CHALMERS

Internal logistics cost model with application at Volvo Powertrain

A bachelor thesis within the program Economics and Production technology

BIRGITTA DANIELSSON
LINDA HOLMKVIST

Department of Technology Management and Economics
Division of Supply and Operations Management
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2016

Report No. E 2016:027

BACHELOR’S THESIS E 2016:027

Internal logistics cost model with application at Volvo Powertrain

BIRGITTA DANIELSSON

LINDA HOLMKVIST

Tutor, Chalmers: Peter Almström

Tutor, company: Johnny Larsson, Henrik Wallström

Department of Technology Management and Economics

Division of Supply and Operations Management

CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2016

Internal logistics cost model with application at Volvo Powertrain
BIRGITTA DANIELSSON
LINDA HOLMKVIST

Bachelor’s thesis E 2016:027

Department of Technology Management and Economics
Division of Supply and Operations Management
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone: + 46 (0)31-772 1000

Chalmers Reproservice
Gothenburg, Sweden 2016

Internal logistics cost model with application at Volvo Powertrain
BIRGITTA DANIELSSON
LINDA HOLMKVIST
Department of Technology Management and Economics
Chalmers University of Technology

Abstract

The marketplace is today more customer oriented and competitive than it has been in the past and this increases the importance of efficiency within the companies. For companies to be efficient they have to focus on optimizing the company's supply chain, both internally and externally. At Volvo Powertrain in Skövde the assembly department has made changes to the assembly set up without much consideration of how this affects the internal logistics. At the same time does the internal logistics department feel that they lack understanding for the cost drivers within their system and can therefore not fully adapt to the new assembly set up. For gaining this understanding a cost model has been created based on throughput times and area costs. The model shows the material flows and the activities within the flows with corresponding costs. An analysis has been made to identify the cost drivers and find more economically sound logistics set ups. The analysis is based on the model where variables have been changed to show how the costs change within the flows. It is found that increasing the batch sizes and raising the fill-rate is economically beneficial for the internal logistics department. Reducing the number of material flows will also reduce the complexity of the material flow set up making it easier to place the part numbers in the most suitable flow. Guidelines should be established regarding what characterizes the different flows to assure that the part numbers will be placed correctly. There are factors not seen in the model that could reduce costs and improve the internal logistics as well. One such factor is the internal supply chain that is seen to be inadequate. It is recommended for the internal logistics department to use the model to spread understanding not only within the department, but to the whole internal supply chain. Furthermore it is important to look at the whole supply chain, and not just the internal supply chain, when considering what changes to implement. Changes that appears to be beneficial for the internal logistics department may not have the same affect on the whole company.

Keywords: internal logistics, cost drivers, supply chain, material flow, logistics costs

Sammanfattning

Marknaden är idag mer kundorienterad och konkurrenskraftig än den varit under tidigare år och detta ökar kraven på effektivitet inom företagen. För att denna effektivitet ska uppnås behöver företagen se över både sin interna och externa värdekedja. På Volvo Powertrain i Skövde har monteringsavdelningen ändrat layout på monteringslinan utan att ta någon vidare hänsyn till hur detta påverkar internlogistiken på företaget. Avdelningen för interlogistik känner vidare att de saknar förståelse för vad som driver kostnader inom avdelningen och kan därför inte anpassa sig fullt ut till den nya layouten. För att hjälpa avdelningen att få förståelse för internlogistiken och de kostnadsdrivare som finns har en kostnadsmodell tagits fram. Modellen visar de olika materialflödena som finns i fabriken tillsammans med aktiviteter och kostnadsberäkningar. Beräkningarna är baserade på ytkostnader och genomloppstider. Utifrån modellen har en analys genomförts för att identifiera kostnadsdrivare och för att hitta mer ekonomiska utformningar av internlogistiken. Genom att variera variabler i modellen har kostnaderna förändrats och på så sätt har slutsatser om kostnadsdrivarna kunnat dras. Med utgångspunkt i analysen har det bland annat hittats att avdelningen för internlogistik kan spara pengar på att öka kvantiteten i olika typer av emballage och höja fyllnadsgraden hos fordon. Det har också upptäckts att det är möjligt att reducera antalet materialflöden vilket skulle leda till minskad komplexitet i internlogistiken. Färre materialflöden skulle också göra det enklare att placera artiklar i rätt materialflöde och på så vis kan onödiga kostnader undvikas. Förutom att minska antalet materialflöden skulle riktlinjer gällande flödenas egenskaper göra det enklare att placera artiklar i rätt flöde. Utöver de variabler som syns i modellen finns det faktorer som också skulle kunna minska kostnaderna och förbättra internlogistiken. Ett exempel på en sådan faktor är den interna värdekedjan där samarbetet mellan avdelningarna skulle kunna förbättras. Rekommendationen här är att använda kostnadsmodellen för att sprida förståelse för internlogistiken även mellan avdelningarna och på så sätt också öka kommunikationen. Vidare bör företaget se över hela sin värdekedja, inklusive externa parter, innan några beslut om förändringar tas. Föreslagna förändringar ser ut att vara ekonomiskt gynnsamma för internlogistiken men utanför avdelningen behöver förslagen inte nödvändigtvis ha samma effekt.

Sökord: internlogistik, kostnadsdrivare, värdekedja, materialflöde, logistiska kostnader

Table of contents

1. Introduction

Below the background and the purpose of the thesis are presented. The problem is defined by two research questions and the limitations are described.

1.1 Background

During the late 1900s the marketplace changed rapidly. Two of the driving forces behind this change was globalization and digitalization of the marketplace, leading to better informed customers with higher demands of quality, price, availability and service (Coyle et al., 2003). This change has increased the importance of logistics, which can be described as strategic aspects of communication channels and organizational structure of material flows (Nationalencyklopedin, 2016). Externally, logistics implies relations and transports between partners within the value chain. Internally, logistics are relations between functional areas within a company and all transportation and handling taking place within the company.

For many years there has been an ongoing work to identify losses and non value-adding activities within the value chain in the Volvo GTO Powertrain production assembly factory in Skövde. The assembly department has made changes in the assembly set up leading to a more efficient assembly line, but losses have instead been pushed backward in the supply chain. Part of these losses have landed on the internal logistics organization. The organization has tried to adjust to be able to deliver material according to the new assembly set up and decrease costs along the material flows, but there is a lack of understanding for the cost drivers associated with supplying material. By creating an understanding for the cost drivers and where they arise in the material flow, the possibility to adjust the internal logistics to the assembly set up would increase.

Volvo GTO Powertrain production, mentioned Volvo, is a part of Volvo Group Trucks Operations and a supplier for AB Volvo's corporations. On the Volvo site in Skövde they develop and manufacture engines and engine components to be shipped to four continents. The engines are most widely used in trucks but they are also manufactured for other applications such as for marine and industrial use. The Skövde site is large with a site area of 265 000 square meters and 2600 employees in total. Except from the assembly factory there are three foundries and one machining factory on the site. Components from these factories are either sold separately or transported to the assembly factory for assemblage.

1.2 Purpose

The purpose of the study is to identify cost drivers within the internal material flow from point of entrance in the assembly factory up to point of use at the assembly line or the kitting station. The cost drivers are analyzed to support a discussion regarding how they affect the internal logistics and how the material flow can be adjusted to decrease costs. To see which cost drivers that have a larger impact on the total cost than others their sensitivity is analyzed. Possible changes in the current material flows are investigated to provide a foundation for recommendations regarding economic benefits.

The cost drivers are presented in a model where it is possible to understand where in the material flow costs arise. The model can be used as a tool for further analyzing the internal logistics, showing how costs change along the material flow with respect to different variables. The analysis is based on the model and the result will be used mainly at Volvo to spread understanding for internal logistics costs.

1.3 Limitations

The study focuses on the internal logistics up to point of use and no regard is taken to what happens to the parts before entering or after leaving the assembly factory. The internal logistics is only a small part of a products full supply chain and most problems raised in the analysis will need to be investigated from a wider perspective before being applied in the factory. To identify the material flows of the internal logistics set up, 17 part numbers representing most of the flows within the factory have been chosen for the analysis. These parts are supposed to give a fair view of the flows that they represent and therefore no other part numbers are investigated. No regard has been taken to empty packages being transported out of the factory or empty transports within the factory.

To find average throughput times for different activities each part number has where possible been studied six times. These six studies are spread out over a time period of one month. As the data has to be up to date, a recent month without much disturbances was chosen. Due to the study starting in January and the factory being closed during winter holidays which would affect the throughput times, December and January were not alternatives. Instead November was chosen and all data possible has therefore been collected from this month. There seemed to be no larger disturbances affecting the throughput times during this time. In cases where data has not been available from November a more recent month has been used.

As the thesis is made for the internal logistics department, focus has been within their area. Because of this, the costs connected to the assembly line has not been investigated in any larger extent. The coverage time by the assembly line is pre-defined by the assembly department to be two hours and the average storage time has therefore been set to be one hour. No further study has been made to cross check this time. Investments by the assembly line have neither been looked up since the assembly department also controls the set up here. Both the storage time and the area cost may contribute to misleading cost calculations for storage by the assembly line.

Since the outcome of this study is a method for identifying cost drivers within the internal logistics set up the focus is not to find solutions to potential problems. On the other hand, problem areas will be analyzed and tests are made on how alternative set ups could be designed. Alternative set ups will be discussed thoroughly and not only from a cost perspective.

1.4 Problem definition

A full current situation analysis has been made for 17 part numbers representing the different material flows in the factory. From the current situation analysis, the objective is to find the logistic cost drivers and understand how different factors affect these costs. To be able to do this, variables had to be defined and varied in the model to be compared to the current logistics set up. The thesis delivers a model showing how these variables affect the internal logistic costs and presents possible changes of the set up to decrease logistic costs. The following research questions were phrased before starting the study:

- How are the current material flows set up and which are the logistic cost drivers associated with the flows?
- With base in the cost drivers, can variables in the flows be changed to decrease costs and can the material flows be changed to become less complex and more cost efficient?

2. Theoretical frame

The study is focusing on logistics, and more exactly on the internal perspective of logistics. An internal perspective confine to an internal supply chain where the material flow and related costs will be in focus (Jonsson & Mattsson, 2011). In this chapter, theory regarding different aspects of the logistics and logistic cost drivers are presented.

2.1 Material flow

The main goal of a material flow is to create a synchronous flow without local build-ups and disturbance (Harrison & Hoek, 2008). To prevent this, all processes in the material flow must be coordinated. The material flow within the logistics system constitutes of transportation, handling and storage of goods (Jonsson & Mattsson, 2011). Creating a synchronous flow is having material and information moving fast without unnecessary waste (Liker, 2006). Flow is also what connects processes to each other, like the internal logistics is connected to the assembly line. Each operation in the material flow contributes to waiting times, which means that the number of operations is affecting the total throughput time (Jonsson & Mattsson, 2011). Having a synchronous flow reduces the time from order to delivery and it will also keep stock levels in the material flow relatively low with processes as just-in-time (JIT). JIT implicates receiving what you need when you need it at the right place (Liker, 2006).

Transportations within the material flows are largely carried out to and from some form of storage (Jonsson & Mattsson, 2011). When designing a storage the purpose is to minimize inventory and handling costs. This is done by attempting to reach as high fill-rate and as low operating costs as possible. When aiming for high fill-rate it is still important to have a number of empty storage sites to handle variations. Handling of material affects the costs and goods should be placed as accessible as possible to not drive extra costs.

The handling equipment used in the material flows may be more or less automated. For more standardized and frequent flows, it can be advantageous to use automated systems (Jonsson & Mattsson, 2011). Conveyor System refers to a mechanical system that automatically move material in the factory, while forklifts and trains are example of more manual means of transportation. Choice of appropriate means of transport and transportation patterns influence the flow of material. It affects the delivery frequency and delivery quantity which have an impact on the tied-up capital and delivery service. A basic principle of all transportation is to strive for as high fill-rate as possible. Transportation costs are dependent on in which degree the vehicle is occupied.

Another principle that applies to the whole production system is that the processes should be visualized and standardized. By doing this, Liker (2009) says that it is easier to find problems in the processes and keep control over the production. Standardized processes lead to less variations and deviations at the same time as it helps maintain the quality and identify defects on products. A good standard is supposed to be simple, clear and visual. There are various methods to eliminate or avoid the loss of time. Reduce the number of processes, create a more consistent and stabile process and implement buffers to reduce the effect of time dispersion are examples of such.

