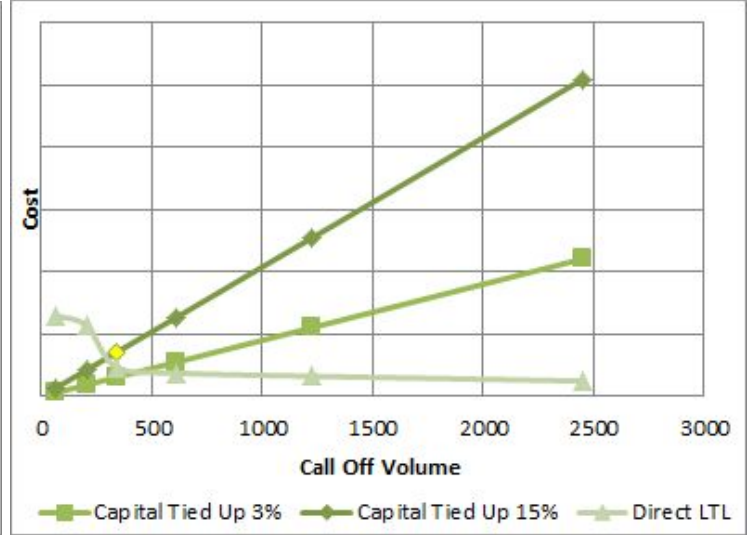## 10.5 Comparing 15% and 3% Capital Tied Up

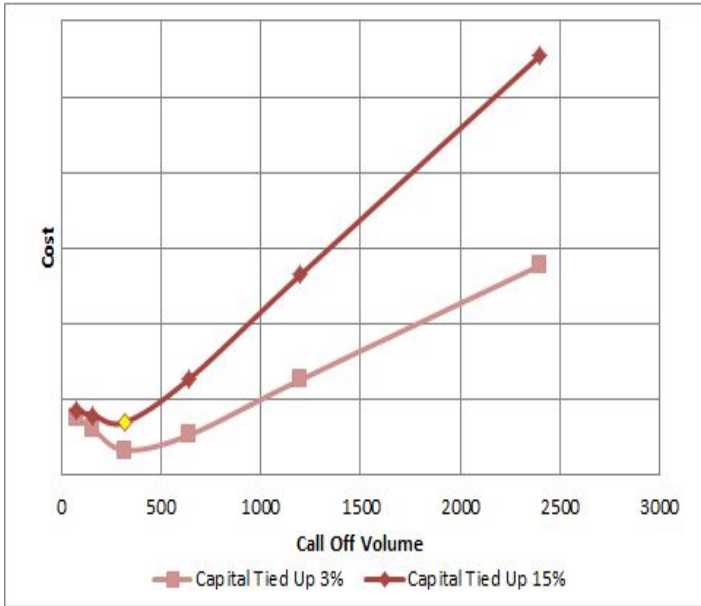Graph 26: TLC Curve (3% & 15%), Supplier A, Long 1 p/n

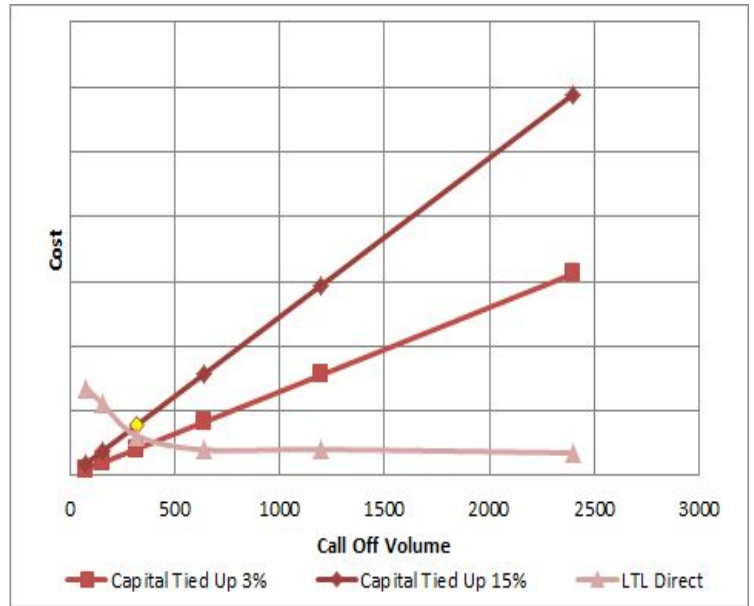Graph 27: Transport and Storage (3% & 15%), Supplier A, Long 1 p/n

