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A comparative study of the material feeding principles kitting and sequencing at Saab Automobile, Trollhättan: creation of guiding principles of which articles to be supplied with kitting.

Master of Science Thesis

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Cover: Saab 9-5 on main assembly line at Saab Automobile, Trollhättan.

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Abstract

This master thesis was initiated by Saab with the purpose to create guiding principles considering the transformation of sequenced material flows into kitted material flows. The background is that in the automotive industry today, large numbers of car models and variants are offered to the end customer. The large number of models and variants create space limitations at the assembly station i.e. it makes it very difficult to display all of the part numbers within the assembly station. This limitation at the assembly line has, by Saab Automobile, traditionally been handled with sequenced deliveries of selected part numbers to the assembly stations, but at the moment Saab is expanding its use of kitting. When introducing kitting some questions arose whether how old sequenced deliveries should be handled.

This thesis started with a review of the literature considering kitting and sequencing as well as a background to third-party logistics (3PL) since 3PL companies are involved in both the kitted and sequenced flow. The current state of the feeding principles kitting and sequencing were investigated in order to get a better understanding of the problem at hand. Then the study continued with case studies where the flow of articles supplied with kitting and sequencing were mapped. A simulation was also performed where sequencing articles suitable for kitting were simulated in a kitted material flow. Analyzes later showed the differences of the material feeding principles considering handling, administration, transport and storage. It was shown that kitting is most beneficial considering the number of handling operations and cost associated to the material flows. The analysis also showed the negative aspect of kitting; the articles supplied with kitting require being stored at several stock locations within the Saab assembly plant. Analysis further showed that depending on load carrier, used to transport the kits to the assembly stations, several constraints exist of which articles can be supplied with kitting.

A template aimed at facilitating the evaluation of sequenced and kitted articles was created taking previously presented results from the analysis into consideration. The conclusion from this master thesis is that kitting is a more beneficial material feeding principle compared to sequencing via a 3PL. It is recommended that as many articles previously supplied with sequencing should be transformed into a kit flow as long as the article qualify to meet the different limitations which involves kitting considering actual load carrier for kitting, article characteristics and space requirements.

Keywords: Material feeding principle, kitting, sequencing, material flow, article characteristics

Abbreviations

ESH – Electrical switch for headlights

FIFO – First in, first out

HATS analysis – Handling-, Administration-, Transport-, and Storage analysis

MFM – Material flow mapping

MPS – Master production schedule

OEM – Original equipment manufacturer

SPS – Set part system

3PL – Third-part logistic provider

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1 Introduction

In this chapter an introduction to the master thesis is made. First a background to the material feeding principles kitting and sequencing is presented. Secondly, a problem discussion concerning the material feeding principles at the studied company Saab Automobile AB is presented. This funnels the field down to the purpose and the objectives for the thesis. And finally, the scope of the thesis is presented.

1.1 Background

In the automotive industry today, large numbers of car models and variants are offered to the end customer. Automotive manufacturers are mass customizing (Alford *et.al.,* 2000) in order to meet customer needs and to stimulate the market. Customization can occur at different stages such as the design-, manufacturing-, and distribution phase but also in the hands of the customer in the form of "self-customization" (Alford *et.al.,* 2000). Although there are other examples, customization most commonly occurs in the manufacturing phase i.e. the car is built-to-order (Fredriksson and Gadde, 2005). Assembly of a product according to build-to-order principles allows largely varied components to be assembled in a standardized way (Fredriksson and Gadde, 2005). In order to be responsive and to produce the products ordered by the customer many companies use mixed-model assembly lines (Liker, 2004). But the large number of models and variants makes it very difficult to display all of the part numbers at the assembly station, hence increasing the focus of the material supply system (Johansson and Medbo, 2004).

Traditionally, continuous supply has been the dominating material feeding principle. This is still true but other material supply philosophies are challenging the old thinking. Kitting is gaining increasing attention from the automotive industry and is becoming an alternative to continuous supply (Hanson, 2009). When using kitting, inventories at the assembly stations are minimized and the parts are instead delivered to the assembly stations sorted by assembly object when needed. Parts that are required for the specific assembly object is grouped together, "kitted", and placed into a kit container (Bozer and McGinnis, 1992). Another material feeding principle used to reduce the inventories at the assembly station is sequenced delivery of single part numbers. Sequenced delivery (sequencing) is similar to kitting when considering the sequence to which parts are delivered to the assembly station. The main difference is that with kitting several parts are picked to an assembly object and with sequencing only single part numbers are sent to assembly object. (Hanson, 2009)

Most often, both sequencing and kitting in comparison to continuous supply require an extra repackaging operation for each handled part number, if not possible from the supplier. This result in a labor-intensive material supply but benefits can be reached when considering the fetching of parts at the assembly area. When kitting is used, the part numbers required for the specific assembly object can be displayed at the assembly station in such a way that walking distance for the assembler can be minimized. Sequencing on the other hand is due to the presentation of single part numbers is restrained to be located in or next to the line side material racks. Other benefits such as flexibility and control are also increased compared to continuous supply since only kitting container is handled and routed through the assembly system apposed to handling the individual component containers (Bozer and McGinnis, 1992).

1.2 Problem definition at Saab Automobile AB

Saab Automobile is an automobile company located in Trollhättan, Sweden. The company is currently producing seven car models: Saab 9-3 SportCombi, Saab 9-3 Sport Sedan, Saab 9-3X, Saab 9-3 Convertible, the all new Saab 9-4X, Saab 9-5 Sedan, and the all new Saab 9-5 SportCombi. The model 9-4X is however not produced in the Trollhättan plant but instead in GM's plant in Ramos Arizpe, Mexico. The final assembly plant at Saab consists of one paced assembly line with several complementary sub-assembly lines. The current takt time is 28 produced cars every hour i.e. a takt of 2.14 min per car. Saab is hopeful that this takt will in near future be increased to 30 produced cars every hour i.e. a takt of 2.0 min per car. The final assembly plant consists of several lines were cars are being transported between the lines either on the ground level or by conveyors that lifts the car in the roof level of the plant. This layout is a result of expanding production, introducing more car models into the program, hence "outgrowing" the current facilities.

The variations of the end products create large inventories of different part numbers, hence occupying a lot of space at the assembly line. The main part of the material has and is still supplied by continuous supply but the problem of space limitations at the assembly line has traditionally been handled with sequenced deliveries of selected part numbers to the assembly stations. The sequencing (picking and placement in sequence) have in these cases been done in different parts of the flow, based on different conditions:

- At the supplier
- Internally within Saab or
- At a third party logistics firm (3PL)

At the moment, Saab Automobile is expanding its use of kitting – on the expense of both continuous supply and sequenced deliveries. Preparation of kits to assembly (i.e. kitting) is intended to be handled at picking spaces internally within Saab's factory. When introducing kitting some questions arise whether how old sequenced deliveries should be handled. Could sequenced deliveries be combined with the kitting to gain synergy effects in the picking and re-packing of articles? How will sequenced deliveries be delivered, in sequence to kitting area to be re-packed, directly to the assembly area or should they be delivered solely via kitting? To answer these questions further investigation must be made considering available space in Saab's factory, the amount of work performed in the material flows, and the costs depending on different kinds of material supply methods.

1.3 Purpose

It is this master thesis intent to create a template which can be used in the evaluation process considering the transformation of sequenced material flows into kitted material flows in accordance with Saab's current strategy. In order to validate this purpose the first question that has to be answered is:

1. Which material feeding principle is preferable, sequencing or kitting.

Secondly, it is intended to create criteria to characterize articles and/or production flows to create a strategy for:

2. Which products should be included in Saabs internal kit assembly (material handling).

3. How material flows for these products should be arranged from supplier to the kit area at Saab.

1.4 Scope

In this master thesis only the automotive industry has been studied. The recommendations are therefore first and foremost appropriate for manufacturing companies working under the same circumstances.

Only material flows connected to either kitting or sequencing will be studied. The studied sequencing flows are limited to the flow via DHL, hence discarding the internal sequenced- and first tier supplier sequenced material flows. The material flows are analyzed from receiving dock at either TTAB or DHL and to the mounting of the article onto the assembly object.

Important to also mention here is that it is not the master thesis intention to improve the current state but rather to evaluate the different alternative material flows kitting and sequencing present at Saab today.

2 Theoretical Framework

The theoretical framework used in this thesis is presented in this chapter. It starts by describing the theory concerning material feeding principles presented with special attention put on kitting (chapter 2.1.1) and sequencing (chapter 2.1.2) which relates to the first research question of "which material feeding principle is preferable, sequencing or kitting". A comparison between the two material feeding principles is also presented (chapter 2.3) aiming to create an understanding for the second research question "which products should be included in Saabs internal kit assembly (material handling)". Finally, theory concerning third-party logistics and consolidation center is presented which relates to the third research question: "How material flows for these products should be arranged from supplier to the kit area at Saab?"

2.1 Material feeding principles

Several material feeding principles for small parts to manual assembly exists. In his model (Figure 1), Johansson (1991) distinguishes between material supply systems in regards to the selection of part numbers exposed at the assembly stations and the way the parts are sorted at the assembly stations. The model depicts three principle material supply systems: (1) continuous supply, (2) batch supply and (3) kitting. Continuous supply presents all part numbers at the assembly line. The material is sorted by part number and distributed to the assembly line in units suitable for handling. Batch supply only presents a selection of part numbers at the assembly station connected to a number of specific assembly objects. Similar to continuous supply, batch supply is sorted by part number. Kitting presents material at the assembly station sorted by assembly object meaning that one kit contains a set of part numbers for one assembly object. The kits are in other words delivered to the assembly station in the sequence in which they will be assembled (Hanson, 2009). One or several kits can be supplied to the assembly station at the same time. (Johansson, 1991)

Hanson (2009) further elaborates on sequenced deliveries and mentions sequencing of single components in addition to previously mentioned kitting. Sequencing of single components does similarly to kitting only present a selection of part numbers at the assembly line sorted by assembly object. This material feeding principle is however not mentioned in Johansson's model (Johansson, 1991).

	Selection of part numbers	All part numbers
Sorted by part number	BATCH	CONTINUOUS
Sorted by assembly object	KITTING	

Figure 1: Categorization of material supply systems (Johansson, 1991)

2.1.1 Kitting

Bozer and McGinnis (1992) defines a kit as "a specific collection of components and/or subassemblies that together (i.e., in the same container) support one or more assembly operations for a given product or shop order." Similarly, Johansson (1991) state that "one kit consists of a set of parts for one assembly object." From these definitions it is understood that kitting requires extra handling compared to continuous supply. It should be mentioned that downsizing i.e. breaking down of supplier pallets into smaller containers occurs in continuous supply. In these cases the numbers of handlings are the same for kitting as for continuous supply. The part numbers have to be kitted somewhere in the material feeding process. Several kits can be supplied to the assembly station at the same time but the parts needed for each specific assembly object are held ("kitted") together (Bozer and McGinnis, 1992; Johansson, 1991). Also true from the definitions are that no material included in the kit have to be presented separately (presented in line-side storage racks) at the assembly station meaning that kitting is more flexible to changes of the assembly line. Presenting only the required parts for each assembly also reduces the manufacturing floor space as well as increasing the control of work-in-progress through parts visibility and parts accountability on the production floor. (Bozer and McGinnis, 1992)

Kitting is particularly advantageous at the assembly station when the total numbers of components, including number of variants, are many. The reverse is also true, i.e. that kitting is less advantageous in serial lines where each assembly station has few components to be assembled. (Johansson and Johansson, 2006) Kitting is many times not the only material feeding principle to the assembly station. Bozer and McGinnis (1992) mention product complexity and product size as motives for using other material feeding principles than kitting. Components such as fasteners, washers are most commonly also not included in a kit (Bozer and McGinnis, 1992; Baudin, 2004).

In the studied literature a large variety of different solutions considering kitting was examined making it very difficult to describe one pure kitting system. Bozer and McGinnis (1992) observed two types of kits: stationary kits and travelling kits. The stationary kit is delivered to one assembly station where it remains until it is fully consumed. The travelling kit on the other hand travels along side the assembly object and can support several assembly stations before it is consumed. Brynzér and Johansson (1995) further examine the different design options of kitting systems in their report. The kitting can either be performed by an assembler or by a picker (i.e. special category of operators) and the kitting activity can be performed in a central picking store or in decentralized areas close to the assembly stations. Several articles discusses higher picking accuracy when the assembler himself is responsible for the whole job since he has a better understanding for the part numbers included in the assembly operations (Brynzér and Johansson, 1995; Johansson, 1991). The articles also recognize reduced administrative work when the picker and the assembler was the same person.

Other differences discovered by Brynzér and Johansson (1995) in their study of kitting in the manufacturing industry where:

1. Batching policy – instead of picking each kit separately, several kits are picked together in order to reduce walking distance and picking times
2. Zone picking - a picking order is divided into picking zones and hence can be picked simultaneously in different zones
3. Picking information – picking list is the most common picking information for the picker but this system has a high risk for inaccuracy through the picker picking the wrong parts. A display at the storage locations indicating what should be picked is another alternative, which reduces the risk for inaccuracies. Another is to assign each finished product a number, letter or color and displaying this symbol at each storage location.
4. Design of picking package – the design of the picking package has to both be functional in the picking process as well as in the assembly process. The parts can either be displayed lying

freely in the package or fixed with a dedicated placing. A dedicated place for each part reduced the flexibility of the package but increases at the same time the safety of the part and the control/speed of the assembly.

2.1.2 Sequencing

The materials feeding principle sequencing is used by several automotive companies under a variety of names; sequential supply, just-in-time sequencing, in-line vehicle sequencing, just-in-sequence, sequence parts delivery, synchronized delivery and body-on-sequence. The companies in the automotive industry is dominated by just-in-time principles and by using sequencing, part numbers are not delivered only just in time but also in a predetermined sequence (Svensson, 2006).

The material feeding principle of sequencing, Figure 2, communicates the final assembly line sequence to the suppliers and makes them deliver parts in the same sequence, to the exact location, and at the time they are needed (Baudin, 2004). Johansson and Johansson (2006) define sequencing as "part numbers needed for a specific number of assembly objects are displayed at the assembly stations, sorted by object." Sequenced deliveries can be favorable where few components are assembled on a serial line instead of kitting, which is less favorable under these circumstances. The sequencing process can be located within or outside the assembly plant (Johansson and Mathisson-Öjmertz, 2000), i.e. the material feeding principle can differ between the assembly station and the supply chain. The increased information exchange needed when sequenced deliveries and the need for frequent deliveries demands greater coupling between supplier and customer in comparison to continuous supply (Baudin, 2004).

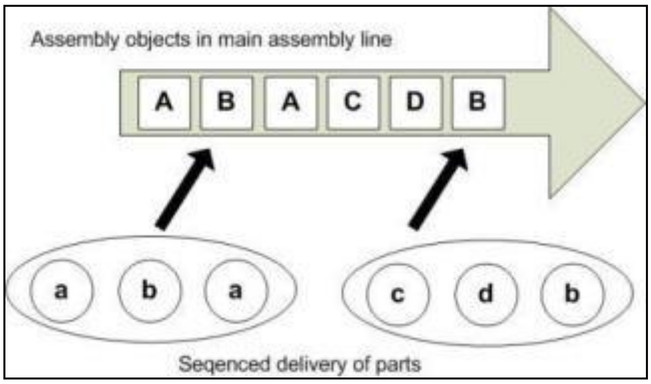

Figure 2: Sequencing principle (Aronsson et. al., 2004)

If materials are fed traditionally with continuous supply to the assembly station, many packages have to be displayed at the station. But if sequencing is used instead, only one package containing different specific part numbers belonging to the same component group has to be displayed at the assembly station (Johansson and Medbo, 2004). The packages which part numbers are transported in are often specially designed for the specific component groups. Sequencing has thus made it possible to produce customized cars with variety of parts such as seats, wheels, mirrors, safety equipment and electronic devices etc. while still maintaining economy of scale (Svensson, 2006).

Information of produced parts can be sent to suppliers several days in advance but if part numbers are picked from a 3PL or produced in sequence by local suppliers this information is not send until the car reaches the final assembly plant (Baudin, 2004). The procedure is specific for the automotive industry where the preceding operation is painting and after this operation the sequence of the cars can be determined (Baudin, 2004). When suppliers get the sequence information they initially respond by picking parts from stocks of finished goods. The idea is not to push inventory back to the suppliers, but this is what happens in many cases (Abraham *et.al.*, 1990). One way to solve the inventory problem is instead to let suppliers increase the frequency of deliveries by sending smaller quantities. This has a significant impact on freight cost, meaning that transportation cost can increase more than the reduction of inventory costs (Abraham *et.al.*, 1990). Another way for suppliers not to pick parts in finished goods stock is to develop the capability to build the parts in sequence. This is what usually happens within a few years (Baudin, 2004), the supplier's assembly process is then triggered by the sequence information. The process of arranging the parts in a sequenced order can either be performed by the first tier supplier, Original equipment manufacturer (OEM) or a 3PL company (Johansson and Medbo, 2004). A specialized 3PL can in many cases achieve this work at a lower cost (Aronsson *et.al.*, 2004).

2.2 Comparison of kitting and sequencing

Johansson (1991) in his model (explained in chapter 2.1) differentiates between material feeding principles by two factors: Are all of the part numbers presented at the assembly station or only a selection and if the part numbers are sorted by part number or assembly object. Kitting was distinguished as only presenting a selection of part numbers at the assembly station and being sorted by assembly object. The same was found to be true for sequenced deliveries. Sequenced deliveries are also distinguished as only presenting a selection of part numbers at the assembly station and being sorted by assembly object. (Hanson, 2009) Although the two material feeding principles share these common traits there are many differences between the two.

