Model for evaluating materials supply methods to assembly stations

Modell för att utvärdera materialförsörjningsmetoder till monteringsstationer
Modell för att utvärdera materialförsörjningsmetoder till monteringsstationer


Nyckelord
Materialförsörjning, Produktivitet, Kostnadseffektivitet, Ergonomi, Kvalitet, Kitning av material, Linje lagring

Abstract (in English)
The purpose of this thesis is to develop a model that is going to be used when wanting to cost-effectively improve the productivity of material supply to assembly with consideration to improve ergonomics and quality of semi-finished products. For this approach a case company’s material supply and assembly station have been studied. By utilising interviews, observations, time measurements and the company’s archival records relevant data have been gathered to review the company’s current materials supply method and assembly station in order to compare it with new possible materials supply methods. A cost break down structure was made in order to identify the different cost drivers for the different materials supply methods. This facilitated the time measurements since they pointed out which operations/activities that should be studied. There were two main types of materials supply methods used in the comparisons, which were line stocking and materials kitting. Line stocking was the first alternative since it was their current material supply method. In materials kitting, the new material supply method, there was two sub types examined, kit carriers and kits in pallets. The conclusion was that that the kit carriers made it possible to improve the labour productivity of one assembly station and at the same time being cost-effective. The kit carriers did also improve the ergonomics for the assembler, but on the contrary worsened the ergonomics for the material handlers. It was also perceived by the assemblers and materials handlers that the quality of the materials was improved when using the kit carriers.

Key Words
Material supply, Productivity, Cost-effectiveness, Ergonomics, Quality, Materials kitting, Line stocking

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Växjö 2011-06-03

______________________   ______________________
Jonas Backsten               Ehsan Hosseini
Definition of key terms
Trough out this study different terms will be used when presenting theoretical approaches or making different statements, thus there will follow a short description of the different key terms. This is done in order to help the reader get a better understanding of what is being read.

Productivity- “Productivity is defined as output divided by the input factors.” (Kuhlang et al. 2011 p. 2)

Cost-effectiveness- “the cost-effectiveness (Ce) of each investment (and consequently the improvement generated) can be examined by using the proportion of the difference between the average cost per unit time before (Bb), and that after the improvement (Ba), to the Bb” (Al-Najjar, 2006 p.266)

Materials kitting- “A materials kit consists of all the components needed to assemble an individual product or a complete part of a product. Materials kitting is the process of producing the materials kit” (Christmansson et al. 2002 p.50)

Abbreviations
Through out this study different abbreviations will be used, here follows an explanation of each.

CBS- Cost break down structure
JIT- Just In Time
MAPICS- Manufacturing, Accounting and Production Information Control Systems
VPS- Volvo Production Systems
TPS- Toyota Production Systems
MRP- Material Requirements Planning
WBS- Work break down structure
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1. Introduction

This chapter gives a general overview of the study, including background, discussion and presentation of the problem, problem formulation and purpose of the study. The relevance, limitations, delimitations and time frame of this study will also be presented in this chapter in order to give the reader a better perception of the content.

1.1 Background

Ever since mankind started organised trade for a couple of thousands years ago, logistics activities have been an actor. However it did not get the recognition of importance until the Second World War, where its contribution was substantial with the supply of materials to the troops. Due to the increasing interest rates and energy costs globally, logistics became to be seen as a major cost driver thus becoming even more interesting during the 1970s (Grant et al, 2006).

In today’s increasing globalisations of markets, logistics activities reach a whole different level of importance. Customers, suppliers, offices, production plants et cetera are nowadays scattered in different geographical positions. Production plants and offices are chosen strategically and some locations of importance like customer markets are areas that can not be chosen. Hence the pressure on logistics activities or rather the importance of it is quite obvious, due to the significant increased movements of materials and information between different locations (Segerstedt, 2009).

Materials handling is seen as a key logistics activity by Grant et al (2006) when required to facilitate the flow of a product from point of origin to point of consumption. Thus highlighting the materials flow within all processes of the production e.g. materials supply to the assembly should be of great importance. The materials handling is a very broad area that covers all aspects of movement in raw materials, work in process or finished goods within a warehouse or factory. In order to being able to reduce travel distance of the materials, inventory levels, bottlenecks, and loss due to waste the primary objective of materials management should be to eliminate materials handling wherever possible.

Christopher (2005) emphasises efficient logistics activities as a way to gain competitive advantage against competitors due to its impact on costs amongst other things. One way to be more efficient is to increase productivity. To be able to do this, investments in improvements processes are inevitable, and in order to justify the investments the cost-effectiveness of the investments should be calculated. Al-Najjar (2006) states that the cost-effectiveness of an investment, thus the improvement generated, can be seen as the difference between the average cost per unit time before investment to the cost per unit time after the implemented investment. Kuhlang et al. (2011) further explain that by increasing the productivity e.g. in a specific time frame (one day or one shift) will lead to an overall added value within the specific time frame. This is because shortening lead times through a process chain gives
higher output as a result and thereby gives higher productivity and in that way increases overall added value within this time frame. Increasing productivity means using fewer resources and at the same time producing more, thus increasing pressure on the humans that works under these conditions. That is why Kuhlang et al. (2011) emphasises the importance of balancing the increased productivity with designing the process with the people in mind. So by taking the ergonomic quality of the design (e.g. ease of assembly, ease of grasp/operability) into consideration when looking to increase productivity, it is possible to achieve better working conditions even when the workforce is put to the test. Battini et al. (2010) says that improving ergonomics for the workforce will improve quality in e.g. the product and operators productivity. This statement is supported by Drury (2000) who sees quality as a function of technological and human factors and in that way is indeed influenced by ergonomics in its broadest sense. He also believes that failures in the process can be derived from the interaction between human and a system and result in poor productivity, product unreliability and also injuries to the workforce.

1.2 Problem discussion
Improving productivity often results in more products produced, or just using less resources to produce the same amount, and when producing a product there are many costs involved, e.g. materials costs, work costs, research costs et cetera. Studies have shown that (Segerstedt, 2009; Jonsson and Mattsson, 2005) more than 65 % of products total costs are materials costs. That is why it is important to be cost-effective in materials handling as well. But the desire of logistics is rather to create a smooth and efficient flow of materials and information from supplier to end customer and materials management amongst other things is a part of that flow, that is to say logistics (Lumsden, 1989; Segerstedt, 2009). Materials management is defined by Lumsden (1989) as those principles and approaches by which we strive to coordinate, develop, plan, organise, direct and control the materials flow from raw materials supplier to final consumption. Not having a well-functioning materials management is according to Segerstedt (2009) devastating and could lead to high uncertainty in given lead times, low utilisation of invested capital in inventories, work in progress and increased overall lead times.

The goal of materials management should be to increase profitability or to maintain an already satisfying one (Lumsden, 1989). Closely related to materials management is the materials supply. Jonsson and Mattson (2005) stress that optimal materials supply strategies and close relationships with loyal suppliers are of great importance due to increasingly tendency by companies to outsource. They also believe that materials supply is of vital importance for every company’s competitiveness. Lumsden (1989) states that the materials supply system and the assembly system are closely related to each other. To be able to reach the best possible total solution these two “systems” should be developed parallel to each other. He also stresses the importance to take ergonomics for the assembly line into consideration as well as the characteristics of the handled materials. The latter consideration is for quality issues due to that each material has its own damage risk, size, price et cetera.
Lumsden (1989) points out that the trend towards parallel assembly systems, as compared to the traditional assembly line, has driven the development of materials supply to be planned for single assembly objects. This trend raises some problem areas that are going to be affected negatively: space (per working stations and total), increasing number of locations for placed materials, increased materials handling, and increased risk of shortages and overuse.

1.3 Presentation of problem

All companies should attempt or are attempting to be productive, i.e. producing more with fewer resources used. The simple and fundamental reason for this is being able to exist as a company in a market since it is possible to increase the competitiveness. Now it is a fact that companies do not always exceed the total costs with the earnings due to different reasons like variations in demand, increased costs due to necessary investments or failures in production, just to mention some. Due to this reason, companies are always after to cut down costs. One way to do that is to improve a certain process. In order to improve a process, an investment is required, so to be able to justify the investment it must be cost-effective. The cost-effectiveness can be investigated by dividing the average cost per unit, before the improvement and with the cost after the improvement. If the improvement is cost-effective the number will be $0 < CE \leq 1$. That is to say the cost-effectiveness has to be greater than zero and smaller or equal to 1 in order to be seen as cost-effective (Al-Najjar, 2006). One measure to gain competitiveness is, as discussed before, by increasing productivity, i.e. to produce at relatively lower levels of inputs (e.g. materials, machines, and man hour’s et cetera). In engineering manufacturing businesses the assembly stations is an area that increased productivity has a major effect on. However, it should also be of importance to take ergonomics and quality issues into consideration when improving productivity since these two aspects, as previously stated, affects the productivity. By taking the ergonomic quality of the design (e.g. ease of assembly, ease of grasp/operability) into consideration when looking to increase productivity, it is possible to achieve better working environment and in that way having increased productivity but no higher impact on the workforce health. Therefore by improving the productivity of an assembly station it is possible to produce more products with optimised resources (money, machines, man hour’s et cetera) and in that way improve/gain profitability, which will lead to staying competitive in a market.

1.4 Problem formulation

- How is it possible to improve cost-effectively the productivity of an assembly station in engineering manufacturing businesses with respect to, ergonomics and quality of semi-finished products?
1.5 Purpose
The purpose of this study will be to develop a model to select the most cost-effective and productive materials supply methodology to an assembly line with consideration to improve ergonomics and quality of semi-finished products in engineering manufacturing businesses.

1.6 Relevance
Improving productivity’s importance for companies’ competitiveness and profitability has been supported by many authors and studies as a fact (Kuhlau et al. 2011; Stevenson, 2009; Eliasson and Samuelsson, 1991). Such areas as assembly stations are key players in a production process where the productivity improvement has a high impact on. Henry Ford revolutionised the industries with the development of mass production in the early years of 1900s and introduced the moving assembly lines in an effort to improve the efficiency of operations. This resulted in tremendous gains in industrial productivity, thus making the contribution of assembly lines for productivity gain undeniable (Stevenson, 2009). A way to improve productivity in assembly lines is to use a proper materials supply method. According to Neumann and Medbo (2010) the materials supply, along with the methods and people, is one of the core necessary elements in a production system. In their case study they evaluated two different materials supply methods used to assembly in a company. They concluded that one of the materials supply methods not only improved productivity but also reduced the risk characteristics of the materials supply system itself. This means that having the correct materials supply method will improve productivity. When searches were made about relevant articles for models that considered materials supply and cost-effectiveness, none were found, hence making this study more relevant.

1.7 Limitations and Delimitations
Due to the time limit set for this thesis certain measurements like time keeping will be constrained. Thus, even if the measurements would need more variables, e.g. increased amount of observations when time keeping or more extensive research in a certain area, this would not be possible. One other reason for the limit of observations is the inability of the materials supply- and assembly departments to allot time for interviews or measurements due to different reasons such as heavy workload or suchlike. There will instead, at some occasions, be old documents or data applied from the case company’s intranet to fill in the “gaps” of the research, which at occurrence will be clarified. Furthermore the focus will only lay on solitarily assembly stations, and not the entire assembly. This is due to studying an entire assembly would not result in a better study and furthermore it would be too extensive. One other note is that this study will only evaluate the materials supply methods that the company is using today, hence no other methods will be presented nor evaluated.
1.8 Related works

The reason why there were no relevant articles in the search word “cost-effective materials supply” was due to that the search engine did not see it as a whole sentence and divided it up into “cost-effective”, and “materials supply”. So the articles were not really about “cost-effective materials supply” but such things as “cost-effective interlending service in libraries” and just “materials supply when implementing an MRP”. Regarding the “cost-effective materials flow in assembly” there were only articles about “effects of chamber shapes of port hole die” and one had a interesting title which was “an integrated design support for flexible assembly systems”. But after reviewing the article, it was found that it was mostly about user-friendly design-aid tools and design decision support systems, which is irrelevant for this study.

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Table 1 Search of related works for this study
1.9 Time frame

In table 1 the time frame of this thesis is presented, it shows each chapter’s and activity’s time estimation. Furthermore it will work as a planning tool in order to being able to meet the deadline of handing in the thesis.

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<td>Adjustments</td>
<td>Week 20</td>
<td>Week 21</td>
<td>1 Weeks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2 Time frame
2. Research methodology

The research methods that are going to be used in this paper are presented here. This includes the scientific approaches that are chosen in order to answer the presented problem formulation. Each section that is presented shows the different methods available and the methods chosen are then explained below each section.

2.1 Scientific research Approaches

There are three alternative approaches when an author or researcher wants to relate theory and practice to one another. Patel and Davidson (2003) state them as inductive-, deductive- and abductive approach.

2.1.1 Inductive approach

Inductive research is according to Patel and Davidson (2003) an approach where the investigated area is studied before any establishment of the research has been made out of previous theory within the area. In context, this means that the researcher can develop and formulate new theory based on the gathered empirical findings. Patel and Davidson (2003) states that inductive research is made to be able to generalize theory based on the empirical findings, there are however problems with this approach since the theory is based on empirical findings that are most often limited to unique events, time or a group of people (Patel and Davidson, 2003).

2.1.2 Deductive approach

Deductive research is according to Bryman and Bell (2003) the most common perception of how the relationship between theory and empirical findings appears. Deduction means that one should derive the considerations and what one actually knows within the area of recognition, to several hypothesises presented that will be put through an empirical review (Bryman and Bell). Deductive work is according to Patel and Davidson (2003) characterized by inference of different phenomenon, based on already known principles and existing theories, which means that objectivity of research is to be strengthened (Bryman and Bell, 2003; Patel and Davidson, 2003).