Graph 28: TLC Curve (3% & 15%), Supplier A, Short 1 p/n

Graph 29: Transport and Storage (3% & 15%), Supplier A, Short 1p/n

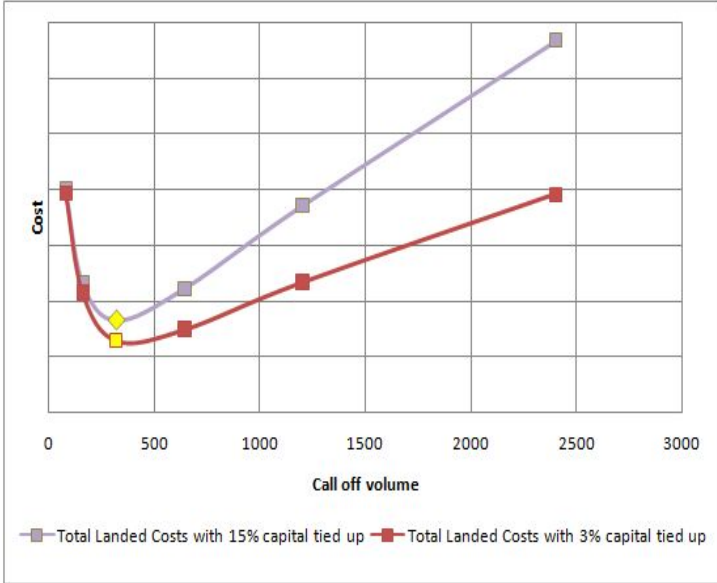Graph 30: TLC Curve (3% & 15%), Supplier B, Short 1 p/n

Graph 31: Transport and Storage (3% & 15%), Supplier B, Short 1p/n

89

Graph 32: TLC Curve (3% & 15%), Supplier B, Short for 4 p/n's

Graph 33: Transport and Storage (3% & 15%), Supplier B, Short for 4 p/n's

Graph 34: TLC Curve (3% & 15%), Supplier A, Long for 4 p/n'