The total internal logistic cost and the throughput time for a detail will change depending on the batch size. Large batches can reduce production costs while storage costs for inventory often increase (Harrison & Hoek, 2008). The throughput time is longer for large batch production giving little flexibility to the production and the result is poor customer service quality. Small batches will instead result in better quality of customer service and theoretically it can decrease the total costs for a part throughout its supply chain. The reduced total cost is a result of lower storage costs and the elimination of overproduction and other waste associated with large batch production. The production is controlled by the assembly department but overproduction can still be avoided by decreasing the batch sizes in the material flow and so the number of parts ready for assemblage.

2.1.1 Material management

Material management is about creating material flow that satisfies existing needs (Harrison & Hoek, 2008). Material management deals with for which part numbers new orders should be scheduled, how big the quantity should be, when the order should be scheduled and when the part number should be delivered to its final destination.

One management philosophy on improving quality and reducing waste is JIT. The base of the philosophy is to only have processes operate when the customer signals for more goods (Harrison & Hoek, 2008). Working with logistics this way is a method of eliminating waste and improving quality in the processes. From the internal logistics perspective, JIT means delivering goods to the assembly line when it is about to be used. To achieve this type of flow some sort of signal is needed for triggering an order from the previous process. These signals, or material handling systems, can be in form of e.g. kanban cards or two-bin systems. A well-functioning material handling system can reduce costs, labor and waste, but also increase safety, productivity and capacity (Bloomberg et al., 2002).

2.2 Logistic costs

Logistic costs are costs that emerge from logistic activities (Jonsson, 2008). The costs that are attributed to logistic activities vary in different situations depending on the business activity and the current perspective. Jonsson (2008) mentions these different types of logistic costs related to the internal logistics:

- Transportation and handling costs
- Package costs
- Storage costs
- Administrative costs
- Capacity-related costs
- Shortage and delay costs

When reducing logistic costs the company can reach a cost advantage toward its competitors (Harrison & Hoek, 2008). The cost advantage imply being able to lower the product price on the market or increasing the margins.

Costs can be broken down into direct and indirect costs. These costs are two types of logistic costs divided upon if the cost arise based on a specific part number or from several part numbers. The direct costs are those costs that can be attributed to a certain detail and a selected activity. An example of a direct cost may be labelling cost for details in a box. Indirect costs are costs that cannot be attributed to a detail but has to be divided upon all details contributing to the cost. An example of this is the maintenance cost for transportation vehicles or the area cost for storage. Both the direct and the indirect costs have to be taken into consideration when calculating the total cost for a detail (Jonsson, 2008).

There are two different methods to estimate costs, bottom-up and top-down (Ax et al., 2009). These can also be combined into a mixed approach. The bottom-up approach is a basic method of estimation adding each expected cost for an object to a total cost. Ultimately, the total cost should be equal to the final cost of the item. The advantage of this method is that it is very accurate when estimating the total costs, but on the other hand it is time consuming since every expense needs to be specified. When calculating costs with the top-down approach the direction is contrary. This method starts with the final cost and then deconstructs it into smaller components.

2.3 Cost drivers

Identifying cost drivers is a way of finding where in a company a cost arises and what activity it depends on (Ax et al 2009). The cost driver is the reason for a cost to be of a certain size and by defining the cost driver it is possible to see what decides the size of the cost. The cost drivers are not applied to the whole company but to a specific activity. When for example looking at the activity train transport, the cost driver could be the distance driven or how many hours the train has been running. The distance and the up-time are variables deciding the total cost for the train transport. By controlling the cost driver it is possible to keep control of the costs (Jonsson, 2008).

ABC analysis is a tool for classifying parts into different compartments based on importance and characteristics (Bloomberg et al., 2002). Setting limits to the ABC classification can affect the cost drivers. The classification can be based on different factors depending on the organization. Some common factors are purchasing price, throughput time, sales volume, profitability and inventory. The products are placed in group A, B or C depending on where they classify according to the factors and limits for each group. It is important to be careful in assuming that B and C parts are less important than A parts as they may still be of great value to the production (Bloomberg et al., 2002).

2.4 Tied-up capital

Another factor for analyzing the material flow is tied-up capital. Tied-up capital is capital that is locked into a company’s material flows (Jonsson, 2008). Another way to explain it is as the average throughput time in a storage point or in a material flow. The longer throughput time and the more valuable part numbers, the higher will the tied-up capital be. Calculating the tied-up capital can be done by adding a percentage to the part number’s purchasing value. The percentage is often on a yearly basis and the tied-up capital depends on the part’s throughput time. In other cases the tied-up capital is calculated by adding costs that arise during the time period that is being looked at.

It can be lucrative for a company to hold inventory as it can prevent shortage of parts (Jonsson & Mattson, 2011). Holding inventory also decreases uncertainties in demand. A disadvantage of a large inventory is that it ties up capital and leads to costs such as storage costs and handling costs. Inventory is the largest asset for most companies which makes it important to investigate (Bloomberg et al., 2002). On the other hand, holding inventory does not agree with the JIT principle.

2.5 Internal supply chain

To manage supply chain operations, integrated logistics and supply management are coordinated to create a continual flow of products or services (Bloomberg et al., 2002). A strategy to make a company competitive and stay competitive in an intense market is by looking at its supply chain (Yang, 2013). As the study focuses on the internal logistics it will also regard the internal supply chain. The supply chain should be viewed as a system, where all processes within the network must be understood to create a continual flow (Harrison & Hoek, 2008). Understanding that different processes in the network interact with other processes is important. The overall performance of the network results from the combined performance of the individual processes.

The internal supply chain is the network of departments within a company and one purpose of looking at the supply chain is to create efficiency (Yang, 2013). As all departments should be working toward a common goal they should also be coordinating their operations and agree in performance. For example must the purchasing department work together with the assembly department to make sure that the purchased raw material can be processed smoothly. They must also check with the sales department if the raw material meet customer demands. One department has the need to both provide facilities for other departments and to meet its own requirements. The cooperation between departments should be favorable for all and adjusted when necessary. Departments in companies have often optimized the supply chain around their own interest but it is also of great importance to focus on collaboration and partnership between the departments (Harrison & Hoek, 2008). The strength in a network depends on each link included.

Supply chain processes can be improved by detailed planning and control of the processes (Harrison & Hoek, 2008). For the internal supply chain to increase the total efficiency of a company, Yang (2003) has presented four key aspects that has to be fulfilled. First, he sees the importance of spreading knowledge about internal supply chain management and its strengths within the company. Second, trust has to be built between the departments to secure long-term cooperation. This means that departments have to trust each other to do the work that is expected from them. Third, departments have to share information to establish close relationships and receive maximum satisfaction. Last, Yang suggests to use the cross-functional procurement forecasting team that is often a central part of purchasing. This team consists of employees representing all departments in a company and its purpose is to improve the procurement process by receiving input from all departments.

3. Methodology

For a deeper insight into the chosen area a case study was carried out. A case study is a research method that aims to provide deeper knowledge about an investigated area. When initiating a case study it is important to have a theoretical frame relevant for the analysis. The theoretical frame helps to understand the data that has to be collected and provides a base for the analysis. Besides relevant theory, a study of the current situation has been carried out together with calculations of area and activity costs before conducting the analysis. In this chapter the research methodology used to fulfill the purpose is described. First presented is the literature review procedure followed by interviews, data collection and a description of what the calculations are based on. Finally, reliability and validity is presented before moving on to look at the model and start the analysis. See the method approach in figure 1.

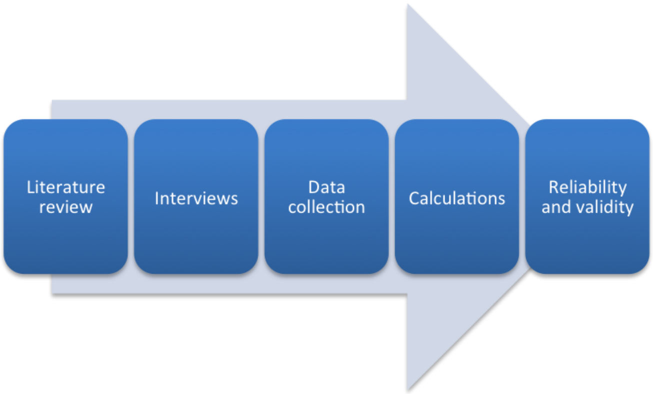


Figure 1 Description of the methodology.

3.1 Literature review

The initial phase of the case study was a literature review. Researching literature is an appropriate first step when the aim is to gain knowledge within an area that is about to be investigated. The review has been performed by looking through textbooks used in university classes, doing library research and by searching for scientific publications in the databases at Chalmers library. Departments investigated have been economics and transportation as well as production technology. The databases that has mostly been used are Summon, Ebesco, Proquest and Scopus. Keywords varied between *internal logistics*, *internal supply chain*, *cost drivers*, *tied-up capital* and alike as they give a knowledge base that is within the scope. When reading scientific articles the search has been limited to recent years.

3.2 Interviews

When entering a factory without previous knowledge about the set up and the logistic system, a first step is to interview employees working with logistics and material handling on a daily basis. By asking questions regarding how the system is set up and how it works it is possible to gain a deeper understanding for the material flows. Since the employees are those who are working with the systems they can provide a clear picture of the material flows, see appendix I for list of interviewed employees. The interviews have been a big part of understanding the internal logistics situation and gaining this understanding is an important part in defining cost drivers associated with the logistic set up. The interviews have been carried out before performing any calculations. The focus of the interviews have been to collect information regarding the following:

- number of material flows
- limitations of the flows
- annual consumption and ABC classification of each part number investigated
- area costs
- purchasing price for part numbers to calculate tied-up capital

3.2.1 Information regarding material flows

In an early stage of the study the areas within the factory were located to understand where in the factory the activities take place, relevant areas can be seen in appendix II. The material flows were later identified by mapping 17 part numbers and their way through the activities in the factory. The part numbers were followed from entering the factory until arriving at point of use. These part numbers were chosen by material preparators to represent all the larger material flows within the assembly factory, see figure 2.

Flow
HANGING LOW VOLUME
HANGING HIGH VOLUME WITH BUFFER
HANGING HIGH VOLUME WITHOUT BUFFER
PALLET WITH TRUCK WITHOUT BUFFER
PALLET WITH TRUCK WITH BUFFER
PALLET WITH TRAIN WITHOUT BUFFER
PALLET WITH TRAIN WITH BUFFER
LOW VOLUME CARDBOARD BOXES
REPACKED MID VOLUME
MID VOLUME FROM SUPERMARKET
REPACKED HIGH VOLUME
HIGH VOLUME FROM SUPERMARKET
PIPE SHOP FLOW
PALLET THROUGH SEQUENCE AREA
GRAVITATION CONVEYOR FLOW
HIGH VOLUME LABELLED FROM SUPPLIER
SUMMER CABIN THROUGH SEQUENCE AREA

Figure 2 The 17 material flows

Together with the 17 part numbers, the main characteristics of the related material flows were presented. Some stations along these flows are mutual for several flows but there are still differences that characterize each flow. The flows have been divided into five main flows with sub flows according to figure 3.

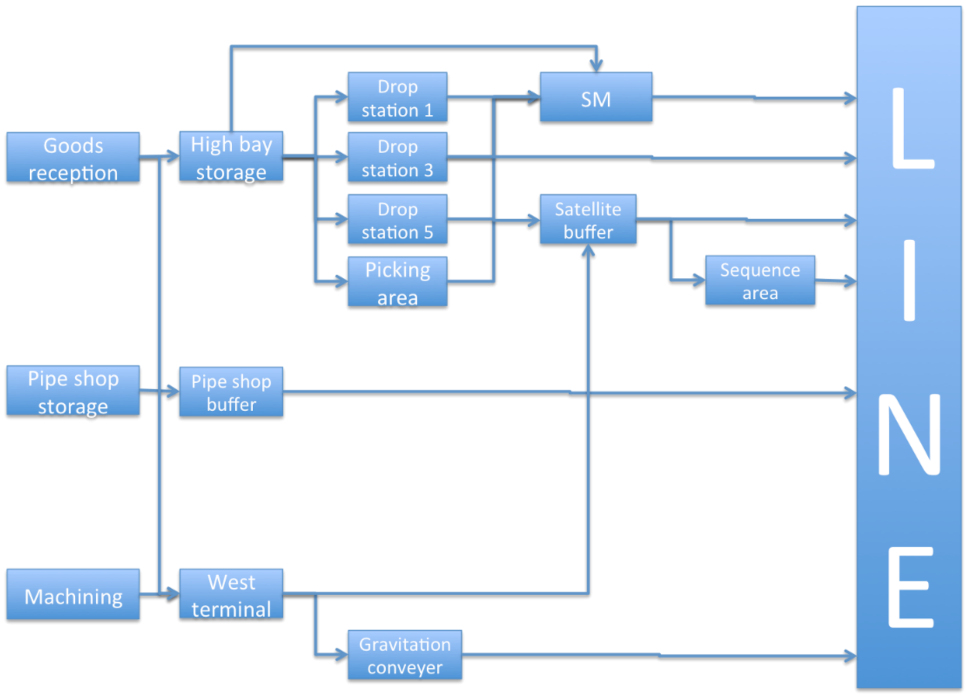


Figure 3 The main flows in the factory with related sub flows.