Comparing the material feeding principles of kitting and sequencing with the traditional material feeding principle continuous supply where all of the articles are presented at the assembly station sorted by part number it is quite clear that benefits can be achieved with the first two mentioned material feeding principles in connection to the assembly stations and control of the material flow. These benefits compared to continuous supply will be listed below and a discussion evaluating the better material feeding principle kitting/sequencing will also be presented.

Reduced space requirements at the assembly station and increased visual control are achieved when the article variants are removed from the line side storage connected to continuous supply and changed to either kitting or sequencing. Kitting presents several different articles in one kit container while the sequenced delivery, often displayed in racks, only carry one article which contain variants of the article sorted by assembly object. This means that if 13 articles are kitted, the space required at the assembly station with kitting is only the dimensions of the kit container/storage for the kit containers/line side storage rack. The sequenced material feeding principle on the other hand still is in need of 13 racks connected to each individual article, i.e. the space required for variants of components has been deleted but not the space required for the individual articles. From this simple example it is obvious that kitting will require less space at the assembly station when many articles needs to be presented at the assembly station.

Another benefit with kitting as a material feeding principle is that the kit container can be placed next to the assembly object and hence move along with the assembly object. This reduces the walking required by the assembler since the material is displayed within reaching distance and hence increases the efficiency of the assembly work. Sequenced deliveries, even though line side storage rack space has been reduced, still require the assembler to walk in order to fetch material for assembly.

Increased quality in assembly work is facilitated by both kitting and sequencing compared to continuous supply since the choice of which article to pick has been removed from the assembler and hence letting the assembler focus on his/her core activity, namely to assemble. Both kitting and sequencing display the articles to be picked in such a way that no one material feeding system can be preferred to the other concerning this matter.

Increased control over the material flow is achieved with both kitting and sequencing compared to continuous supply. Since, continuous supply displays all of the part numbers sorted by part number at the assembly station a huge inventory is created. The material feeding principles kitting and sequencing reduces the inventory levels since only selected articles sorted by assembly object is displayed hence increasing the control and limiting the articles exposed to theft, damage etc.

2.3 Third party logistics (3PL)

Companies are more and more focusing on their core competences and outsourcing all other activities to companies that can perform the specific activities better. (Skjott-Larsen *et.al.*, 2007) The transport and logistics activities of companies are no exception. Today companies outsource their logistic activities to a 3PL to an ever-increasing extent (Aronsson *et.al.*, 2004). Murphy and Poist (2000) define 3PL as "a relationship between a shipper and third party which, compared with basic services, has more customized offerings, encompasses a broader number of service functions and is characterized by a longer-term, more mutually beneficial relationship. However, the degree of customization can vary greatly depending on each individual relationship between shipper and service provider. Relationships can span from simple market exchanges with a low degree of integration and small competence exchange to in-house logistics solutions with high degree of integration and competence exchange. (Skjott-Larsen *et.al.*, 2007)

The services that the 3PL provides can according to Skjott-Larsen *et.al.* (2007) also vary greatly. He divides the 3PL providers into: asset-based logistics providers, network logistics providers, and skill-based logistics providers. Asset-based logistics providers own assets such as trucks, airplanes, warehouses, and terminals and offer 3PL as an extension of their core business. Network logistics providers have a strong global transportation and communication network and can hence expedite express shipments faster and more reliably. Finally, skill-based logistics providers do not own physical logistics assets but rather offer consultancy, financial services, information technology and managerial skills to their clients.

The driving forces for outsourcing activities are as mentioned earlier that companies more and more focus on their core competences. Outsourcing converts fixed costs i.e. buildings and trucks into variable costs, 3PL companies have transportation and logistics as their core competence and can therefore more easily reach economy of scale and scope in their operations. The shipper is able to streamline operations and to create a leaner and more flexible organization. (Skjott-Larsen *et.al.*, 2007) Baudin (2004) mentions economic reasons such as the higher wages in the automotive industry as motives for outsourcing activities to 3PL, it is cheaper to let a material handler at the 3PL handle the product than the employees in the automotive industry. Lacking space in the factory is also a motive for using a 3PL.

2.3.1 Consolidation center

A consolidation center (see Figure 3) is a facility that is located close to the manufacturer, which receives components and parts from many suppliers to later be consolidated and delivered to the manufacturing plant (Baudin, 2004). The consolidation center is preferable if components are delivered from a great distance where frequent milk runs may not be practical (Wu, 2003). Usually a separate company operates the consolidation center.

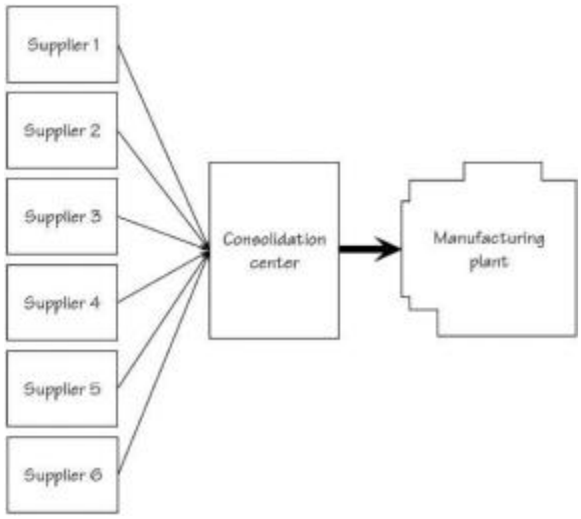

Figure 3: Consolidation center (Baudin 2004)

There are some different motives for having a consolidation center. It can work as a domestic center, working as it made its own parts on day-to-day basis, which shields the manufacturer from dealing with overseas suppliers with monthly lead times. Another motive is when working with suppliers who will not work with kanban or returnable containers. These suppliers should be weeded out but this process will take time and in the meanwhile their products will be delivered through the consolidation center (Baudin, 2004). The last motive according to Baudin is the ability to reduce labor cost. Compared to the assembly plant where operators are paid with high salary a separate facility can recruit low-wage personnel.

Every item does not need to be delivered through a consolidation center. Apart from overseas suppliers with long lead times and domestic suppliers who do not deliver in the right quantities that the plant wants, the rest of the components should be delivered directly to the manufacturing plant (Baudin, 2004). The following types of articles should not be delivered through a consolidation center; sequenced delivered parts and standard components such as bolts, nuts and washers. There are also some functions a consolidation center should not perform; activities like kitting, quality control should be performed within the assembly plant where product knowledge is greater (Baudin, 2004).

3 Methodology

In this chapter theory of how to perform research and also what to consider when performing the research is presented. It is also presented which are applied for this study. Finally the work procedure for this master thesis is explained.

3.1 Research strategy

Below are the different approaches and strategies presented and also which of them are used in this master thesis.

3.1.1 Qualitative versus quantitative strategy

The research strategy is most often divided into two methods depending on assault approach, quantitative and qualitative. The difference between the two methods is whether soft data (e.g. interviews and observations) or cold figures (i.e. measured or evaluated numerically) are used. Qualitative methods are based on a deeper understanding of the studied problem complex as well as a description of the context surrounding the problem (Holme and Solvang, 2001). The goal of the qualitative methods is to gain insight rather than to use statistical analysis (Bell, 1995). Quantitative methods on the other hand are more formalized and structured. These methods are characterized by their selectiveness and distance in relation to the information source (Holme and Solvang, 2001). The process of measurement is central and gathering of facts and studying of relations between constellations of these facts through scientific techniques is focused upon (Bell, 1995).

In this report qualitative methods are mainly used where interviews and observations are the fundamental source of information.

3.1.2 Inductive versus deductive approach

The relations between the theoretical world and the empirical world also influence the method in a study, two different approaches are most often named in academic literature: inductive and deductive. Abnor (2009) say that the inductive approach constructs theories using factive knowledge i.e. facts from the empirical world are used to construct theories in the theoretical world. The same authors say that deduction on the other hand is the logical analysis of what the theoretical world says about a specific event tomorrow. A third method, apart from the inductive- and deductive methods, is the abduction method. The method is a combination of both inductive- and deductive method where a single case is placed in a general hypothetical pattern, which is proven to be true explains the case. The explanation should afterwards be confirmed with new observations (new cases)(Abnor, 2009).

3.1.3 Case study

There are several different ways of doing a scientific research; experiment, survey, history, case study etc. (Yin, 2009). In this master thesis it was decided that case study was the most appropriate scientific research. The strength of a case study is that the researcher can focus on one special occasion, a case study, to find the factors which all affect the case. This case will then symbolize a larger system, which the case is a part of. Conclusions drawn from the case study can then be applied to the whole system (Bell, 1995). According to Wallen (1996), the main benefit of a case study is that phenomenon's are studies in real situations. Other benefits are that deeper knowledge is attained from the study, and that a case study can validate that the phenomenon exists (Wallen, 1996).

3.1.4 Data collection

There are mainly two types of data: primary data and secondary data. Primary data are those, which are not gathered before (Dahmström, 2005). Then the researcher has to collect it for the specific research purpose. This can either be done by surveys, interviews or direct observations (Dahmström, 2005). Secondary data is information collected and analyzed by other researcher for another purpose. This information can be found in different publications, register or official statistics. This data can either be used directly or sometimes further analysis is required (Dahmström, 2005). In this thesis both primary and secondary data will be used.

3.2 Work procedure

Saab initiated the master thesis with the purpose to establish guiding principles of which articles previously supplied with sequencing should be supplied with kitting. In appendix 1, a template, which includes important decisions regarding implementation of sequencing articles to be supplied with kitting is presented.

Before evaluation whether an alternative solution would contribute to a better result or not, knowledge of the present processes is required (Aronsson *et. al.,* 2004). The empirical description aims to get an understanding of the current materials feeding principles, described in current state (chapter 4), interviews with involved engineers were held. It was also decided to map the current material flows of kitting and sequencing. For this purpose, Finnsgård *et.al.,* (2011) proposes a methodology, Material Flow Mapping (MFM), where flows are compiled into materials flow maps. The first important step in this methodology is to decide which study objects to follow and the scope of the study. In this master thesis it was decided to start the mapping at a 3PL where the materials first arrive from the first tier suppliers, either at the consolidation center TTAB or at DHL where sequencing is made. The studied flow ends where the assembler at the final assembly station fetches the materials to be mounted on the assembly object.

In consultation with SAAB four articles where chosen to be studied and to be representative for the material feeding principles kitting and sequencing. This selection was done since it was neither possible nor wanted to study all of the existing articles in these flows. It was decided that the article *Dashboard panel* was a suitable study object concerning sequencing. *Dashboard panel* is a very big article with many variants and requires two operators for the assembly operations. In contrast to *Dashboard panel*, *Antenna* is a small article with many variants also supplied with sequencing, thus *Antenna* was decided as study object. This was done in order to study the effects of the material feeding principles due to articles with different characteristics. Currently, Saab supplies one article *Instrument cluster* in sequence to Saab to be picked in a kit preparation area. In order to investigate potential benefits or drawbacks from this solution, Instrument cluster was chosen as a study object. *Instrument cluster* has many variants and is considered a medium sized article (smaller than *Dashboard panel* and bigger than *Antenna*). The article *ESH* was chosen to represent a typical kitting article since it is relatively small in size with many variants. An article variant, of each chosen article, was chosen to map. The selection was made thus annual volume should coincide i.e. inventory levels should be comparable for best comparison of the material feeding principles kitting and sequencing. Summarized, four flows were chosen to be followed, two flows supplied with sequencing, one flow supplied with kitting and one flow supplied with sequencing to be kitted. The studied articles are presented in Table 1.

Sequencing articles:	Kitting articles:
Dashboard panel	ESH
Instrument cluster	Instrument cluster
Antenna	

Table 1: Chosen articles to be studied in the material flow maps.

Finnsgård *et.al.,* (2011) emphasize the importance of video recording. To record the entire flow with included activities will provide timestamps for all the activities. In this master thesis it was decided to video record the chosen flows. However, the internal flows within Saab´s factory were not permitted to record thus these flows were instead studied by live observations. Then the flows were compiled into material flow maps, which were then later validated by involved actors. Parallel to the empirical description, a review of the literature was initiated. As well as from empirical description, different characteristic affecting kitting were also search for from literature.

According to Aronsson *et.al.,* (2004), storage, handling, transport and administration are the foundation to calculate cost in logistics thus these factors are the most relevant to study. Also Finnsgård *et.al.,* (2011) suggests the analysis of the flow to consist of summarized number of handling, administration, transports and storage, a HATS analysis. Therefore in this master thesis the empirical analysis consists of an analysis of these factors, a HATS analysis. From this analysis the number of handling operations, administration, transport and storage required for each studied flow is investigated. Storage analysis is complemented with investigation of the required space necessary for each flow.

Furthermore, variable cost associated to handlings is calculated to compare kitting with sequencing from an economical perspective. From Saab it was given the times for handlings within the flows at Saab. From these times costs could be calculated. Costs for handlings at TTAB and DHL were also gathered from personnel at Saab. Then, further analysis of characteristics considering the load carriers used in kitting has been made to be able to decide which articles would be suitable for kitting. Finally a simulation was made where articles suitable for kitting were simulated into a kitting flow. The analysis is then the foundation for the guiding principles, which intends to make the selection of which articles to supply with kitting clear.

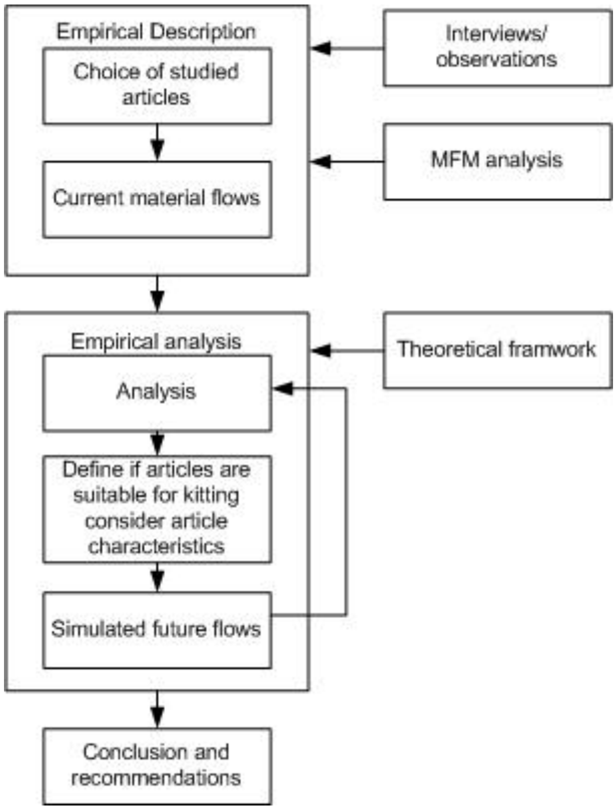

Figure 4: Schematic picture of the work procedure

3.3 Validity and reliability

In concern to the validity of this master thesis, the aim was to get as much data as possible validated. The interviews with involved engineers concerning kitting and sequencing were recorded. This made it possible to go back and listen to the interviews again if any issues concerning the data arose. The material flow maps were also recorded as extensively as possible and involved personnel validated the finished material flow maps.

Concerning reliability, in calculations of both cost and space requirements some assumptions had to be made. In the cost calculations for the current studied flows these assumptions had a negligible impact on the total cost hence not affected the outcome of the cost analysis. Regarding cost and space requirements for the simulated flows, it was assumed that both *Antenna´s* and *Instrument cluster´s* all variants should be fed exact according to the studied article variant *ESH*. This is probably not how it would be done in reality, articles with approximately same annual volume as the studied articles would be fed according to the simulation and some articles in another way. However the outcome from the simulation still shows that kitting is more advantageous then sequencing.

4 Current state at Saab

In this chapter the current state at Saab is described. The layout of the assembly plant is described in order to facilitate for the reader to follow the continuation of the report. The current material flows at Saab is described where the actors are first introduced and then a general description of the material feeding principles kitting and sequencing is made.

4.1 Layout of the assembly plant

To get an understanding of Saabs assembly plant, the layout of the plant is presented in Appendix 2. The interesting areas for this thesis are marked with a number from 1 to 7 in the layout. The presented areas are:

1. Northern gate, arriving goods from DHL
2. Southern gate, arriving goods from DHL
3. Kanban gate, arriving goods from TTAB
4. Kanban storage
5. *Dashboard panel* kit preparation area
6. *Dashboard panel* assembly line
7. Final assembly line

Which gate that is used for deliveries from supplier is connected to the destination point within the Saab factory. The northern gate is e.g. used for deliveries to the Dashboard panel assembly line, while the kanban gate is used for deliveries to the kanban storage, and the southern gate is used for among other things the article *Antenna,* which is assembled in the south part of the main assembly line. The philosophy of delivered goods is in other words to minimize the transportation within the factory. Worth mentioning is that the Dashboard panel assembly line is a sub assembly line to the final assembly line.

4.2 Current material flows at SAAB

In this chapter a brief presentation of all the different material flows to Saab will be described. As can be viewed in Figure 5 below, Saab currently has many different material flows supplying the factory with materials. Among these flows are articles supplied via the material feeding principle continuous supply i.e. are delivered to the line assembly station on supplier pallet. Another flow is the sequenced deliveries directly from supplier. These articles are big, bulky articles delivered from suppliers located close to Saab e.g. car seats and the roof panel. Sequence is also performed internally within the Saab factory; these material flows are most often combined with some form of pre-assembly activity. The remainder of this chapter will however focus on the chosen material feeding principles kitting and sequencing.