Graph 35: Transport and Storage (3% & 15%), Supplier A, Long for 4 p/n's

90

Graph 36: TLC Curve (3% & 15%), Supplier A, Short for 4 p/n's

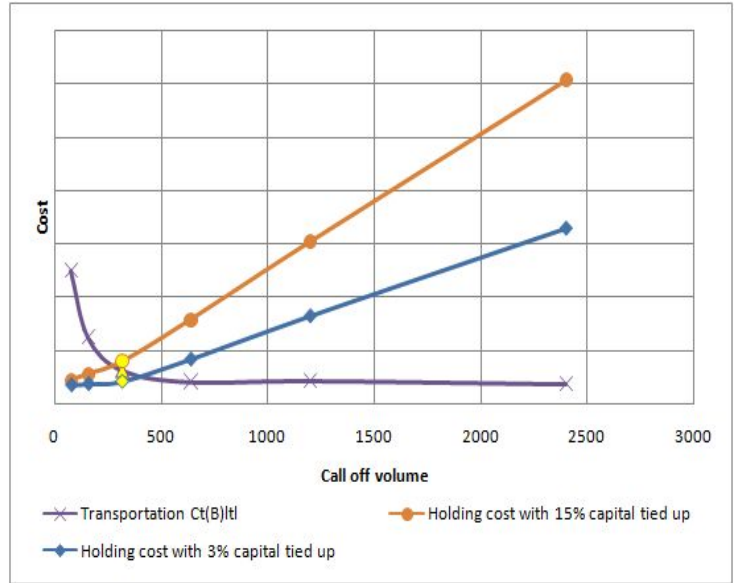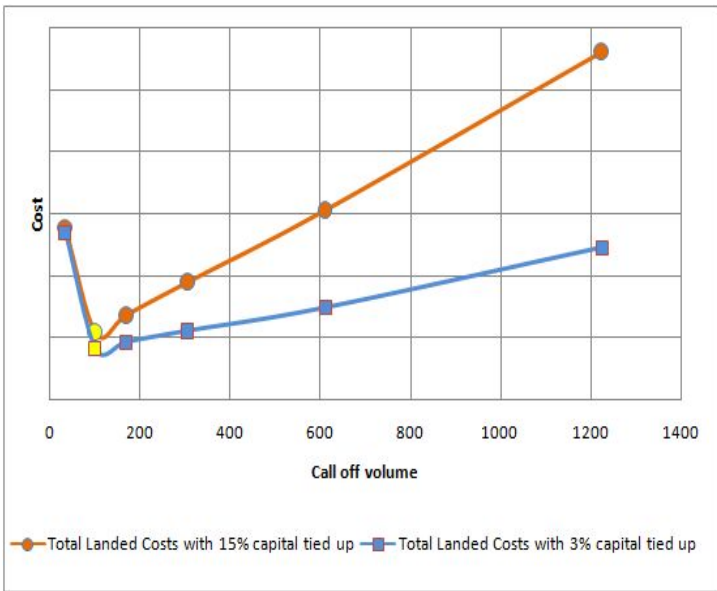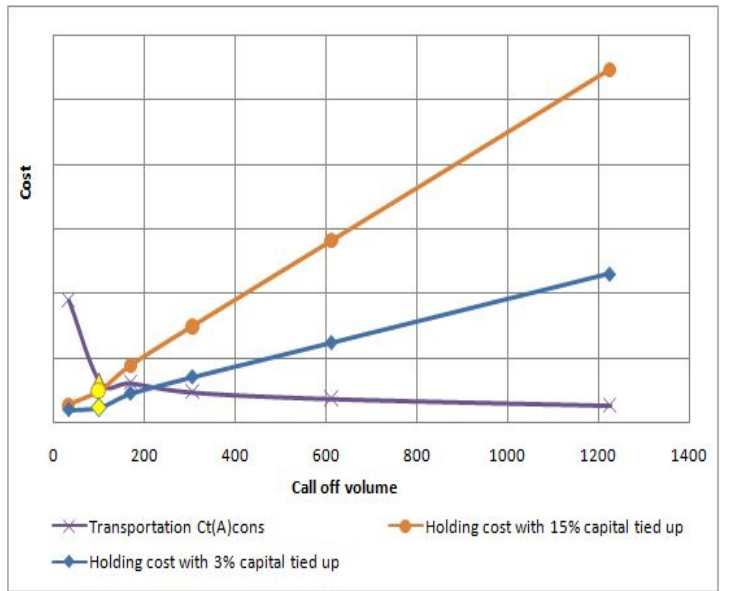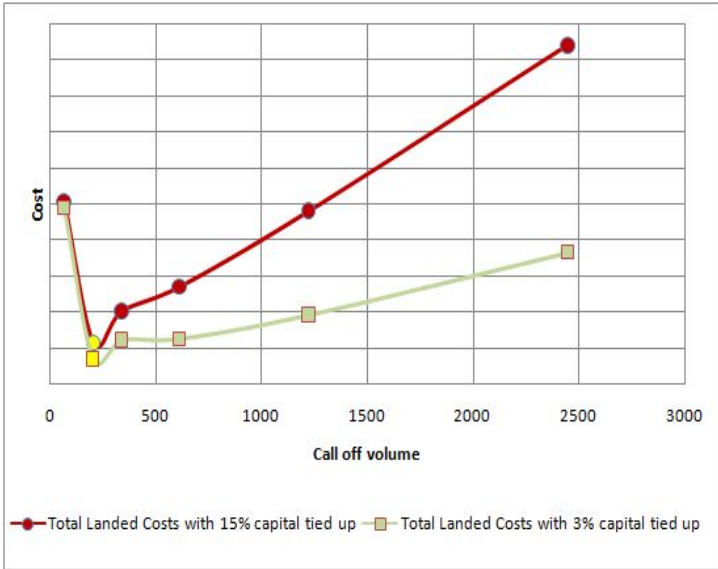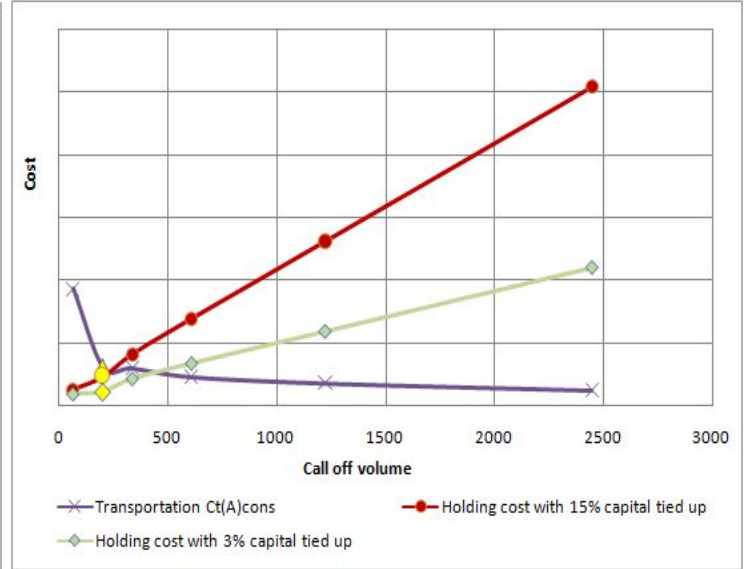Graph 37: Transport and Storage (3% & 15%), Supplier A, Short for 4 p/n's