Once the flows were mapped, questions were asked regarding potential limitations of the flows that have been seen from the material handlers' perspective. It was found that there are limitations regarding maximum weight per package and maximum storage time by the assembly line. Another limitation is the amount of high volume details which fills the high volume flows to the limit, making part numbers having to be placed in other flows.

3.2.2 Administrative information

The annual consumption of each part number was given from the department external material control. The information is registered in their computer system and the annual consumption of 2015 was looked at since this is the year most of the data is collected from. The information regarding the ABC classification was given from the same department. At Volvo the factors for classification are purchasing price, annual consumption, lead time for delivery and number of pick-up days per week.

Since all transports, storage areas and operations are not fully occupied, different levels of fill-rate have been taken into consideration when performing calculations. The fill-rates have been given or estimated by employees from different departments where this has been possible. Where the fill-rate has not been known a study has instead been carried out.

3.2.3 Economic information

Economic data is divided upon different divisions which involves several contact persons, including the transportation department and the economic department. The costs for the material flows regard investment costs in form of depreciation, maintenance costs for storage areas and transports, storage costs, labor costs and costs for vehicles. Most costs have been calculated but where needed, standard costs used in the company today has been taken.

In this study, the bottom-up approach has mainly been used for calculating costs in the model. This is done by adding the cost for each activity making the total cost for each flow. Where the bottom-up approach has not been possible to use because of lack of data, the top-down approach has instead been applied. An example of cost calculated this way are depreciation costs and maintenance costs that have been given and divided upon all part numbers.

When calculating tied-up capital this was desired to be done the way Volvo does it today with an annual capital cost of 7% of the purchasing price. As the study focuses on 17 part numbers representing the flows in the factory the tied-up capital has been calculated for these specific part numbers and cannot be considered general for the flows. The purchasing price was received from the manufacturing technology manager who also provided the information regarding tied-up capital calculations.

3.3 Data collection

For deeper insight into the material flows, information regarding storage times and transportation times were collected together with package quantities and package types. The major part of the data collection took place in the internal material control system, MACS. This is the program used for all material handling at Volvo and contains information regarding inventory within the factory. Once the details pass through the identity scan when entering the factory, all transportation orders for the part numbers will be registered in the system. This means that you can use the system to check where a specific package is and how it has been handled in the flow.

By looking at the chosen part numbers in MACS, specific packages for each part number can be followed through the material flow. For most of the part numbers, three different delivery occasions to the factory were looked at. Two packages for each delivery occasion were investigated, one with a short storage time in the high bay storage and one with a long storage time. The reason for choosing packages this way is to clarify differences in throughput times and to receive an as correct throughput time average as possible.

The first step to be able to follow a detail is to enter the part number into historical data in MACS. If the detail enter the factory in the goods reception and passes through the high bay storage most data needed can be found in MACS. What cannot be found are some of the transports. MACS generally shows the time when a package arrives at different locations and not the transportation in between. For this information a complementary system have been used called NTRP which is the internal transportation system. NTRP works a little differently than MACS and here all transports taking place in the factory are registered with time for ordering of a transport, starting time of the transport and the transports finishing time. Once having the transportation time, the previous storage time can easily be calculated.

By using the finishing time for a transport from MACS it is possible to receive the starting time of this transport in NTRP. If the starting time instead is known it is possible to find the finishing time. When the start and finishing times are identified the transportation time can be calculated. The NTRP system was also used as a complementary to MACS to identify part numbers that cannot be found in MACS at all. For example, NTRP had to be used for packages that are repacked or labelled and therefore change ID number within the flow. Lastly, NTRP has been used for details not passing through the high bay storage as MACS do only register details passing through here.

Those part numbers that pass through the picking area are repacked into smaller boxes and are as mentioned given a new ID number. The same goes for part numbers going through the labelling area. The transports up until the picking area or labelling area can be seen in MACS through a package number, but after the details have been repacked or labelled the new ID number has to be found in NTRP. The finishing time for the activity can be seen in MACS and this time is a starting signal for a transport that is registered in NTRP. By matching these two times the detail's new ID number can be identified and used for further data collection in NTRP.

Where none of the systems provided the necessary information, time studies were carried out. This applies mostly to transports as these times are easy to measure with a regular stop watch. In the studied transportation times, loading and unloading of goods were included. Storage times, which are often quite long compared to transportation times, has where needed been estimated by employees working with these processes on a daily basis. Where neither estimations, time studies, nor the two systems have been able to present representable data, a calculation of storage times had to be done, see formula below. This calculation could be done as there is no safety stock for any of the part numbers investigated. Deviant measurement methods have been clarified for each part number in appendix III.

$$Storage\ time = \frac{Working\ hours\ per\ year}{Annual\ consumption\ for\ part\ number}$$

There are a few flows not passing through the goods reception. These flows either start in the machining factory on the Skövde site and enter the assembly factory by the West terminal, or are manufactured in the pipe shop within the assembly factory. To collect data for these flows NTRP has been used along with time studies.

For a few of the part numbers simplifications of activities in the flows have been made. This includes transports that are difficult to follow where the costs of these transports are not considered to affect the total cost of the flow in any extent. An example of such is that the transport from supermarket buffer to the supermarket has been disregarded and these storage times have been joined together. This transport is only a lift between two shelves and take no more than a few seconds. The simplification makes the flows *hanging high volume with buffer* and *hanging high volume without buffer* look exactly alike in the model. The throughput time will still be specifically collected for each flow. The same applies to the flows *pallet with train/forklift with buffer* and *pallet with train/forklift without buffer*. The transports going outside the factory have also been simplified as they are often divided into several different sub transports. These have been joined together in the model. Last, a simplification has been made regarding the storage times at point of use.

Once all data regarding the material flows was collected it was structured into an excel document. The document shows exact date and time for arrival and departure of packages at specific points in the factory. Calculations could from this information be made by comparing arrival and departure times to each other and thereby obtaining storage and transportation times for the part numbers. As every part number has been measured up to six times an average was calculated to be a base for further calculations in the model. The measured times for transportation were much alike for most details and the average is therefore considered to be fair. The storage times on the other hand could vary in different extent, but since the storage times drive less costs than what transportations do the deviation will not make a big difference when looking at the total cost.

3.4 Calculations

A new sheet in the excel document was created for area cost calculations. These costs regard storage areas, means of transportation, employees and packages and are a base for the cost calculations in the model. The costs are based on uptime, maintenance, rent and investments and for storage the cost has been calculated per square meter. Uptime costs and rent have been given as standard costs at Volvo while the maintenance costs have either been calculated from a losses report or given by employees. From this report all costs related to maintenance have been summarized for the specific area or transportation type. For the areas not represented in this report the maintenance costs have been given from related departments. This applies to the transportation vehicles where maintenance is included in the operating cost.

The investments were taken from a facility register where every investment done from 1989 until today is documented. Different investments have different depreciation times and an average of these has been calculated to be eight years. The depreciation cost for each investment have been spread out over the relevant eight years to show the yearly cost for each investment. All investments done in one area have then been summarized to show the total depreciation cost per year for that area. Once this was done an average of the total depreciations costs for each area during the last eight years was said to represent the total depreciation cost for the area. Investments that have already been depreciated eight years ago is not a part of this average. No consideration has been taken to inflation and if any investments are not in the facility register they are left out.

Costs for storage areas can be applied to details whether the factory is running or not as inventory always will be held here. Costs for transports are calculated to only occur when the vehicle is actually being used as this is the time when the cost can be applied to a detail. Therefore investments for transports have been spread out over the number of working hours per year while investments for storage areas are spread out over a whole year. Investments that cannot be applied to any specific area in the factory have been divided upon the entire factory by adding the depreciation cost to the cost per square meter.

Repacking parts into different packages does not only result in a handling cost, but the package that the detail is repacked into also drives a cost. This cost was given from the manufacturing technology manager and includes cleaning, transportation and storage of the package.

3.5 Reliability and validity

Validity and reliability are important criteria when it comes to evaluate the quality and trustworthiness of a study (Bryman & Bell, 2011). Validity refers to whether a research measures what is relevant and what it is supposed to measure while reliability refers to the confidence and reliability in the measurements. Reliability also refers to that the investigation had given the same answer if it was carried out again.

To strengthen the validity research questions were formulated. This helps when collecting relevant theory and data, and provides guidelines to stay inside the scope of the thesis. To create reliability all methodology used has been well documented and written down as the work progressed. Most interviews and observations were performed during attendance by the both authors which means that misinterpretations could be more easily avoided. Where assumptions and simplifications were made these are explained in the report. Estimations done by employees can be misleading but where this had to be done the information has as far as possible been cross checked with other employees.

The model is mostly based on calculated costs from reports and figures. If standard costs instead had been used in a larger extent different result would have been achieved. This would also be the case if deciding not to include investments and/or maintenance in the costs. The tied-up capital is another factor that may look different depending on the company and their model for calculating tied-up capital.

4. The model

The model has been created with a base of showing internal logistics costs, but all logistics costs have not been able to be demonstrated in the model. The main focus has been upon storage costs, packaging costs, capacity-related costs and transportation and handling costs. Administrative costs have for example not been taken into account and neither have shortage or delay costs.

The model is created in excel and has been used as a tool for the analysis. For the model to be applicable in other companies than Volvo a general picture of the model is presented not containing specific numbers, see appendix 3. The model shows the costs per detail for each activity within the flows. It also shows information regarding amount of details per package and purchasing price for each part number. The purchasing price has been used to calculate the tied-up capital for each detail which is shown in a separate column in the model.

The costs for the activities in each flow have been summarized in two columns. One column shows the cost per detail in the flow including the tied-up capital and the other column shows the cost per detail excluding the tied-up capital. The last column in the model shows, instead of the cost per detail, the total cost per year for all details with their specific part number. This sum includes the cost for tied-up capital.

4.1 Formulas

Below the formulas used in the model are presented.

$$Cost\ for\ tied\ up\ capital = \frac{Purchasing\ price * Percentage\ representing\ tied\ up\ capital * Average\ throughput\ time}{Days\ per\ year}$$

$$Storage\ cost = \frac{Time\ in\ storage * Storage\ cost\ per\ time\ unit * Fill\ rate}{Details\ per\ package}$$

$$Transportation\ cost = \frac{Time\ for\ transport * Vehicle\ cost\ per\ time\ unit * Fill\ rate}{Details\ per\ package}$$

$$Repacking\ cost = \frac{Time\ for\ repacking * Cost\ for\ labor}{Details\ per\ package} + \frac{Cost\ for\ blue\ box/pallet}{Details\ per\ blue\ box/pallet}$$

$$Labelling\ cost = \frac{Time\ for\ labelling * (Cost\ for\ employee + Cost\ per\ table^{1})}{Details\ per\ package}$$

All data needed for the calculations is found in sheets in the excel document. The sheets contain information regarding:

- costs for means of transportation, storage areas, labor and packages
- average times for activities
- annual consumption for all part numbers

[1] The cost per table consists of area cost and depreciation cost for the labelling area.

- sizes of areas in the factory
- fill-rate for means of transportation and storage areas
- package types and package costs

4.2 Applications

The model has been used as a tool to analyze the internal logistics set up. The main purpose of the model is to locate cost drivers and find new, more economically sound set ups. The calculations in the model are dependent on different variables and these can be changed to provide different results. By looking at the model the current situation can be explained and changing the variables new logistics solutions can be analyzed. Based on the model the flows can be investigated and cost drivers can be found within the different activities. The model shows which flows that are more expensive and which activities in each flow that drives the highest costs. Variables to be changed to perform the analysis are quantity per package, number of activities in the flows and number of flows. Other factors that may affect the logistics set up are also investigated.