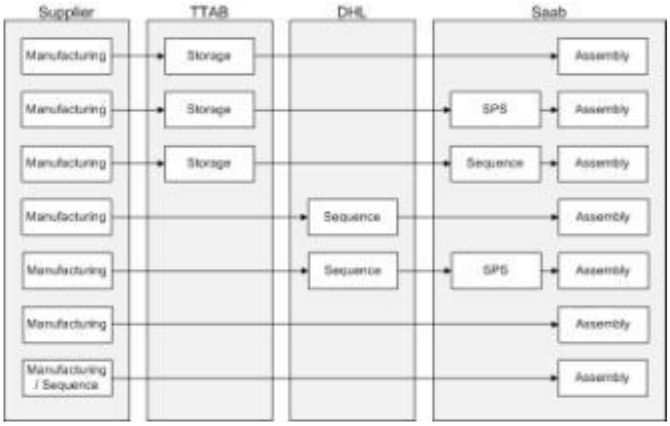

Figure 5: Material flows at Saab

4.2.1 Actors

The actors included in the supply chain and the scope of this master thesis is the 3PL companies DHL and TTAB. Below a short description of the actors are made.

DHL

The decision to sequence material externally was made in the beginning of 1990s when the second generation of Saab model 900 was introduced. Sequencing from a 3PL company was first introduced in 1997 when the first generation of the Saab model 9-5 was introduced. The reason for this decision was the limited floor space for continuous supply and pallets inventory within the Saab factory. At the time, Saab's material organization was not able, and did not have the system support, to supply the assembly stations with internally sequenced material flows (Friedenthal, 2011). Instead the 3PL company, CD (Sequenced Deliveries), owned by former Saab employees was chosen to provide this service. As more material was delivered via sequence another 3PL partner Exel was introduced since CD had reached their capacity limit. After a couple of years with two 3PL providers Exel got the full responsibility for the sequenced deliveries. Exel later changed name to DHL and is still to this day the 3PL partner to Saab.

When the existing Saab 9-3 model was introduced in 2002, Saab found that the space for material presentation next to the assembly station would increase. The space requirements together with the directive from the former owners, GM, that Saab should focus on building cars (core business) and not surrounding activities initiated the building of DHL's warehouse. The DHL warehouse employs 57 people and is dedicated to Saab as a customer. Some of the employees at DHL are recruited via a contingency firm meaning that DHL easily can adjust the staffing of the warehouse according to Saab's needs.

The DHL warehouse includes 17 000 m^2 in total where approximately 14 000 m^2 is storage. 1 500 m^2 is goods receiving area and another 1000 m^2 (approximately) is offices. 36 picking stations sequence the material to Saab. Some pre assembly operations e.g. the 9-3 *dashboard panel* where *decorative-strip* is mounted postpone the differentiating of article variants hence reducing required inventories. The warehouse is located (2.8 km) to Saab, hence facilitating fast deliveries to the plant. When the assembly object at Saab reaches the first station after painting of body, DHL gets the order, which contain all articles delivered in sequence by DHL. The articles are then packed and goods are transported by four trucks to Saab. The materials are supplied with kanban and the trucks contain several different racks of 12, 16 or 24 positions depending on location of assembly station.

TTAB

The Katoen Natie Group is a privately owned company with over 9300 employees in 28 countries. It has been the sole owner of Trollhättan Terminal AB (TTAB) since 2000. TTAB is a multi-customer warehouse, located 4.8 km from the Saab factory, which offers Saab storage space, just-in-time deliveries and preforms repackaging activities such as sorting, planned and unplanned repackaging as well as parts assembly. Saab was first introduced as a customer in 1998. In the same year, TTAB opened a 7380m^2 regional distribution center for Saab. Today these facilities has grown to a 14000m^2 covered warehouse + 3000m^2 external. TTAB is currently employing 32 – 42 employees, working in 3 – shift.

4.2.2 Material feeding principles

In this master thesis focus is put on the material feeding principles kitting and sequencing. Below, a short description of these material flows and the including parameters of these flows are explained.

Kitting

At Saab, kitting is referred to as set part system (SPS). SPS uses a kit container that travels alongside the assembled car i.e. a travelling kit. The kit container for the *Dashboard panel* assembly line is prepared in a Kit preparation area, by specialized pickers, located next to the *Dashboard panel* assembly line. This is more thoroughly explained later in this chapter when the studied material flows are described. In the remainder of this master thesis the terms kitting and kit preparation area will be used since these terms are more commonly used in academic literature.

The reason for implementing kitting as material supply method at Saab was due to the lack of space at the assembly stations. The limited space at the assembly stations made it impossible to store all of the articles needed at the assembly station in the line side storage racks due to the large amount of variants of articles available. Major factors in the implementation of kitting was also to reduce the number of steps that the assembler had to walk for fetching material, remove packaging handling and subassembly (if possible) from assembly line as well as the reduction of the number of choices the assembler had to make during assembly, hence increasing the efficiency of the assembly station.

It is the intent of the management at Saab to introduce kitting to as many assembly stations as possible, with the goal to have as many articles as possible kitted to the assembly line. Benefits achieved in the pilot areas are: reduction of line side storage racks, which increase available space in the assembly stations, and reduced walking distance for fetching material compared to other material feeding principles. Kitting as well as other material feeding principles e.g. sequencing was shown to facilitate the elimination of fixed material facades hence facilitating the re-balances of the assembly line. Benefits were also shown where the assembly operator can focus on the assembly task and do not need to focus on which materials to fetch to the given assembly object. This benefit is also shared with sequencing. Hence reducing the risk for errors done by the assembler when fetching articles.

Three different variants of kitting are currently being used or tested at Saab: kit container, kit-to-car, and kit-to-fixture. Kit-to-car is currently being tested at the assembly line. Articles to be assembled are placed directly in the car, upstream of the point of assembly. Benefits of kit-in-car are: that the inner dimensions of the car facilitate the kitting of large articles, since no kit has to be carried, heavier articles considering ergonomics can be handled. Difficulties are: that articles placed in the car can interfere, hinder, with assembly performed upstream of the point of assembly, the articles are placed without fixture in the car increasing the risk for damages to the articles, the articles are still stored by the assembly line although internally sequenced. Kit-to-fixture is currently being used at the motor assembly line. The motors attached to fixtures, which are placed on a driven assembly line. The kitted articles are placed directly on to the fixture. Benefits of kit-to-fixture are: that heavier articles can be kitted since no kit container is manually handled. Drawbacks are that: the number of articles and size of the articles included in the kit is limited to the dimensions of the fixture, the articles are not fixed hence increasing the risk for damages to the articles. In this master thesis only the kit variant kit container will be analyzed.

Kit preparation area

With kitting as supply method space is reduced at the assembly station but still kitting requires an area for the assembling of the kits, the kit preparation area. Depending of the number of articles in the kitting container and the number of kitting containers at the assembly stations, the size of the kit preparation area varies. At Saab there does not exist any stated recommendations for the location of the kit preparation area, it varies depending on which assembly station that will be fed. The factors that decide the locations are; how much material will be picked, what is the cost for transports and if there exist any available space next to the assembly line. The placement of the kit preparation area next to the assembly line is preferred due to minimized transports of kits. The short distance is also beneficial considering fast deliveries if material errors occur and have to be quickly changed. The current locations of kit preparation areas vary for the assembly stations. The kit preparation areas for *Dashboard panel* and engine are located next to the assembly line with minimized transports for the kits. Figure 6 below shows the kit preparation area for *Dashboard panel* to the right and the *Dashboard panel* assembly line to the left. The kit preparation area for door assembly on the other hand is located apart from the door assembly line due to limited space close to the assembly line.

Figure 6: Truck lane between Dashboard panel assembly line and kit preparation area

The presentation of articles in the material racks at the kit preparation area is optimized for picking. At the kit preparation area for *Dashboard panel*, pick-to-light has been introduced to facilitate picking and avoiding errors made by the picker. The articles have been moved here from the line side storage racks hence containing the same amount of articles, but the surface required in the material racks have effectively been reduced in the new designed kit preparation area. At the kit preparation area supplying the *Dashboard panel* assembly line, the pickers belong to the assembly organization. However, these pickers are not assembling anything at the line. The reason that the pickers belong to the assembly organization is the product knowledge and commitment increases the quality of the picked kits since the pickers has experience with the articles kitted.

Kitted articles

Currently, no documents concerning the selection of kitting articles exist. The selection of which articles that could be fed with kitting is made from some factors of which articles are most suitable for picking; is the material sensitive, could it be fitted in a kitting box, can the article be mounted directly or does the material need a tool that synchronously must be collected at the assembly station, how many steps can be reduced at the assembly station and how many variants of the article exist. Currently, 65 article families are kitted for the *Dashboard panel* assembly line amounting to 200 article numbers. Of these 200 article numbers, 150 are picked with the help of pick-to-light indicators.

Kitting package

For economic reasons, existing containers at Saab are used with foam fixtures so that each article included in the kit has a dedicated place. The foam fixture secures the article in order to avoid scratches but does also facilitates standardized picking procedure since the picker can pick the article from the same place every time. According to Saab, the plastic box is the most suitable alternative for present kits.

Figure 7: Kit container for Dashboard panel assembly line

The containers should hold as many articles as possible to minimize the amount of kits necessary to feed the assembly stations. The container should not be too heavy and easy to handle, the articles should be displayed in such a way that picking is enabled. The weight of the current kit container at the dashboard assembly line is 7.2 kg. Limits to the kit container are; the container must fit in a rack for storage next to the assembly line, the container must be stored next to the assembly objects without disturbing the assembler. The dimensions of the current kit container connected to the *Dashboard panel* assembly line are 800x400x200 mm. The available container at Saab should not be a constraint to which articles that should be kitted. If there does not exist a suitable container it has to be purchased.

Sequence

Today, Saab has three alternatives for sequencing of part numbers: internal sequence, sequence from first tier supplier and sequence from 3PL. Examples of internally sequenced articles are rear and front bumpers. The internal sequence is however often associated with some form of pre assembly task e.g. fog lights and engine warmer contact is mounted onto front bumper. Although the material organization has gained the possibility for internal sequence deliveries to assembly stations the main issue still remains, space limitations, hence warranting external sequencing. Sequenced articles from first tier suppliers are big, bulky articles with many variants e.g. seats, door panels, and exhaust pipes. These first tier suppliers are located in a fairly close distance to the factory enabling this solution. Obvious benefits of this sequenced flow are the reduced number of handlings since the material is displayed accurately from the start. In this master thesis only sequence from 3PL is analyzed.

Sequence from 3PL is as explained earlier handled via DHL. DHL is responsible for the storing and sequencing of a large amount of Saab's articles as well as simpler administrative activities. Saab has the owner ship of the articles in the DHL warehouse and is in charge of all planning such as inventory levels and replenishment except for three articles (*wing-mirror*, 9-3 convertible *handle* and *net*). For these articles the ownership is transferred when the delivery reached Saab.

Sequence preparation area

At DHL, the sequenced racks can either be prepared in the high storage location or in a specifically designed preparation area. Benefits from preparing the kit directly in the high storage location is the elimination of extra handling activities when the articles are moved to the specific preparation area. The picking of the articles that are sequenced from DHL are validated with the help of scanned barcodes. A barcode of the article to be picked is scanned (e.g. from a picking list) and is validated first when the barcode, on the article or storage place is no barcode on article exists, is scanned and matched. This is done to avoid human errors in the picking of articles. The picker can operate several sequencing stations at the same time depending on how demanding the picked article is.

Sequenced articles

Sequenced articles as described earlier have been chosen due to space requirements in the assembly stations at Saab. Large articles, articles with many variants have been chosen for sequencing. Examples of these articles are *Dashboard panel*, *pedals*, *loom*, *Instrument cluster*, *Radio*, *glove compartment*, and *Antenna*.

Presentation of sequenced material

In Figure 8 different handling equipment for sequenced deliveries are displayed. Figure 8 shows a rack for *looms*, where each container includes one *loom* for one assembly object. Also included in this rack is the sequence box for Antennas (bottom right). The sequencing stations for Antennas and *looms* are located next to each other at the 3PL and are therefore combined in transport to reduce wastes. The rack for *looms* is attached to the line side storage racks and containers are automatically transferred, taking away the activity of transferring containers between transport fixture and line side storage racks. Size of the article is of course a major factor considering which transport packages to use, *Antenna* can because of their small size easily be sequenced in a container (Figure 8).

Figure 8: Picture of rack and box for Antenna

4.3 Studied material flows

Three material flows to Saab where studied with the tool material flow mapping: kit to assembly, sequence to assembly, and sequence to kit to assembly. The articles chosen to represent these flows are *Instrument cluster* (sequence to kit to assembly), *Antenna* (sequence to assembly), *Dashboard panel* (sequence to assembly), and *ESH* (kit to assembly). The studied material flows are highlighted in Figure 9. As explained earlier, the material flows of *Antenna* and *Dashboard panel* are both similar in their handling i.e. sequenced flows directly to assembly line. The characteristics of the studied articles are however so varying that a study of the two flows are of interest to the thesis. The complete material flows can be viewed in the appendix 3-6.

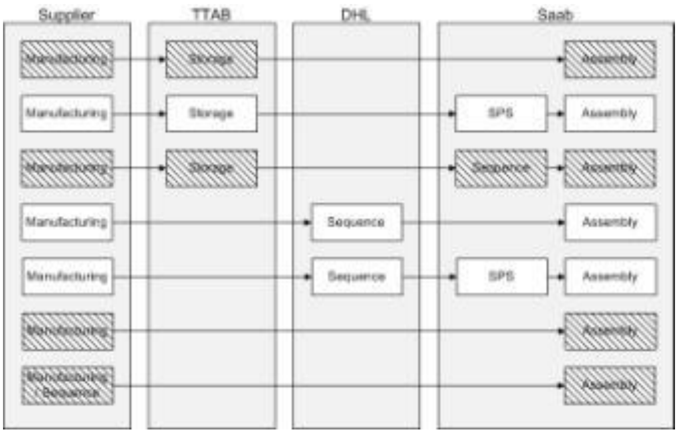

Figure 9: Studied material flows

4.3.1 Description of flow for Instrument cluster

Currently Saab has one article, which is first supplied to the kit preparation area with sequenced deliveries and then delivered in kits to the assembly station, *Instrument cluster* (Figure 10, MFM presented in Appendix 3). The *Instrument cluster* is mounted on the dashboard of the car giving vital information to the driver regarding speed, rpm, fuel level etc. One *Instrument cluster* is required for each car assembly. The article has 26 variants, is 7875 cm^3 big and weighs 800 gram.

Figure 10: Instrument cluster

The article is by Saab considered suitable for kitting but the article was supplied in sequenced deliveries before kitting was implemented at Saab. Changing the flow of an article is difficult, especially when another actor (DHL) is involved. For this reason the article is currently being supplied in sequence to the kit preparation area.

Flow at DHL

When the article is delivered to DHL from suppliers, the truck is unloaded and pallets are transported to the receiving dock area by forklifts. The forklift operator makes a visual control of the goods and also checks the consignment note before handing it over for labeling and reporting into MPS system. The goods are reported into both Saab´s and DHL´s MPS system, an activity that has to be performed twice due to the incompatible system interfaces. After the pallets are labeled, they are transported to a high storage. The high storage for *Instrument cluster* is located on top of the picking station i.e. the article is picked from the ground level of the high storage, when a pallet is empty a new full pallet is retrieved from the upper levels of the high storage. The signal for replenishment to the picking station is when the forklift operator visually identifies an empty pallet in the picking area (visual control). The operator manually checks his list of available pallets and replenishes the picking station with a new full pallet.

The sequence in which order the picker at DHL picks *Instrument cluster* is determined from the printed picking list, which the picker retrieves from DHL´s MPS system. The information regarding which sequence the cars are built on the assembly line at Saab is sent to DHL when the car reaches the final assembly line. The picker labels the specially designed rack, i.e. giving it an identity and information regarding included articles, with which articles are transported to Saab. The picker checks the picking list, picks article, and then put the article in the rack. The pick list, which consists of labels, is then matched with the part number on the article and the article is labeled. The article has now two barcodes that the picker scans to eliminate picking errors. When the rack is ready the picker marks the rack “ready”.

A tow tractor driver visually controls that the rack is ready for pick up and transports the rack to the loading dock. Here the goods are waiting for a new truck to enter the dock. The trucks between Saab and DHL are constantly in motion. The system has the function of a kanban system. When a truck arrives at DHL, empty racks to be replenished are unloaded and waiting finished racks are loaded and transported to Saab. The deliveries do not need any system support, if no racks have arrived, no picking have to be made. The tow truck driver is the operator who also loads the racks onto the truck.

Flow at Saab

The sequenced goods are either transported to the northern gate or the southern gate depending on the location of the articles final consumption on the assembly line. *Instrument cluster* is transported to the northern gate since this is located closest to the Dashboard panel assembly line. When the truck arrives at Saab, the goods are checked for damages. When the truck is unloaded the responsibility of the goods is turned over to Saab, it is therefore important to identify damages before the goods are unloaded. The worker manually unloads the racks and transports them to the receiving area.

The signal that triggers the tow tractor driver to pick the rack from the receiving area is "material andon". When the rack is empty at the assembly station or kit preparation area, the assembler or picker at kit preparation area presses a button that tells the tow tractor driver to pick up the empty rack and replenish the station with a full rack.