10.6 Conducted Interviews, Observations and Data Collection

Interviews				
Interviewee	**Interviewer**	**Type**	**Topic**	**Date**
Global Supply Chain Developer	Asanee, Melanija	F2F	Guidance and contacts	February 19,2018
Transport developer	Asanee, member of steering committee	F2F	Understanding of transport processes and mapping of transport possibilities	February 28, 2018
Strategic Packaging Planner	Melanija	F2F	Packaging processes and packaging options	March 2, 2018
Packaging Engineer	Asanee, Melanija	Skype	Packaging options	March 8, 2018
Packaging Engineer	Asanee, Melanija	Skype	Packaging options	March 9, 2018
Transport developer	Asanee	F2F	Mapping out current transport scenario	March 12, 2018
Global Supply Chain Developer	Asanee, Melanija	F2F	Data on storage, packaging, general information and guidance on cost calculations	March 14, 2018
Transport developer	Asanee, Melanija	F2F	Transport costs	March 15, 2018
Supply Chain Director	Asanee, Melanija, members of steering committee	Skype	General information	March 9, 2018
Logistics Specialist	Asanee, Melanija	Skype	Mapping of current logistics flow (understanding of process and data collection)	March 19, 2018
Quality Supervisor	Asanee, Melanija	Skype	Environmental impact of storage and handling equipment	March 21, 2018
Junior SCM Engineer and SCM Engineer	Asanee, Melanija	Skype	Packaging instructions and environmental impact of packaging and storage	April 3, 2018

Key Account Manager	Asanee, Melanija	Skype	Handling and packaging at the supplier	April 11, 2018
Supply Chain Director	Asanee, Melanija, member of steering committee	F2F	Logistics operations at VPI	April 16, 2018
Quality Supervisor	Asanee, Melanija	F2F	Process of quality control and damages and quality of the component	April 17, 2018
Sourcing Buyer	Asanee, Melanija	F2F	Purchasing and ordering process	April 17, 2018
Junior SCM Engineer and SCM Engineer	Asanee, Melanija	F2F	Packaging instructions, environmental impact	April 17, 2018
Logistics specialist and Senior Supply Chain Engineer	Asanee, Melanija	F2F	Logistics set up (mapping out current scenario and suggestions on alternatives, recommendations); Data collection	April 18, 2018
Project and Operation Buyer	Asanee, Melanija	F2F	Mapping of current logistics flow, focus on handling at the buyer and packaging	April 26, 2018
Transport developer	Asanee, Melanija	F2F	Transport costs	May 5, 2018
Business Controller	Asanee, Melanija	F2F	Storage costs	May 14 2018,
Transport developer	Asanee, Melanija	Skype	Transport costs	May 18, 2018

Table 5: Conducted Interviews

Observations			
Guide	**Participants**	**Topic**	**Date**
Logistics Leader	Asanee, Melanija	Observation of warehouse activities (storage, handling and packaging)	April 17, 2018
Logistics specialist and Junior Supply Chain Engineer	Asanee, Melanija and member of steering committee	Observation (storage of component, packaging, emballage and handling)	April 18, 2018

Table 6: Observations

Data from emails	
From	**Data collected**
Quality Supervisor	Environmental impact of storage and handling equipment
Transport Developer	Transport data
Junior SCM Engineer	Storage data, VPI
Junior SCM Engineer	Packaging instructions
Transport developer	Transport data
Consultant	Data on the component (images of the part, part numbers, dimensions)
Supplier A	Data on packaging, emballage and handling at supplier
SCM Engineer	Packaging instructions, layout of warehouse, handling equipment