All variables are not linked to each other in the model. One example of such variables are the throughput times that do not change when changing the package quantity. When increasing the quantity per package the throughput time should increase. This does not happen automatically and instead the time must be changed manually. When changing the package quantity, the storage time is assumed to change while the transportation time is constant. This is because the transportation time will be the same no matter how full the package is. Based on this, doubling the package quantity should lead to a twice as long storage time while the transportation time does not change. The effect on the total throughput time will be an increase of 80% since the storage times make up most of the total throughput time. If decreasing the quantity to half, the total throughput time is instead estimated to be 60% of the original throughput time. These percentages are not based on measurements but are estimated averages based on what is seen in the model.

The throughput times will also have to be overlooked when changing the number of activities in the flows. When eliminating an activity, the time for the activity can either be eliminated or it can be moved to another activity. An example of this is eliminating the activity of storage in the satellite area. The storage time for this activity will have to manually be moved to another storage area within the flow. This will affect the storage time and the level of inventory in this storage. This extra inventory may not be necessary but to lower the level of inventory deliveries from the supplier have to be investigated. Deleting the labelling activity on the other hand and assuming that the activity will be moved to the supplier, the time could be eliminated. Both moving and eliminating storage times will result in a decreased number of transports within the flow.

Just as when changing the number of activities in the flows, the throughput time must be taken into consideration when changing the number of material flows. The storage times are assumed to be specific for each part number and do not change when putting the part number in a different flow. This is the case for all storage times except for the time by the assembly line. This time has been adapted to be representable for the amount of details in the package if the type of package is changed. This is based on keeping the annual consumption constant for the specific part number. The transportations on the other hand will change to the new flow's transportation times if the distances or transportation types are different between the flows.

The model can be used not only to adjust the variables in the flows, but also to change the area costs. In area costs all storage costs, transportation costs and labor costs are included. By investigating area costs it is possible to understand how sensitive they may be and how much they affect the activity costs. The sensitivity analysis can be performed by decreasing and increasing depreciation costs in each area since these are the easiest costs to control. The area costs are also dependent on the level of fill-rate which can be changed and analyzed with base in the model.

As the study has been made at Volvo their model for calculating tied-up capital has been used. The tied-up capital does not take value-adding processes into account and is only looking at the throughput time and the purchasing price as variables. This means that the value added will be the same weather the part numbers lie in storage or are handled. Changing the percentage is easy but calculating tied-up capital in any other way requires adjustment of the model.

5. Flow analysis

Once the model has been structured an analysis of the material flows can be performed. The analysis has goals to question the flows lay out and point to the cost drivers that raise the total cost. By looking at the costs of the flows today and then changing variables these goals can be targeted.

The model is built upon costs of how the material flow is set up today both including and excluding tied-up capital. It is seen that the tied-up capital is a major cost driver where a high purchasing price and a long throughput time affects the total cost for the flow. As tied-up capital is such a large cost driver the analysis will mainly focus on the total cost for all activities in the flows without regard to tied-up capital. Analyzing costs this way makes the focus lie on the flow and not on the part number in the same extent. As the purchasing price differs for part numbers within the same flow the tied-up capital will not be representable for the flow itself.

5.1 Current costs

Based on the model it is clear that the cost for transportation is generally higher than the cost for storage. Transportation costs also differ depending on the vehicle. The automated transportation system EHB, located in the ceiling in the factory, is by far the cheapest means of transport but it is very limited to only handle transports in and out of the high bay storage. Investment levels in the EHB are relatively low since the automated system is at the end of its depreciation cycle. Comparing the hourly rate for the EHB to other means of transport, Volvo could add depreciation costs of over 60 million SEK per year and it would still be the cheapest means of transport in the factory. The capacity of the different means of transport has not been included in this calculation since different vehicles transport different types of packages. Looking at the less automated transportation alternatives, the trains have a cheaper hourly rate than the forklifts. This is based on the forklifts only transporting one pallet at the time. The difference in price becomes more distinct as most trains can load more parts at once, lowering the cost per part additionally. Looking at storage areas the main differences in costs are caused by the amount of investments made in each area and the number of places for packages. Large depreciation costs result in a higher area cost to divide upon the parts in that area. Where few parts can be stored or handled at once the cost is higher than it is in an area where many parts can be stored or handled. Examples of these more expensive areas are the gravitation conveyor, picking area and labelling area.

Another cost that appears in the picking area and in the labelling area is the direct cost for labor. The flows passing through these areas are in general more expensive than similar flows not passing through these areas. In some flows the part numbers passing through the picking area are being repacked into smaller packages. When details are repacked into a different package a cost for the new box or pallet is added to the details. This extra cost includes handling, washing and storage of the boxes while not being in use. The cost becomes large as it only applies to the few details being placed inside the new box or pallet.

In the model, it appears that it is less expensive to store parts in the high bay storage than it is to store them in the supermarket or in the sequence area. This is not only because of the large amount of parts that can be stored in the high bay storage, but costs for labor can be kept very low since it is primarily managed by computer systems. The high bay storage is a smart storage solution where essentially no packages are blocking the accessibility to other packages. In the high bay storage the packages are placed where space is available without regard to whether the part is frequently used or not. Although large investments have been made in the high bay storage and maintenance costs are high, the high bay storage still appears to be economically beneficial. It is on the contrary less expensive to store parts in the pipe shop storage and the satellite buffer than it is in the high bay storage. This may be due to that these buffer locations are not burdened with any depreciation costs since these investments are already written off. The cost for storage is also less by the assembly line than in the high bay storage. This mainly depends on that no investments have been taken into account regarding the assembly line.

Many throughput times depend on the type of package and not as much on the type of detail. The time in the high bay storage is one storage time that does depend on the part number and foremost the supplier. Different suppliers have different number of pick-up occasions and also different delivery times. The cost in the high bay storage is relatively small and therefore a storage time of days or a few weeks does not make a big difference when looking at the cost for the material flow. On the other hand, different storage times will affect the tied-up capital and the decision of suppliers is therefore an important aspect. Changing suppliers has not been looked into as this is not part of the internal logistics.

The cheapest flow shown in the model is *low volume cardboard boxes*. The most apparent explanation for this flow being the cheapest one is that the number of details per pallet and per box is high. The cost for each activity will therefore be divided upon more details. But if changing the quantity per pallet and per box in the flow it will still be the cheapest one compared to flows with alike quantities. This means that there are more reasons for this flow being low in costs. One activity that is cheaper for this flow than for others is the cost for repacking. This depends on the part being delivered to the factory in boxes making it easy to repack and making the process quick. The part neither has to be packed into a new package, where the new package would add an extra cost, but is only picked out of the pallet. The part also has a short storage time in the supermarket making this activity cheap as well. The flow is not only considered to be the cheapest one, but it also has the longest throughput time. Having more details in one package or batch will result in a long throughput time. A long throughput time generates a high tied-up capital, but this does not affect the total cost of the flow much as the detail is relatively cheap. Another reason for this part having a long throughput time is that it is classified as a C part.

Something that could have been expected is that the flows going through the most activities would be the more expensive ones. However, this is not a conclusion to be drawn from the model. No connection can be seen between higher costs and several activities in the flow. The most expensive flow, *repacked mid volume*, are going through the exact same number of activities as the cheapest one, *low volume cardboard boxes*. Neither can a connection be found between flows with long throughput times and high costs. What does seem to matter is what activities the part number goes through together with the number of details in one package. On the other hand, more activities result in more cost centers and reducing the number of activities can therefore reduce total costs.

Looking at the total throughput times for all flows, these vary from four hours up to 21 days. The throughput time has a large impact on the tied-up capital but the purchasing price also matters. The throughput time and the tied-up capital has a 1:1 ratio, doubling one factor will lead to a duplication of the other the same ratio applies to the purchasing price and the tied-up capital. It can be recommended to focus on decreasing the throughput time for the part numbers with higher purchasing price to keep the tied-up capital relatively low. A longer throughput time will result in a higher capital cost for a detail with a high purchasing price than for a detail with a low purchasing price.

Most of the throughput time is located in the beginning of the flows, mostly in the high bay storage. As this is the central storage of the factory longer throughput times here are planned for. Out of the four flows with the longest throughput times, three of the flow's part numbers are classified as C parts by the external material handling department. As this means the parts are of low volume and less expensive they can be stored longer in the factory than A and B parts. The fourth part number with a long throughput time is not a C part but a part that is classified as B. The reason for this part having a long throughput time is that Volvo has had problems with the deliveries from the supplier. Most of the throughput time is as mentioned storage time and the long throughput time rather depends on the part number and the supplier's delivery days than the flow itself. Therefore it cannot be said that an A part in one of the flows with a long throughput time would not still have a short throughput time.

5.2 Changing quantity

Changing the quantity refers to changing the amount of details in one package. The package can be either a pallet, a blue box, a cardboard box or a pick. Changing the quantity per package and assuming the consumption to be constant the throughput time will be affected. This is not shown in the model since throughput times are not connected to the quantity but they are still important to take into account. When doing calculations below the storage times have been changed manually, as explained in chapter 4.2, to apply for the new batch size.

The flows containing both pallets and boxes have been investigated to show differences when changing quantity. First, the quantity of the boxes has been varied meanwhile the quantity of the pallets has been held constant. It is considered easier to change the quantity of the boxes than of the pallets since the boxes mostly are packed within the factory. The pallets on the other hand are packed by the suppliers and the number of details is not as easy to change. By increasing the quantity in a pallet or a box, the transportation cost per detail decreases as the transportation cost will be split over more details. Since the cost for repacking into blue boxes is a big part of the total cost per year, this cost can be decreased by adding more details in each box. Storage times will on the other hand increase but since the storage costs are divided upon more details the cost will not change much. Consideration must here be taken to the maximum weight of a blue box which is twelve kilograms. Going the other direction and decreasing the number of details in a box will increase the total cost of the activities in a flow. The transports will be more costly per detail while the storage costs stay the same. By keeping the quantity of the blue boxes constant and instead changing the quantity of the pallets, a similar conclusion as above can be drawn - the transportation cost will be decreased when increasing the quantity and the other way around.

When choosing to change quantity per pallet or per box it is relevant to look at the total cost of transportation for each package together with the current number of details in the package. If the cost for all transportations in a pallet is higher than the cost for all transportations in a box, the pallet quantity should be changed. On the other hand, the factor regarding the number of details in each package needs to be taken into account. The fewer details in a package when changing the quantity, the greater difference in cost per detail. It is important to consider both aspects before deciding which package quantity to change to make the largest impact. Note that this implies when changing the quantity with the same percentage. A limitation worth considering when increasing the quantity is the storage time by the assembly line which currently is set to be two hours. This means that the quantity per package must be used within two hours. If increasing the quantity too much, the limitation of the storage time by the assembly line may be exceeded.

By changing the quantity, the total throughput time will change leading to either a higher or a lower cost for tied-up capital. It is seen that increasing the quantity for both pallets and boxes will reduce the cost for the flow excluding tied-up capital. Doubling the package quantities will show a cost reduction of up to 50% in the model. If instead dividing the quantity into half of the original quantity the cost without regard to the tied-up capital will increase with up to 120%. When instead looking at total costs including tied-up capital the effects will be the opposite in both cases. Doubling the quantity will result in a higher total cost, up to 75% higher than it is today. Decreasing the quantity to half of the original quantity will result in a cost of up to 36% lower than today. It has not been analyzed whether more labor will be needed in the material handling as the number of boxes increases if decreasing the box quantity. Neither has regard been taken to reducing the number of employees when increasing the quantity. Depending on looking at the problem with or without tied-up capital the result will vary as the costs for the activities and the cost for the tied-up capital are affecting the total cost in different directions.

Having less details in each package will not only be cheaper including tied-up capital, but shorter throughput times also lead to a reduction of waste in the factory and higher service quality towards the customer. The customer for the internal logistics department is the assembly line and high service quality is shown by having the right amount of details by the line at all times. If this can be achieved less rework is needed and overproduction can more easily be avoided. It is important to understand that smaller batch sizes in the material flow is not what controls overproduction in first hand as the speed for manufacturing should be set to avoid this by the assembly department. Smaller batches are also a way to simplify JIT production as JIT implies receiving what you need when you need it.