The picker picks a picking list that contains the information of which articles should be included in the kit. Since the articles are sequenced from DHL they are presented in the right sequence and the picker therefore does not need to choose which variant to pick. The article is placed in the kit and when the kit, which also includes several other articles, is ready it is placed on a cart containing several full kits (eight kits).

The assembly station at the assembly line contains two carts of kits (Two-bin-system). When a cart is empty the tow tractor driver, which also is responsible for replenishment of kits, return the empty boxes and fills the cart with full boxes. The assembler at the assembly line picks one kit and places the kit in a fixture next to the assembly object. This facilitates the assembly and reduces the amount of steps the assembler has to walk in order to retrieve articles.

4.3.2 Description of flow for Antenna

The Antenna receives signals e.g. for radio, GPS and television depending on the equipment chosen for the car. One Antenna is required for each car assembly, except for the cab model, which has another solution due to the canvas roof. The article, Figure 11, has 43 variants, is 560 cm^3 big and weighs 82 gram.

Figure 11: Antenna

Flow at DHL

Since the material flow for Antenna, presented in Appendix 4, similarly to *Instrument cluster* passes through DHL, detailed description of goods reception and included activities for Antenna are referred to previous section (*Instrument cluster*). The pallets containing Antennas are retrieved from the receiving dock and placed in a high storage located close to the sequence preparation area. High volume part numbers have dedicated pallets from the supplier but part numbers with low volumes are combined onto mixed pallet. At the picking station the Antenna is no longer presented on pallets so the pallet is "broken" in the high storage and transported in supplier packages (number of articles per package varies from 9 – 42) to the sequence preparation station.

The picker retrieves a picking list from the MPS system. The kitting box is labeled and each individual place for Antennas in the fixture is labeled with a barcode. The picking begins with the picker scanning the individual *Antenna* barcode from the fixture, the picker then walks to the storage place for the Antenna and scans the barcode connected to the storage place. This is done in order to avoid picking of the wrong article. The article is then placed in the kitting box and when all of the articles are picked the box is labeled "ready". The picker brings the kitting box to the *loom* picking station and placed it on the rack for *loom*. These stations are located close to each other both at DHL and Saab. Combining the articles in transport reduces the number of handlings required for the two articles. When the rack is fully packed, a tow tractor makes a visual control, collects the rack and delivers it to the delivery bay. Note that this rack is consumed in the other end of the Saab factory compared to the *Instrument cluster* and *Dashboard panel* and is therefore delivered with another truck that goes to the south port at Saab.

Flow at Saab

The goods are as mentioned earlier delivered to the southern gate at the Saab factory. The rack with *looms* and the *Antenna* container is picked up by a tow truck and transported to the assembly stations by the assembly line. The kit container for Antennas is first delivered and the kit container is simply replaced in the rack with an empty kit container. The second stop is the assembly station where the *looms* are consumed. The rack is connected to the fixture by the station and becomes part of the line side storage rack (Figure 12). Empty racks are returned to the delivery bay for transport back to DHL.

Figure 12: Line side storage rack for Antenna

4.3.3 Description of flow for Dashboard panel

The *Dashboard panel* is placed in the front in the interior of the car facilitating among other things the display of vital instruments to the driver e.g. previously mentioned *Instrument cluster*. One *Dashboard panel* is required for each car assembly. The article, presented in Fig. 13, has 24 variants, is 358400 cm^3 big and weighs 9960 gram.

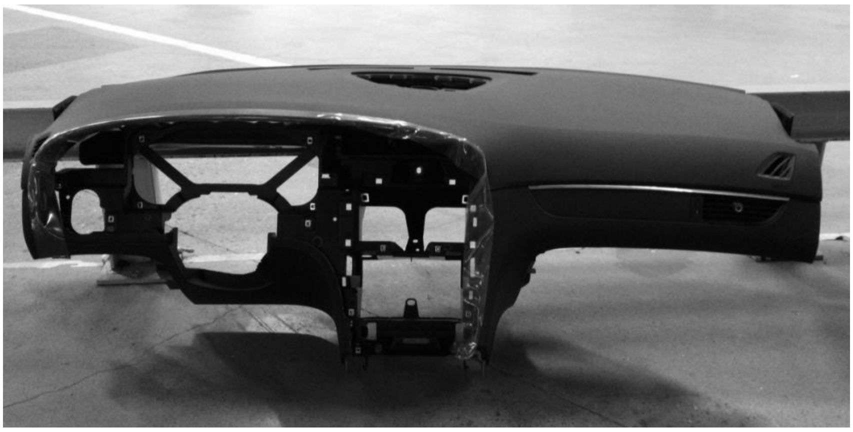

Figure 13: Dashboard panel

Flow at DHL

The material flow for *Dashboard panel* (Appendix 5) is as the two previous studied flows, *Instrument cluster* and *Antenna*, also handled through DHL. For a description of the goods receiving at DHL, previous text is referred to (*Instrument cluster*). The *Dashboard panel* is a very big and bulky article and therefore only four articles are fitted onto the pallet from the supplier. The pallet is bigger than the normal EU-pallet and has a box fitted onto it to protect the articles. The pallet is transported from the receiving dock and placed into a high storage located close to the sequence preparation area. As explained earlier, the design of the transport pallet is very customized for the transportation of *Dashboard panel*, the pickers working in the sequence station have to open a lid and remove a wall of the pallet in order to pick *Dashboard panel*. The operator of the forklift that replenishes the picking station with material uses visual control to trigger replenishment. Since the operator of the forklift cannot see how many *Dashboard panel* is present in a pallet due to the walls of the pallet a closed pallet box gives the operator the signal to replenish.

The *Dashboard panel* is very large and bulky and requires two operators to pick and place into the transport rack. The pickers get information about what to pick from a printed picking list. The picking list consists of labels with barcodes, when a new picking is initiated the picker scans the barcode and then picks the *Dashboard panel* from its storage place. Two operators pick the *Dashboard panel* and place it onto the transportation rack. When the rack is filled it is placed in a pickup zone for the material tow truck. The material tow truck visually identifies that material is ready for pick up and transports the rack to the shipping bay. Since the assembly line for instrument panel is located closer to the northern port (same as for *Instrument cluster*) the *Dashboard panel* is delivered to the delivery truck destined for this port.

Flow at Saab

Deliveries to Saab are checked and unloaded in the receiving bay. A tow tractor collects the racks at the receiving bay when signal of replenishment is sent from the assembly line (material Andon) and transports it to the assembly line. *Dashboard panel* requires a pre-assembly operation before the article is transported to the assembly object. This means that two operators picks the article from its rack and transport it to the fixture where pre-assembly is made. Then both operators transport the article to the assembly object.

4.3.4 Description of flow for ESH

The electrical switch for headlights (ESH) is a switch used to control parking light/driving light and fog lights (MFM presented in Appendix 6). One *ESH* is required for each car assembly. The article, Figure 14, has 22 variants, is 576 cm^3 big and weighs 113,4 gram.

Figure 14: ESH

Flow at TTAB

The goods delivered to TTAB is unloaded into the unloading bay and checked for defects/damages and the number of pallets in the consignment note. This information is entered into Saab's MPS system directly and labels are printed with information regarding storage place at Saab is printed and put on the individual pallet. The material flow of *ESH* at TTAB is special since it does not go in to the TTAB storage, the pallets from the supplier is simply unloaded from the truck, "flagged" and put on another truck destined for Saab. The trucks from TTAB goes regularly every hour so the goods are almost always unloaded and loaded onto another truck without any considerable waiting time.

Flow at Saab

The receiving dock for TTAB goods is located next to the kanban storage at Saab. When the truck arrives, the forklift driver empties the truck and places the pallet, containing 16 boxes with 30 *ESH* in each box, on the receiving dock. Another forklift driver, which is responsible for replenishment of picking locations within the kanban storage, also is responsible for transport of TTAB goods from receiving dock to high kanban storage. This storage location is designed to hold the average mean value of stock. If the number exceeds this mean value articles first have to be placed at an overflow storage location. Then when space at the high kanban storage is available, the operator makes a visual control and move pallets from the overflow storage to this stock location. Many articles have overflow stocks adding one storage place in the article flow, which also is true for *ESH*.

When the picking location gets empty, the forklift driver makes a visual control and replenishes the location with the principle of FIFO (fist-in, first-out) from high kanban storage. The materials from kanban storage to Kit preparation area are supplied with kanban principle. When the picker starts to pick from a new box, which contains a kanban card, the operator place the card in a box. The card is then collected with other cards to be sorted and handed on to the tow tractor driver, which uses the cards as a picking list. Two boxes containing 30 *ESH*/each is then picked and transported to the Kit preparation area. The picker picks a picking list, which is printed with information of which articles should be included in the kit. To minimize picking errors, picking indicators in form of lights above picking location show the picker to pick the right variant at right location. The picker verifies the pick by putting the hand under the light to switch off the picking indicator. The article is then placed in the kit and by same procedure as *Instrument cluster* transported to the assembly station.

5 Analysis

The analysis of this thesis is presented in this chapter. It starts by analyzing the studied material flows from the parameters: Handling, Administration, Transport, and Storage (HATS). This is done in order to evaluate the appropriateness of the material feeding principles kitting and sequencing. Secondly, an analysis of parameters for article characteristics is done and the studied articles are evaluated. Finally, a simulation of studied material flows transformed from sequenced- to kitted material flow is done in order to study the effects on the articles in the two different material flows and to validate previously presented data in the analysis.

5.1 Hats analysis

All of the activities from the MFM, presented in appendix 3-6, of the studied articles are categorized into handling-, administration-, transport- and storage activities, (HATS) in order to facilitate analysis. First, handling is analyzed. According to Johansson and Öjmerz (2003) a handling operation is defined as the "picking up and putting down a unit, as for example when the units are picked up, transported, and put down by a fork-lift truck". This definition has been used in this master thesis i.e. the activities picking up, transporting, and putting down has been accumulated into one handling operation. The analysis of the handling operations has further been divided into two sections: material handling to line side storage racks, and material handling at the assembly station in order to achieve a better clarity in the analysis. Secondly, administration- and transportation analysis is presented. Thirdly, the storage analysis is presented. The storage analysis is complemented with analysis of required space at the stock locations. Finally, a summary of the findings from the HATS analysis is presented.

5.1.1 Analysis of material handling to line side storage racks

In the left pile of Table 2, the numbers of material handling operations to the assembly station for the studied articles are presented. The majorities of these operations are standard handling procedures and occur within all of the studied flows i.e. these handling operations correlate in the respective flows. The sequencing articles *Antenna* and *Dashboard panel* has 10 respectively 9 operations. Even though these articles vary greatly in their characteristics, *Antenna* is a small and light article while *Dashboard panel* is big and heavy, the performed handling operations are correlated in each step of the flow. The only difference is that a "break bulk" operation is performed for *Antenna* to minimize the inventory at the sequencing station while *Dashboard panel* is maintained on supplier pallet in the sequencing station hence adding one operation to the *Antenna* flow. Since kitting as explained earlier in the report is a form of sequencing (Hanson, 2009), hence performing the same handling operations as sequencing, it is no surprise that the flow of the kitted article *ESH* is comparable to that of *Antenna* and *Dashboard panel*. *ESH* has 11 handling operations. Just like *Antenna*, *ESH* breaks the supplier pallet before the kit preparation area (sequence preparation area for *Antenna*) but due to an overflow storage solution at Saab another handling has to be performed due to one extra storage place. *Instrument cluster*, which is first supplied in sequence to the kit preparation area and then supplied in a kit to the assembly station, i.e. is subjected to a double handling, has ten handling operations.

Article	Number of required handlings:	Handlings per hour:
Dashboard panel (sequencing)	9	65.6
Antenna (sequencing)	10	42.1
ESH (kitting)	11	34.6
Instrument cluster (both sequenced and kitted)	10	72.8

Table 2: Number of required handlings and handlings per hour

The number of operations that are required for each of the studied flows does however not give a fair comparison of the required workload. Comparing the number of handling operations does not give an accurate picture of the work performed in each individual handling i.e. even if the required numbers of handling operations are almost the same for the studied flows the frequency of each handling can vary greatly. How often the handling operations are made thus have to be considered.

Assuming that Saab has a takt time of 2 minutes, 30 cars have to be assembled every hour. The frequency with which an article has to be handled per hour is dependent on two factors; the quantity handled on each occasion, and quantity required per hour. For example, a pallet of 480 *ESH* divided by the quantity required per hour (30) equals the run out time of the pallet (16 hours). This means that the pallet has to be replenished every 16 hours i.e. 0.0625 handlings per hour. To get the required handling per hour for an article each individual handling in the flow has to be calculated as mentioned above and summarized. In the right pile of Table 2 above, the required number of operations in one hour for each studied article is presented.

It would be beneficial to compare the handling operations to the time on each handling, however, in this master thesis it was not permitted to study the cycle times (monitor workers) in the Saab factory, thus only the number of handling operations for one hour is considered. The number of articles handled depends on several factors: (1) a very large article e.g. *Dashboard panel* can only fit four articles per pallet in comparison to previously mentioned *ESH*, which amounts to 480 articles per pallet, (2) postponing the break of supplier pallets closer to the end costumer means that more articles are handled in each step of the flow minimizing the required frequency. The kitting of articles next to the assembly station is preferable since the breaking of supplier pallet is done late in the supply chain. Similarly, sequencing at supplier is less favorable since smaller quantities of articles are handled in the flow. The article *Instrument cluster* is handled in both sequence preparation area and kit preparation area and handling at these areas is the most frequent because here the handling is done for one article at the time. This results in *Instrument cluster* being the most handled article per hour of all of the studied flows.

5.1.2 Analysis of material handling at the assembly station

Comparing how frequent handlings have to be performed by the assembler at the assembly line does not give as an accurate picture of the work done as it did in the previous section for material handling to the assembly station. Analyzing the frequency that an article has to be handled does not consider the other articles that are handled at the same time, e.g. articles in a kit container, but only how frequently the handling has to be performed. At the assembly line the articles are handled in a one-piece-flow meaning that the handling is done for each assembly object, once every second minute but depending on the choice of either sequencing or kitting, different amount of articles are handled at the same time.

The sequenced articles are displayed next to the line side storage racks sorted by part number, meaning that the assembler has to walk to the line side storage racks once for every assembled article. The kitted articles on the other hand are displayed together next to the assembly object hence minimizing the need to walk for materials. If one kit contains 13 articles the assembler only has to walk to the line side storage racks one time in order to fetch a kit container containing the articles while for the sequenced articles the assembler has to walk to the assembly station 13 times. The distances between the material presentation and the assembly object are presented in Figure 15. As explained earlier, the sequenced articles are presented at a further distance from the assembly object than the kitted articles.

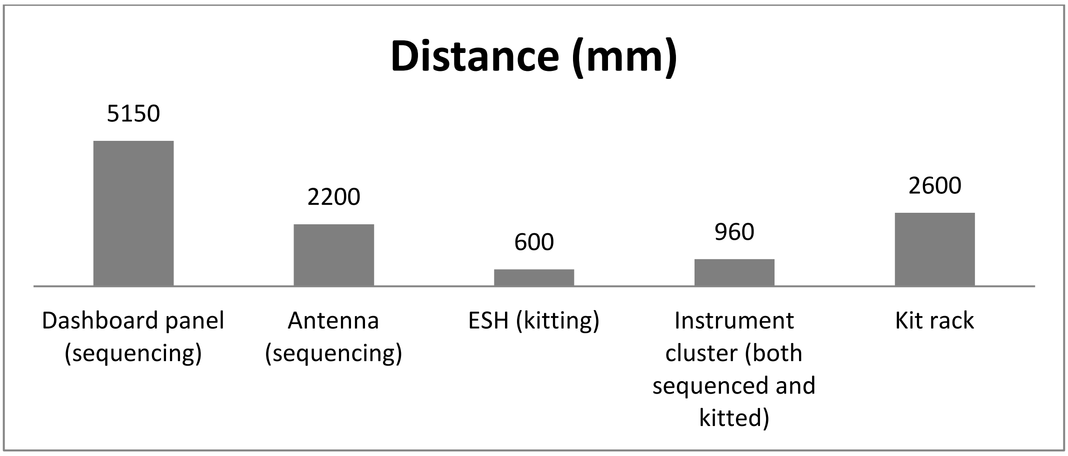

Figure 15: Distance for assembly operator to transport articles to assembly object.

5.1.3 Administration

The same administrative activities are performed in the studied material flows indifferent of the specific material feeding principles. The divides the administrative activities into the categories control (control of consignment note, quality check, and replenishment signal), registration (input to MPS system, scan barcode), and labeling (barcode, signing performed activity). Although the nature of the administrative activities do not differ between the material feeding principles the execution of the performed activities can differ depending on which actor in the supply chain who is performing the specific activity.

At DHL, all of the picked articles for sequencing are scanned in order to validate accurate picking. This gives little room for human errors hence increasing the quality and control of the material supplied to Saab. In the case of the *Instrument cluster*, the numbers of administrative activities are especially high (see Table 3). *Instrument cluster* is as explained earlier first handled in a sequenced flow to the Kit preparation area where it is then supplied to the assembly station via kitting. But the extra number of administrative activities is not due to the “double handling” sequencing/kitting. Instead, the added administrative activities are connected to the fact that the article does not have a barcode from supplier thus has to be properly identified, barcoded and scanned. Since the articles are carefully administrated at DHL, Saab does not need to perform this activity. At DHL however, the articles have to be reported both in to DHL’s own MPS system and Saab’s MPS system resulting in another form of “double handling”.