2.1.3 Abductive approach

Abductive research is according to Patel and Davidson (2003) a sort of combination between inductive- and deductive research where one wants to explain the case by formulating a pattern based on a particular case. First step in abductive research is according to Patel and Davidson (2003) to formulate a suggestive theory within the study area which is an inductive approach, step two incorporates deductive approach that can be used to develop and expand the initial theory to become more general (Patel and Davidson, 2003).

When conducting this study the deductive approach will be used for the reason that we will compare already existing theory gathered to the empirical findings.
2.2 Qualitative and quantitative approach

Qualitative methods are used according to Holme and Solvang (1997) as a tool when investigating a problem area. Nevertheless qualitative methods are used in great extent, but most often scientists and researchers have to argue for their results being sustainable and accurate. Holme and Solvang (1997) say that this can overshadow discussions of the actual outcome. Qualitative methods incorporates not just one approach, it comprises several different techniques and approaches that combines according to Holme and Solvang (1997) participant observation, direct observation, informant interviews, respondent interviews and analysis of sources. Qualitative methods are generally based on interviews, observations and analysis of sources in which a limited amount of persons, processes etc. is incorporated (Holme and Solvang, 1997).

Quantitative research methods relies in great extent to numbers and tables of various forms and Holme and Solvang (1997) say that people in general shows resistance in tables and numbers it is evident that quantitative methods constitutes a major and important approach for studies and research. However Holme and Solvang (1997) points out that numbers and tables can be misleading in some aspects, due to this, it is important that the assorted selection is chosen based on related area and common denominator. Quantitative methods is characterized by techniques such as surveys, statistics, tables, graphs, numbers etc. that is to say large amount of information that can prove a proposition to be true (Holme and Solvang, 1997).

For this study we will be performing qualitative approaches for investigating our problem area, since different types of interviews and observations will be used. Furthermore there will be a limited amount of persons that will be interviewed and observed, due to time limitations for this thesis. Observations will be the key area or rather the major part when conducting this study.

2.3 Research strategy

This report will be conducted through a case study approach. Graziano and Raulin (2010) states that case study research allows the researcher to be flexible which offers the ability to shift the attention to whatever seems interesting and relevant. Graziano and Raulin (2010) also say that case study research methods can be applied to many issues. Yin (2009) states that case study research is one of many research methods except that case studies are more suitable and preferred when “why” and “how” questions are posed, when investigator has very little control over events that is occurring and when focus lies in contemporary events in real life context (Yin, 2009; Graziano and Raulin, 2010).

This strategy has been chosen due to its flexibility and possibility to shift attention to the different important areas of focus that will emerge. For the reason that we have little control of the occurring situations in the company we feel that conducting a case study will be the most suitable approach.
2.4 Data Collection methods

Yin (2009) states that data collection or collecting case study evidence can come from various sources, there are however six sources for data collection that are more frequently and commonly used for case studies. These are: archival records, documentation, interviews, direct observations, participant-observations and physical artefacts.

Archival records are most often revealed in forms of computer files and records. Yin (2009) gives examples of archival records as public files such as statistical data made by government, service records, organisational records, charts and maps about geographical data of a place. Documentation is to be relevant for every case study topic and documents for data collection can be comprised from e.g. letters, personal documents, agenda of meetings, administrative documents, and formal studies of similar cases. This type of information should be the object of supporting data collection plans, since it consider a variety of documents that can come to be used in the case study. Interview is a method that is one of the most important ones, since by using interviews one can follow the specific line of inquiry necessary for the study. Discussion and conversation is the key for successful interviews by asking questions that are well defined and organised.

Observations are a vital source of information for case studies and can be done during study visits that are less formal than for example study protocols where a certain area is to be studied. Direct observations rely on real time study of e.g. new technology implemented. Participant observations on the other hand are rather the opposite to direct observations, because here one takes a more active role as an observer. This technique is however more frequently used in anthropological studies but can also be used in everyday settings, in both large and small organisations.

Finally, artefacts can be used as a source and it can either be cultural or physical e.g. artwork, tools or instruments, technical devices etcetera. This technique can also be used for case studies but are as stated more extensively used in anthropological studies (study of humanity) (Yin, 2009).

*Interviews, observations (direct and participant), documentation and archival records are all data collection methods that will be used in this thesis. Interviews will be used to collect relevant information from employees in the assembly and materials supply departments. For the reason that ergonomic and productivity issues are indeed related to how the workforce perceives it. Thus making it very interesting to get “actual” input for how the different methods are functioning. Observations on the other hand will be conducted by us and how we perceive the current state of materials supply and assembly. This will give us relevant input to solve the proposed problem. Archival records are going to be used to be able to make a comparison of historical data and the gathered data of the current state. Due to the reason that complex information will also be gathered from meetings, instruction manuals and policies amongst other things, the documentation method is therefore relevant to support the empirical data collection for this study.*

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2.5 Validity and Reliability

Construction of validity is to be used when establishing certain criteria for judging the quality of research designs. Yin (2009) says that validity is to identify the correct operational measures of the study. There are three tactics important for validation; to use multiple sources of evidence to support validity of collected data, chain of evidence that proves that statements are correct and finally have key informants to review the draft case study report. However Yin (2009) states that validity can be sorted into internal and external validity where internal validity means how well an investigator can derive how events impacts on one another without having any correct base for the statements. External validity incorporates whether the findings of a study can be generalized beyond the current case study. Yin (2009) points out that the objectives of reliability is that if a new investigator follows the same procedures as an earlier investigator and conducted the same case study all over again, would lead the later investigator to come up with same findings and conclusions. Yin (2009) also mentions that minimizing errors and biases in a study is the main goal of reliability (Yin, 2009).

During this study different sort of measurements will be performed. There will be only two measurements on each focus area which can increase the variance in the measure, but to cover this gap somewhat we will use one subject person to perform all the different tasks during the measurements. In this way the measurements are more correct due to that one person can not perform tasks differently, as compared to two different persons. When making interviews, a note pad will be used for taking down notes immediately as the interview is lasting. This is due to ensure the reliability in the information gathered, since information can be forgotten or perceived differently as time passes. The same principle goes for observations were taking down notes will also be performed immediately as the observations are lasting. Some documentation will be collected continuously from the case company’s internal database, which is a common database that is used by the employees for collecting different information for their daily work.
2.6 Summary
A model of the different methods used in this study has been presented (see figure 1). This shows our intended way to progress our work in.

Figure 1 Summary of used research methods
3. Theory

The theory chapter will outline the key theoretical concepts that are relevant to this study. These concepts will also serve as a foundation for the analysis that will be presented in a later chapter.

3.1 Logistics

Logistical events are a part of one’s day to day activities. Lai and Cheng (2009) states that logistics as a term has long been associated and connected to military events originating from the beginning of the 1900 century. Lai and Cheng (2009) say that definitions of logistics are interpreted differently but that most of definitions share commonalities. Lai and Cheng (2009, p.34) define logistics as follows.

“Getting the right goods or services to the right place, at the right time and in the desired condition, while making greatest contribution to the firm”

The goals of logistics are to push down all of the activities total costs or to optimise the total costs within the organisation without affecting the qualities within the organisation (Lai and Cheng, 2009).

3.1.1 Logistics Management

Logistics management is according to Schönsleben (2007, p.7) defined as:

“Logistics management deals with efficient and effective management of day-to-day activity in producing the company’s or corporation’s output”

Logistics incorporates according to Lai and Cheng (2009) four primary activities that is considered to have significant importance for achieving cost and service objectives of logistics, they are: customer service, inventory management, transportation and order processing. These four objectives are also considered as key elements since they carry the majority of the costs related to firms’ logistics activities, but they are also important considering that they are essential for effective coordination of the tasks that lies on the logistics activities.

There is however additional logistics activities that should serve as support activities for the primary ones, although it can be of great importance that having these support activities they do not function as contributors to a firm’s logistic mission. The supporting activities are however warehousing, materials handling, purchasing, packaging, information, maintenance and production scheduling (Schönsleben, 2007; Lai and Cheng, 2009).
3.1.2 Transports
Such things as materials, components, finished goods et cetera or actually physical items needs transports in everyday situations. Transportation of such refers to in which these are transferred between different locations or parties e.g. distributors, raw materials suppliers, retailers and customers in a supply chain. Lai and Cheng (2009) states that transportation stands for the majority of a company’s expenditures, which can be derived to about two thirds of the total logistics costs. So it is of vital essence that a company ensure their transportation systems to be in line with the rest of the logistics mix, this to remain or even exceed efficiency and effectiveness. There are also several benefits of having a well-functioning transportation system such as facilitating accurate production scheduling, but also to grant the competitiveness by adding value to by creating time and place precision by making products available at designated time.

The basic alternatives for transports available are according to Lai and Cheng (2009) several such as rail, motor, water, air and pipelines. These alternatives can also be combined which makes it possible for the company to tailor the transports that in some cases can offer lower costs that single transport modes cannot. There are also several support transports within factories to manage transports activities such as different sorts of fork lifts, automatic lifters, gantries, wagon trains, conveyors, et cetera.

Certain attributes of an item also determines which transportation strategy that a company will use such as: weight, volume, shape, flammability, breakability, substitutability and perishability. These attributes determines whether the company should use train, trucks, boats, plains et cetera (Lai and Cheng, 2009).

3.1.3 Inbound and outbound
Inbound and outbound logistics are according to Lai and Cheng (2009) two aspects of logistics activities addressed within a firm or company’s immediate supply chain. Inbound logistics are focusing on materials management and outbound logistics main focus lies on the physical distribution of finished items. A more thorough explanation of inbound logistics is that e.g. spare parts, assembles, raw materials can be said moving into a firm instead of away from it, Lai and Cheng (2009) also denotes that inbound logistics activities involves storing, receiving and disseminating inputs to the operational areas of a firm, to manage the flow of finished products from the end of the line to the end customer. Inbound logistics should act as propelling to satisfy the operations needs service operations and manufacturing lines. Outbound logistics on the other hand is according to Lai and Cheng (2009) the flipside of inbound logistics and its primary tasks is to deal with the finished and the semi-finished products, which means that these products are such that does not need further processing.

3.2 Materials management & Materials handling
Within a manufacturing company there is a constant flow of materials and information, and materials management ensures that flow working smoothly. The materials management must see to that when there is a demand, the goods required are provided according to schedule and
cost effectively. It handles such things as end products, semi-finished goods, single parts, raw materials and information (Schönsleben, 2007). There are according to Jonsson and Mattsson (2005) four key questions that have to be “answered” by materials management:

1. **Article question:** For what items/articles should new orders be scheduled for?
2. **Quantity question:** How large should the quantity be for each ordered article?
3. **Delivery time question:** When should the order for each article get delivered into stock, directly to production or directly to customer?
4. **Starting time question:** When should the order for each article be placed to supplier and when should it be started within own production?

In order to answer these questions materials management uses different methods that occur within companies. Each method and the initial decision basis affect the answer of these questions differently. Some examples of methods within materials management are discussed by Jonsson and Mattsson (2005). *Balancing of needs and assets* consider the need of materials against the access of materials in the flow. If the assets of materials are less than the need of materials, the materials flow must be increased through planning new purchase orders or manufacturing orders. On the other hand, if the assets of materials are more than the need of materials, the incoming deliveries and released orders must be postponed as far as possible. Thus, having unbalance between assets and needs could lead to having unnecessary extensive stock or just the opposite, that is to say shortages and bad delivery capabilities. *Synchronisation of materials flow* aims to synchronise time aspects of assets and needs of material. E.g. if delivery of materials occurs to soon there will be unnecessary tied up capital. But if delivery of materials occurs to late, it will lead to shortages and unwanted interruptions in production, thus impairing lead-times to customer. Therefore Jonsson and Mattsson (2005) emphasises the importance of synchronising time so that the need of the materials coincides with time of receiving the materials. Hence having reliable supply of materials will help with synchronising the flow of materials. Moreover reliable supply of materials will, according to Boeck and Vandaele (2008), also lead to improved productivity.

Tompkins et al, (2003) states that materials handling can be observed in one’s day to day activities e.g. mail delivery, distribution of boxes and pallet loads, waste management, people moved in buses et cetera. Materials handling accounts for according to Tompkins et al, (2003) 25% of all employees, 87% of production time or 55% of all factory space and is expected to represent approximately between 15-70% of the cost for a manufactured product or item.

Tompkins et al, (2003, p.176) definition of materials handling that captures the essence of functions is:

“*Material handling means providing the right amount of the right material, in the right condition, in the right place, in the right position, in the right sequence, and for the right cost, by the right method (s).*”

There are several views of scopes to consider materials handling but Tompkins et al, (2003) advocates the progressive view since it includes the entire system view. Progressive view treats materials handling activities from all suppliers, distribution facility and manufacturing materials handling finished goods distribution et cetera.
Tompkins et al, (2003) say that there are ten materials handling principles that can function as guidelines and that can be helpful when one want to solve materials handling problems and these are:

- **Planning principle** - defines the materials and its movements.
- **Standardisation principle** - means less variety and customisation in the equipment and methods used.
- **Work principle** - take measurements of the work.
- **Ergonomic principle** - seeks to adapt working conditions or work to suit employees.
- **Unit load principle** - make use of unit loads which means to use containers or pallets that can be moved as a single entity.
- **Space utilisation principle** - count space as cubic space due to that materials handling is three-dimensional.
- **System principle** - a unified whole created by collection of interacting and/or independent entities.
- **Automation principle** - to control multiple electro mechanical devices by creating a system that can be controlled by programmed instructions.
- **Environmental principle** - to be conscious not to waste more resources than necessary, but also to try to eliminate negative effects that daily work can have on the environment.
- **Life cycle cost principle** - to be aware of all cash flows that will occur from procurement to replacement (Tompkins et al, 2003).