Table 7: Data collected from emails

Meetings with Steering Group	Date	Topic
Meeting 1	November 22, 2017	Introduction of thesis problem
Meeting 2	December 1, 2017	Thesis project acceptance
Meeting 3	December 6, 2017	Determining of thesis scope
Meeting 4	December 11, 2017	Preliminary planning of thesis
Meeting 5	January 17, 2018	Preliminary planning of thesis
Meeting 6	January 30, 2018	Meeting with Tutor
Meeting 7	February 11, 2018	First Weekly Meeting
Meeting 8	February 22, 2018	Second Weekly Meeting
Meeting 9	March 8, 2018	Third Weekly Meeting
Meeting 10	March 15, 2018	Fourth Weekly Meeting
Meeting 11	March 22, 2018	Fifth Weekly Meeting
Meeting 12	March 29, 2018	Sixth Weekly Meeting
Meeting 13	April 5, 2018	7th Weekly Meeting
Meeting 14	April 12, 2018	8th Weekly Meeting
Meeting 15	April 23, 2018	Additional discussions
Meeting 16	May 17,2018	Presentation of preliminary results
Meeting 17	May 22, 2018	Additional discussions

Table 8: Meetings with Steering Group

10.7 Interview Guide

10.7.1 Packaging

Packaging Process

1. Can you explain the process of packaging the long and short components?

2. How many employees are needed to package the long and short components?

3. How long does it take to package one long and short component?

4. According to Volvo Packaging instructions, are mixed loads allowed?

Current Packaging Scenario

1. What packaging (plastic, cardboard etc.) will be used for the component?

2. What is the cost of the packaging?

3. How long does it take to package one component?

4. Does the packaging allow stackability?

5. What are the dimensions of the packaging (length, width, weight etc.)?

6. Is the packaging going to be provided by the supplier or shipped from Volvo to the supplier? In the latter case, how does the supplier order the packaging from Volvo and how is the transportation for the packaging from Volvo to the supplier arranged?

7. Which packaging options have the greatest environmental impact?

8. Are the packagings recycled after the components arrive at the goods receiving location?

Alternative Packaging Scenarios

1. What other packaging options could be used for the component?

2. What type of packaging would be better for the component in terms of cost, stackability, loading efficiency and space utilization on the trailers?

10.7.2 Emballage

Emballage Process

1. What is the process of filling the emballages with long and short components?

2. How many employees are needed to fill one emballage with long and short components? Is it done manually or with the aid of machinery (forklift etc.)?

3. How long does it take to fill one emballage with long and short components?

4. What is the recycling process for the emballages?

Current Emballage Scenario

1. What type of emballage (metal, wood etc.) will be used for the long and short component?

2. What is the cost of the emballage?

3. How many components can fit inside one emballage (volume, weight and length wise)?

4. How long does it take to fill one emballage of long and short components?

5. Does the emballage allow for stackability?

6. What are the dimensions of the emballage (length, width, weight etc.)?

7. Are the emballages reusable or one time use?

Alternative Emballage Scenarios

1. What other emballage options could be used for the component?

2. What type of emballage would be better for the component in terms of cost, stackability, loading efficiency and space utilization on the trailers?

3. What are the advantages and disadvantages of different types of emballages in regards to:
   (a) Which materials require return flow (aka extra transport costs)?
   (b) Which material is more reliable and will minimize damages to component?

10.7.3 Loading (Handling at the Supplier)

Loading Process

1. Can you explain the process of loading the emballages with the components onto the trailer?

2. How many employees are needed to load one emballage?

3. How long does it take to load one emballage with long and short components onto a trailer?

Current Loading Scenario

1. What is the physical and administrative cost for handling one emballage?

10.7.4 Transport

Transport Process

1. What is the transportation process for the long and short components from Supplier A/B to VPI and the return flow?

2. What type of truck and trailer are used?

Current Transport Scenario

1. How are the components transported from Supplier A/ B to VPI (FTL, LTL with Consolidation or Direct)?

2. What is the transport route from Supplier A/B to VPI?

3. What is the transport distance from Supplier A/ B to VPI?

4. What is the total transport lead time from Supplier A/B to VPI?

5. Is Volvo responsible for the transport flow and return flow of the components?

6. How are the freight rates calculated at Volvo?

7. What type of trailer is used and what are the dimensions (max volumetric weight capacity, length, width, height)?

8. How many filled emballages of the short and long components can fit on one trailer?

9. How many empty emballages can fit on one trailer?

10. What are the fuel consumption levels of the truck and what Euro standards does it uphold?

Alternative Transport Scenarios

1. What alternative transport options are there for Supplier A and B (FTL, LTL with Consolidation or Direct) that would result in:

   (a) Lower transport cost
   (b) Lower transport lead time
   (c) Lower transport environmental impact

10.7.5 Unloading (Handling at Goods Receiving)

Unloading Process

1. What is the unloading process when the components arrive at the goods receiving?

2. Where are the goods received?

Current Unloading Scenario

1. How long does it take to unload one emballage?

2. How many employees are needed to unload one emballage?

3. What type of machinery is used to unload the emballages?

4. How many employees are needed for the administration of a shipment of components?

5. What quality control procedures are there when the components arrive at the goods receiving?

10.7.6 Storage

Storage Process

1. What is the storage process for the long and short components?

2. How are the storage costs and tied up capital calculated?

Current Storage Scenario

1. Where are the components stored?

2. What is the cost of storing the components (cost per square meter)?

3. How much storage space is allocated for the components?

4. Are the emballages stacked in storage?

5. What percentage of the components get damaged during storage?

Follow up Questions

1. What are the costs of storing the components internally vs. externally?

Alternative Storage Scenarios

1. Are there alternative storage areas that the components could be stored at?
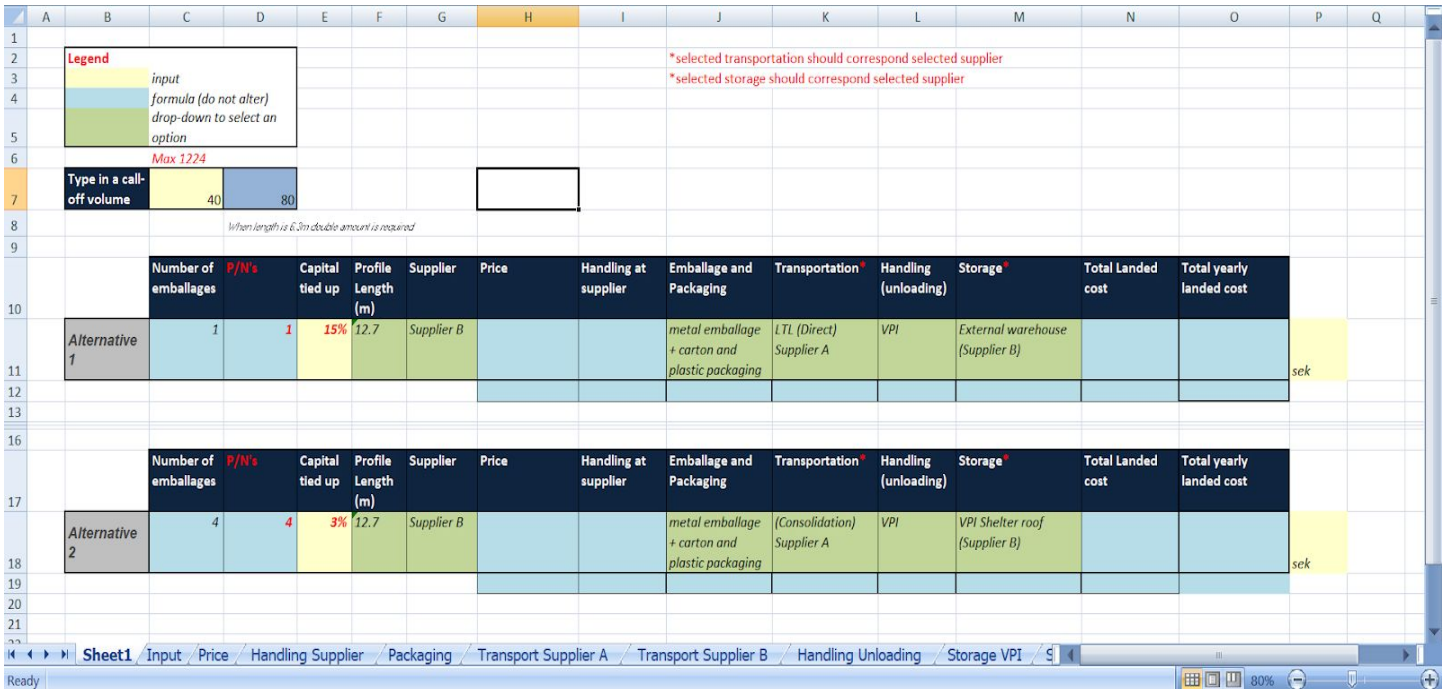
10.8 Tool

Figure 11:Tool used for generating different scenarios