TTAB, which is used for continuous supply and kit articles, only reports to Saab's MPS system. The main part of the articles is kept on supplier pallet thus eliminating the need for advanced pick validation equipment. TTAB performs other forms of picking but the studied flow, *ESH*, is only redistributed via the TTAB facility keeping the supplier pallet intact and administrative activities to a minimum, hence making analysis of these other picking alternatives difficult.

Saab performs many administrative activities within the borders of the factory. Activities such as control of consignment notes do not have to be performed for articles from TTAB and DHL since this has already been performed. But Saab has articles that are sent directly to Saab which require this administrative activity. Saab has introduced picking systems to parts of the kit station in order to facilitate picking. A picking light visualizes what the picker should pick and the picker validates the pick by switching of the light. Since there are articles presented in the kit station that does not have a kit signal a higher risk for wrong picking exist. Saab has had problems introducing picking systems to their internal material handling systems due to the changes of factory layout and cost connected to introductions of new car models. Important to mention is that the kit station at Saab is located so close to the assembly line that this can be corrected more easily than if the fault was made at DHL.

Article	Number of administration activities:
Dashboard panel (sequence)	12
Antenna (sequence)	15
ESH (kitting)	11
Instrument cluster (sequence/kitting)	19

Table 3: Number of administration activities

5.1.4 Transport

Both the sequencing flow and the kitting flow require one transport between either DHL and Saab or TTAB and Saab. The time and distance between TTAB and Saab and DHL and Saab does not vary that much. The distance between TTAB and Saab is 4.8 km (8 min) and between DHL and Saab 2.8 km (6 min).

The main difference between the sequencing flow and the kitting flow are how often articles are transported between the facilities. All sequencing articles are transported in either a box (*Antenna*) or on racks (Dashboard panel and Instrument cluster). The information regarding which articles to deliver in sequence is sent late from Saab to DHL. In this time, between order signal and delivery, the articles have to be handled and picked in sequence. Thus quite few articles are transported on each transport. The number of articles on each truckload is for sequencing articles: *Antenna* (24), *Dashboard panel* (16) and *Instrument cluster* (16). Important to mention here is that the size of the articles, such as Dashboard panel, due to space limitations in the truck also influence the amount of articles on each truck. In contrast, the kitted articles, which are stored at Saab, are sent to Saab from TTAB on whole pallets containing a larger number of articles, 480. Since a fewer number of articles are sent on each truck for sequenced articles these has to be delivered more frequent than kitting articles. In Table 4 the frequency required for each transport with a takt time of two minutes is presented.

Article	Number of transports per hour:
Dashboard panel (sequencing)	1.875
Antenna (sequencing)	1.250
ESH (kitting)	0.063
Instrument cluster (sequence/kitting)	1.875

Table 4: Number of transports per hour

Because of the space efficiency in transporting supplier pallets a lot more of other goods can be loaded onto the same truck. The opposite is true for the sequencing flow where articles are transported on racks, which are not space efficient.

5.1.5 Storage

In the mapped flows, all the inventories are presented and symbolized by a triangle. But it is only at some of these locations where goods are actually stored i.e. the stock locations (marked with storage in MFM). The rest of the locations are buffers where material is temporarily stored pending further handling. Both the stock locations and the buffers however fill the purpose of decoupling points i.e. a break between upstream and downstream handling activities and are therefore important to map. The further analysis will however only focus on the stock locations required for each studied article since the buffers are as explained earlier only temporary and can vary between every handling occasion.

The sum of stock locations differs among the studied flows. As presented in Figure 16 the two sequencing articles *Dashboard panel* and *Antenna* have three locations each where the articles are stored. These locations are the high storage (1) where supplier pallets are stored at DHL before they are moved to the storages at the sequencing preparation area´s (2). In this location, smaller amounts of articles are stored and the picker retrieves material here for the sequencing activity. The third stock location is located at Saab, at the assembly station (3), it is from this location that the assembly operator picks articles to be mounted on the assembly object.

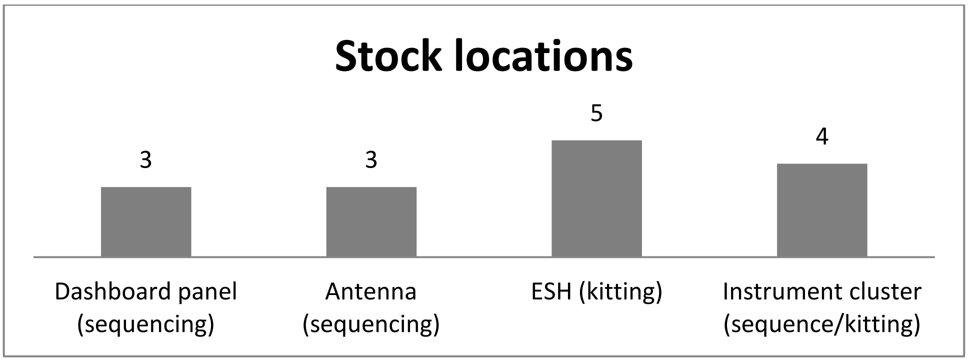

Figure 16: Number of stock locations

The kitting article *ESH* also has these three stock locations but they are all located within the Saab factory, instead of the location at sequencing preparation area it is located at the kit preparation area. Further stock locations required for the kitting article, *ESH*, is the overflow storage (4) and the stock location at the kanban picking storage (5). *Instrument cluster*, which is supplied in sequence to the kit preparation area, has the same stock locations as the sequencing articles but does also have storage in the kit preparation area.

Space requirements

In the material flow, the studied articles are individually presented in a variety of different load carriers e.g. supplier pallet, supplier box, sequencing rack or container and kitting container. The choice of load carrier is connected to the requirements of the specific section of the material flow (Lumsden, 2007). In Table 5 below the different load carriers for the studied articles are presented along with the dimensions for the load carriers.

	Supplier pallet	Supplier box	Sequencing rack	Seq./Kit cont.
Dashboard panel	1630x1220x1400		2700x1570x1800	
Antenna	1200x800x1000	600x400x280		800x400x200
Instrument cluster	1200x800x1000	600x400x415	1500x800x1880	800x400x200
ESH	1200x800x1000	600x400x200		800x400x200

Table 5: Dimensions of load carriers (mm)

In the high storage, the numbers of pallets for the studied material flows are: *Dashboard panel* (83), *Antenna* (10), *Instrument cluster* (229). The quantity for the article *ESH* in high storage was unfortunately impossible to retrieve from Saab's MPS system, only the quantity available in the entire factory was available. All studied material flows are displayed in supplier pallets in the high storage and handled with forklift. The *Dashboard panel* is as explained earlier a very large article hence limiting the unit load down to four articles per pallet. The size of the article and the high number of variants (24) strongly affects the high number of pallets in the high storage. At the same time, the close distance to the supplier means that inventories are kept down due to more frequent deliveries. The *Instrument cluster* is another article that stands out when considering the number of pallets in the high storage. There is however a factor distorting this number since Saab has bought the article stock from suppliers filing for bankruptcy resulting in higher inventory levels than normal operations require. This is off course not an ideal situation but a situation that Saab would have to deal with if the company where to handle the inventory internally instead of DHL. Other factors affecting the high number of pallets in the high storage are the long distance to the supplier and the size of the article. *Instrument cluster* can only fit six articles per box and 10 boxes per pallet (60 articles per pallet) hence increasing the number of pallets. The amounts of pallets are however somewhat reduced since the pallets contain a mixture of different article numbers. The variants of the article *Antenna* are similarly to *Instrument cluster* packed onto the same pallet, hence reducing the number of pallets in the high storage. The small size of the article (588 articles per pallet) also contributes to the low amount of pallets in the high storage. *ESH*, is similarly to *Antenna* a small article and therefore the quantity of a pallet amounts to 480 articles.

Depending on the function of the storage place different amounts of space are required e.g. the high storage, which is a main storage (large volume) and handled with forklift handles pallets. As shown in the previous text, the amount of space is also depending on the articles characteristics. The preparation areas for both of the material flows are another example of a different storage function. From these stock locations, articles are picked by a picker and hence needs to be presented to the picker in a way that facilitates picking. The articles *Dashboard panel* and *Instrument cluster*, which are the two larger articles, are presented on whole pallets. Both articles have one pallet represented for each variant within the article family in the sequence preparation area. The smaller articles *Antenna* and *ESH* are on the other hand broken down from supplier pallet and are presented in smaller boxes instead which reduces the required space at this stock location. These articles also have one stock location for each variant of the article represented. The size of the load carrier chosen is connected to the run out time of the article meaning that the chosen load carrier should comply with chosen inventory levels and the space available at the stock location.

The required space at the assembly station for a kitting article compared to a sequencing article is very dependent on the size of the article and its rack where the article is presented in. The size of the rack with finished kits does not differ much in size compared to the size of the rack of sequenced article *Dashboard panel*. The difference is that the kits contain several different articles while the racks for sequenced articles are specific to the individual article family hence occupying much more space. The article *Instrument cluster* will of course require the most space while it is presented in both sequencing preparation area and kit preparation area.

5.2 Cost analysis

In this analysis the variable costs for each studied article is focused upon. The fixed costs include costs associated to buildings, equipment and transports between DHL and Saab i.e. these costs exist whether the article is included in the flow or not i.e. these costs are divided among all of the articles at DHL. A further parameter that affects cost is tied up capital. Due to the fact that Saab has the ownership of the material at both DHL, TTAB, and Saab this cost will not change hence will not affect the cost of the tied up capital in this study.

The variable costs considering the flow at DHL (sequenced articles) include the time spent on handlings for each flow per hour for a blue-collar employee. Further, a variable cost for material handling equipment is also included. This sum corresponds to approximately 10 % of the total variable cost. It must be noted that a variable cost for material handling equipment is not included in the times calculated from handlings at Saab. Only the costs for time spent on each article (both sequencing and kitting) for either an assembler or a forklift operator is calculated.

The cost calculations for the flows shows that cost is related to the number of handlings per hour, previous mentioned in “handling analysis”. What stands out from this relation is *Dashboard panel* whose handling operations was kept low but is substantially the most expensive article. The reason, as stated in the MFM, is that *Dashboard panel* requires two handling operators in both the sequencing preparation area as well as in the assembly station. This has a considerable effect on the cost and would apply even if the article only was handled at Saab. Furthermore, considering handling it was concluded that the kitting flow was the most beneficial. The calculations of cost also show that kitting is considerably more beneficial than sequencing not only with handlings in consideration.

The calculations show that costs from handling at DHL is the major cost for the articles supplied with sequencing. All of the handling operations for the individual articles that occur at DHL are included in one summarized cost thus making the analysis of the costs of individual handling operation impossible. What can be stated is that it is the cost for handling at DHL that is the major cost within the sequencing flows. For *ESH* it is the handling at TTAB that is the major cost. In the studied flows within Saab´s facility, the most expensive handling is when the articles are handled within the kit preparation area. This is true for both *ESH* and *Instrument cluster*. The transport of racks within

Saab´s facility is for the *Instrument cluster* the second most expensive activity excluding the costs from DHL. The corresponding transport for the *Dashboard panel* rack is even more expensive. The reason is that when transporting the *Instrument cluster* rack several other articles are transported at the same occasion. The opposite is true for *Dashboard panel*, which is handled separately (eight articles per transport). At DHL, where articles often are handled on racks which in turn often are transported with less articles on each occasion thus to some extent motivate the large difference of cost between a kitting article and a sequencing article. At the assembly station the cost for fetching the articles, which are presented, in a kit container (*ESH* and *Instrument cluster*) is lower for both articles compared to *Antenna*, which is presented in the line side storage rack.

5.3 Article characteristics

It was shown in the previous section that kitting has advantages compared to sequencing when considering handling in the studied material flows. It is therefore beneficial, from a handling and economical point of view, to discard sequencing via DHL and to arrange all sequenced articles via kitting instead. However, other factors have to be considered before this decision is made. System borders could put restraints on the material handling, making kitting disadvantageous. In this chapter, characteristics connected to the selection of material feeding principles will be discussed.

5.3.1 Size

The size of an article is strongly connected to the appropriateness to supply the article via kitting. The size of the article can either be big concerning volume (cubic centimeter) or bulky i.e. have an unwieldy largeness. Kitting can as explained earlier, at Saab, be divided into three alternative solutions: kit-in-box, kit-in-car, and kit-to-fixture. The three different alternatives put different limitations to the possibilities of supplying the article via a kit due to the dimensional constraints of each container. The alternative kit-in-car can include the biggest individual kitting articles since the dimensions of the car cabin where kitted articles are placed are bigger than both a box and a fixture. During the trial of kit-in-car, large articles for the assembly of the car cabin was placed in the car cabin, among these articles where the *A-, B-, C-, and D pillars*. These pillars are not very big articles measured in volume (cubic centimeters) but are instead big concerning bulkiness i.e. they are long and small. The dimensions of the alternative kit-in-box are smaller compared to the car cabin since the boxes have to be handled easily both by the picker and the assembler in the material flow. The boxes can vary in size depending on the requirements from the kitted articles but does still put limitations to the size of the articles. The kit-to-fixture alternative is only used at the engine assembly line at Saab. The kitted articles are placed onto the transport-fixture of the engine assembly line. This is a small area hence further limiting the size of the articles included in the kit.

5.3.2 Weight

Similarly to the size of the article, weight is also an important parameter in the evaluation of the appropriateness of supplying the article via kitting. The weight is limited to ergonomic constraints in order to secure the safety of the operator and is also affected by the choice of kitting alternatives mentioned earlier. Both the alternatives kit-in-car and kit-to-fixture place the articles individually into the kit container hence avoiding the heavy lift of the accumulated kitted articles. These alternatives are comparable to sequenced deliveries where each article also is handled separately. The kit-to-box alternative on the other hand has to be handled in parts of the flow with the accumulated weight of all of the included articles in the kit hence reducing the maximal weight of the individual articles. The currently largest weight of a kit box at Saab is 7,2 kilogram. However, the calculated ergonomic maximum weight is 13.9 kilogram considering an 8 hour work day and a takt time of 2 minutes (calculation can be found in Appendix 7).

5.3.3 Special handlings

Some articles require special handling and can therefore potentially not be suitable for kitting. One example is the sequenced article *loom,* which has to be preheated to facilitate bending in assembly. The article is run through a heater device before the assembly station, an operation that could potentially damage other articles included in a kit. Another example is the studied article *Dashboard panel*, this article requires a pre-assembly operation that in turn requires a fixture located next to the assembly line. Having an article, which requires fixture at the assembly station supplied with kitting, can reduce the benefits of this feeding principle.

5.3.4 Sensitiveness

An article can be sensitive to many different factors such as humidity, dust, temperature, scratches etc. A sequenced flow and a kitted flow require, as proven earlier, the same amount of handling activities. Sensitive articles could therefore be assumed to run the same risk of damage in both of the flows, however, there are some differences affecting the security of the article. A sequenced flow is broken from supplier pallet earlier in the material flow while kitted articles are maintained in supplier boxes until the kit preparation area located close to final assembly. This can potentially increase the risk of damage to the article since protective wrapping from supplier is removed. Kitted articles are on the other hand placed together with other articles increasing the risk e.g. for scratches. Many kits have inner matrixes preventing that articles move while handling but kit-in-car and kit-to-fixture are examples of kitted articles displayed loosely in their container while sequenced articles are placed in either racks with fixed positions or fixtures hence preventing movement.

5.3.5 Article characteristics of the studied articles

The studied material flows will in the next chapter be simulated in a kitting flow and it is therefore relevant to compare the articles against the compiled parameters. Since *ESH* already is kitted, this article will not be analyzed further here. Size is the first parameter from which the articles are compared. The size can vary a lot depending on the load carrier that will be used in the flow. The largest load carrier currently at Saab for kitting is the car cabin (kit-in-car). Both *Antenna* and *Instrument cluster* are relatively small articles and can fit into all of the existing load carriers. *Dashboard panel* on the other hand is as explained earlier a very large article and does not even fit into the car cabin, hence is excluded from further analysis and labeled as not appropriate for kitting. The remaining two articles, *Antenna* and *Instrument cluster*, are very different concerning weight but are still considered light (82 gram and 800gram) compared to the ergonomic maximum weight hence are still suitable for kitting. None of the articles require any special handling such as preheating and is therefore further qualified. Finally, the articles are evaluated on the parameter sensitiveness. Sensitiveness is an intangible parameter and requires a more in-depth analysis. Both *Antenna* and *Instrument cluster* are products visible to the end customer, increasing the importance to protect the articles from e.g. scratches. The *Antenna* is currently from supplier placed in a plastic bag, which is removed first by the assembler at the assembly line hence is protected from damages. In a kit flow this protective plastic bag is removed in the kit preparation area to this activity from the assembly station. The *Instrument cluster* is also more exposed to scratches and does therefore require extra protection in the case of kitting. An inner matrix, which allows articles to be fixed while handled, is one solution. This is how the Instrument cluster is currently being displayed in the kit container.

Therefore it is suggested that both articles are appropriate for kitting and further analysis in the simulation chapter.

5.4 Simulated kitting flows of Antenna and Instrument cluster

In the previous chapter it was concluded that the sequenced articles, *Antenna* and *Instrument cluster*, are appropriate for further analysis concerning the transformation of the article material flows from a sequenced flow to a kit flow. The articles will in this chapter be simulated in a kitting flow (TTAB to Saab). The existing kitting article *ESH* will act as a base for the simulation i.e. the *MFM* for *ESH* is assumed to be valid for *Antenna* and *Instrument cluster*. The results from the simulation will thereafter be evaluated in comparison to the results from chapter 5.1 where the current material flows of the articles are analyzed.