### 3.3 Materials supply to assembly

According to Formoso and Revelo (1998) the materials supply should be considered as a process instead of a department due to its complex net of internal clients and suppliers. This supply net can be divided into three levels:

1. **Internal supply net**: Those departments in the company that are involved in the supply process, such as production, assembly, planning and costing, accounting, design, and purchasing.
2. **Immediate supply net**: Here the client and direct suppliers are included
3. **Total supply net**: This includes all of the different suppliers concerned, even the suppliers of suppliers.

Furthermore it is important to understand the limitations and needs of the different participants in the supply net, to be able to improve each individual operations’ performance and in that way make the process profitable. To avoid affecting the performance of the actors in the supply net all inefficiency in the net should be eliminated or minimised as much as possible (Formoso and Revelo, 1998). The strategic posture of a firm is strongly related to the efficiency of materials supply, due to its dependency on the kind of relationship that is established with each supplier.
In a production system the supply of materials is one of its core necessities, along with employees and methods. Furthermore materials supply to assembly is a key point for performance, and is also a transition between two distinct businesses processes namely logistics and assembly operations (Neumann and Medbo, 2010). More than 50% of the prime cost of manufactured products can be traced to bought components and other inputs (Jonsson and Mattsson, 2005). For this reason the importance of having an efficient materials supply is apparent, and also vital for a company’s competitiveness.

3.4 Lean Production

Taiichi Ohno was the founder of Toyota production systems (TPS) and the term lean production, Liker (2009) states that Toyota was the pioneer within the area of effective automobile manufacturing by developing the method of lean production. This concept brought Toyota as a car manufacturer to leading positions within the global market at rapid pace. Liker (2009) states that lean production is not only a set of tools such as Just-in-time, 5S, Kanban et cetera but rather a refined system where all the different pieces cooperates into a single entity. Jacobs et al (2009) states that lean production is to enable and achieve production by using minimal inventories of raw materials, work-in-process and finished goods with the help of an integrated set of activities. Lean production also refers to focusing on trying eliminating as much waste as possible, or to use minimal resources to achieve rate of production needed (Liker, 2009; Jacobs, 2009).

3.4.1 Push and Pull systems

There are mainly two different ways of moving work around in a production process and Stevenson (2009) say that push systems pushes finished work to the next workstation without any consideration of the readiness of the next workstation. This means that the possibility that work piles up at that next workstation gets almost inevitable, since there is always a possibility that equipment might fail or that quality specifications is not fulfilled. In that sense push systems are more exposed to disruptions. Stevenson (2009) say that pull systems on the other hand works in a way that the coming workstation pulls the output from the preceding one as it is needed. This means that the final output is pulled based on either customer demand or a master schedule. Basically it means that output is pulled based on demand either by previous workstations, customer demands or master schedules. Pull systems works by the principle of Just-in-time, where the work moves around as it is requested. Stevenson (2009) points out that this approach although means that a small inventory must be required since if a workstation would have waited to produce on request from the next workstation then the next workstation must wait for the preceding workstation to perform its work. For avoiding these occurrences each work stations can produce enough to supply the next workstations based on anticipated demands. To succeed with this, communication becomes evident; to announce the input need ahead in time, which enables each workstation to deliver input just in time for the next workstation when it is required (Stevenson, 2009).
3.5  **Just-In-Time (JIT)**

The Just-In-Time philosophy originates from Japan as a management approach in the 1950s, and was a part in the Toyota Production System (TPS) developed by the Toyota Motor Company (Lai and Cheng, 2009). TPS was developed as a framework of methods and concepts for improving productivity and quality. It got considerable attention much later by the western manufacturing businesses in the 1970s when the substantial benefits were apparent. This was due to its considerable success in increasing productivity by eliminating different types of waste (Schönsleben, 2007). He further explains that JIT is not only an aid but is also a prerequisite for efficient use of all simple planning and control techniques in logistics. The main aim with JIT is to have the needed inventory when needed, reducing lead times by reducing setup times and lot sizes, improving quality to zero defects, and change the operations themselves to the better (Schönsleben, 2007).

3.6  **Quality**

Quality is an area that has many different meanings, Bergman and Klefsjö (2007 p.25) defines Quality as: “Quality in products is its ability to satisfy and preferably exceed customer needs and expectations”. Many organisations tends according to Bergman and Klefsjö (2007) to direct terms of quality towards customer oriented perspectives, but there are however more than just specifications of products when a customer decides to buy a product, anticipatory causes such as brand, availability of spare parts, services et cetera are considerations that customers thinks of when accommodating a product. Due to this quality can be seen as a relationship with the organisation that either sells or manufactures the product. ISO 9000 standard is according to Bergman and Klefsjö (2007 p.25) defining Quality as “the degree to which the inherent characteristics fulfils requirements”.

3.6.1  **Quality related costs**

According to Lai and Cheng (2009) it should be of great importance to not overlook the cost of quality when seeking to improve quality. Due to that there are different costs associated with quality and they have divided the costs into two elements:

1.  **Cost of non-conformance** – when producing products or service, there is costs when either do not meet the customer expectations or the set quality requirements from the company. E.g. bad reputation, loss of sales and high inventory levels et cetera.
2.  **Cost of conformance** – is the expenditures that the firm put on when establishing performance standards e.g. training the workforce, preventive measures, procedures for self-inspection and so on.

Lai and Cheng (2009) further explain that the cost of non-conformance can sometimes be seen as the cost of failure. This is due to that these costs are a result from when producing products or services that are not acceptable. Some of the frequent costs that compose this wide area of failure costs are re-work, scrap, court expenses (lawsuits) and warranty. Cost of conformance can however be further split up into prevention and appraisal costs. The costs for
prevention consist of procedures utilised for reducing or eliminating the costs for failure and appraisal. Left are the costs for appraisal that are the costs incurred when assessing the quality of a firm’s service and products.

When reducing the cost of quality the concept of “value added” plays an important role. So those activities that are commonly carried out but are not able to add any value to services or products should be eliminated. One example of these activities are when inspecting the final product for quality issues, due to that it does little to prevent the production of a defective lot of products. Thus highlighting prevention rather than detection should be more important. Obviously the costs related to detection would decrease as supervision and inspection are minimised. Costs associated with prevention will on the contrary and logically increase due to increased training and action-oriented efforts. But according to Lai and Cheng (2009) it is still justified to emphasise prevention due to its ruling benefits. Those benefits will be in significant reduction in failures, both internal (e.g. return, repair, re-work) and external (bad public relations, cost for service, handling of complaints).

3.6.2 Quality improvement

Working with quality improvements has become evident for every company that wants to stay competitive, Bergman and Klefsjö (2007) say that external customer demand is increasing all the time, in which new business activities are to be created due to new technical solutions. Due to this it is vital that companies continuously work with quality improvements within the organisation and its processes but also towards its products. Bergman and Klefsjö (2007 pp. 46) states that continuous improvement is an important cornerstone in quality development and that “Ones who stop to improve will soon stop being good”. However continuous improvement should never be neglected even if external demands for higher quality are low, due to cost savings that can be gained out of this.

Bergman and Klefsjö (2007, pp. 47) states that there is a ground rule for quality development that is “There is always a better way to achieve higher quality to a lower cost” which means that there is a way to accomplish better products and customer value which at the same time requires less costs. There is a Japanese concept for continuous improvements which also has impact of increased quality and that is Kaizen were conscious systematic work, both small and big improvements are carried out although depending on situation. TQM or Total Quality Management is another approach that functions as an overall quality approach within the entire organisation, Bergman and Klefsjö (2007) interprets TQM as a constant strive for fulfilling and most preferably to exceed customer needs and expectations to the lowest cost possible through a continuous work with improvements where focus lies at the organisations processes by having an dedicated and engaged workforce. The main aspect for succeeding with TQM is to have a motivated and engaged management with an urge for quality improvements (Bergman and Klefsjö, 2007).
3.7 Productivity

Productivity is a critical determining factor for cost efficiency, it is the comparison between actual inputs of resources to the actual output of production (Schönsleben, 2007; Eliasson and Samuelsson, 1991). Some examples of input that can be identified are such things as: materials, capital (money), man power, machines, energy et cetera. Outputs are considered as goods, work, and services.

3.7.1 Productivity in assembly

When evaluating the productivity in an assembly station there is several key factors that need to be considered (Engström and Medbo, 1993). Those are as follows:

1. Assembly time, included the completed subassemblies in the plant
2. Different types of losses such as balance loss, system loss, and division of labour loss
3. The required number of tools
4. Quality, measured as the number of quality remarks per product that is assembled
5. Flexibility and model change costs
6. Space requirements

Balance loss can derive from imperfect balancing of subsequent tasks in the assembly process. When there is a variation in time required for a given assembly task there is system loss. One example of division of labour loss could be the time needed for the operator to manage or handle the tools and materials (Kadefors et al. 1996). There is also several ways to measure the productivity in general, but when focusing on labour productivity the outcome is for example hours per car, hours per car unit et cetera. Depending on what productivity aspect you are calculating, it can be executed as follows (Eliasson and Samuelsson, 1991):

\[ \text{Labour productivity} = \frac{\text{Direct time}}{\text{Total time}} \]

Formula 1 Example 1 of productivity assessment (Eliasson and Samuelsson, 1991)

Direct time means the time when a value adding activities is occurring, consequently the indirect time means the time when a non value adding activity is happening. The direct time and the indirect time put together are then the total time. Hence a higher share of direct time than the indirect time is an indicator of higher productivity (Eliasson and Samuelsson, 1991).

3.8 Cost-effectiveness

Cost-effectiveness has several definitions and calculations depending on which area of interest that are examined. Al-Najjar (2006) defines cost-effectiveness in the maintenance area as:

“the cost-effectiveness (Ce) of each investment (and consequently the improvement generated) can be examined by using the proportion of the difference between the average cost per unit time before (Bb), and that after the improvement (Ba), to the Bb” Al-Najjar (2006 p.266).
This is calculated as:

\[ C_t = 1 - \frac{B_o}{B_h} \]

Formula 2 Cost-effectiveness assessment (Al-Najjar, 2006)

Blanchard (2010) has a definition of cost-effectiveness as system effectiveness and defines it as:

“Cost-effectiveness relates to the measure of a system in terms of mission fulfilment (system effectiveness) and total life cycle cost and can be expressed in various ways, depending on the specific mission or system parameters that one wishes to evaluate” Blanchard (2010 p.442).

Blanchard (2010) gives some examples of how to calculate the cost-effectiveness:

\[
(FOM) \text{ Figure of merit} = \frac{\text{System benefits}}{\text{Life cycle cost}}
\]

Formula 3 Cost-effectiveness example 1 (Blanchard, 2010)

\[
FOM = \frac{\text{System capacity}}{\text{Life cycle cost}} \quad FOM = \frac{\text{System effectiveness}}{\text{Life cycle cost}}
\]

Formula 4 Cost-effectiveness example 2 (Blanchard, 2010)

3.9 Ergonomics in assembly stations

Traditional assembly lines (serial flow assembly) in companies had usually single workstations where the operators were confined to a defined workspace along the assembly line. This usually led to the companies having a high workforce turnover and also high rate of sick leave among the employees due to the bad ergonomic conditions (Kadefors et al. 1996).

For this reason companies started to investigate to see if there are alternative solutions for a new assembly style that could be developed in order to prevent the bad ergonomic conditions when seeing the negative impacts it had.

Kuhlang et al. (2011) emphasise the importance of having the ergonomic aspect in mind when designing different processes such as new assembly lines. As an alternative to traditional line assembly, kitting could be a great candidate due to its better accuracy and less work in progress (Christmansson et al. 2002). Even though kitting, in terms of ergonomics, indicates a working situation that has low levels of physical exposure with respect to muscular activity and work postures there is according to Christmansson et al. (2002) a lot of repetitive work involved. In their case study of materials kitting and its impact on, among other things, physical workload they saw that, besides the repetitive work, some working situations was experienced as physically stressful by the workers.
These working situations were what they called “necessary work” (e.g. grasping and placing materials in general, and rearranging items in picking packages) and “handling and transportation (e.g. lifting heavy plastic storage packages, and pulling plastic storage packages to the picker stacker truck). However picking materials from pallets was perceived as more physically stressful than picking from plastic containers.

3.10 Line stocking

There are a large number of feeding models and techniques available, line stocking method is the most common and traditional in material supply management in manufacturing companies. Wänström and Medbo (2009) says that in line stocking material and/or components are placed and stored alongside the assembly line and is according to Caputo and Pelagagge (2010) replenished periodically as the materials and components are running out. Caputo and Pelagagge (2010) says that compared to JIT materials supply the line stocking method is rather discontinuous, there are although positive sides, i.e. the material handling effort is needed, but since in most cases the material is stored in big containers or pallets the holding costs are utterly high. This is in context to i.e. the kitting approach where all items for assembly line are placed in the same container and not in many pallets. The positive sides with line stocking is that the operator can take a new part if the one before is damaged or missing, but this causes shrinking space at the shop floor. Besides from high space utilization and high holding costs, line stocking can cause confusion which could be that the operator wastes time by searching for the correct part. Caputo and Pelagagge (2010) also says that line stocking method is not appropriate for variable product mixes since this will create additional need for coordination and control requirements. (Caputo and Pelagagge, 2010)(Wänström and Medbo, 2009)

3.11 Kitting in assembly

This method means according to Caputo and Pelagagge (2010) that much of the parts inventory is kept at assembly stations, where all part required managing the assembly are grouped together and placed in a kit container. Most commonly the kits are prepared in a nearby room called a stockroom, the kits originating from the orders bill of materials as a foundation are then picked into the kit container which later will be sent to the assembly station in mind. See example of a kitting system in figure 3. Caputo and Pelagagge (2010) says that in a kitting process, all the materials are stored centrally because this will increase control of physical inventory security.
but also raw materials inventory for a given service level is to be reduced. Hermansson (2009) declares that the kitting method requires specific personnel that manages the composition of materials, this means that the assemblers can fully concentrate on their work task. The downside Hermansson (2009) says is that the persons in concern managing the kit gathering also costs money and that these person/persons cannot be reduced or be given new work tasks if the pace is needed to be changed. The kitting approach is according to Caputo and Pelagagge (2010) a good way to reduce space allocation, control and cleanness of the shop floor. Hermansson (2009) states resembling propositions like greater share of value adding time for assemblers, fewer faults when choosing parts and simplified training. Hermansson (2009) states that there are a several challenges to manage the kitting method as smooth as possible: first of all the design phase is important to manage smooth assembly, design kit so that gathering of the kit is easy in context to the assembly, decide how the right kit gets to the right assembly station and to solve the issue of exact allocation of parts in the kit. Caputo and Pelagagge (2010), Wänström and Medbo (2008) and Hermansson (2009) says that ergonomic improvements are a positive factor of kitting that can occur (Caputo and Pelagagge, 2010; Wänström and Medbo, 2008; Hermansson, 2009).