For some part numbers that are repacked, the quantity per box or per pick does not break even with the quantity per pallet. One example is the part number that goes through the flow *hanging low volume*, where each pallet contains 48 details and each blue box contains 10 details. This causes transportation with an almost empty pallet going back and forth to the high bay storage once in a while. A complication of this, two pallets must occasionally go down to result in a full pick. For this part number a pick of twelve details would eliminate the problem and transportation costs could be saved.

5.3 Changing the number of activities in the flows

When looking at the model it is seen that some flows consist of many activities. To decrease the complexity of the material flows one part of the analysis is to reduce the number of activities in the flows. Not all flows will be going through this part of the analysis as not all flows are considered to be able to be simplified. Focus will instead lie on the flows being longer and more complex as more activities imply more cost centers. By reducing the number of activities it is easier to achieve standardization which can reduce the complexity and the costs.

The first flows to be looked at are the ones going through labelling. Both the flows *mid volume from supermarket* and *high volume from supermarket* are being labelled. If the suppliers would be responsible for delivering the parts with the right label this activity could be eliminated. If the activity would be removed, the costs for the transportations to and from labelling would also be removed as these transports are no longer needed, see figure 4. To calculate the potential save, the costs of the three activities were summarized. If looking at the two analyzed part numbers going through these flows the savings vary between the flows. The model shows that Volvo would save up to 33% per detail on removing these activities in the flow *high volume from supermarket* e.g. There are many pallets passing through labelling each day and all will be affected by this change. The analysis has not taken into account the cost for having the suppliers putting the right label on the package from the beginning. For Volvo to consider the suggestion on removing the labelling, the cost from the suppliers must be less than the money saved.

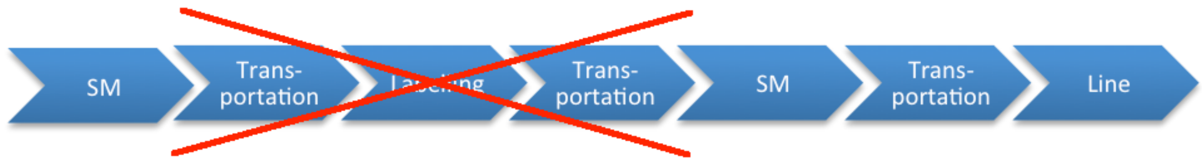


Figure 4 Activities that can be removed if having the suppliers label the packages.

Another flow with parts that are labelled in the factory is the *pipe shop flow*. Since these parts are manufactured internally the activity of labelling is unavoidable. Either labelling occurs during packaging to blue boxes or it occurs when the boxes are moved from the pipe shop storage to the pipe shop buffer as it does today. Pushing the cost backwards upon the pipe shop will not make a difference on the total cost for the company.

Second, one of the flows that are repacked from a pallet to blue boxes is investigated. The *repacked mid volume flow* is one of the more costly ones and most of the cost arises from changing the package. The details are repacked into blue boxes which add an extra cost per box. Repacking one pallet for this part number results in 45 blue boxes. The extra cost for the box is 13,1% of the detail's total cost. These 13,1% could be saved for the internal logistics department if looking at the option of having the supplier deliver parts in the right package. This is only the cost for the boxes and eliminating the work for repacking as well would result in a save of 51,8% of the flow's total cost. Assuming that labelling can be done by the supplier neither this would have to be done in the factory. Having the suppliers label the part numbers would reduce the costs for the internal logistics department. The flow could after these changes still look as it does today but the work load in the picking area would decrease along with the costs. Another alternative if having parts arrive in the right packages with the right labels is to have the part numbers go in a flow through the supermarket.

One activity that could be simplified is one that is only found in the *hanging low volume flow*. The parts are being repacked in the picking area and then taken to a rack outside the picking area for pick-up by train. This rack is placed approximately 20-40m away from where the repacking is taking place depending on which station in the picking area being used, see figure 5. Instead of moving the repacked parts to this rack they could be placed on a surface next to the picking station in the picking area waiting to be transported. This surface is being used for blue boxes and cardboard boxes that has been repacked and the hanging parts may also be placed here. Changing the pick-up location would shorten the time through repacking but it would also require a different vehicle for the transport, a forklift instead of a train. As a forklift is more expensive than a train this change would not affect the costs very much, but it would eliminate activities that are specific for this flow and instead use more standardized paths through the factory.

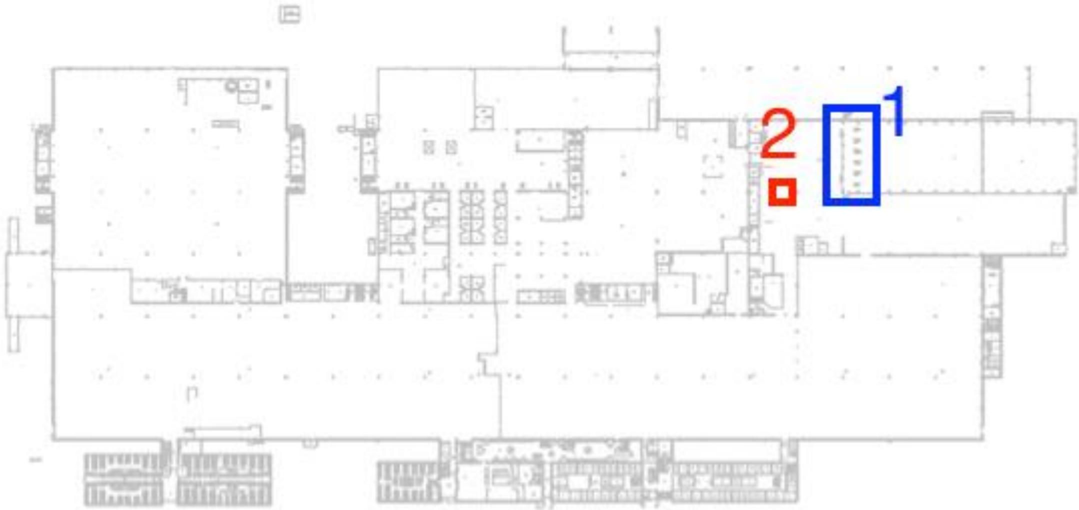


Figure 5 Map of 1. The picking area and 2. The pick-up rack outside the picking area.

Both the flows *mid volume from supermarket* and *high volume from supermarket* are going through the activities shown in figure 6 below. These activities include receiving the goods in the goods reception, transportation of the goods through the inbound to the outside area and storage time in this area. By instead delivering the part numbers directly to the inbound in the supermarket the three first activities in this flow can be removed. When eliminating these activities an assumption is made that the transport from the outside area to the pallet place in supermarket will be approximately as costly as the transport from the inbound in supermarket to the pallet place. This leads to a save 18% for the *high volume flow*. The total cost of the *mid volume flow* is much larger and the cost for these three activities does only stand for 2,5% of this flow's total cost. Up to 1,5 hours could be saved on the throughput time per part in the flow *mid volume from supermarket* and in the flow *high volume from supermarket* almost one hour could be saved. Shorter throughput time results in lower tied-up capital costs, this cost could be reduce by up to 1,6% per part.

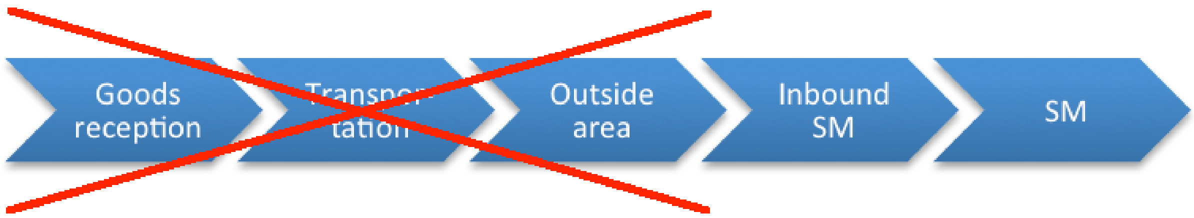


Figure 6 First activities of the flows mid/high volume from supermarket.

When eliminating activities in a flow the throughput time for other activities may increase as handling or storage time is transferred. Looking at the flow *pallet through sequence area* there are three different storage areas before the part is transported to line. The first storage is the high bay storage followed by the satellite buffer and the sequence area, see figure 7. If removing the storage time in the satellite buffer, this time will instead be moved to the high bay storage or to the sequence area. As there is very limited space in the sequence area most of the storage time is likely to end up in the high bay storage. Removing the satellite buffer from the flow will also eliminate the transport between the satellite buffer and the sequence area. As these areas are located very close to each other the transportation time from the drop station to the satellite buffer is considered to be equal to the time from drop station to the sequence area. Doing a calculation on removing the satellite buffer from the flow would save 17% of the flow's total cost. As the transport from the high bay storage including forklift/train transport from the drop station can take up to one hour this means that for parts to go directly to the sequence area they need to have an annual consumption of less than 115 500[2] details per year. For the investigated part number, the annual consumption is lower than this which implies that this change is possible.

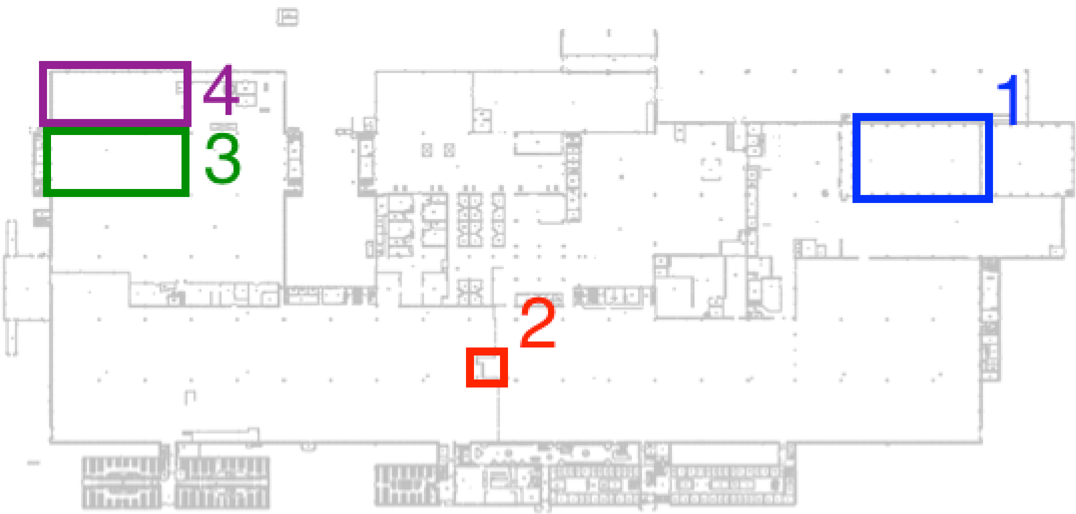


Figure 7 Map of 1. The high bay storage 2. Drop station three 3. Satellite buffer and 4. The sequence area.

5.4 Changing the number of material flows

There are no clear guidelines when placing part numbers in their specific flow. Primarily, the parts are placed in different flows depending on the annual consumption. Some part numbers have other characteristics as well and may fit into more than one material flow. Which flow they end up in may be a result of how many part numbers are in the flow at the moment and where capacity is available. In what flow the parts are placed could have a great impact on the costs. In this part of the analysis part numbers have been moved from one flow to another in order to reduce the complexity of the flow set up and find a more economically sound set up.

When having calculated the transportation costs it is as mentioned clear that the cost for the train is less than the cost for forklift. The model shows that comparing a forklift transport to a pallet train transport the cost will be 12% less if choosing the train. The part number in the flow *pallet with forklift without buffer* was investigated and the total saving of having the pallet transported with train instead of with forklift could be 6,2% for the flow. This calculation has been made with no regard to that the pallet train transport may take longer than the forklift transport as more pallets have to be loaded and unloaded from the train. The study does shows that a train transport can take more than double the time of a forklift transport to still be a cheaper alternative.

[2] Considering the time for delivery, the maximum consumption per hour is 30 details.

If using the train transport instead of the forklift transport for the flow *pallet with forklift without buffer* this flow would look exactly as the flow *pallet with train without buffer*, see figure 8. Except from making the existing flow cheaper, changing means of transport will make the two flows look exactly alike. Having one flow instead of two will reduce the complexity of the material flows and increase the standardization. Having more transports going by train could also increase the fill-rate of the trains. The same change could be done to the flow *pallet with forklift with buffer*, see figure 9. Changing the means of transport here would be merging it together with the flow *pallet with train with buffer*. The save for this change would be about the same as for the flow *pallet with forklift without buffer*.