The handling operations per hour are calculated in the same way as in the previous chapter (see chapter 5.1.1) with the new quantities connected to *Antenna* and *Instrument cluster* replacing *ESH*. In Figure 17 below, the required handling operations per hour in a kitting flow for *Antenna* and *Instrument cluster* are presented. They are also compared to previous handlings per hour where the articles are supplied with sequencing.

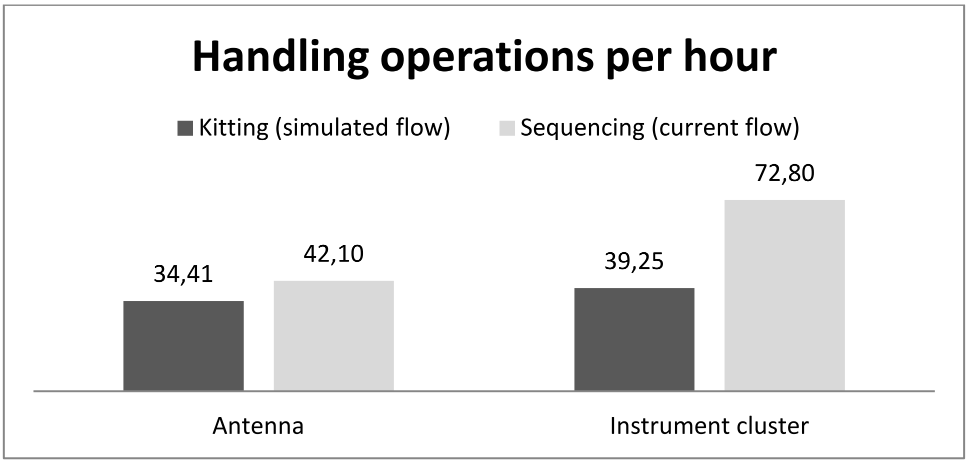

Figure 17: Handling operations per hour

As can be seen in Figure 17 both flows will reduce the number of handlings per hour if supplied with kitting. Of the two articles, *Instrument cluster* is the article where handling has been reduced the most, a reduction of 33 handling operations per hour. The difference of the simulated flow and the current flow of *Instrument cluster* can be referred to the double handling currently being used including both sequencing and kitting in the material flow. As discussed previously kitting is more beneficial concerning handling in the studied material flows compared to sequencing since larger quantities are handled at each occasion and the break of bulk is postponed in the supply chain. This is also shown in this simulation. From calculations considering the variable costs at TTAB, DHL, and Saab considering handling further evidence of the appropriateness of kitting is presented. Costs from the existing sequenced flow for the studied articles are compared with the cost in the simulated kitting flow for the articles *Antenna* and *Instrument cluster*. The results show great reductions in cost when transforming the material flow from sequencing to kitting. Similar to the analysis of the material handling at the assembly station (chapter 5.1.2), the walking distance will also be minimized if the article *Antenna* is presented in a kit (*Instrument cluster* is already presented in a kit). This conclusion is based on the assumption that more articles are suitable for kitting in the station for *Antenna* assembly.

Considering the storage and space requirements that a new kitting flow demands, the stock locations at DHL will simply be transferred to Saab. At the stock location of supplier pallets (high storage), the corresponding inventory level at DHL has to be located at Saab at either the overflow storage or the kanban storage (high storage). The levels of inventories are assumed to maintain the same levels for both *Antenna* and *Instrument cluster*. The overflow storage is today used at Saab due to the limited amount of storage space in the factory meaning that stock places have to be under dimensioned, when the stock places are full additional stock places (over flow) has to be used in order to store the articles. This signals that space in the factory is scarce even today. When many articles exist for an article, many times several articles are not as frequently used as other within the same article family. The articles can either be presented on whole pallets (as the studied kitting article *ESH*) for frequently used articles presented in supplier box for less frequently used articles, which reduces required space. This means that the articles are picked from the same place as where they are stored. Still, the corresponding inventory levels at DHL have to be presented at Saab, 229 pallets of *Instrument cluster* and 10 pallets of *Antenna*. Important to mention is that storage location at TTAB has not been discussed here since *ESH* is not stored at TTAB. It is however possible to store more articles at TTAB in order to save space in the Saab factory.

The storage in the kit preparation area will require a greater amount of available space as well. To store all variants of both *Antenna* and *Instrument cluster* in a kit preparation area would increase the space at Saab significantly. At this stock location all variants of each article has to be presented. In this area articles are mainly presented in their supplier boxes, which would apply for both *Antenna* and *Instrument cluster*. Today, the kit preparation area covers a total length of line side storage racks available for picking of approximately 132 running meters (Appendix 8), all 65 articles included. Running meter is the length of the summarized rack bin length. Instrument cluster alone would require a length of approximately 16 running meters (variants*length of load carrier required in the line side storage rack). *Antenna* would also require a length of approximately 16 running meters. Even if this article is considerably smaller than an *Instrument cluster* and the reason is that the article has so many variants, which need to be stored. This number of 16 meters can be compared to the article *ESH* which is one of the articles with most variants within the kit preparation area requires a length of approximately 8 meters in the line side storage rack available for picking.

It is not only the package´s length in the line side storage rack in the kit preparation area, which decides the quantity of required space. The depth of the line side storage racks i.e. how many packages that can be stored at the same time in depth are also important to consider. This is however connected with the frequency of number of handling activities. The number of handlings from the kanban storage picking location to the kit preparation area was calculated to transport 12 *Instrument cluster* each time. With this high frequency of transports, the amount of articles in depth can be kept low. *Antenna* contains a higher number of articles within each supplier box meaning that inventory levels at this location will be fitted within the line side storage rack. The depth cannot exceed 1.8 meters (depth of line side storage racks in kit preparation area), if so the transport from kanban picking place has to be more frequent or the articles will require more space at the kit preparation area. Since the *Instrument cluster* is already presented in a kit at the assembly station, no space reductions will occur. In order for space benefits for *Antenna* to occur, more articles in the station have to be kitted. If not, the line side storage will only change from one load carrier to another hence implying that further analysis of the station is required.

The increased amount of space required also results in an internal cost for space at Saab. The cost for the spaces are calculated by summarizing the spaces required for *Antenna* and *Instrument cluster*, (see calculations in Appendix 9), and multiplied with the cost of 700 SEK per square meter and year. The yearly cost per square meter was gained by a consultation with Kjell Lövqvist (personal correspondence, 23 May, 2011). Assuming that 51 000 cars are manufactured per year (30 takt) the cost per car can be calculated as shown in Table 6 below:

Article	Square meter cost per assembled car:
Antenna (kitting)	0.71 SEK
Instrument cluster (kitting)	1.60 SEK

Table 6: Simulated square meter cost per assembled car.

The cost associated with space at DHL is a fixed cost, which Saab is paying for. This means that this cost will not disappear if articles are transferred from DHL to Saab but instead moved over to the remaining articles in the sequenced material flow at DHL. The previously presented gains considering the variable cost however changing sequenced articles to be supplied by kitting where so big that even though that Saab will have to pay an extra cost for space it is still considered to be motivated.

As mentioned in the HATS analysis (chapter 5.1), Saab has had trouble introducing appropriate picking systems due to costs associated with implementation and more frequent layout changes. Introducing even more articles into Saab's internal flow will further affect this problem. The number of administrative activities in the individual flows will not be greatly affected since the large amount of activities connected to the *Instrument cluster* was due to an extra labeling not connected to sequencing. The same is true for Antenna since the administrative activities can be transferred from DHL to Saab. Transports can also be explained by viewing the comments from chapter (5.1). As mentioned in chapter 5.1.3 the transports between DHL and Saab is done more frequent. If *Antenna* and *Instrument cluster* are integrated into the kitting flow, the DHL transport will be replaced by the less frequent transports between TTAB and Saab.

6 Results

The results of this master thesis are presented in this chapter based on the previous analysis chapter. First, the question "which material feeding principle is preferable, sequencing or kitting" from the master thesis purpose is answered. Secondly, the template which aim is to facilitate the decision whether to kit individual sequenced articles according to the second question "which products should be included in Saabs internal kit assembly (material handling)" is presented. And finally the third question "how material flows for these products should be arranged from supplier to the kit area at Saab" is answered.

The results from the analysis all point towards kitting being a preferable material feeding principle for Saab compared to sequencing via a 3PL company (DHL). The analysis of the studied material flows and the following simulation of the articles *Antenna* and *ESH* showed that although the number and the characteristics of handling activities where comparable between the sequenced and kitted material flows huge differences could be identified concerning the work load (Table 2 and Figure 17). When considering the frequency of each individual operation in the studied flows, a completely different picture appears. It was identified that the kitting of articles next to the assembly station is preferable since the breaking of supplier pallet is done late in the supply chain. Handling one single article or handling a pallet of article creates great differences to the frequency the article has to be handled but also the individual work performed at each occasion. In other words it can similarly be stated sequencing at supplier is less favorable since smaller quantities of articles are handled in the flow. From the results from the analysis it was also shown that flows combining both sequence and kitting activities where the least favorable concerning these parameters (Table 2 and Figure 17). A cost analysis performed further support this conclusion where it was seen that the variable costs was lower for the kitted articles compared to the sequenced articles.

The resulting template can be viewed in Appendix 1. As the result previously presented showed, it is beneficial for Saab to kit as many sequenced articles as possible. However, system boundaries such as available space within the Saab factory, for storage, or kit preparation areas, and also limitations in the presentation of the kit have to be evaluated. These parameters are presented in the suggested template and thus are intended to facilitate the work structure connected to the transformation of sequenced articles into kitted articles.

The load carrier in which kits are presented can as previously mentioned vary depending on the chosen kit alternative existing within Saab: Kit-in-car, kit-to-fixture, and kit-in-container. The article characteristics can vary hugely depending on the choice of load carrier and it is therefore important in the initiation part of a kitting project to know which alternatives that are present at the specific line section. The second step in the template is to evaluate the individual article according to the parameters presented in chapter 5.3, Article characteristics. These parameters are strongly connected to the previously introduced load carrier and have to be evaluated with the choice of load carrier in mind.

The final step in the template is to evaluate the potential kitting articles in connection to the system boundaries present at Saab. As shown in chapter 5.1.5 Storage and the following space requirements, a transformation of the sequenced material flows into kitted material flows will require a lot of space in an already strained facility concerning space. It is thus important to evaluate the implementation of the articles on this basis.

7 Discussion

The results from the analysis are discussed in this chapter.

In accordance with the purpose of this master thesis to analyze which material feeding principle, kitting or sequencing, is more advantageous it is shown that kitting is advantageous compared to sequencing considering the studied material flows. This result consorts with Saab's chosen strategy to continue the implementation of kitting to more sections of the assembly line within the factory. The HATS analysis with the following simulation of the sequenced flows for the articles *Antenna* and *Instrument cluster* showed that kitting was beneficial considering the amount of handling work performed in the kitted material flow compared to the sequenced material flow. This result was further validated in the cost analysis where the variable costs connected to the handling in the material flows where analyzed.

From the reviewed academic literature studied for this master thesis a comparison between the studied material feeding principles kitting and sequencing where not found. It is a stated fact that little has been written within the area of kitting and the existing literature focuses upon the comparison between kitting and the material feeding principle continuous supply. However, Hanson (2009) explains that kitting is a form of sequencing; the difference being that sequencing only handles one article family in the material flow while kitting can handle several. Our findings from the study of the material flows validate this statement. It was shown the activities performed concerning HATS are comparable between the studied flows, the difference being the amount of articles handled in each occasion.

From the literature (Baudin, 2004; Aronsson *et.al.*, 2004) it was also mentioned that having a 3PL responsible for activities such as sequencing could be beneficial considering costs. Costs associated to the material handling such as the employees, "blue collars", are according to the literature lower because of e.g. lower salaries compared to the automotive industry. Saab did not have figures confirming or disconfirming such a statement but in this master thesis it is shown that costs are reduced by moving the sequenced flows to Saab hence disconfirming previous statements from literature. The cost for a sequencing flow performed by DHL is considerably more expensive than doing these activities within Saab´s factory in a kit preparation area.

The material flow of the article *Instrument cluster* was especially interesting to analyze since it included both a sequenced flow from DHL to the kit assembly station at Saab only to be changed into a kitting flow for the material flow to the line assembly station. Saab was curious whether the sequenced and kitted flows together could create synergy effects hence where interested in further analysis of this material flow. From the analysis it was concluded that this "double handling", sequencing and kitting, increased the handling work performed and the costs of the material handling in comparison to a regular kit flow hence being discarded in this master thesis as an appropriate material flow.

It was further shown in the simulated flows showed that kitting is more advantageous compared to sequencing. As mentioned, the kitting flow requires more available space in Saab´s facility. In this thesis it is assumed that the simulated flows of *Instrument cluster* and *Antenna* should be stored exactly like the studied kitting article *ESH*. To store all inventories of supplier pallets in kanban storage at Saab is probably not the best solution. According to the literature a consolidation center can act as a domestic center for goods arriving from abroad, TTAB has this possibility and a lot of materials delivered to Saab are stored at TTAB. To keep inventories at TTAB would probably be the alternative for these articles, especially for *Instrument cluster*, which requires 229 pallets to be stored at this storage location. This will thus result in limitations for available spaces can be solved by TTAB, which enables the articles to be supplied with kitting.

It is important to keep in mind that the cost for surface space at DHL is a fixed cost that Saab currently is paying for. If articles are removed from DHL, the fixed cost will not be changed but instead transferred to the remaining sequenced articles at DHL. As shown in the master thesis, the earnings from the variable cost when introducing articles into the internal kit are however so big that this still motivates the decision to internalize the article material supply. And even though articles might be removed from DHL, other articles will be transferred to DHL hence keeping the fixed cost low.

The master thesis however also shows that there are several parameters that have to be further analyzed before the decision can be taken to internalize articles previously supplied via sequence and DHL. All of the possible parameters opposing the transformation of material flows from sequencing to kitting are connected to the system boundaries that exist at Saab. These boundaries are: available space within Saab, available storage space in kit-preparation-area considering efficiency, and capacity limitations of the load carriers.

This master thesis has developed a template (Appendix 1), which aims to facilitate the decision-making regarding these issues. In this template a suggested work structure is introduced, explaining the factors that have to be considered in the transformation of a sequenced material flow to a kitting material flow. The structure proposes that the appropriate load carriers for the line section first should be investigated. The capacity and characteristics of the load carrier is important to reflect upon in the characterization of the potential kit articles, which is shown from this reports analysis. Secondly, the articles are evaluated on a set of characterization parameters selected to discard inappropriate kitting articles. As explained in the report it is not only the appropriateness of the article, which decides if an implementation can be made. System boundaries also have to be investigated to evaluate the capacity limitations within Saab. If the article is discarded from any of the steps in the template it is suggested that the article continues to be supplied in its present sequenced flow.

It is important to mention that the results of this master thesis are dependent on the current supply chain setup of Saab Automobile AB. A different supply chain setup could potentially alter the results hence it is our hopes that this master thesis act as support in other companies kitting implementation and that the results of this master thesis are validated at the companies.

8 Conclusion

In this chapter the conclusions from this master thesis are presented along with the contributions that the master thesis has made. Finally, prospects of future research within the topic of the material feeding principle kitting are suggested.

It is shown in this master thesis that the material feeding principle kitting is advantageous compared to the material feeding principle sequencing considering parameters such as handling and cost of material supply. The results from the performed MFM, the simulation of the transformed sequence to kit material flow, and the cost analysis state that as much sequenced articles should be transformed into a kitting flow instead. Limitations (system boundaries) however exist in the material feeding principle and within Saab contradicting this conclusion. Characteristics of articles exist such as size exists, which means that they cannot properly be handled in the kit flow. Limitations to the possibility to insource articles also exist within the Saab factory such as size hence limiting the possibility of kitting the article. The result of this report is guiding principles, which can be used in the evaluation of whether a sequenced article should be supplied via kitting or not. Also presented is a recommendation for how these chosen kitted articles should be supplied.

During this study (master thesis) areas of interest for further studies have been identified. The choice of which articles that should be supplied with kitting is as explained very dependent on the available spaces within the kit preparation area as well as spaces required for the kit preparation areas. To investigate how many articles that can be stored in a kit preparation area future research have to be made considering how a larger kit preparation area affects the picking efficiency. With a larger area the picking operator has to walk longer distances and how this affects the material feeding principle of kitting is currently unknown. With increased extent of kitting as feeding principle, Saab has to investigate the available spaces at Saab where kit preparation areas can be located. In collaboration with this issue it must be investigated how the placement of these areas affects kitting. A study of the appropriate placing of a kit preparation area connected to a specific assembly line station should be further investigated. To our knowledge a study of this specific area has been initialized within Saab. Kit-in-car is a load carrier that was implemented on a trial basis during our study at Saab, further investigation concerning the benefits of this alternative and the appropriate way to place/hold the material in the car should be studied.

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10 Appendix

Appendix 1: Template of which articles to be supplied with kitting

Load Carrier

1. **What type of load carrier can be used in the studied line section?**

Existing alternatives at Saab are: kit-in-container, kit-in-car, and kit-to-fixture. Kit-in-container is by far the most utilized load carrier at Saab. Both kit-in-car and kit-to-fixture have limitations to where they can be used.