3.12 Cost break down structure (CBS)

According to Blanchard (2004) CBS is performed in a chart were all the costs that are relevant for an investment is broken down into smaller categories (see figure 4). The CBS is a tool that is to be tailored for its specific purpose. The objective and the main thing of the CBS is relative to the key functional activities that should display a visibility of an investment’s all costs.

Blanchard (2004) says that there are two structure categories to get full control of all costs: The first is the bottom-up which helps to summarize and collect all costs for the investment evaluation. The second is the top-down structure which is done to include the several categories of costs and to allocate costs as “a design-to-cost” requirements. Blanchard (2004) says that the CBS structure should contain the following five characteristics to be successful:

1. All essential costs related to the investment must be considered and allocated.
2. Categorising the costs which are to be identified with a function. The categories must be well defined so that doubling of cost does not occur, because poor definitions of the categories can cause inconsistency to occur in the decision and evaluation process.
3. The areas that are considered is to be well structured so that they can be coded in a way that one can analyze the costs for i.e. energy consumption, maintenance costs, spares etc. while other areas not of interest are virtually concerned.
4. The related investment should, through for example cross-indexing or codes, be compatible with the procedures of the work break down structure (WBS) and management accounting.
5. The cost structure of specific work packages should allow for identification which could require close control and monitoring to be able to separate for example costs related to a supplier from other cost drivers. (Blanchard, 2004)
Figure 3 Example of a CBS chart
4. **Model development**

In this chapter contains the development procedure of the model that is going to serve as a guideline to improve cost-effectively the productivity of an assembly station. Furthermore a cost break down structure and formulas for calculating the costs will also be presented here.

4.1 **Model of procedures to choose an materials supply method**

Above, in figure 4 there is an overview of the developed model presented. The model consists of six different steps, which will serve as a guideline for anyone that want to utilise the same approach as this thesis have done, and consequently get the desired input for improving the materials supply. The trigger behind starting the use of this model could be many; one is the continuous improvement mentality, that is to say constantly reviewing the current processes in a company to see what that could be done better, even if the specific process is working
properly. Secondly there could be technological improvements in newly developed materials supply methods that is worth to further investigate and compare it to the company’s current materials supply method. Consequently, the indication when to stop using the model should be when the productivity and cost-effectiveness calculations have been finished and an desirable result is achieved, meaning a suitable method have been selected.

**Step 1, define materials supply problem area:**
Assessment of the current situation is the first thing to do by gathering relevant data about the materials supply through observations. However gathering relevant data can be hard to do, since the material supply area is such a broad area it is easy to gather a lot of information that may not be relevant. That is why it is important to try to determine what data that is relevant and actually needed. The observations should be performed in the materials supply area, assembly line or stations (that is connected to the specific materials supply method). Additional information is collected to be able to further verify the problem area within the materials supply. Here unstructured and structured interviews have been added to the data gathering methods besides the observations. These interviews serves as a complement to the observations, since all needed data cannot be gathered only by observing the problem. Through the unstructured and structured interviews some additional data should be gathered from those personnel that are connected to the materials supply and assembly, such as production engineers, materials pickers, truck drivers, and assemblers. By going through the archival records of the company, i.e. intranet, verification can be done to further strengthen the perception of the considered problem area.

**Step 2, Develop different alternatives for materials supply:**
When having defined and verified the problem area within materials supply it is then time for finding alternatives for solving the issue and also evaluate them. The different alternatives chosen must be based on previous gained knowledge within the current materials supply situation thus fitting the company’s current processes. Not forgetting that the current materials supply method used in the company most definitely must be included in one of the alternatives, since it could turn out to be the best alternative after all.

**Step 3, Gathering data for CBS:**
An important step in the process is to identify the cost drivers for the different materials supply methods. This is made in a cost break down structure, and by doing this; it helps to get a more reliable decision base to stand on when must choose between the different alternatives. At the end of the day it all comes down to costs, and to be able to justify any alternative they have to be compared in their costs amongst other things. The cost drivers that are identified in the CBS should relate to time measurements that have been made for each activity within the different materials supply options. This is due to that it is easier to put a cost on time than it is to put costs on an operation and not to forget that time is also a variable to measure the productivity. In below figure the cost break down structure used in this study is presented:
This CBS should work as a framework when defining the cost drivers for each materials supply alternative. Now this framework may change depending on which kind of specific materials supply method and company that is studied. However it is important to keep in mind that some costs that are not identified here may be added in the model in that specific case. Regarding the time measurements, the time keeping have been divided up into two different categories which are, materials supply methods and assembly line. The reason for measuring time in assembly line is for seeing how the different materials supply methods affect selected operations in the assembly. Materials supply concerns the materials supply operations and consequently the assembly line concerns the assembly operations. Each category has different operations that are time kept; note that each time keeping of the different operations must be executed for each materials supply method.

*Materials supply* (concerns materials handler in table 3):

- Truck assignment to picking spot
  - Starting from the specific materials supply method area and retrieving replenished materials to fill the picking spot in the warehouse stock (which then is picked by the materials handler)
- Transport of materials (of the chosen materials supply method) to the assembly line.
- Starting from the specific materials supply method area and taking the articles from the pallet spot and transporting it to the assembly line and getting back to point of origin.
- Picking materials (of the chosen materials supply method)
  - The time it takes starting from the specific materials supply method area administration place and taking the articles from the materials facade in the warehouse and back to point of origin.

**Assembly line** (concerns assembler in table 3):
- Retrieving materials from the materials facade (for each materials supply alternative)
  - Starting from the assembly object and the time to get the materials from the materials facade and back to the point of origin.

<table>
<thead>
<tr>
<th>Materials supply method</th>
<th>Cost per hour for the operator (SEK)</th>
<th>Products produced per hour</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Materials handler (minutes)</th>
<th>Assembler (minutes)</th>
<th>Tot time / product (minutes)</th>
<th>Cost per product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternative 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alternative 3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 Costs per product for each alternative

So when calculating the cost per product in this table, the total materials handler time of articles per product is added with the total time that the assembler takes to handle the articles per product which gives the total time used per product. Since the time for each operation is in minutes the total time per product is divided with one hour (60 minutes). This, multiplied with the cost per hour for the operator, multiplied with the products per hour produced gives the cost per product. So this calculation should be executed for each alternative thus being able to compare it to each other. All of the calculations in this thesis based on the company’s costs are altered since it is sensitive information for the case company. The real costs have been divided with a specific factor and multiplied with another, thus it is still valid costs since it reflects the real information.

**Step 4, Assess productivity:**
The productivity is defined as the comparison between actual inputs of resources to the actual output of production (Schönsleben, 2007; Eliasson and Samuelsson, 1991). This simply can be calculated as:

\[
\text{Labour productivity} = \frac{\text{Direct time}}{\text{Total time}}
\]

Formula 5 Example 3 of productivity assessment (Eliasson and Samuelsson, 1991)
For this study the same assessment as the formula above will be used that is to say the labour productivity. The direct time concerns the time that a value adding activity is performed. Consequently the indirect time is when a non-value adding activity is occurring. Direct time for the assembler is when he/she is working on the assembly object, and the indirect time is when he/she is retrieving the materials from the materials facade. Total time represents how long time it takes to assemble one hauler (so called takt time). This assessment is to be made for each materials supply methods, and the out come will show in % how much time that is value adding time, and thus the rest will show how much in total that is non-value adding. An example is if the labour productivity is 94%, the remaining 6% is indirect time hence the non-value adding time.

**Step 5, Assess cost-effectiveness:**
Cost effectiveness \( C_e \) is defined as each investments cost for an improvement compared to each other, i.e. the proportion of the difference between the average cost per unit for the cost before the improvement \( B_b \) and the cost after the improvement \( B_a \) (Al-Najjar, 2006). It is calculated as follows:

\[
C_e = 1 - \frac{B_a}{B_b}
\]

*Formula 6 Cost-effectiveness example assessment (Al-Najjar, 2006)*

For this thesis, the cost-effectiveness will be calculated as:

\[
C_e = 1 - \frac{\text{Cost per product for the new materials supply method}}{\text{Cost per product for the Current materials supply method}}
\]

*Formula 7 Cost-effectiveness assessment for this study*

The cost per product only includes the costs for man hours for each selected operation in the different materials supply methods.

**Step 6, Selecting most suitable material supply method:**
Based on the productivity and cost-effectiveness the best suitable alternative must be chosen. A comparison of the productivity gain and the cost-effectiveness will be made. The comparison will be between the method which have the highest gain in productivity and consequently the highest cost-effective method. These two alternatives (or one alternative, meaning if one alternative has the highest score in both assessments) are compared to see which assessments that have the highest impact on profitability. It is also important to take the cost drivers, which may not have been identified with a specific cost in the CBS, into consideration.
5. Empirical findings

This chapter presents the data and information gathered at the case company and also a company description. It contains such things as the Volvo production systems, the kitting and line stocking processes, types of kits, and Volvos groups’ ergonomic standard.

5.1 Company description

Volvo Construction Equipment, here after called Volvo CE, originates from Volvo’s purchase of the tractor manufacturer Bolinder-Munktell in the 1950s. Not until 1937 did the company change its name to Volvo BM, after this they purchased Lihnells Vagn AB (Livab AB) that produced the dump trucks. In 1995 the company changes its name to Volvo CE after acquiring all the shares in the VME Group that was founded by Volvo BM and Clark Equipment. Today, Volvo CE belongs to the Volvo Group as one of its business units and employs about 13600 workers. The company is one of the world’s leading manufacturers of construction equipment products. Their products are mainly used in segments such as construction work, road construction, maintenance, waste disposal-, mining-, and forest industries (Volvo CE 175 years, 2007).

Within Volvo CE’s product range there are articulated haulers, which is assembled and partly produced in the Braås factory located in Sweden. This factory was built in 1955 by former named company Livab, which as previously stated was bought by Volvo in 1973. The worlds first articulated hauler called “Gruskalle” (see figure 7) was produced in 1966 by Livab. Today there are four base models assembled and partly manufactured at the company and those are A25, A30, A35, and A40 (see figure 6). The different models look almost exactly the same but differ in size and equipment. At present time, there are about 850 employees there. Volvo CE had a net turnover of 53.810 billion SEK in 2010 (Volvo CE annual report, 2010; Volvo CE:s intranet, 2011).
5.2 Volvo Production Systems (VPS)

Volvo construction equipment utilises an approach similar to the original version derived from Toyota Production Systems (TPS). Volvos goal with VPS is to raise the quality on their product by streamline and improve its businesses continuously. VPS aims to create common ways of work and common terminologies due to that there are many countries involved in the Volvo group and it is also vital for Volvo since this approach gives them the opportunity to remain competitive and to be able to retain the jobs in the high-cost countries.

Volvo CE uses VPS to detect and eliminate sources of waste. Volvo developed VPS by compiling the essentials both within the Volvo organisation and by studying external companies. VPS also try to offer value towards their four stakeholder groups that are owners, customers, society and co-workers. Benefits and value from the owner perspective could be higher profit in context to invested capital, the customers can gain increased quality and delivery precision, and society on the other hand can gain value in the shape of increased tax revenue, internships / educations, less environmental impact et cetera. Finally the co-workers can be provided a better work environment, secure employment and opportunities to develop within their way of working.

Volvo VPS approach is shown in figure 8 and takes form as a pyramid where the base is The Volvo Way. This serves as a foundation where the beliefs are that every individual has the ability, wish and strive to develop as human beings but also towards the interests of the company. VPS consists of five principles that serve as a backbone throughout the entire business to accomplish a vision of continuous improvement of quality, deliveries and productivity. The five principles are teamwork, process stability, built-in quality, just-in-time and continuous improvement. Team work means that with the help of cross functional teams, target controlled groups and a production adaptive organisation enables and encourages improvements of work processes. Process stability incorporates improvements of production results by decreasing variations in the production processes by using help tools in form of e.g. 5S, compensated production, standardised work tasks et cetera. Built-in quality is essential due to that it focus is aimed at the initial processes, to manufacture a product with accuracy from the beginning; this is done by having a system and company culture that is aware of the benefits it brings. Just-in-time principle means that by using takted flows, pull system, flexible staffing systems et cetera the company is given the opportunity to produce what is required in the right amount and at the right time. Continuous improvements is the propelling force for Volvo and by focusing on e.g. core activity development, design of improvement organisations and various help tools as VSM, Volvo tries to standardize processes which serves as a base that enables further conditions for improvements. The top of the pyramid which symbolises the value for the customers is the most important goal for Volvo to manage, this is in terms of customer satisfaction where Volvo strives for top of the line quality which inquires products to the lowest costs within the shortest time possible. (Volvo CE: Intranet 2011)
5.3 The line stocking process

Line stocking is the most utilised material supply method at the case company for the moment. The process starts with that the material gets received in the incoming goods reception (see figure 9 section 1). It is then transported on conveyor belts into the warehouse, which is then unwrapped and tagged with a specific part number and a location for it to go to. A truck then comes and picks it up to transport it to its given pallet rack location. When a task is given to pick the pallet (from MAPICS) from its location it is then transported by a truck to the specific area in the assembly. The procedure then repeats itself when the pallets are empty and need to be replenished.