Figure 8 The activities in the flows pallet with forklift without buffer and pallet with train without buffer.

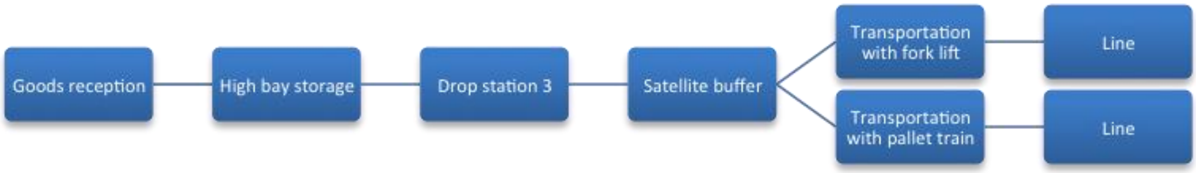


Figure 9 The activities in the flows pallet with forklift with buffer and pallet with train with buffer

When considering to use the pallet trains in a larger degree the inflexibility of the vehicle must be taken into account. The forklift can pick up and leave off packages at most places in the factory while the pallet train needs either a pick-up location or a forklift loading the packages. Today there are one pick-up location within the assembly factory but this may not be sufficient if expanding the transportation system of the pallet trains. The money saved on changing means of transport may be needed for investing in making the pallet trains more flexible.

Even though flows or parts in the flows do not look alike it may still be possible to join flows together. It is tried taking the part number in the flow *repacked mid volume* and instead of repacking the parts placing them in the flow *pallet with train without buffer*[3], see figure 10. This would not only eliminate the repacking but also the storage time in supermarket and the transport in between. The repacking is known to be costly and changing the flow for the investigated part number this way could theoretically save 99% of the flow's cost. Instead of the part number in the *repacked mid volume flow* being the most expensive one it is now the second cheapest. Doing the same thing to the part number in the flow *high volume labelled from supplier* will result in a save of 74%, this flow is also seen in figure 10. As this flow was not very high in cost before the change it implies that there are costs to save in using the high bay storage instead of the supermarket and keeping the pallets throughout the flow. The calculation is based on the throughput times in the flow *pallet with train without buffer* for the activities that are changed. The storage time in supermarket has been added to the storage time in the high bay storage and the time by the assembly line has also been recalculated as

[3] Based on the parts being categorized as mid volume with an annual consumption of 3 000 details no buffer is considered to be necessary.

the number of details per pallet will last longer than the details in the box did. The time by the assembly line does now exceed the time limit of two hours and the pallet will also take up a larger space than what the blue boxes did. Exceeding the time limit should be discussed with the assembly department.

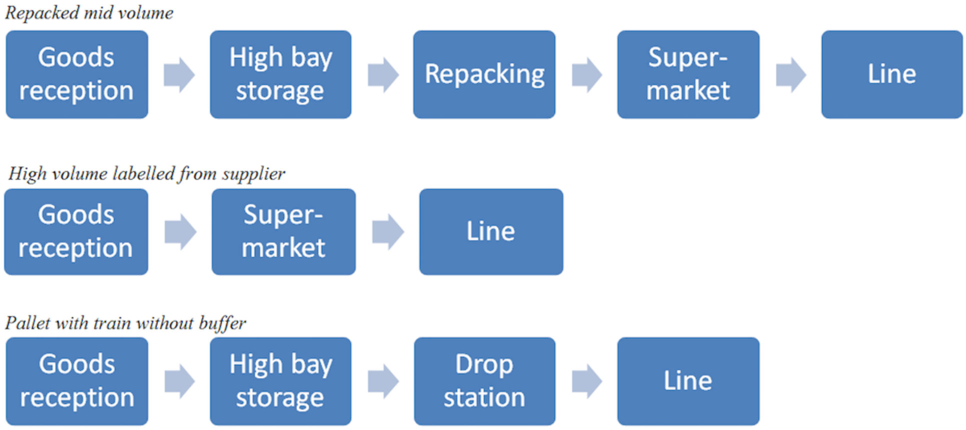


Figure 10 The two first flows are suggested to be places in the third flow.

Another suggestion on a flow that perhaps could be merged together with another one is the flow *pallet through sequence area*. This flow starts by going through the high bay storage as most flows do. After that the pallet is taken to the satellite buffer and the sequence area before being transported to the assembly line. The investigation has been to put this part number in the flow *pallet with train with buffer*. The part number's annual consumption is high and therefore a flow containing a buffer was chosen. By placing the part in the new flow the total cost will be 56% lower than before. The part will now need to be delivered to the kitting station by the assembly line to be kitted instead of being placed by the assembly line on the sequence train. The cost for kitting is not included in the cost reduction. The need for kitting this part number emerges as it has to be emptied of oil before assemblage. Emptying the detail of oil is done by placing it upside down, preferable on the kitting station. This was previously done in the sequence area. Before this type of change is implemented it has to be checked whether the pallets for the part numbers it involves can be placed by their respective kitting station. See changes in figure 11.

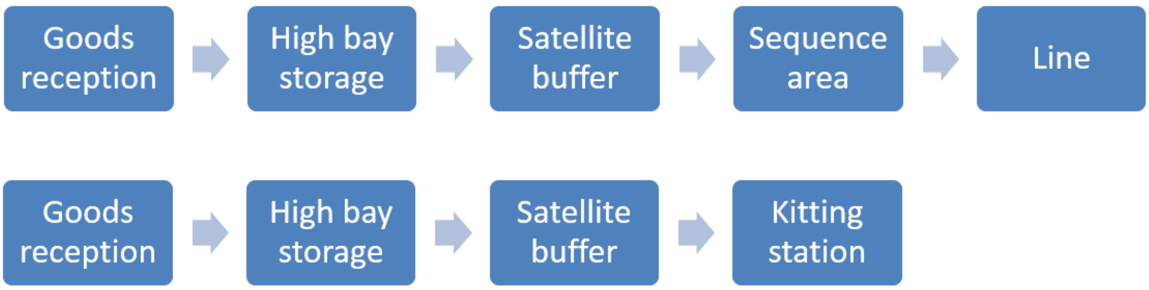


Figure 11 The flow before and after the change.

5.5 Other factors

In addition to the variables analyzed above, there are other factors that will have an impact on the cost drivers. Some of these factors are not shown in the model but are potential problem areas that have been seen when performing the study and will therefore be investigated further.

One finding is that there are several departments contributing to the fact that the material flow is built the way it is and pitfalls have been identified between departments. One reason behind this study is that the assembly department has changed the assembly set up without taking too much consideration into how this affects the internal logistics. Already here, there is a defect in the internal supply chain as the departments do not seem to have agreed on what is best for increasing total efficiency within the company. It has also been found that new part numbers are purchased without the material preparators knowing where to place them in the material flows. Parts are placed in a flow without clear guidelines on what the characteristics are for the parts in each flow and what sets the flows apart.

Part numbers can quickly change consumption volume, e.g. from being a mid volume detail to becoming a high volume detail. This affects in which flow the part number should be placed. It is important to have someone working with moving part numbers to the right flow when such changes in volume occur. If a high volume detail is placed in a low volume flow, for example in the *hanging low volume*, one effect will be shorter intervals between transportations up and down to the picking area. This may be a problem if there are queues delaying the transportation. It will also increase the number of forklift transports in the picking area. Though, some flows are suitable for all types of volumes.

A factor that affects the transportation costs is the fill-rates. If first looking at the pallet trains, the cost for these will be 15% less per pallet per hour if the train would be full every time instead of the fill-rate of today which has been estimated to be 85%. If doing the same test with the train for blue boxes, increasing the fill-rate to 21 part numbers per transport instead of 18 the save would be 14% per blue box. For the train transporting hanging parts it would be 37,5% cheaper having a 100% filling degree compared to today's 62,5%. A conclusion is that it is more beneficial to try to increase the fill-rate where there are few part numbers that can be transported at the same time. The fill-rates for both the pallet train and the train for hanging details were increased from 85% to 100% and the difference in cost is clearly greater for the pallet train, which contains fewer places for pallets.

Even though the internal perspective of a part's supply chain is very small it is important to make the manufacturing efficient. Efficient manufacturing is reached by having involved departments understand each other's processes and work together toward a shared goal. At Volvo there are different opinions on how to develop the manufacturing to become more efficient which leads to conflicts between departments. To solve this problem, departments within Volvo have to see the strengths of working together and sharing information with each other. If the departments together decide they want to decrease the batch sizes it is important that all departments understand what the effects will be within each department. Decreasing the batches may be positive for the assembly department but for the internal logistics to make this cost efficient, investments have to be made to improve the repacking. By working together it is possible to see the common best for the company and the overall performance can improve.

For some areas there have been large investments made contributing to a higher area cost. One area that is expensive per square meter is the gravitation conveyor. This area cost constitutes to 81% of depreciation costs, which means that once the investments are depreciated the area cost will decrease with this percentage. The total cost for the flow will not decrease more than 3,7% as the largest part of the total cost arises in the transport from the gravitation conveyor to the assembly line. Another area with large depreciation costs is the high bay storage. Here 48% of the area cost is caused by investments. Having less depreciation costs here would result in a lower area cost, but as the cost for keeping parts in the high bay storage is low already this would make a small cost reduction. Comparing the total cost for all flows with and without investments in the high bay storage the cost difference is 2,4%.

In some cases, the parts are not delivered to the drop station that is geographically closest to the next activity in the flow. This applies to the two flows, *pallet with forklift with buffer* and *pallet with train with buffer*, where the packages are delivered to drop station three. Instead, drop station five would be a better alternative since this is placed closer to the sequence area which is the next location the part number will be delivered to, see figure 12. If changing drop station the transportation distance becomes longer for the EHB but shorter for the forklift, since the EHB is the cheaper option this will in the long run result in economic benefits. It should also be taken into account that the different vehicles take different amount of time, but this is assumed to have such minimal affect that it will not make any great difference.

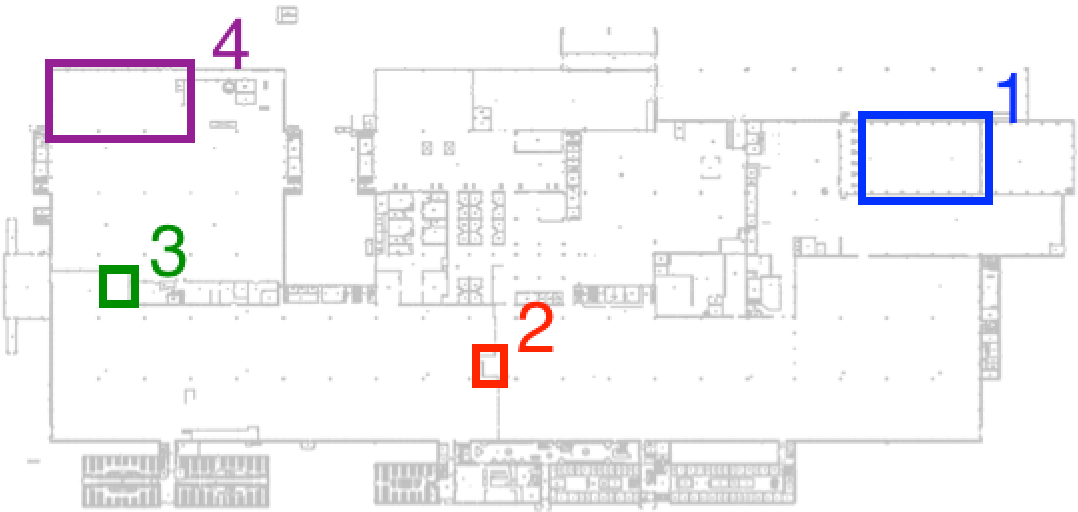


Figure 12 Map of 1. The high bay storage 2. Drop station three 3. Drop station five and 4. The sequence area.

Two of the investigated flows, *repacked mid volume* and *repacked high volume*, are today repacked into a blue box called 750, see figure 13. This box has a cheaper transaction cost than the box called 780, but the degree of filling is 57% less according to the Volvo logistics department. This means that the filling degree could be higher if using the larger 780 box. If instead repacking the details in these flows into 780 boxes, a cost reduction of up to 46% could be made for this activity. Investigation has also been carried out regarding whether it would be cheaper to repack the parts into 800, 840 or 460 boxes. However, it was found that this would generate higher costs. No further investigation has been made regarding if larger boxes could be handled in the following activities in the flows.