Article

2. **Special handling.**

The article is discarded if it requires special handling prior to assembly that e.g. potentially can be harmful to other articles included in the kit such as preheating or preassembly operations requiring fixtures hence interfering with the flow of assembly.

3. **Size of article.**

The article is discarded if it is too big to fit into a load carrier. Also consider bulkiness.

4. **Number of variants.**

This parameter is connected to the previous mentioned parameter size since the two explain the volume required at different storage locations. The article is discarded if the volumes of articles are to big in relation to available capacity within Saab.

5. **Weight of the article.**

The article is discarded if it is heavier than recommendations considering lift ergonomics. Considerations also need to be taken to the total weight of the kit container since it is also handled manually.

6. **Sensitiveness.**

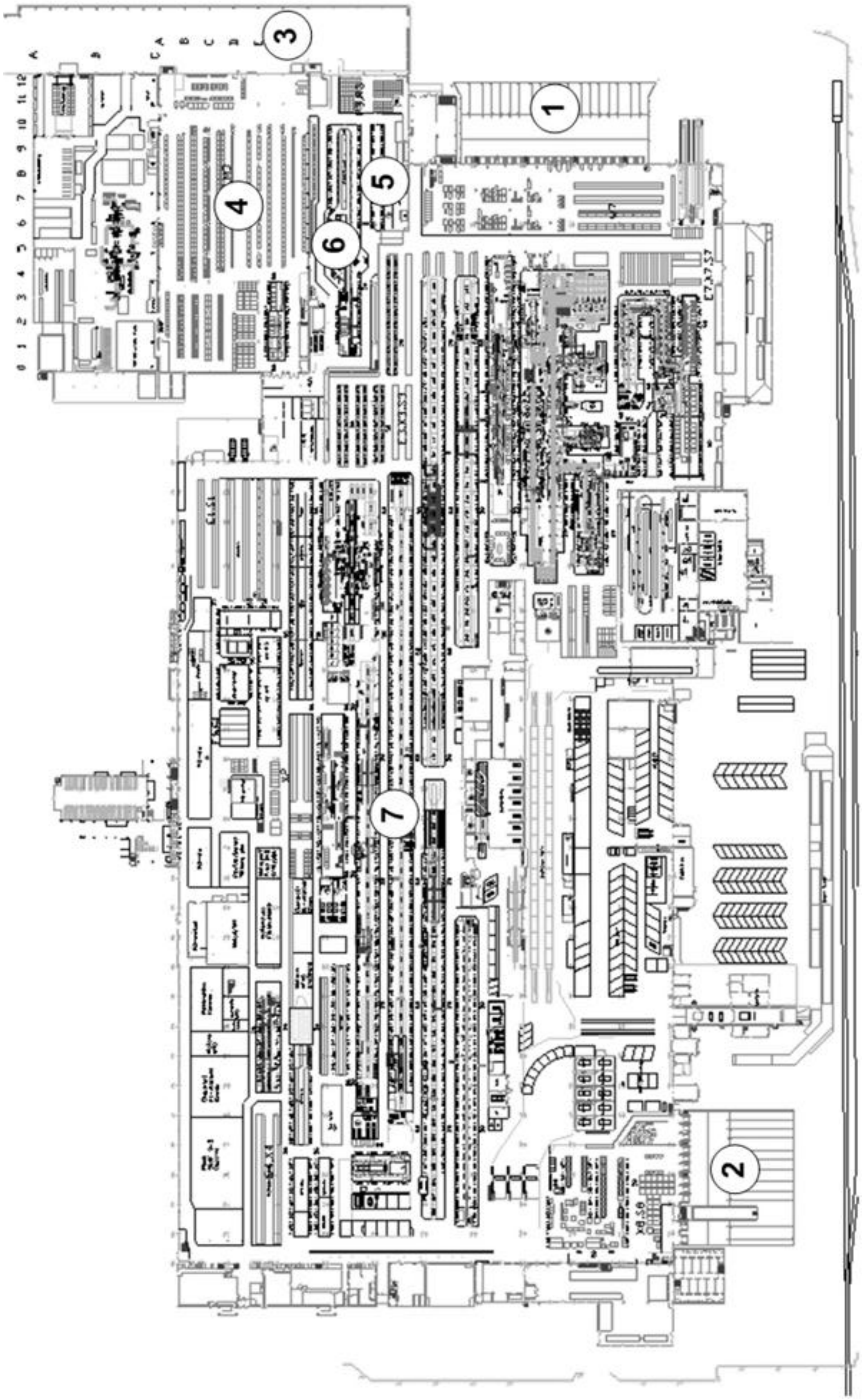
If the article is sensitive to damages such as scratches special considerations have to be taken considering placement in the kit load container. Potentially more space is required in the kit load container in order to properly secure the article.

System boundary

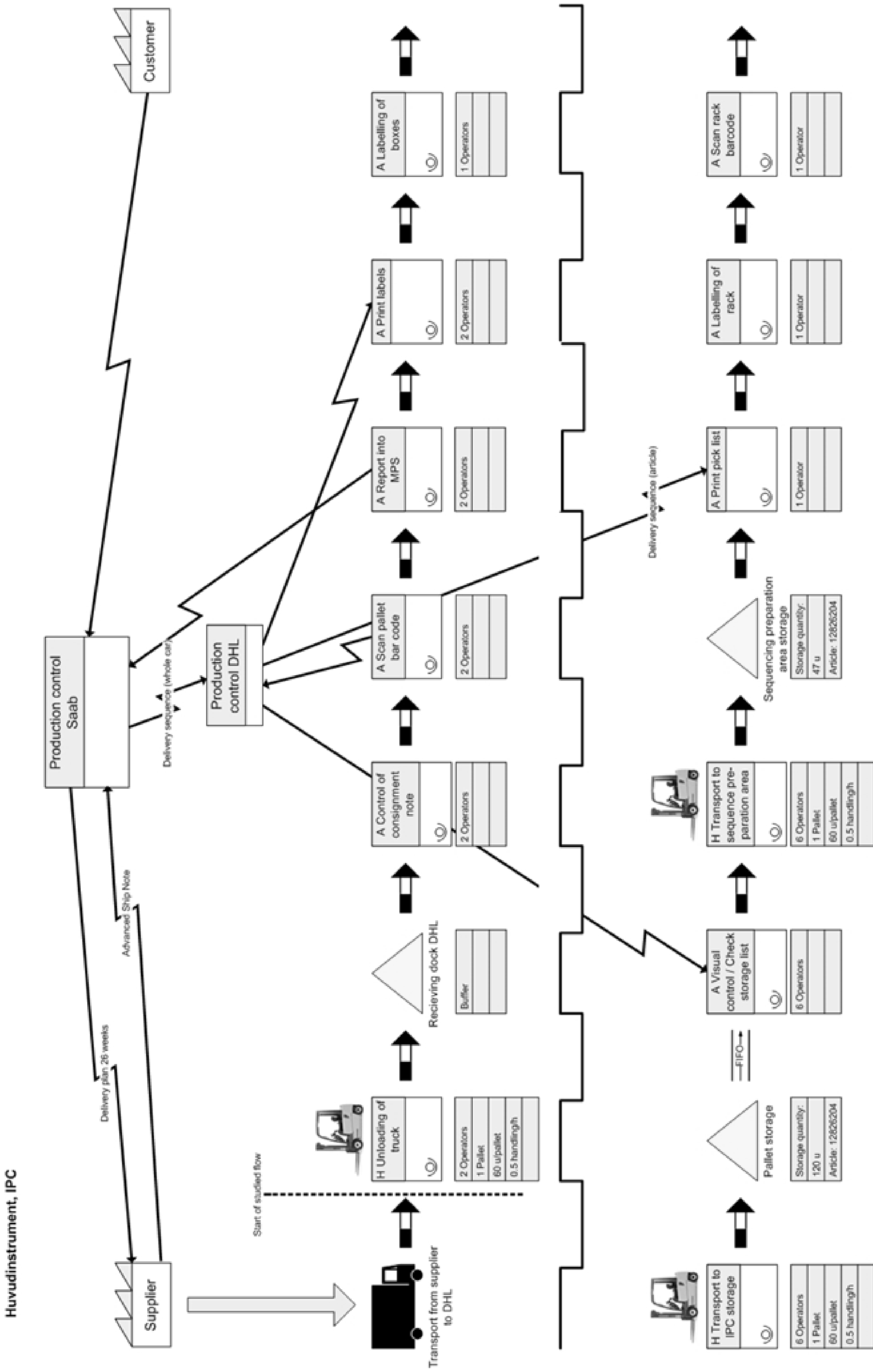
7. **How much space is available at Saab?**

Do the system boundaries, space within the Saab factory and available storage space present limitations to the introduction of the article.

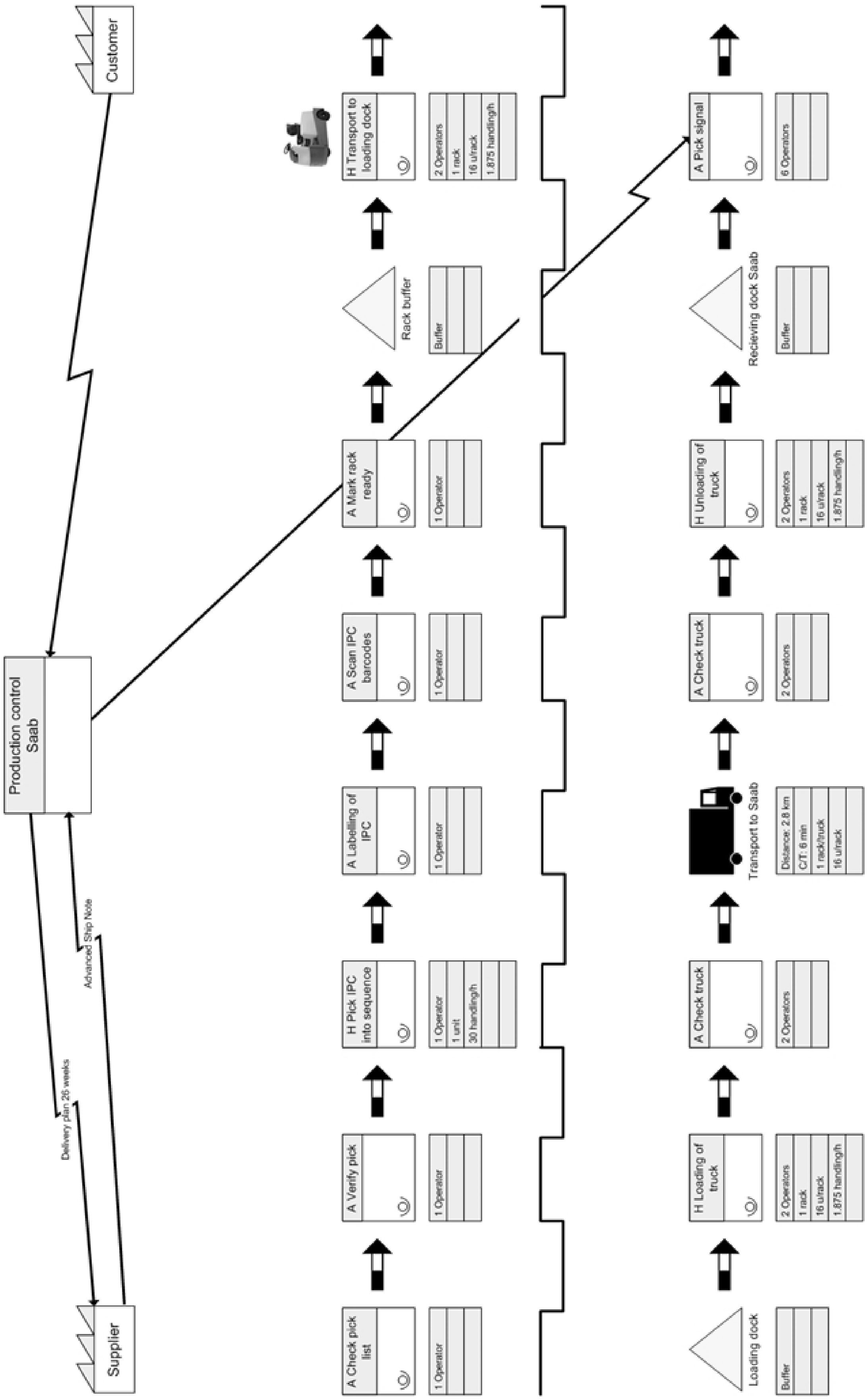
Appendix 2: Layout of Saab´s final assembly plant