5.4 The kitting process

Ever since materials kitting was introduced as a pilot project for materials supply it has been used for small and medium sized parts. Section 2 in figure 9 is the area where all kitting activities are performed, depending of what kit that is going to be picked the procedures varies. In the right corner of section 2 in figure 9 the buffer zone for picked kits can be seen. The centre left in the same section is the place where the computer for kit work orders are allocated, this area is also the point of start for the kit attendee. The surrounding pallet racks offers short movements for the kit attendees which makes it easier to pick the kits. All kits have to be picked before the next takt time expires, which means that the attendees have a time limit to compile the new kits.
For kits in arranged pallets and half pallets the assembly demand for more parts is made visual by the kit attendee when empty pallets get loaded in the buffer zone. These kits are handled as standardised kits where no order has to be printed out from the materials system MAPICS since the kits looks the same for all haulers. The kit attendee then follows the picking list that is placed on the pallet, to see if the picking spot, article number and amount are correct. When the kit attendee has reached the picking spot then he/she controls that correct article has been chosen by looking at a picture of the article and article number. After these steps the article gets placed in the arranged compartments where one further control is made to assure that right article and amount have been picked. When the kit is ready it is placed in the buffer zone waiting for the truck driver to get an order of the specific kit from the assembly. The truck driver then transports the ready kit to assembly and retrieves the empty kit pallet to the buffer zone.

The kits placed on carriers on the contrary have to be printed out from the system since these kits are not standardised and can vary in some extent dependent of required customer specifications for specific haulers. These kits are however also picked based on visual overview of the kit attendee when empty carriers have reached the picking area near the computer. The kitting process for carriers starts with visual recognition of the intended carrier to get picked, after that the kit attendee prints out a picking list out of the system MAPICS. Then the kit attendee grabs the carriers and pulls it to each section that is stated for the picking list and checks if it is the correct article and then puts it on the marked position on the carrier, this step also confirms further that it is the correct article that has been picked. When all articles have been gathered then the carrier is placed in the buffer zone. The final step is
then to sign of the picking order that was received from MAPICS. Kits free arranged in pallets are as for the carriers printed out from the system since these also varies based on specific customer specifications, the picking procedure does also look almost the same. These two types also have to be picked within the time limits of the takt time. (Volvo CE observations in kitting area; Volvo CE:s Intranet 2011)

5.5 Types of kits
When materials kitting was introduced in Volvo CE Braås not long ago as a pilot project, there were not many different types of kits. As time has progressed, the amount of types of kits has also progressed. There are currently two main types of kits which are in use at the company, and these are kit carriers and kits in pallets. However the “kit carriers” type has two sub-types of carriers, i.e. two different models of carriers. The kits in pallets have also two sub-types, each main type with its sub-types are described below:

Kit carrier SL10201
In figure 10 the first type of kit carrier is displayed which is named SL10201. The prefix SL stands for “Standard/Large” and the containing materials are intended for the articulated hauler models A35F and A40F (which can be seen in figure 6 in the company description section). This carrier is specially designed for being able to hold mainly hydraulic hoses and cables, especially longer ones. As seen in the figure below the carrier has four wheels in order for it to be more flexible, so that the assembler can move it around the assembly station. There is also a packing slip pocket (*a) that is attached to the carrier so that the kit attendee can check of the materials that he/she has put on. In this kit a picture of how a full kit carrier looks like is attached (*b). This has the purpose of minimizing the risk of putting on wrong types of materials, and making it easier for the employee who gathers the materials to see how to put them on. Below the hoses some small boxes (*c) are placed with purpose of holding smaller materials that are needed in the kit.

Figure 10 Kit carrier SL10201
Kit carrier SM10202
This type of kit carrier (see figure 11) have a more mixed set of materials kit, for example racks, pipes, and hoses. However they are intended for the smaller size model such as articulated hauler models A25F and A30F, thus the prefix SM, which stands for “Standard/Medium”. Furthermore, as the previous carrier, a packing slip, picture of full kit and a small box is also attached.

![Figure 11 Kit carrier SM10202](image)

Kits free arranged in pallet
This kit type (see figure 12) fulfils its purpose although not as organised, because here all parts needed for an assembly station is put into an L-pallet where no particular consideration of parts allocation has been thought of. But since this type of contains more or less bigger parts it is not easy to make arranged pallets due to this. Kits free arranged in pallets was the initial way of kitting, kit carriers and kits in arranged L and K-pallet which is described below is new and developed spinoffs of free arranged kits.
Kits in arranged pallet
Kits arranged in L-pallets are most commonly utilised at Volvo and are used for medium sized parts. As can be seen in figure 13 there are parts arranged in compartments that is fitted for the parts with the help of a wooden frame. In order to ease the work for the kit attendees there are in some cases pictures on the inside of the pallet which shows where the parts in mind should be placed. For kits arranged in K-pallets and L-pallets it is common that they are prepared for three machines at a time for a specific assembly station.
Kits in arranged half pallet

Kits arranged in half pallets as can be seen in figure 14 is managed for small components, mainly for the SL series which incorporates as previously said the models A35F and A40F. SL stands for standard-large, although arranged pallets are to be standardised, the wooden frame within the pallet is removable due to that it have to be flexible for possible changes of component arrangement. Since request of customer demands can come to change which means that the inner frame may have to be reconstructed. Half pallets are commonly used when there are either enough space requirements to fit mentioned pallet size or if the materials facade in assembly requires it due to lack of space. There are however problems with pallets of this size because it requires several events of movements when the empty pallet are to be replaced since there are always two pallets assigned to each pallet rack. Movement means time consumption and time means money. But the positive side is that it saves space allocation. (Volvo CE observations in kitting area; unstructured interviews with production engineer)

5.6 Cost break down structure of materials kitting

When the cost of kitting is going to be calculated there will be several cost factors that will be focused on (see figure 5). The cost of kitting in this case means the cost of utilizing materials kitting and not implementing it. Certainly there are several other cost drivers that is impacted by materials kitting, but three main focus areas have been selected in this case that are going to affect the calculation of the kitting cost. These are kit attendee, trucks, and assemblers which each and one have their sub costs. For the kit attendee the first sub cost is cost for man hours i.e. salary per man hour which only includes the time that it takes for the employee to compound the complete kit.

Second sub cost is the cost of ergonomics which is extremely hard to put a cost on due to that it is almost impossible to derive how ergonomic improvements caused by kitting is affecting e.g. sick release, injuries et cetera in either a positive or negative way. However it is very important to take into consideration since it most certainly has an impact on the workforce, due to that there will always be different ways of handling the materials involved e.g. lifting, bending, kneeling et cetera. Hence it will still stay as a cost factor, but no specific cost can be identified only if it will involve proper or bad ergonomics. The cost of quality in the case of the kit attendee involves how many times that the worker picks wrong materials for the kits and how much time it takes to correct the mistake. Same principle goes here as the previous sub cost, i.e. that no specific cost can be identified. This is due to that it is not possible to
calculate how picking wrong materials for the kit can impact the total cost, even though it should have an impact on the cost but in a way that it will not be possible to calculate during this study. However, it is very relevant to simply take into consideration.

The second main focus area is the trucks with their operators, and here there are three sub costs identified. These are cost of man hours (salary per man hour that it takes to transport the kits), amount of tasks (how many tasks for the trucks that are related to the kits), cost of quality (damage to the materials when handling).

For the assemblers three different sub costs has also been identified. Cost of ergonomics is also very hard to determine as previously said, though important to consider. In the case of the assembler the “quality cost” incorporates approximately how many times the materials that come from the kits are wrongly assembled, which also will not include a “real” cost but just as a consideration. Cost of man hours includes the time that it takes to assemble the materials when the materials’ kitting is used. (Volvo CE observations in general; Volvo CE unstructured interviews with production engineer)

5.7 Volvo groups ergonomic standard

Volvo is a company that takes work environmental issues very seriously and to be able to have clear guidelines to follow, the corporate group have set up an ergonomic standard conforming to the European council directive 90/269/EEC. This standard also refers to European demands about machinery safety. The standard is not only meeting the demands of the Volvo group, it also falls under categories within the Swedish work environmental authority regarding ergonomics and manual handling (AFS 1998:1 and AFS 2000:1). Volvo uses the standard as base for developing both new and old workplaces and workplace design changes. This standard is also important when it comes to the actual procedures involved in the entire corporation, from material supply to assembly. Work postures and work movements are important aspects incorporated in the standard and include many factors to take into considerations. This means that at least 80 % of the total work time is to be performed within the boundaries of comfortable and accurate ergonomic posture. Requirements for proper work posture mean that the muscles and joints are applied with work load when standing up straight (neutral position).

Figure 15 shows the ergonomic boundaries that workers preferably should stay within; the following text will be explaining the issues and set targets regarding ergonomics within the work environment. In the standard it says that the grip and working distance is taken into consideration and that is to work mainly within a range of a fore arms distance from the body. There are also set standards concerning the maximum load of using one hand only, which is 0.5 kg for overhand grip and five kg for underhand grip. Certain targets or goals in the standard concerns which work posture angles that are acceptable e.g. less than 20° forward bending, less than 15° twisting, and less than 15° bending sideways of the back is the goals to achieve with good work postures. The goals for the neck includes to have less than 15° bending forwards, 15° twisting, sideways bending and 0° bending backwards. There should
also not have more than a 30° between the upper arm and the body, the wrist should also not be put over more than 30° bent upwards and less than 20° bent sideways seen from the sides of the thumb and little finger. If the some of the criteria’s in the above mentioned text are exceeded then the risk of injury increases.

There are however set goals in the standard concerning the work movement as well. Where proper work movements mean that there should be variations and opportunities for recovery for joints and muscles between work movements. There shall also not be movements that are monotone or highly repetitive; it should instead allow dynamic muscular work with reasonable pauses. Bottom right in figure 15 shows postures that shall not occur in longer periods or often, the postures shown are squatting, sitting on both knees, on one knee, stepping and inclining plane. Bottom left in figure 15 shows a table of which lifting frequency per hour and weight allowed in respective ergonomic zone i.e. green, yellow and red. (Volvo CE Intranet, 2011)
6. Data gathering and analysis

This chapter presents the execution of our model developed. Each step that was in the model have been analysed and explained throughout this chapter.

6.1 Define materials supply problem area

Here the current state of the materials supply has been studied and presented to get an understanding of the current problem. Furthermore a description of the facility process layout is presented in order to get a holistic view of how the materials are transported between the warehouse and to the assembly area. Further unstructured interviews and observations have been executed here.

![Facility process layout](image)

In figure 16 a facility map over the materials centre and the assembly is presented. Just outside the materials centre lays the incoming goods reception (1.) where all incoming delivery trucks unload their cargo. The materials that are unloaded are put on conveyor belts which transport the materials into the warehouse. This is then unpacked and receives a pallet id for the reason of knowing what kind of material it is and where to stock it. When this is finished the pallets are picked by trucks that transport it into the specific pallet space somewhere in the warehouse facade or the materials kitting area (2.). The materials is both picked in kits and transported to the assembly line which house 25 assembly stations (altered...
amount) (3.) or transported directly in ordinary pallets and placed along side the assembly line i.e. line stocking. (Volvo CE observations in warehouse and assembly)

6.1.1 Current materials supply method
Today the majority of the materials supply to assembly at the company is the traditional line stocking. That is to say that material is placed in pallets just alongside the assembly line stations and is replenished as it is running out. In October 2010 a pilot project began, this projects purpose was to introduce materials kitting to the assembly lines as an alternative materials supply method. One improvement team suggested an implementation of this method in order to improve the materials supply. However the materials kitting was already in use before but in a different form and actually not intended to be a “kit”. Before there was a major shortage of places to place the pallets, which housed one sort of part each but in larger quantities, alongside the assembly lines (which is still in some extent the current state as well). This led to placing different materials in one pallet for being able to have all materials close to the assembly, and in that way, not intentionally, creating kits. Important to note is that these “older” versions of kits did not have the same structure and implication as it has today, hence the “real” introduction of materials kitting was not until much later. The problem here is that there are no proper measurements of how materials kitting impact e.g. the material centre i.e. material handler since the need of a material handler will increase with the introduction of kits. However there have been sorts of measurements of how the materials kitting impact the assembly, but no exact and reliable figures. They know that this alternative have a positive impact on the productivity, and presumes that the same impact goes for ergonomics and quality, but as stated not entirely sure. The other aspect is that their current state has not been compared to the new suggested material supply method, which could turn out to be the best alternative after all. (Volvo CE observations warehouse and assembly; unstructured interview with production engineer)

6.2 Develop different alternatives for materials supply
Based on the previous gained knowledge there are actually two main types of materials supply that are going to be studied. These are materials kitting and line stocking, however the materials kitting has several sub types which are presented as kit carriers, free arranged kits in pallet, and arranged kits in pallet. The reason for why no other alternatives were chosen was because they fitted into the company’s current layouts and processes. First type of materials supply alternative was line stocking which is mainly their current materials supply method today. The kits however, have just started as a pilot project and have not been studied in any major depth to see if it has flaws or how it really affects the company.