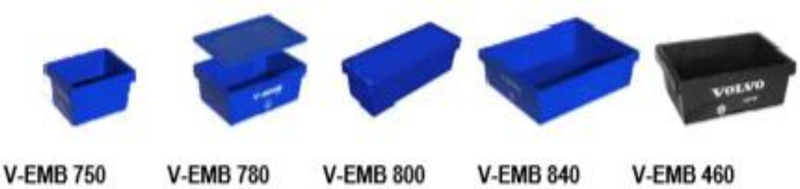


Figure 13 Different sized blue boxes.

6. Discussion

In summary there are a few conclusions to be drawn from the analysis. One of them is that it is more beneficial to transport parts with train than it is with forklift. This is based on the lower hourly rate and the higher capacity in parts per transport. Reducing the forklift transports and replacing these with train transports would result in not only economic benefits, but also flows being merged together. Fewer flows in the factory will lead to a more standardized material flow set up. Other factors that will affect the transportation costs are the package quantity and the fill-rate. By increasing the quantity and fill-rate in a package the transportation cost will be reduced. Looking at the total cost of the flow when increasing the quantity this will instead be higher than before, mostly consisting of the cost for tied-up capital. It is therefore more desirable to decrease the package quantity, leading to reduced total costs, shorter throughput times and higher service quality.

The internal logistics is a small part of the full supply chain. Making changes within the internal logistics can result in economic benefits for the internal logistics department, but these changes may on the other hand not be beneficial when looking at the full supply chain. An example of this is the changes in quantity discussed above. Decreasing the quantity is shown to lower the costs from an internal perspective if including the tied-up capital, but doing this may drive other costs outside of the factory. Example of such a cost is empty packages being transported to make a full order. If looking at the full supply chain, the total cost constitutes to a large part of transportation outside of the factory. If going through with decreasing the quantity, the costs that could be saved on the tied-up capital should be higher than the increased cost for transportations throughout the supply chain. The conclusion is that an internal perspective is not sufficient to base lucrative decisions but the full supply chain has to be taken into account.

By increasing the fill-rate in the vehicles it is possible to lower the transportation cost per part number. In the analysis the fill-rate has been increased to 100% for the different means of transport. This may not be reasonable as empty seats will always occur, though a better coordinated transportation system could help reduce empty seats and so increase the fill-rate. Reducing forklift transports by merging flows together could also lead to higher fill-rates for the trains. Coordinating flows, merging flows together and eliminating activities will all be part of decreasing the total number of transports and increasing the fill-rate, thus leading to less vehicles needed in the factory. Fewer vehicles in the factory would be beneficial from a sustainability perspective. These changes would affect the factory positively as fewer vehicles in the factory would result in waste reduction and could also lead to a safer and a less noisy environment for the employees.

Another suggestion that would result in economic benefits is looking at receiving the right label on the packages from the suppliers. This could result in a cost saving of up to 33% per detail for the internal logistics department. The change will reduce the number of activities in the flows it applies to, also contributing to shorter throughput times and a less complex material flow set up. Shorter throughput times would lead to lower tied-up capital and therefore a lower total cost for the flows. As seen in the analysis, the effect is greater when shortening the throughput times for part numbers with a high purchasing price.

An important aspect to consider when making changes in the material flows is the ethical one. By eliminating the labelling station the employees are affected as those who are working here would not be needed. The transports to and from the labelling area would also be eliminated, affecting the employees working with transportation. It is important to try to reallocate the employees instead of dismissing them to avoid bad atmosphere at work. It is also important to show that improvements in the factory does not necessarily lead to dismissal of employees.

Today there are no specific guidelines regarding how to place parts into material flows. Guidelines would make sure that parts will not drive unnecessary costs. The idea of placing a part number in a specific flow is to keep the total cost low and making sure to deliver the part numbers just-in-time. For every flow there should be clear definitions of what characterizes the parts being placed here. A part matrix could be developed to help the material preparators use a standard when placing part numbers into its specific flow. Volvo already has a form of part matrix but this has to be updated and used in a wider extent. The matrix should be based on factors such as annual consumption, type of package, ABC classification, diversity of parts and where in the factory the details are supposed to be delivered to. New part numbers can be added to the matrix while others can be deleted if no longer part of the production. The factors characterizing a part can change over time and it is therefore important to always keep the information updated to make sure right part number is placed in the right flow.

An assumption made in the report is that the 17 investigated part numbers give a fair view of the flows in the factory. If other part numbers would have been chosen to represent the flows, would the result have been different? Yes, depending on which part numbers to investigate, the result may be different. All part numbers in one flow should have alike characteristics and they go through the same activities. What may differ between the part numbers is the annual consumption, purchasing price and quantity per package. This variance has been attempted to be removed where possible by excluding the tied-up capital in most of the analysis. Sensitivity analysis has also been carried out regarding the impact of quantity per package. As the study has progressed it has been found that there may be more than 17 flows. These additional flows have not been investigated but should be included if further investigation is to be conducted.

The initial phase of the study was gathering data about the current situation in the factory. This was done through the internal data systems, through interviews and through time studies. The data gathered through MACS and NTRP has been noticed to vary for similar parts and may therefore not be as trustworthy as expected. If executing the study again it can be recommended to use time studies in a larger extent. Where data has been missing and time studies seemed difficult estimations have been made. These estimations are based on the current situation in the factory and if the study was carried out in a different time period the result may have been different. Data collected from interviews should not be very different if other employees had been interviewed as the information have been cross checked. Most data collected, both from estimations based on studies and from interviews, have been discussed with other employees to make sure to give a fair view of the situation.

In most of the changes done in the analysis no regard has been taken to the time limit at the assembly line. This time limit is set to be two hours by the assembly department, but when changing different factors in the model this limit has sometimes been exceeded. The storage costs by the assembly line may also be incorrect as no investments have been included and the calculated activity cost could therefore be misleading. In the model, it is shown that the area cost by the assembly line is very low which implies that storing parts here could be cost efficient. If doing further research for the study, it would be recommended to use correct costs for this area. It is also recommended to investigate the time for storage by the assembly line further and question the time limit. The study should involve the assembly department for this to give a fair result.

Costs are very dependent on investments. Depending on whether large investments have been recently made or if the costs for a specific investment have been depreciated, the cost will differ widely. The supermarket area has within recent years been restructured leading to a high area cost, see figure 14. Performing this study in the future will imply different area costs and therefore a different result. The cost should regularly be updated to make sure an as correct model as possible is presented. This goes for all other costs used in the model as well.

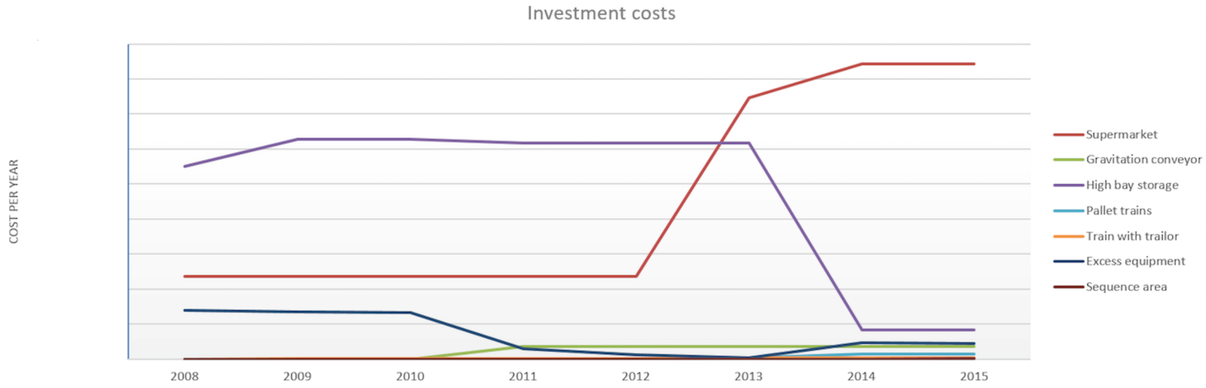


Figure 14 Depreciation costs over the last eight years.

Although parts in different flows are going the same distances in the EHB, the transports can take different amount of time. The transportation time is not due to in which flow the part is placed but rather depends on where in the high bay storage it is located. Another factor that affects the EHB transport is if parts have to queue in and out of the high bay storage. The model is based on measuring times for specific part numbers representing the different flows, causing time differences. It can differ up to 29 minutes for the transports in the model even if a part goes between the same activities. Instead of measuring the transportation time for all part numbers it may be fairer to calculate an average representing all EHB transports between the same locations and apply to all flows.

The model, as it is presented in the report, is considered to be applicable at other companies than Volvo. The costs and the activities can be changed to apply to new situations and calculations can be made from the formulas described. All data regarding throughput times is specific for the assembly factory at Volvo in Skövde and this part of the study will have to be remade for other locations. The result of the analysis is also specific for this factory and cannot be directly applied to any other factory without further investigation.

Some of the changes suggested in the analysis may be easier to implement than others. An example of such is to change the picking quantity when repacking part numbers. What can be done here is to make sure that the number of details in a pallet break even with the number of boxes that are repacked or the number of details in a pick. Eliminating the activity in the picking area in the flow *hanging low volume* is another change which is considered to be of the simpler kind. These changes neither requires large financial investments or a great work load and are therefore recommended to start with. The changes are also small and are not assumed to take much time for employees to learn. Changes that require larger investments and are more time consuming should be analyzed from a wider perspective. These changes are often the ones making the greatest impact. One such change is replacing forklift transports with train transports. Other large changes include letting the suppliers label all parts and removing material flows. These changes result in major alterations and to make sure they are economically beneficial all activities in the supply chain must be taken into account.

Further investigations regarding means of transport and guidelines on how to place part numbers into specific flows should involve more part numbers. Based on more part numbers an even more correct picture of the material flows can be established helping to perform more accurate calculations. From these calculations the changes recommended could be more deeply investigated. Focus of these further investigations should be the effects of changing the means of transport and what characterizes each material flow. Once characteristics for each flow have been identified it is possible to review that all part numbers are placed in the most suitable material flow. The characteristics will also enable a more abstract analysis where it is possible to see alternative flows for each part number. The changes discussed above are recommendations based on the analysis and it is important to take into account the limitations of the thesis. As the internal logistics is only a small part of the internal perspective it is an even smaller part of the total supply chain. This is important to keep in mind when considering which changes to implement and which to analyze further.

References

Ax, C., Johansson, C., Kullvén, H. (2009). Den nya ekonomistyrningen. Stockholm: Liber AB.

Bloomberg, D. J., LeMay, S. A., & Hanna, J. B. (2002). Logistics. Upper Saddle River, N.J: Prentice Hall.

Bryman, A., Bell, E. (2011). Business research methods. Oxford: Oxford Univ. Press.

Coyle, J. J., Langley, C. J., & Bardi, E. J. (2003). The management of business logistics: A supply chain perspective (7.th ed.). Cincinnati, Ohio: South-Western/Thomson Learning.

Harrison, A., Hoek, R. I. v. (2008). Logistics management and strategy: Competing through the supply chain (3.th ed.). Harlow: FT Prentice Hall.

Jonsson, P (2008). Logistics and Supply Chain Management. Maidenhead: McGraw-Hill Education

Jonsson, P., Mattsson, S. (2011). Logistik: Läran om effektiva materialflöden Studentlitteratur, Lund.

Lumsden, K. (2012). Logistikens grunder (3.,[utök. och uppdaterade] uppl. ed.). Lund: Studentlitteratur.