6.3 Gathering data for CBS
When having created a cost break down structure of the identified cost drivers, the data for this purpose is gathered. This includes such things as measurements of time within the
different operations in the materials supply and the assembly, ergonomic movements and postures, and quality issues.

6.3.1 Cost drivers for the CBS
In figure 6 in the model development chapter the identified cost drivers are presented. In this case, the cost of the material supply method concerns line stocking and kitting. For line stocking the identified costs for the material handler are removed since there is no requirement of a material handler when using line stocking. There are only the other cost drivers for the assembler and means of transportation that is included in line stocking.

Cost of material supply methods
The cost for man hours is 1000 SEK per hour (altered cost) for every operation (material handler, means of transportation and assembler) in both the material supply department (which includes both line stocking and kitting) and assembly department. This cost includes overhead costs such as, rent, energy costs, insurance, maintenance, and also all other direct costs such as labour and materials, which is divided with the amount of production hours for all employees.

Cost of ergonomics for both material handler and assembler was not possible to add costs to, due to time limitations set, but also due to the complexity to determine which costs that can be derived from ergonomic issues. The possibility of putting costs on ergonomic issues would be plausible if the study were to be conducted for a very long period of time. Therefore it is a very important aspect to consider in the CBS. Likewise is the cost of quality which was very hard to put costs on, but if there were enough reliable documentation on previous quality issues related to material handler, assembler and transports there would most definitely be possible to put cost on quality.

Means of transportation for material handler in all alternatives concerning line stocking only incorporates the transport from warehouse to the materials facade of the assembly and back (which also uses the cost of man hours to be able to calculate the cost), so no costs for further material handling is considered. The downside here is that the assembler needs more time to retrieve the articles from the materials facade. But the cost per product is still not that high compared to the other alternatives. Transportation costs do not either differentiates much between kits free arranged in pallets or in arranged pallets (lower than line stocking), in these alternatives it is the picking time that generates most of the costs.
Table 4 Cost of materials supply methods

<table>
<thead>
<tr>
<th></th>
<th>Material handler (minutes)</th>
<th>Assembler (minutes)</th>
<th>Tot time / hauler (minutes)</th>
<th>Cost per product (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SL10101</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
<td>0.96</td>
<td>2</td>
<td>2.96</td>
<td>49.3</td>
</tr>
<tr>
<td>Free arranged in pallet</td>
<td>2.21</td>
<td>3</td>
<td>5.21</td>
<td>86.8</td>
</tr>
<tr>
<td>Arranged pallet</td>
<td>2.31</td>
<td>2</td>
<td>4.31</td>
<td>71.8</td>
</tr>
<tr>
<td><strong>SL10302</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
<td>0.73</td>
<td>1.4</td>
<td>2.13</td>
<td>35.5</td>
</tr>
<tr>
<td>Free arranged in pallet</td>
<td>2.23</td>
<td>2.1</td>
<td>4.33</td>
<td>72.2</td>
</tr>
<tr>
<td>Arranged pallet</td>
<td>2.22</td>
<td>1.4</td>
<td>3.62</td>
<td>60.3</td>
</tr>
<tr>
<td><strong>SL10201</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
<td>1.05</td>
<td>2.2</td>
<td>3.25</td>
<td>54.2</td>
</tr>
<tr>
<td>Free arranged in pallet</td>
<td>2.02</td>
<td>3.3</td>
<td>5.32</td>
<td>88.7</td>
</tr>
<tr>
<td>Kit carrier</td>
<td>6.15</td>
<td>0.58</td>
<td>6.73</td>
<td>112.2</td>
</tr>
<tr>
<td><strong>SM10202</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
<td>1.21</td>
<td>2.2</td>
<td>3.41</td>
<td>56.8</td>
</tr>
<tr>
<td>Free arranged in pallet</td>
<td>2.15</td>
<td>3.3</td>
<td>5.45</td>
<td>90.8</td>
</tr>
<tr>
<td>Kit carrier</td>
<td>6.45</td>
<td>0.58</td>
<td>7.03</td>
<td>117.2</td>
</tr>
</tbody>
</table>

In table 4 all the time measurements made (figures are round off) in each operation (for material handler and assembler) have been multiplied with the cost of man hours and production rate per hour (altered rate), which is then presented as the cost per product for each alternative. In the material handler operations the transportation time measurements are also incorporated. This table have been based on the data from appendix 5 and 6.

In appendix 8 a picking list for one kit is presented. Each article from the kits that arrive to the warehouse (in full pallets and displayed as qty per inner emb.) where divided with the amount of articles that where in the kits (displayed as qty), this led to getting the total time for both pallets and small box (SB) assignments per hauler. This data together with the raw data from appendix 8 are then used in both appendix 5 and 6.

### 6.3.2 Ergonomic movements for kit attendee

When the kit attendee is gathering the parts for the intended kit, he/she will perform different movements in order to reach the materials. Following the ergonomic standard set by Volvo CE, each kit has been studied for its ergonomic movements and the following movements have been identified. Important to note is that the amount of movements shown in each kit is only calculated for one order i.e. for one machine. The amounts of movements vary depending on what kind of kit that is picked, what kind of materials, and the amount of materials. It is impossible to determine exactly how many movements there is due to that there is different height on persons that is attending the kits and some may pick several parts in one movement. For this reason every movement represents only one material picked.

(Measurements made at Volvo CE 2011; Volvo CE Intranet, 2011)
6.3.3 SL10101 ergonomic movements

For this kit, which was a kit in a pallet, there were these movements identified (see figure 17). Five movements where in the red area for which the kit attendee was forced to either kneeling down or bend more than 60°. Furthermore, some materials picked required standing on tows and reaching over one’s head. The two movements in the green area had materials that were rather heavy. Regarding the three yellow area movements no special notes were taken down. (Measurements made at Volvo CE; Volvo CE Intranet, 2011)

6.3.4 SL10302 ergonomic movements

For this kit, which also was a kit in a pallet, there were these movements identified (see figure 18). Four movements where in the red area for which the kit attendee was, as previous kit, forced to either kneeling down or bend more than 60°. As the previous kit, some materials picked required standing on tows and reaching over one’s head. The three movements in the green area had materials that were not that heavy. No movements in the yellow area were identified for this kit. (Measurements made at Volvo CE; Volvo CE Intranet, 2011)

6.3.5 SM10202 ergonomic movements

For this kit, which was a kit on carrier, there were these movements identified (see figure 19). Seven movements where in the red area for which the kit attendee was, as previous kit, forced to either kneel down, bend more than 60°, raise arms higher than the head and twist the hand depending on which component that was picked. The three movements in the green area had materials that were not that heavy. There were also on movement in the yellow area due to that the parts pallet was put on a withdrawable compartment, which means that one did not have to bend down to exceed the 60° angle applicable for the red area. (Measurements made at Volvo CE; Volvo CE Intranet, 2011)
6.3.6 SL10201 ergonomic movements

For this kit, which also was a kit on carrier, there were these movements identified (see figure 20). Seven movements where identified in the red area for which the kit attendee was, as previous kit, forced to either kneel down, bend more than 60°. As the previous kit, some materials picked required standing on tows, reaching over one’s head and twist of hands. The three movements in the green area had materials that were not that heavy and offered the attendee good work postures and movements. As for the previous kit there were one movement identified in the yellow area, where the posture and movement touched upon the boundaries of green but not quite. (Measurements made at Volvo CE; Volvo CE Intranet, 2011)

Figure 20 SL10201 Ergonomic movements (own edited picture from Volvo CE:s intranet, 2011)

6.3.7 Outcome for material handler ergonomic movements

For the material handler the ergonomic movements and postures are not that positive in the case of kitting. The kits in pallets have somewhat poorer ergonomic movements since they require a lot of bending down to put the materials in the pallets. Kit carriers on the other hand offer the material handler to place the material in the ergonomic strike zone. Otherwise the activity of picking and reaching the material from the materials facade in order to place it in the kits, have likewise movements and does not differ in any extent. Line stocking is consequently lacking ergonomic movements due to the fact that the pallet is handled only by trucks.

6.3.8 Ergonomic movements for assembler

When the assembler is gathering the parts for the intended hauler, he/she will perform different movements in order to reach the materials. Compared to the material handler the ergonomics for the assembler has not at all the same impact since the material handler has to go to many different article locations to attend the kits. For the assembler there are two different ways to get materials, one is from a kit carrier and the other is from a pallet. The pallet on the other hand can be either a kit pallet or an ordinary pallet. The reason why there were only two different types of ways to get materials considered is because the ergonomic movements for both the ordinary pallet and kit pallet does not differ anything regarding height, weight, and size. For the assembler, the major ergonomic issues are when they assemble the materials on the hauler itself, and not so much when picking the materials from the pallet racking which is irrelevant to study since the assembly activity does not have anything to do with how the material is supplied.

However, there are still specific methods of materials supply that are preferred by the workers. First up is the kit carrier, due to the reason of the flexibility of the carrier, i.e. the possibility of moving it around the assembly object and reaching it easy, unnecessary travel distances are thus minimised. In terms of ergonomic movements for kit in pallet or ordinary
pallet there were no specific method preferred due to that the movements of reaching the materials, and amount of heavy lifting did not differ anything (Interview of assembler and supervisor, see appendix 1).

6.3.9 Outcome of ergonomic movements for assembler
On the contrary to the ergonomic movements for the material handler, the ergonomics for the assembler is much better depending on what material supply method that is used. Kits in pallets (both free arranged and arranged) compared to line stocking ergonomic movements are somewhat better since the kits in pallets are placed on withdrawable compartments that do not require bending down as much as the line stocking requires. Kit carriers have the best result of ergonomic movements and postures for the assemblers, due to that the materials are placed in the ergonomic strike zone and also that the carrier comes on wheels and can be moved around to fit the assemblers desired position.

6.3.10 Quality aspects for the kit attendee and the assembler
The quality aspect for the kit attendee involves picking wrong materials for the kits, and amount of damages occurred on the kitted materials. At the moment there are a rather frequent rate of picking wrong materials for the kits, this is due to different reasons. One is the stress factor, when a kit have been used in the assembly they do not always send it immediately back to the kitting area and stock several kits before sending them back. This leads to heavy workload for the kit attendees sometimes when several kits get returned at once for replenishment. The reason for why the assemblers send the kits in such a way is due to that it is more convenient for them to wait until most of all kits are used instead of ordering a new kit as each kit is used up. There are actually not many damages on kitted materials, due to that the kit attendee can check the materials for quality issues before picking it for the kit and also that it is placed in such a way that the risk of damages are minimised. The only damage risk that is involved in kits is the ones that are placed in free arranged kits. This is due to that the materials is “loose” and can move around when e.g. the truck driver makes a fast turn, and in that way damages to the paint can arise (Unstructured interview with kit attendee).

According to the assemblers there are some times per week that they do pick wrong materials from the kits. But this is however most often due to that the kit attendee has put in wrong materials in the kit itself. At rare occasions there are wrong materials assembled on the hauler even if the kits are in order, this is due to that some components looks alike but have different article numbers hence there have been mistakes concerning putting on the wrong materials. The most preferred materials supply for quality concerns are also the kit carrier. Even though that both the kit carrier and the kits in arranged pallet have pictures and article numbers attached on them to minimise the risk of assembling wrong materials, the kit carrier is still preferred since it is visually better in contrary to the kits in arranged pallets which is also the secondly preferred materials supply method. There are rarely damages occurred on the materials from the kits, so no specific amount of times that it had happened was reported. However the occurrence of damages is most common when supplying materials in ordinary pallets, i.e. line stocking. (Interview of assembler and supervisor, see appendix 1)
6.3.11 Quality outcome
The most quality issues were found in line stocking since there were a lot of materials put together in one pallet thus it could damage the material in the pallets when handling it. Kits on the other hand is hand picked by the material handler and in that way gets a sort of visual “quality check” before placing it in the kits. Amongst the kits the free arranged pallets had the poorer quality since it was placed “loose” in the pallets thus when the truck driver transported it and made any quick turns it could move around and in that way get damaged. The kit method that had the least quality issues was the kit carriers due to that it was placed in such a way that the movements when transporting it was minimised and the articles were not in contact with each other.

6.4 Assess productivity
In this step, the calculations of the productivity are going to be displayed

6.4.1 Productivity assessments
In figure 21 the results from the productivity assessments are presented which are based on the calculations from appendix 3. The calculations that are presented in figure 21 are calculated as:

\[
\text{Labour productivity} = \frac{\text{Direct time}}{\text{Total time}}
\]

Formula 8 Labour productivity assessment (Eliasson and Samuelsson, 1991)

The direct time represents the indirect time subtracted from the total time; indirect time in this case can be seen in appendix 2. Total time is the time it takes to assemble one hauler, which is 60 minutes (takt time). When the labour productivity is presented as 0,963 (for line stocking in SM10202, in figure 21) it is that 96,3% is value adding time which means the assembler is doing assembly activities on the hauler. The remaining 3,7% is the non-value adding time where the assembler only retrieves the materials before assembling. In order to calculate the direct time it is needed to calculate the indirect time, which can be seen in appendix 2, assembler (minutes) for kit carrier in SM10202 as an example. Indirect time is then subtracted from the total time, takt time (minutes) as seen in appendix 3 which gives the direct time. Labour productivity is then calculated as:

\[
\frac{\text{Direct time}}{\text{Total time}} = \frac{59,42}{60} = 0,99 = 99\%
\]

Formula 9 Labour productivity for this study

In figure 21 it can be found that the kit carriers were the most productive alternative. Higher productivity in the kit carriers are due to that the assembler saves some time in the material handling/retrieving.
Kits in arranged pallets have the same productivity as line stocking. This is due to that the assembler takes approximately the same time to retrieve the materials from kits in arranged pallets as to retrieve the materials from line stocking.