Nationalencyklopedin, logistik. http://www.ne.se/uppslagsverk/encyklopedi/lång/logistik (hämtad 2016-04-06)

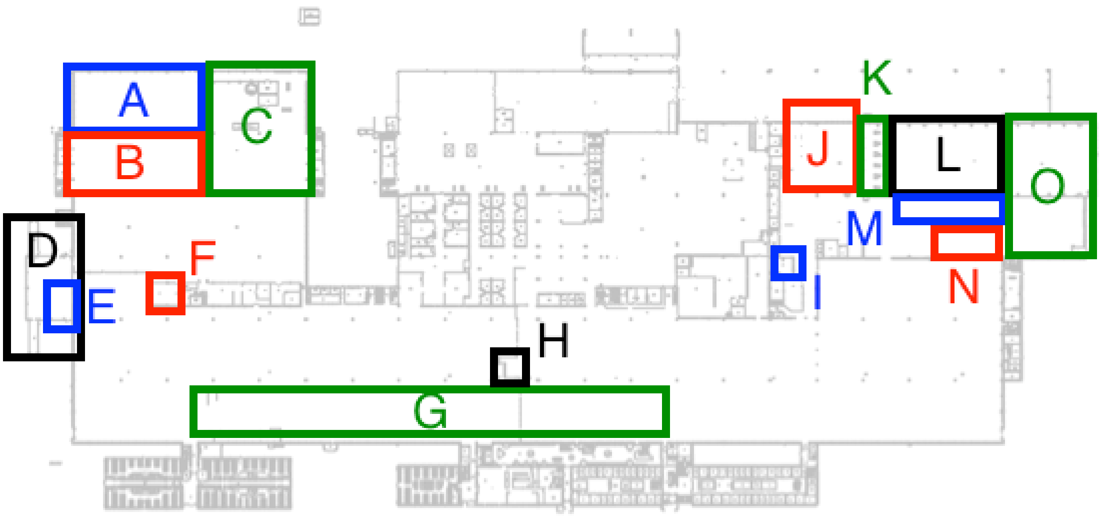
Yang, W. X. (2013). Discussion on optimizing internal supply chain of chinese enterprise. Applied Mechanics and Materials, 347-350, 1244. doi:10.4028/www.scientific.net/AMM.347-350.1244

APPENDIX

Appendix I: Titles of the employees being interviewed.

Logistic Ambassador 1
Logistic Ambassador 2
Logistic Ambassador 3
Manufacturing Technology Manager
Manufacturing Technology Specialist
Material preparator 1
Material preparator 1
Process and Solution Key User
Production Engineer 1
Production Engineer 2

Appendix II: Map of the assembly factory



A: Sequence area
B: Satellite buffer
C: Pipe shop
D: West terminal
E: Gravitation conveyor
F: Drop station five
G: Assembly line
H: Drop station three
I: Drop station one
J: Goods reception
K: Picking area
L: High bay storage
M: Supermarket shelves
N: Labelling area
O: Supermarket

Appendix III: Deviant measurement methods

Part number	Description	Deviant measurement methods
22225447	CCV pipe	Measured only three times and in January since low volume and not avaliable in November. Time study of picking time, storage time after picking and transportation to line.
20541940	Sealing strip, oil pan	Time study of transportation to line.
21840671	Heat shield	Time study of storage time in supermarket and transportation to line.
20792248	Vibration damper	-
21644620	Reinforcement frame	-
22365535	Pipe set	-
21627152	Valve cover upper	-
21024032	Joint M18*18	-
21469531	Pulley	-
20869387	Bowl (24V Heater)	Time study of labelling.
20711223	Pulley, coolant pipe	Time study of transportation to line. To move a pallet from supermarket-buffer to supermarket includes in the transportation time to supermarket-buffer, this will not make a difference on the overall supermarket cost.
20869391	Bowl (24V)	Time study of labelling. The average time for labeling is longer than the shortest time for labelling and therefor transportation time to labelling seems to be non existing in two of the studies.
22026389	Pipe to oil cooler	Calculation of storage time in pipe shop storage. Time study of transportations from pipe shop storage to pipe shop and to line.
21110365	Pump servo steering	Estimation of storage time in sequence area. Time study of trasportation to line.
22467253	Cylinder head	Time study of transportation from machining factory to West terminal (main flow), unloading from KTT to gravitation conveyer and from gravitation conveyer to line. Calculation of storage time in gravitation conveyer. Only the main flow to West terminal has been studied.
20555313	Connection pipe	To move a pallet from supermarket-buffer to supermarket includes in the transportation time to supermarket-buffer, this will not make a difference on the overall supermarket cost.
17430646	Oil pan, aluminium	Time study of transportation to West terminal and to line. Estimation of storage time in sequence area.

Appendix IV: Picture of the model part 1/4

Flow	Part number	Description	Details per pallet	Details per box/pick	Purchase price	Tied-up capital
HANGING LOW VOLUME	22225447	CCV pipe	48	10		
HANGING HIGH VOLUME WITH BUFFER	20541940	Sealing strip, oil pan	100	10		
HANGING HIGH VOLUME WITHOUT BUFFER	21840671	Heat shield	84	21		
PALLET WITH fork lift WITHOUT BUFFER	20792248	Vibration damper	42			
PALLET WITH fork lift WITH BUFFER	21644620	Reinforcement frame	36			
PALLET WITH TRAIN WITHOUT BUFFER	22365535	Pipe set	30			
PALLET WITH TRAIN WITH BUFFER	21627152	Valve cover upper	10			
LOW VOLUME CARDBOARD BOXES	21024032	Joint M18*18	2500	500		
REPACKED MID VOLUME	21469531	Pulley	90	2		
MID VOLUME FROM SUPERMARKET	20869387	Bowl (24V Heater)	80	8		
REPACKED HIGH VOLUME	20711223	Pulley, coolant pipe	138	8		
HIGH VOLUME FROM SUPERMARKET	20869391	Bowl (24V)	240	10		
PIPE SHOP FLOW	22026389	Pipe to oil cooler	675	25		
PALLET THROUGH SEQUENCE AREA	21110365	Pump servo steering	30	3		
GRAVITATION CONVEYOR FLOW	22467253	Cylinder head	6	1		
HIGH VOLUME LABELLED FROM SUPPLIER	20555313	Connection pipe	160	10		
SUMMER CABIN THROUGH SEQUENCE AREA	17430646	Oil pan, aluminium	6	1		

Appendix IV: Picture of the model part 2/4

Flow	Cost: activity 1	Cost: activity 2	Cost: activity 3	Cost: activity 4
HANGING LOW VOLUME	Transportation from goods reception to high bay storage	Storage time in high bay storage	Transportation to picking area	Repack and transportation to picking area-out
HANGING HIGH VOLUME WITH BUFFER	Transportation from goods reception to high bay storage	Storage time in high bay storage	Transportation with EHBn to drop station 1	Storage time in drop station 1
HANGING HIGH VOLUME WITHOUT BUFFER	Transportation from goods reception to high bay storage	Storage time in high bay storage	Transportation with EHBn to drop station 1	Storage time in drop station 1
PALLET WITH fork lift WITHOUT BUFFER	Transportation from goods reception to high bay storage	Storage time in high bay storage	Transportation with EHBn to drop station 3	Storage time in drop station 3
PALLET WITH fork lift WITH BUFFER	Transportation from goods reception to high bay storage	Storage time in high bay storage	Transportation with EHBn to drop station 3	Storage time in drop station 3
PALLET WITH TRAIN WITHOUT BUFFER	Transportation from goods reception to high bay storage	Storage time in high bay storage	Transportation with EHBn to drop station 3	Storage time in drop station 3
PALLET WITH TRAIN WITH BUFFER	Transportation from goods reception to high bay storage	Storage time in high bay storage	Transportation with EHBn to drop station 3	Storage time in drop station 3
LOW VOLUME CARDBOARD BOXES	Transportation from goods reception to high bay storage	Storage time in high bay storage	Transportation to picking area	Storage time in picking area
REPACKED MID VOLUME	Transportation from goods reception to high bay storage	Storage time in high bay storage	Transportation to picking area	Storage time in picking area
MID VOLUME FROM SUPERMARKET	Transportation from goods reception to outbound conveyer	Lift off outbound conveyor	Storage time in outside area	Transportation to supermarket
REPACKED HIGH VOLUME	Transportation from goods reception to high bay storage	Storage time in high bay storage	Transportation to picking area	Storage time in picking area
HIGH VOLUME FROM SUPERMARKET	Transportation from goods reception to outbound conveyer	Lift off outbound conveyor	Storage time in outside area	Transportation with fork lift to supermarket
PIPE SHOP FLOW	Storage time in pipe shop storage	Transportation to pipeshop buffer	Storage time in pipe shop buffer	Transportation with train to line
PALLET THROUGH SEQUENCE AREA	Transportation from goods reception to high bay storage	Storage time in high bay storage	Transportation with EHBn to drop station 5	Storage time in drop station 5
GRAVITATION CONVEYOR FLOW	KTT-transportation from machining factory to West terminal	Unoading with fork lift from KTT to gravitation conveyer	Storage time in gravitation conveyer	Transportation with fork lift to line
HIGH VOLUME LABELLED FROM SUPPLIER	Storage time in goods reception	Transportation with fork lift from goods reception to supermarket-buffer	Storage time in supermarket	Transportation with train to line
SUMMER CABIN THROUGH SEQUENCE AREA	Transportation with fork lift from goods reception to outside area	Storage time in outside area	Transportation to satellite in F-leg	Storage time in buffer in F-leg

Appendix IV: Picture of the model part 3/4

Flow	Cost: activity 5	Cost: activity 6	Cost: activity 7	Cost: activity 8	Cost: activity 9
HANGING LOW VOLUME	Storage time in picking area-out	Transportation with train to line	Storage time by the assembly line		
HANGING HIGH VOLUME WITH BUFFER	Transportation with fork lift to supermarket	Storage time in supermarket	Transportation with train to line	Storage time by the assembly line	
HANGING HIGH VOLUME WITHOUT BUFFER	Transportation with fork lift to supermarket	Storage time in supermarket	Transportation with train to line	Storage time by the assembly line	
PALLET WITH fork lift WITHOUT BUFFER	Transportation with fork lift to line	Storage time by the assembly line			
PALLET WITH fork lift WITH BUFFER	Transportation with fork lift to satellite buffer in F-leg	Storage time in satellite buffer in F-leg	Transportation with fork lift to line	Storage time by the assembly line	
PALLET WITH TRAIN WITHOUT BUFFER	Transportation with pallet train to line	Storage time by the assembly line			
PALLET WITH TRAIN WITH BUFFER	Transportation with fork lift to satellite buffer in F-leg	Storage time in satellite buffer in F-leg	Transportation with pallet train to line	Storage time by the assembly line	
LOW VOLUME CARDBOARD BOXES	Repack	Transportation with train to supermarket shelves	Storage time in supermarket shelves	Transportation with train to line	Storage time by the assembly line
REPACKED MID VOLUME	Repack	Transportation with train to supermarket shelves	Storage time in supermarket shelves	Transportation with train to line	Storage time by the assembly line
MID VOLUME FROM SUPERMARKET	Storage time in supermarket	Transportation with fork lift to labelling	Labelling	Transportation with fork lift to supermarket shelves	Storage time in supermarket shelves
REPACKED HIGH VOLUME	Repack	Transportation with fork lift to supermarket	Storage time in supermarket	Transportation with train to line	Storage time by the assembly line
HIGH VOLUME FROM SUPERMARKET	Storage time in supermarket	Transportation with fork lift to labelling	Labelling	Transportation with fork lift f to supermarket	Storage time in supermarket
PIPE SHOP FLOW	Storage time by the assembly line				
PALLET THROUGH SEQUENCE AREA	Transportation with fork lift to buffer in F-leg	Storage time in buffer in F-leg	Transportation with fork lift to sequence area	Storage time in sequence area	Transportation with train to line
GRAVITATION CONVEYOR FLOW	Storage time by the assembly line				
HIGH VOLUME LABELLED FROM SUPPLIER	Storage time by the assembly line				
SUMMER CABIN THROUGH SEQUENCE AREA	Transportation with fork lift to sequence area	Storage time in sequence area	Transportation with train to line	Storage time by the assembly line	

Appendix IV: Picture of the model part 4/4

Flow	Cost: activity 10	Cost: activity 11	Sum activity 1-11	Sum activity 1-11 + tied-up capital	Total cost per year including tied-up capital
HANGING LOW VOLUME					
HANGING HIGH VOLUME WITH BUFFER					
HANGING HIGH VOLUME WITHOUT BUFFER					
PALLET WITH fork lift WITHOUT BUFFER					
PALLET WITH fork lift WITH BUFFER					
PALLET WITH TRAIN WITHOUT BUFFER					
PALLET WITH TRAIN WITH BUFFER					
LOW VOLUME CARDBOARD BOXES					
REPACKED MID VOLUME					
MID VOLUME FROM SUPERMARKET	Transportation with train to line	Storage time by the assembly line			
REPACKED HIGH VOLUME					
HIGH VOLUME FROM SUPERMARKET	Transportation with fork lift to line	Storage time by the assembly line			
PIPE SHOP FLOW					
PALLET THROUGH SEQUENCE AREA	Storage time by the assembly line				
GRAVITATION CONVEYOR FLOW					
HIGH VOLUME LABELLED FROM SUPPLIER					
SUMMER CABIN THROUGH SEQUENCE AREA					