The kits in free arranged pallets are somewhat less productive than line stocking. The reason for this is because the articles are placed free and it takes longer time for the assembler to find the right article amongst the other kitted materials. In line stocking there is only one article to retrieve, which is why there is no need for the assembler to take the time to figure out what article to pick.

### 6.4.2 Productivity outcome

As seen in figure 21 the productivity of each alternative is rather different. The alternative with the best productivity was the kit carriers, due to the fact that it saved a lot of time for the assembler when retrieving the material. Free arranged pallets were found to be less productive than all the other material supply methods. This was due that the time for “finding” the right material in the free arranged took longer time to find than in the arranged pallets. One reason for this was because the arranged pallet was a lot more visually better for the assembler, with pictures and article numbers under the material itself indicating what material that is used. Arranged pallets were found to have the same productivity as the line stocking.

<table>
<thead>
<tr>
<th>Labour Productivity in assembly</th>
<th>Productivity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SL10101</strong></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
<td>0.937</td>
</tr>
<tr>
<td>Free arranged pallet</td>
<td>0.960</td>
</tr>
<tr>
<td>Arranged pallet</td>
<td>0.967</td>
</tr>
<tr>
<td><strong>SL10302</strong></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
<td>0.977</td>
</tr>
<tr>
<td>Free arranged pallet</td>
<td>0.986</td>
</tr>
<tr>
<td>Arranged pallet</td>
<td>0.977</td>
</tr>
<tr>
<td><strong>SL10201</strong></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
<td>0.980</td>
</tr>
<tr>
<td>Free arranged pallet</td>
<td>0.985</td>
</tr>
<tr>
<td>Kit carrier</td>
<td>0.980</td>
</tr>
<tr>
<td><strong>SM10202</strong></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
<td>0.980</td>
</tr>
<tr>
<td>Free arranged pallet</td>
<td>0.985</td>
</tr>
<tr>
<td>Kit carrier</td>
<td>0.980</td>
</tr>
</tbody>
</table>

Figure 21 Labour productivity outcome

### 6.5 Assess cost-effectiveness

In this step, the assessment of the cost-effectiveness is going to be displayed.

#### 6.5.1 Cost-effectiveness assessment

All the different material supply alternatives were compared to the current material supply method, which was line stocking. The cost-effectiveness assessment include the cost per product (for each material supply method in table 4), indirect time for assembler (see table 4 assembler (minutes) column), price per minute for assembly (price per hauler divided with 60 minutes, see table 4 price per hauler column), and x which stands for the not known
production costs per hauler (includes materials costs). Price per hauler represents how much a customer will pay for one hauler.

The cost-effectiveness assessment (see formula 10) was made based on formula 7, which was based on Al-Najjars (2006) formula for cost-effectiveness (see formula 6).

\[
C_e = 1 - \frac{x+(\text{indirect time} \times \text{price per minute})+ \text{cost per product} (\text{New materials supply alternative})}{x+(\text{indirect time} \times \text{price per minute})+ \text{cost per product} (\text{Current materials supply alternative})}
\]

Formula 10 Cost-effectiveness assessment for this study

Results achieved in formula 11 and 12 were based on formula 10, which is calculated as: not known production costs plus the indirect time for the assembler multiplied with the price per minute plus the cost per product he cost per product. This is made for both the current and new materials supply alternative and divided with each other.

An example of a calculation made for the cost-effectiveness would be (taken from SM10202 kit carrier / Line stocking):

\[
1 - \frac{x+(0.58 \times 66667) + 117,2}{x+(2,2 \times 66667) + 56,8} = 1 - \frac{x+38784,06}{x+146667,4}
\]

Formula 11 example assessment of cost-effectiveness

Another example of a calculation made for the cost-effectiveness would be (taken from SL10101 Free arranged in pallet / Line stocking):

\[
1 - \frac{x+(3 \times 66667) + 86,8}{x+(2 \times 66667) + 49,3} = 1 - \frac{x+200087,8}{x+133383,3}
\]

Formula 12 Example 2 assessment of cost-effectiveness

6.5.2 Cost-effectiveness outcome

As can be seen from formula 11 the most cost-effective alternative is the kit carriers. Even if the kit carriers cost per product is higher than line stocking cost per product it does not affect the outcome since the time saved in assembly is worth a lot more. All essential costs that are taken into consideration makes the cost-effectiveness much more fair since if it would only be up to the cost per product, the outcome would not be the same. Important note is the not known production cost; since it was not possible to get this cost it was included in the assessment as an x. In this case it is not possible to get an exact number of how much more cost-effective or less cost-effective any alternative is. However in the case of formula 11 it can be found that the kit carrier alternative will always be positive no matter what the value of x is. This is due to the numerator is higher than the denominator. Arranged pallets was found to be almost exactly the same in cost-effectiveness as line stocking, this not due to the cost per product, even if line stocking was also cheaper than arranged pallet, but it was due to that they had the same indirect time which gives the same price per minute. Regarding the free arranged pallets it was found that they were the least cost-effective alternative amongst all as
can be seen in formula 12. This was due to that the assembler time (indirect time) was higher than the time for the line stocking and in that way increased in costs.

6.6 Selecting most suitable materials supply alternative

Based on the gained knowledge from the ergonomic outcome, quality outcome, cost-effectiveness- and labour productivity assessments it was found that the kit carrier was the most cost-effective and had the highest labour productivity. Ergonomic measurements showed that the materials kitting had worst impact on the materials handler, but the best impact on the assembler. However the kit carriers were the best alternative concerning ergonomic postures and movements of the assembler. Same outcome was for the quality issues where kit carriers had the fewest quality issues. Line stocking had the lowest score in quality, i.e. highest quality related issues of damages to the materials.

Just to show how labour productivity is beneficial in costs, an example calculation will be shown below:

Cost for one articulated hauler: 4 000 000 SEK (altered cost)

Labour productivity for kit carrier (SM10202, see figure 23): 0,99 (99%)
Labour productivity for line stocking (SM10202, see figure 23): 0,963 (96,3%)

\[
\begin{align*}
0.99 \times 4 000 000 &= 3 960 000 \text{ SEK} \\
0.963 \times 4 000 000 &= 3 852 000 \text{ SEK} \\
3 960 000 - 3 852 000 &= 108 000 \text{ SEK}
\end{align*}
\]

This shows that the indirect cost (non-value adding activity) is 108 000 SEK more per hauler for using the line stocking method compared to the kit carriers. Now comparing cost-effectiveness calculations to the labour productivity calculations it is clearly shown that it is more beneficial to use the kit carrier alternative than using line stocking in this specific case.
7. Results

This chapter presents the results achieved based on the data that have been analysed in the previous chapter. Furthermore, the developed model in this thesis will be discussed in order to see how it has worked out.

7.1 Outcome of the model utilised

The model developed for this thesis was divided up into seven different steps, which showed how to proceed when wanting to investigate a material supply problem area and selecting the most suitable alternative to solve the problem. Each step in the model will be discussed to see how it has worked out throughout this study, and what result it gave.

7.1.1 Step 1, Define material supply problem area

This step involved a lot of observations, to try to find the specific material supply problem area. It was really hard to be 100% sure of the problem just by doing the observations, however it gave a lot of information that was going to be analysed to be able to specify the problem. This information can provide a lot of irrelevant data for the intended problem, but should be analysed to get a holistic view of the material supply and assembly.

With having made the observations and analysed all gathered data, it was now time to verify the problem area. By adding archival records search (company intranet), unstructured and structured interviews to the research method, besides further observations, it was possible to go into further depth of the problem area. All the data gathered in this step was sorted out in order to eliminate the irrelevant data. This made it possible to gain further knowledge and verify the problem.

7.1.2 Step 2, Find different alternatives for material supply

When the problem was identified and verified it was found that there was only two main types of alternatives that fitted into the company’s current layout and process. That is why these two alternatives were selected and no further investigation about other possible solutions was made.

7.1.3 Step 3, Gathering data for CBS

The cost break down structure that was made to find the cost drivers was really helpful. This gave the possibility of really seeing what costs that was going to affect the coming assessments. Furthermore it served as a guideline when doing the time measurements, since the cost-drivers identified, pointed out what kind of activities and operations that should be measured, and calculated. Since there are many different operations and activities in the material supply and assembly, it was of great relief that there was some kind of indications of what to investigate.
7.1.4 Step 4, Assess productivity
When searching for productivity formulas, formula 7 was found. The formula concerned labour productivity. This type of productivity assessment was chosen since it fitted this study in that sense that there was time saved in labour that the measurements concerned. Assessing the productivity is very important since it is this assessment that can determine what alternative to use in the end. Even if the new materials supply alternative could be less cost-effective than the current materials supply alternative, the new alternative could be more productive and more beneficial in the long run. The productivity assessments executed in this study have been satisfying, and are believed to be accurate and reliable.

7.1.5 Step 5, Assess cost-effectiveness
There were actually several cost-effective calculations made, first the yearly costs for each alternative were calculated in the formula which was found to be somewhat wrong. This was due to that the formula said that the calculations should be with the cost per unit, which in this case was one hauler, before and after the improvements were made. So the second calculations were made with respect to the cost for one unit instead of the cost for the yearly production. However, it was still very hard to assess the cost-effectiveness since it was not possible to get hold of a relative production cost. This led to that the variable x was implemented in the assessment, which represented the not known production cost. So it was not possible to get an exact number of cost-effectiveness, but it was still possible to see if the cost-effectiveness outcome was positive or negative. No matter what the x would be the assessment would be the same, since the indirect cost, price per minute and cost per product are still the same. Since the kit carrier had the lowest numerator and the highest difference between the denominator and the numerator compared to line stocking, it is believed to have the highest cost-effectiveness compared to the other alternatives, even if it was not possible to get an exact number. Consequently a lower numerator compared to a higher denominator will give a positive result (see formula 11), and vice versa a higher numerator compared to a lower denominator there will be a negative result (see formula 12).

7.1.6 Step 6, Selecting most suitable materials supply alternative
There were several factors that had to be taken into consideration when selecting the most suitable materials supply alternative. Since some factors, i.e. ergonomics and quality, were not possible to put any numbers on it was only considered as the employees saw it. That is why these considerations may not be very objective; however it does reflect how the employees perceive the different alternatives. Regarding the productivity and cost-effectiveness calculations it was found that the kit carriers had the highest result in both. Ergonomic and quality considerations was also seen as most beneficial in the case of kit carriers, with one exception which was that the ergonomic movements and postures was poorer for the material handler than for the assembler when using kit carriers. But even with this exception it is a fact that the kit carrier is more beneficial than line stocking and the other kit types. Using kit carriers will give 108 000SEK less costs per product than the use of the current material supply method (line stocking) with the labour productivity increase. The cost-effectiveness assessment also concluded that the kit carrier was more cost-effective than the line stocking alternative but not exactly how much.
8. Conclusions

Our conclusions that are based on the analysis and results are presented here. It is also here where we answer our problem formulation.

Our problem formulation reads:
- How is it possible to improve cost-effectively the productivity of an assembly station in engineering manufacturing businesses with respect to, ergonomics and quality of semi-finished products?

In this specific study it was concluded that it was possible to cost-effectively improve the productivity of an assembly station with the chosen material supply alternatives. Thus it is more cost-effective and productive to implement the new material supply method (kit carrier) when comparing to the other alternatives (line stocking, kits free arranged in pallets, kits arranged in pallets). This was due to several reasons; first one was because the kit carriers allowed the assembler to save a lot of indirect time, i.e. retrieving and looking for material, and in that way the direct time became higher. The direct time was worth a lot since they produced one hauler per hour, which meant that it gave an income of 4MSEK per hour. Consequently 66 667SEK per minute, and since the kit carrier saved at the lowest one minute per hour compare to line stocking, the earnings are evident.

As seen in the ergonomic analysis of the material supply methods it was found that the kit attendee has more non-ergonomic movements for reaching/retrieving the material from the materials facade than the assembler. For the latter employee the kit carriers gave the best ergonomic results since it was so flexible and easy to handle within the assembly station. So if the materials kitting method would to be used in a more extent, the ergonomic pressure would be much higher for the material handlers than the assemblers.

It is always hard to implement a material supply alternative that does not fit in the company’s current processes since it could require a lot of changes e.g. restructuring the facility, major investments et cetera. Thus by choosing a method that fit in the current process, it is easier to get acceptance from top management to implement. This is actually also the reason for why there were no further investigations to develop other material supply alternatives. It was found through interviews that no major investments for new material supply methods where to be possible from the management’s point of view. Thus it was felt that searching for and developing other alternatives would be unnecessary since it would come to no use, and instead focusing on alternatives that would be used and not require a major investment.
If this study were to be conducted once again, with sufficient enough time, all activities within both the assembly line and the material supply area would be studied so that the measurements and results would be more accurate and reliable. It would also have been relevant to have the real production cost per product/hauler to get an even more exact result from the cost-effectiveness assessment.

The model developed for this thesis is applicable in other engineering manufacturing businesses, since it contains very basic activities to be performed in order to collect and analyse relevant data for selecting a suitable material supply method. Each step of the model must be executed in order to be able to select the most suitable materials supply alternative. However, the cost break down structure can be adapted to the company’s specific situation.
9. Recommendations

Our recommendations for the company and for further studies are included in this chapter. We will, based on our conclusions, give our recommendation on what we think is the best possible solution.

9.1 Recommendations for the company

Our recommendation for the company, based on the outcome of this study, is to implement the materials kitting, especially the kit carriers in a larger extent. Due to that, in this case, it is more cost-effective and has a higher labour productivity than the current materials supply method. The quality of semi-finished products was found to be better with the kit carriers. Ergonomics was also improved at the assemblers working stations with the materials kitting. However, in the case of implementing the materials kitting the company must take the ergonomics for the material handler into consideration since it was found that the ergonomic pressure was rather high for these employees. They have to review the ergonomic aspects of the materials kitting concerning the kit attendee if wanting to implement it. Not taking this aspect into consideration could, in the long run, lead to different sorts of injuries to the workforce. So it is not enough to use the increased labour productivity and better cost-effectiveness as a reason for implementing it since without a healthy workforce this productivity would not be possible.

9.2 Recommendations for further studies

After making this study we came to insight that there are still areas that should be put under light for further investigations. That is the possible impact of what ergonomics have by materials kitting on the company’s costs. There have been studies that imply kitting as a positive impact on the ergonomics of the workers, but there have been a lack of studies that cover the cost aspect of better ergonomics when kitting. The same principle goes for the quality aspect of materials kitting, there have been no studies found that indicates how much quality “costs” when having implemented materials kitting.

It is also noticed that the materials handling is increased by using materials kitting, hence another interesting area for future research could be to investigate if it is possible to improve the materials handling when using materials kitting. I.e. the ideal case should be keeping the materials handling low even with the introduction of materials kitting as a materials supply method. One solution to further look into is to make use of wagon trains when transporting the materials internally. The wagon trains might minimise the transports of materials since there would only be one truck that handles the pallets and carriers et cetera. So this could be an interesting option to make further studies in.
The model of procedures to choose a material supply method developed for this thesis, could for future reference be further developed in that sense that two more steps (step seven and eight) could be incorporated. These two steps would be implementation and follow up, so that a continuous improvement mentality could be a part of the model.
10. References

All references used throughout this thesis are presented here. It ranges from literature to internet pages.

Scientific articles:

- Engström, T., Medbo, L. (1993) Some important principles and findings concerning long cycle time assembly work' in Digest 26th International Symposium on Automotive Technology and Automation (ISATA), Aachen, Germany
Literature:

- Raju, K. S. Kumar, D. N. (2010) Multi Criterion Analysis in Engineering and Management, Prentice Hall India, new Delhi, India.
Annual report


Internet:


Intranet:


Interviews:

- Production engineer (2011) Volvo CE. Continuous contact between 29 February to 30 May 2011
- Assembly supervisor (2011) Volvo CE Interview 11 May, 2011
Appendix

This chapter contains all the appendixes that have been referred to during this study. It contains calculations, interview questions, time measurements, and table and figures that have been made by our selves.

Appendix 1 Interview questions for the assembler and supervisor

Quality related
1. Have it occurred that you have picked wrong articles from kits? If yes, how often? What was that reason?
2. Which types of kits do you feel are the easiest to perform assembly from?
3. How often do damages occur on the articles? Which are they?

Ergonomics related
1. How do you experience the ergonomic issues of the kits?
2. What type of kits do you feel is the best, kit on carrier or pallet kits?
3. Do you think that there are a lot of heavy lifts from the kits? Are there any differences between the kits in this matter?
4. What possible improvements of the kits would you like to make in order to improve the ergonomic features?

Appendix 2 Time assessment and cost per product produced for each option

<table>
<thead>
<tr>
<th></th>
<th>Price per hour (SEK) (altered)</th>
<th>Production rate per hour (altered)</th>
<th>Takt time (minutes) (altered)</th>
<th>Cost per product (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1000</td>
<td>4 000 000</td>
<td>1</td>
<td>60</td>
</tr>
<tr>
<td>SL10101</td>
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<td></td>
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<td>2,96</td>
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<tr>
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<td>3</td>
<td>5,21</td>
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</tr>
<tr>
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<td>2</td>
<td>4,31</td>
<td>71,8</td>
</tr>
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<td></td>
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<td>Line stocking</td>
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<td>2,13</td>
<td>35,5</td>
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<td>2</td>
<td>4,33</td>
<td>72,2</td>
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<tr>
<td>Arranged pallet</td>
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<td>3,62</td>
<td>60,3</td>
</tr>
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<td>SL10201</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>2</td>
<td>3,25</td>
<td>54,2</td>
</tr>
<tr>
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<td>5,32</td>
<td>88,7</td>
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<tr>
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<td>0,69</td>
<td>6,73</td>
<td>112,2</td>
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<tr>
<td>SM10202</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
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<td>3,41</td>
<td>55,8</td>
</tr>
<tr>
<td>Free arranged in pallet</td>
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<td>3</td>
<td>5,16</td>
<td>90,8</td>
</tr>
<tr>
<td>Kit carrier</td>
<td>6,45</td>
<td>0,66</td>
<td>7,03</td>
<td>117,2</td>
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</table>
In appendix 2 the material handler and assembler time for the line stocking supply method comes from the red and green column in appendix 6. Regarding the kits in pallets and kit carriers times, they derive from appendix 5 red column and blue columns. Total time per hauler is consequently the two numbers added with each other. Furthermore total time, takt time (minutes) represents how long it takes for a hauler to be assembled in.

Appendix 3  Calculations of productivity for each option

<table>
<thead>
<tr>
<th>SL10101</th>
<th>Labour Productivity at assembly</th>
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</thead>
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<td></td>
<td>Materials supply method</td>
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</tr>
<tr>
<td>Free arranged (New)</td>
<td>57</td>
</tr>
<tr>
<td>Arranged pallet (New)</td>
<td>58</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SL10201</th>
<th>Labour Productivity at assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Materials supply method</td>
</tr>
<tr>
<td>Line stocking (Previous)</td>
<td>57,8</td>
</tr>
<tr>
<td>Free arranged (New)</td>
<td>56,7</td>
</tr>
<tr>
<td>Kit carriers (New)</td>
<td>59,42</td>
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</table>

<table>
<thead>
<tr>
<th>SL10302</th>
<th>Labour Productivity at assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Materials supply method</td>
</tr>
<tr>
<td>Line stocking (Previous)</td>
<td>58,6</td>
</tr>
<tr>
<td>Free arranged (New)</td>
<td>57,9</td>
</tr>
<tr>
<td>Arranged pallet (New)</td>
<td>58,6</td>
</tr>
</tbody>
</table>
In these calculations the indirect time comes from the assembler time in appendix 2, since that is the time that the assembler spends on non-value adding activities (retrieving materials). Total time represents the time that it takes to assemble one articulated hauler, i.e. the direct time is given when the indirect time is subtracted from the total time.

### Appendix 4  Productivity outcome comparison

<table>
<thead>
<tr>
<th>Materials supply method</th>
<th>Labour Productivity in assembly</th>
<th>Productivity (%)</th>
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</thead>
<tbody>
<tr>
<td><strong>SL10101</strong></td>
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<td></td>
</tr>
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<td>Line stocking</td>
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</tr>
<tr>
<td>Free arranged pallet</td>
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</tr>
<tr>
<td>Arranged pallet</td>
<td>0.967</td>
<td></td>
</tr>
<tr>
<td><strong>SL10302</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
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<td></td>
</tr>
<tr>
<td>Free arranged pallet</td>
<td>0.965</td>
<td></td>
</tr>
<tr>
<td>Arranged pallet</td>
<td>0.977</td>
<td></td>
</tr>
<tr>
<td><strong>SL10201</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
<td>0.963</td>
<td></td>
</tr>
<tr>
<td>Free arranged pallet</td>
<td>0.945</td>
<td></td>
</tr>
<tr>
<td>Kit carrier</td>
<td>0.990</td>
<td></td>
</tr>
<tr>
<td><strong>SM10202</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line stocking</td>
<td>0.963</td>
<td></td>
</tr>
<tr>
<td>Free arranged pallet</td>
<td>0.945</td>
<td></td>
</tr>
<tr>
<td>Kit carrier</td>
<td>0.990</td>
<td></td>
</tr>
</tbody>
</table>

These numbers derive from appendix 3 where the labour productivity calculations have been made, and work as a compilation of all the productivity calculations.
Appendix 5  Time keeping measurements and cost calculations for each alternative

<table>
<thead>
<tr>
<th>Material supply methods</th>
<th>Picking time excluding administrative time (min)</th>
<th>Sorter pallet assignment (kit pallet, pallet, box) (min)</th>
<th>Time for still assignment to picking specified area (min)</th>
<th>Time for transporting of kit pallet to assembly line (min)</th>
<th>Time for transportation of kit center to assembly line (min)</th>
<th>Total time (min)</th>
<th>Palleting kit center to assembly object (min)</th>
<th>Retrieving materials from kit center as you drag them into the assembly (min)</th>
<th>Retrieving materials from the arranged pallets (min)</th>
<th>Retrieving materials from the arranged pallets (min)</th>
<th>Total time (min)</th>
<th>Cost per material supply method type / hauler</th>
<th>Cost for materials supply method type (3000 haulers per year) total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL10101 (Arranged pallet)</td>
<td>1.55</td>
<td>0.09</td>
<td>0.25</td>
<td>0.45</td>
<td>2.01</td>
<td>2.00</td>
<td>2.00</td>
<td>5.25</td>
<td>0.35</td>
<td>0.35</td>
<td>6.00</td>
<td>71.01</td>
<td>215740.48</td>
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<tr>
<td>SL10302 (Arranged pallet)</td>
<td>1.55</td>
<td>0.09</td>
<td>0.25</td>
<td>0.45</td>
<td>2.22</td>
<td>1.40</td>
<td>2.62</td>
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<td>0.35</td>
<td>5.25</td>
<td>50.34</td>
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<tr>
<td>SL10201 (Kit center)</td>
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<td>0.21</td>
<td>0.12</td>
<td>0.45</td>
<td>1.55</td>
<td>1.52</td>
<td>0.15</td>
<td>0.25</td>
<td>0.35</td>
<td>0.35</td>
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<tr>
<td>SM10302 (Kit center)</td>
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<td>0.12</td>
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<td>2.11</td>
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<td>6.55</td>
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<td>2.21</td>
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<td>0.25</td>
<td>0.35</td>
<td>0.35</td>
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<td>6.55</td>
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<td>0.35</td>
<td>0.35</td>
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<td>5.45</td>
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<td>0.35</td>
<td>0.35</td>
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<td>5.45</td>
<td>272453.69</td>
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</table>

Appendix 6  Table of timekeeping for line stocking (derived from each kit)

<table>
<thead>
<tr>
<th>Line stocking</th>
<th>Amount of pallet assignments / hauler</th>
<th>Amount of SB form / SB assignments / hauler</th>
<th>Total time pallet assignments</th>
<th>Total time SB assignments</th>
<th>Total time (min)</th>
<th>Receiving material from the stocking that are placed along side the materials facade</th>
<th>Total time</th>
<th>Cost for materials supply method type / hauler</th>
<th>Cost for materials supply method type (3000 haulers per year) total</th>
</tr>
</thead>
<tbody>
<tr>
<td>SL10101 (Line stocking)</td>
<td>0.09</td>
<td>0.21</td>
<td>0.34</td>
<td>0.16</td>
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<td>0.02</td>
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Appendix 7  Table of quantity and time requirement

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<th>Description</th>
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<th>Qty per inner emb</th>
<th>Inner Emb</th>
<th>Outer Emb</th>
<th>Amount of pallet assignments / hauler</th>
<th>Amount of SB assignments / hauler</th>
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<td>K1</td>
<td>K1</td>
<td>0.01</td>
<td></td>
</tr>
</tbody>
</table>

0.09  0.34
Total amount of pallet assignments hauler(min)  Total amount of SB assignments hauler(min)

Appendix 8  Time keeping measurements (raw data)

Kit picking time keeping

Measurement 1
**SL10201** (Kit arranged on carrier)
Cycle time 1: 5 min, 29 sec. - admin
Cycle time 2: 5 min, 28 sec. – admin
Free arranged in pallet: (only pick time) 3 min, 21 sec.

Measurement 2
Cycle time 1: Tot time: 4 min, 13 sec. Printout: 45 sec, Picking: 3 min, 8 sec, To buffer: 47 sec, sign of: 18 sec
Free arranged in pallet: Tot time: 4 min, 52 sec, Get pallet: 20 sec, Printout: 42 sec, Picking: 2 min, 45 sec, Sign of: 1 min, 5 sec.

Measurement 1
**SL10302** (Kit arranged in pallet)
Cycle time 1: 3 min, 33 sec.
Cycle time 2: 3 min.
Free arranged in pallet: (only pick time) ?

Measurement 2
Cycle time 1: 4 min, 40 sec.
Free arranged in pallet: Tot. Time: 5 min, 52 sec, Admin: 1 min, 10 sec.

**Measurement 1**

**SM10202** (Kit arranged on carrier)
Cycle time 1: 4 min, 43 sec. incl. admin
Free arranged in pallet: (only pick time) 3 min, 7 sec.

**Measurement 2**
Cycle time 1: Tot. Time: 5 min, 43 sec, Printout: 45 sec, Picking: 3 min, 36 sec, To buffer: 51 sec, Sign of: 31 sec.
Free arranged in pallet: Tot. Time: 5 min, 7 sec, Get pallet: 22 sec, Printout: 45 sec, Picking: 3 min, 5 sec, sign of: 55 sec.

**Measurement 1**
**SL10101** (Kit arranged on carrier)
Cycle time 1: 4 min, 15 sec.
Cycle time 2: 3 min, 46 sec

**Measurement 2**
Cycle time 1: Tot. Time: 4 min, 26 sec, Admin time excluded

**Measurement 3**
Cycle time 1: Total time: 4 min 46 sec.
Free arranged in pallet 2: Tot. Time: 5 min 20 sec, Get pallet: 21 sec, Printout: 38 sec, Picking: 3 min 4 sec, Sign of: 40 sec, To buffer and back: 36 sec