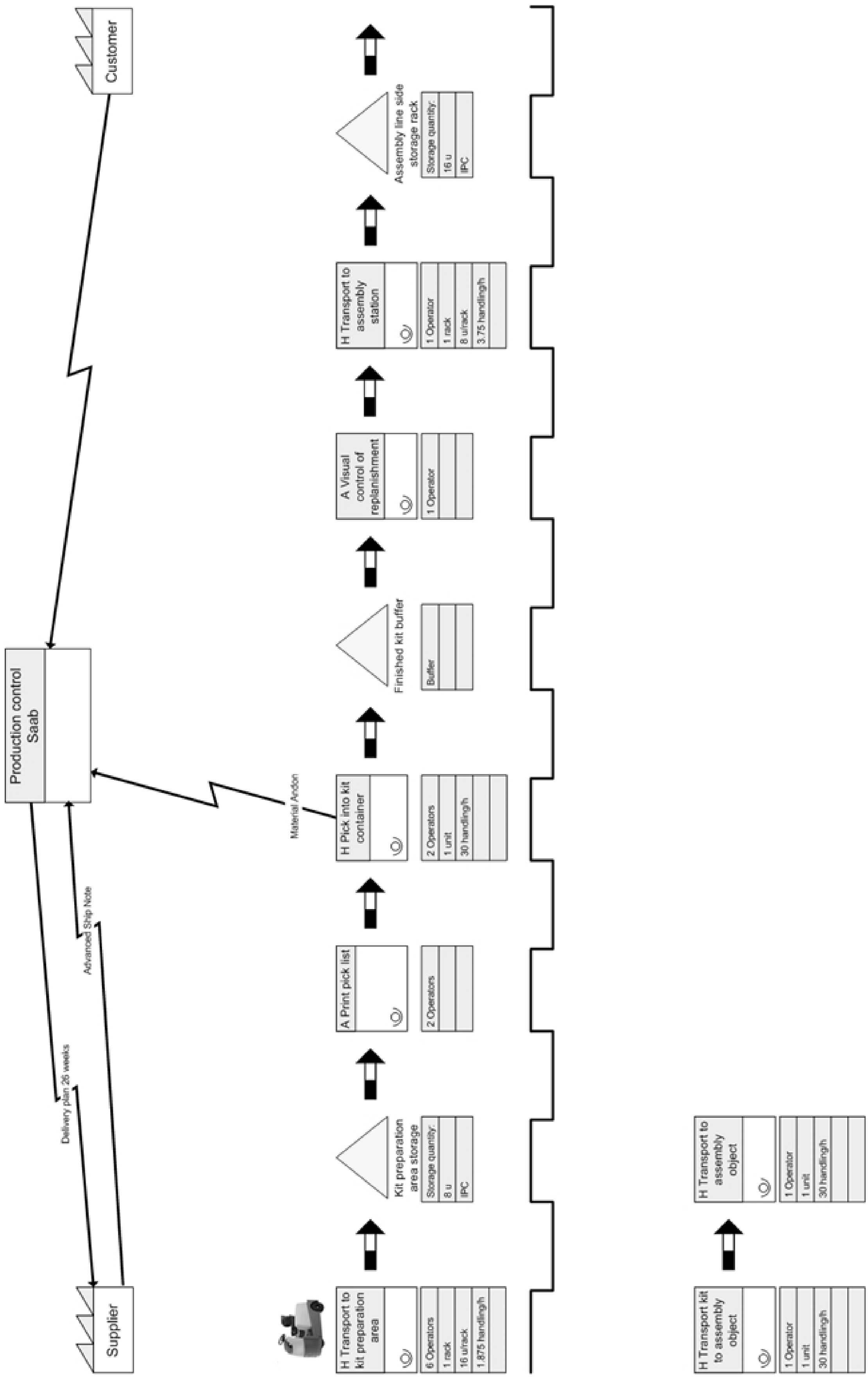
Appendix 3: MFM Instrument cluster



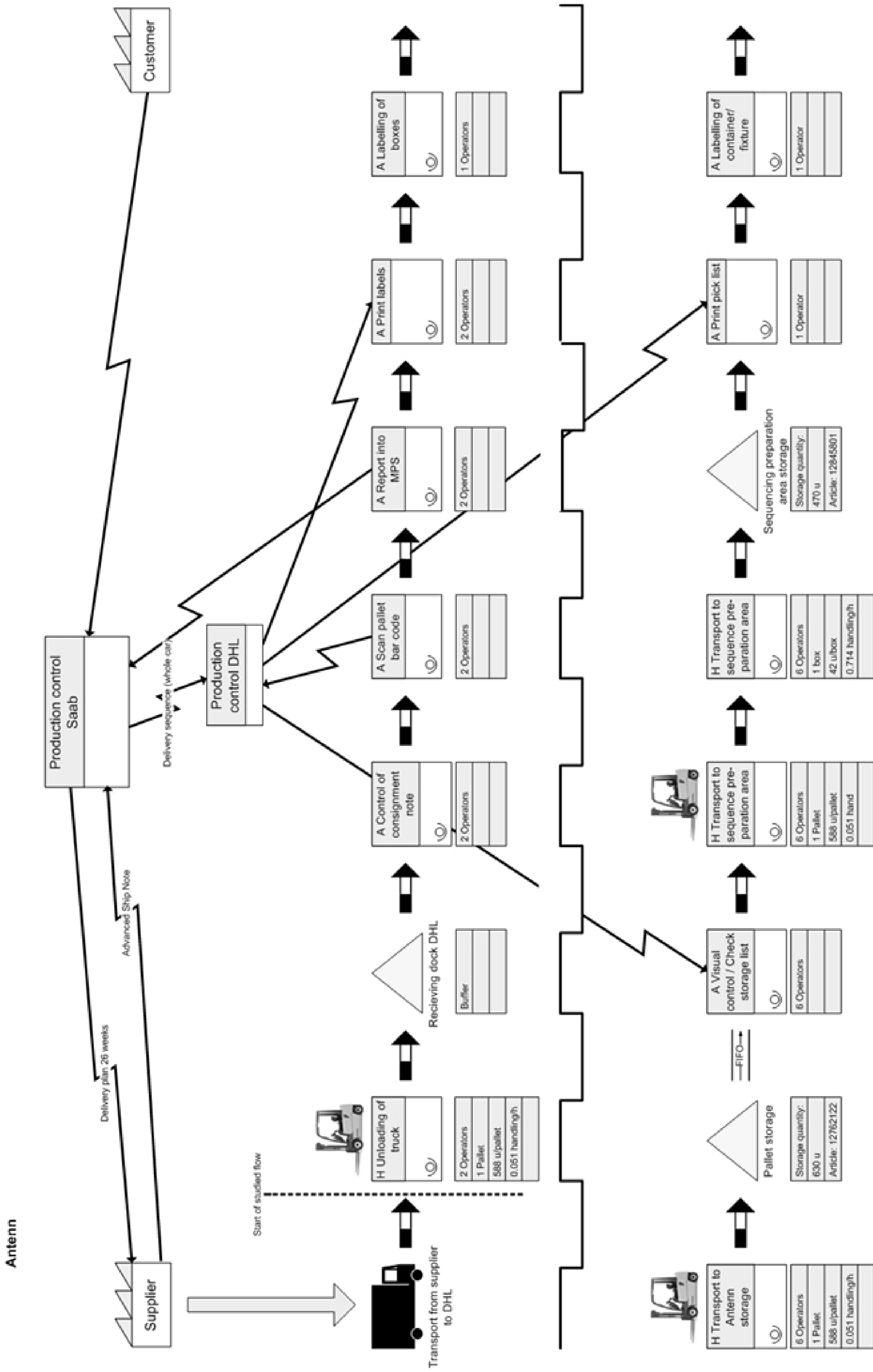
Appendix 3: MFM Instrument cluster



Appendix 3: MFM Instrument cluster

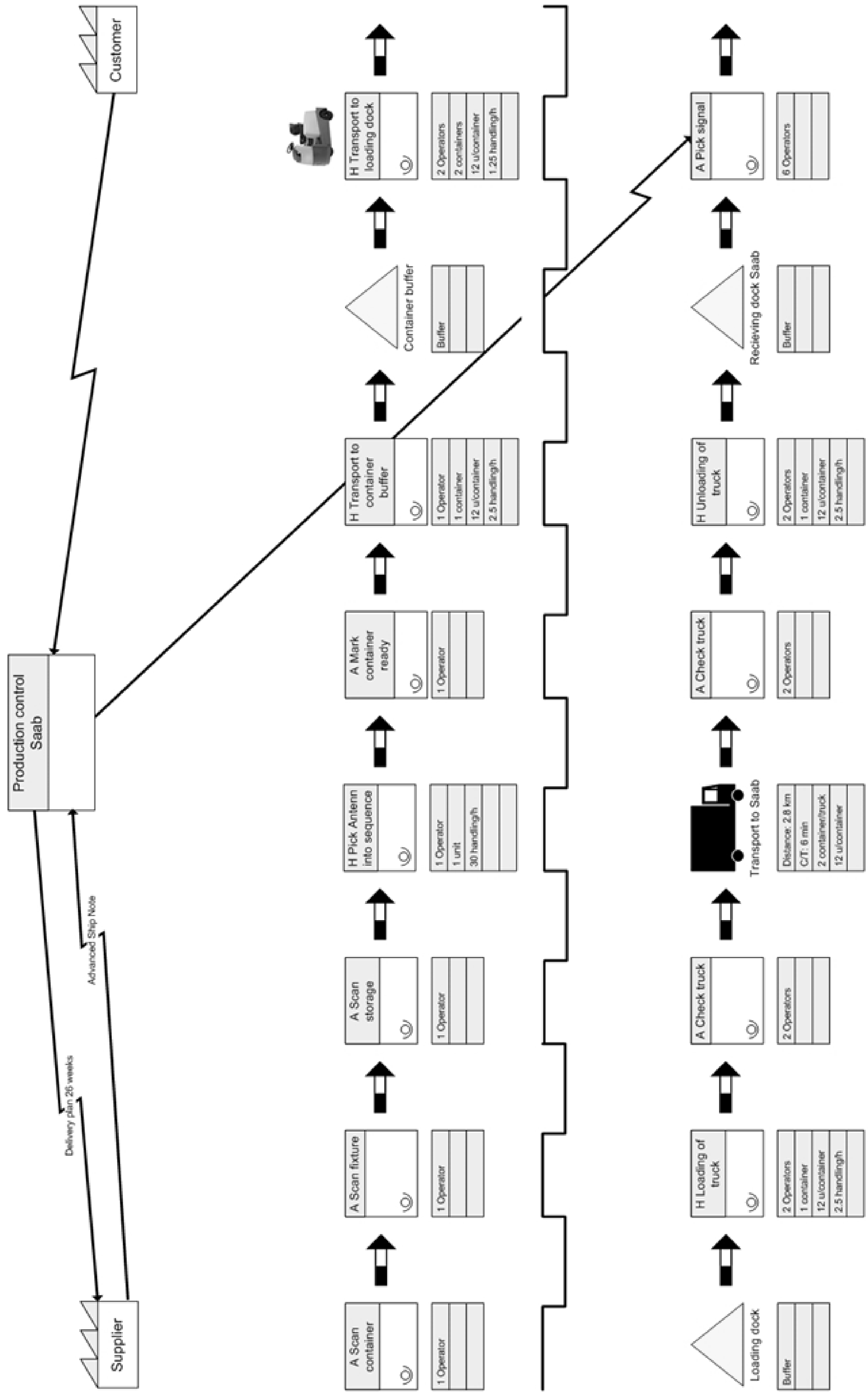


Appendix 4: MFM Antenna



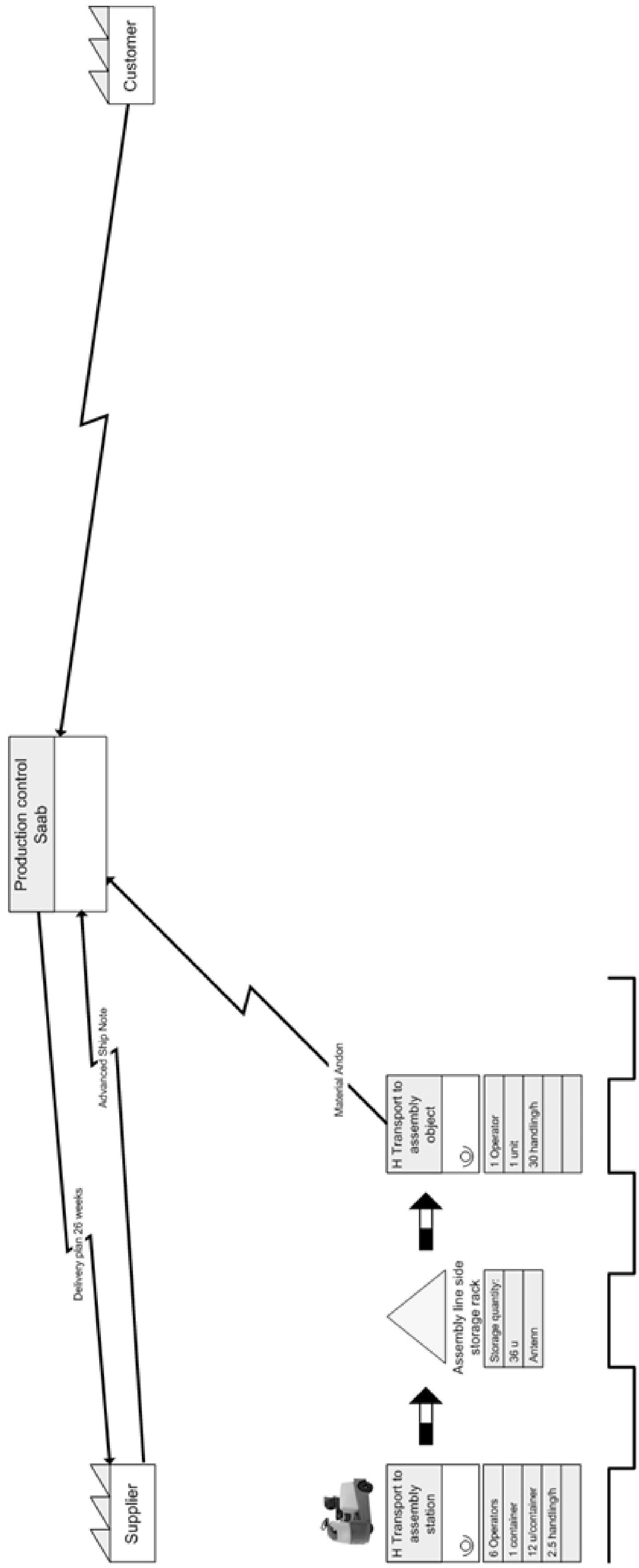
Appendix 4: MFM Antenna

2/3



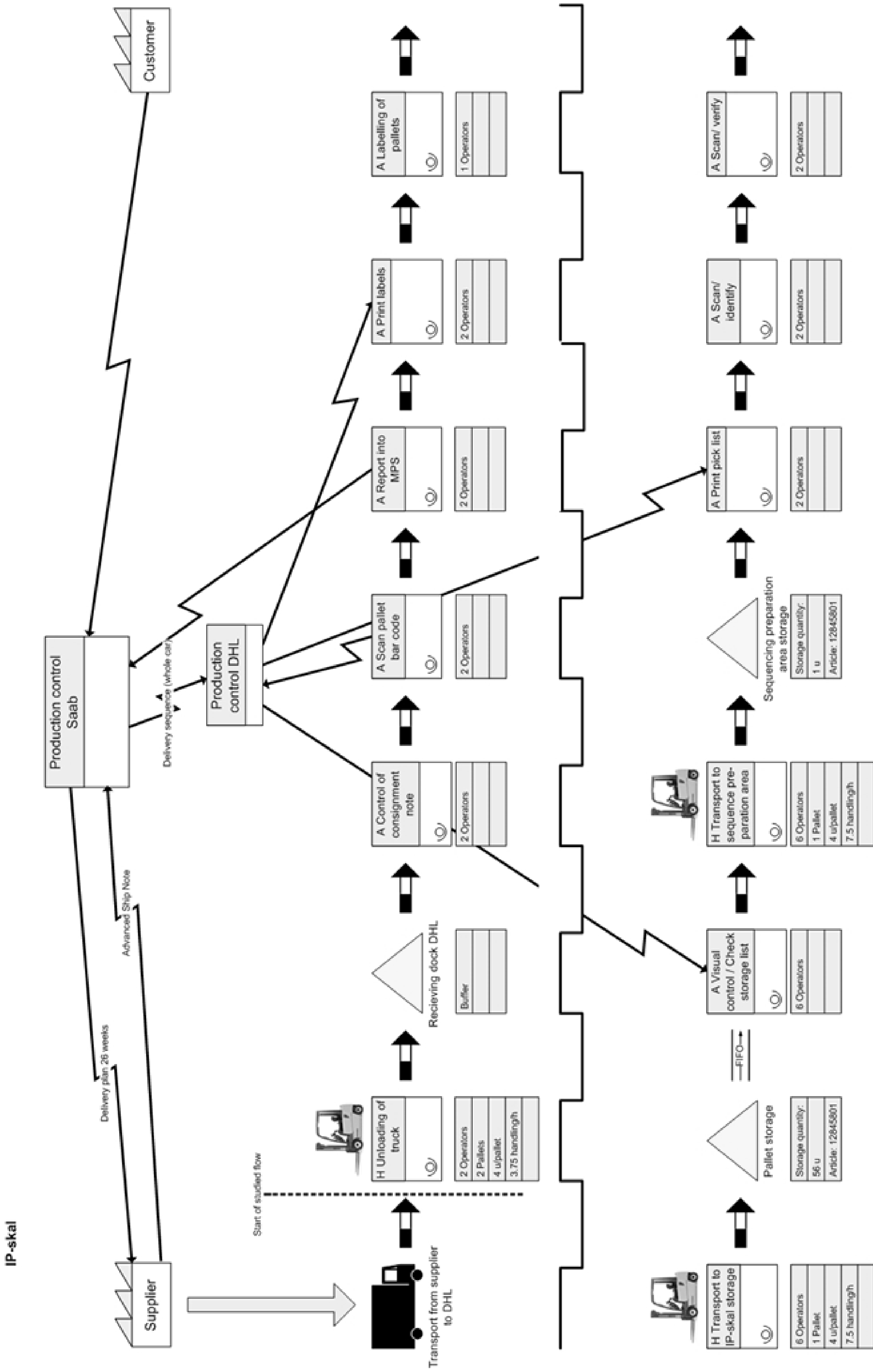
Appendix 4: MFM Antenna

3/3



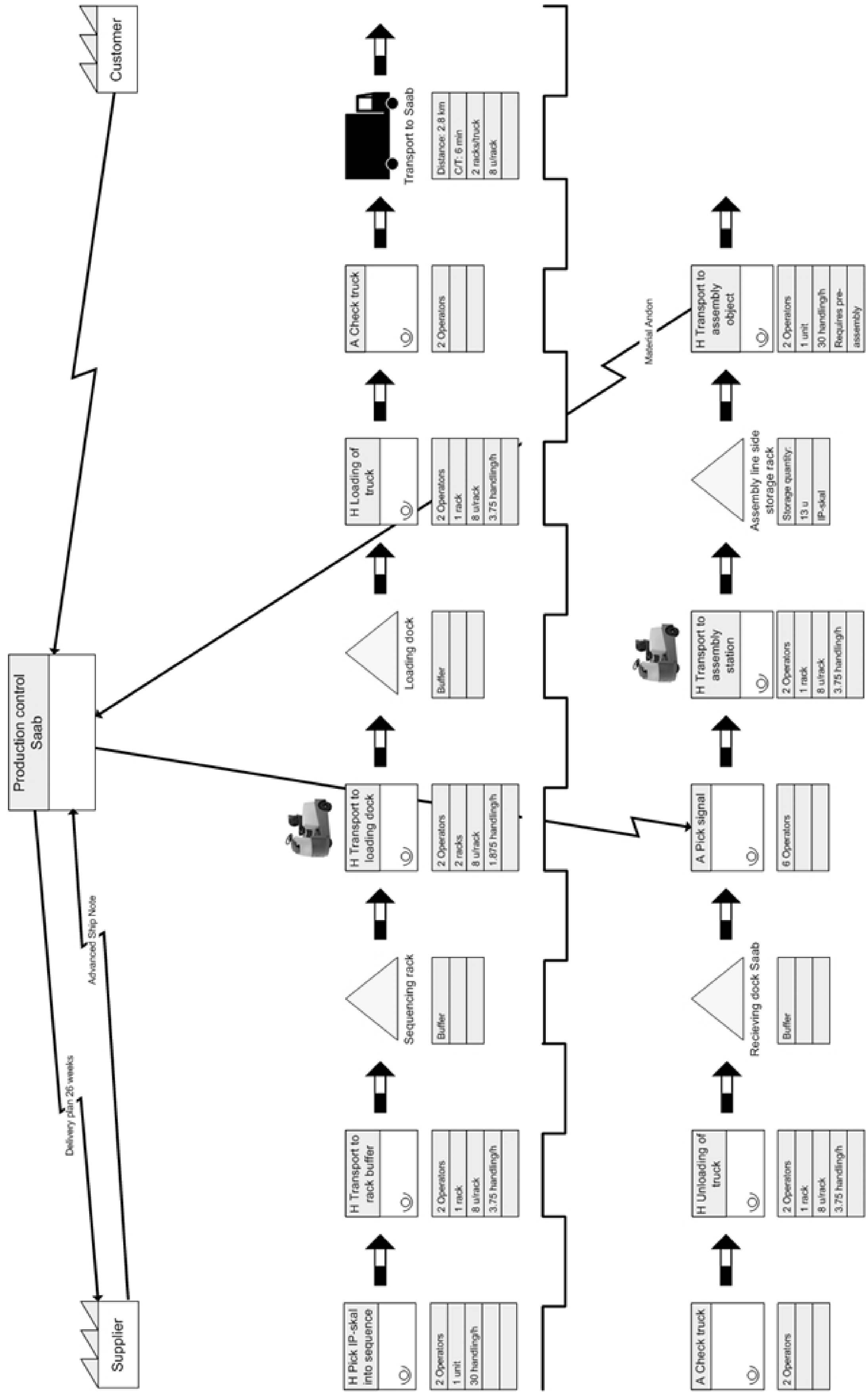
Appendix 5: MFM Dashboard panel

1/2



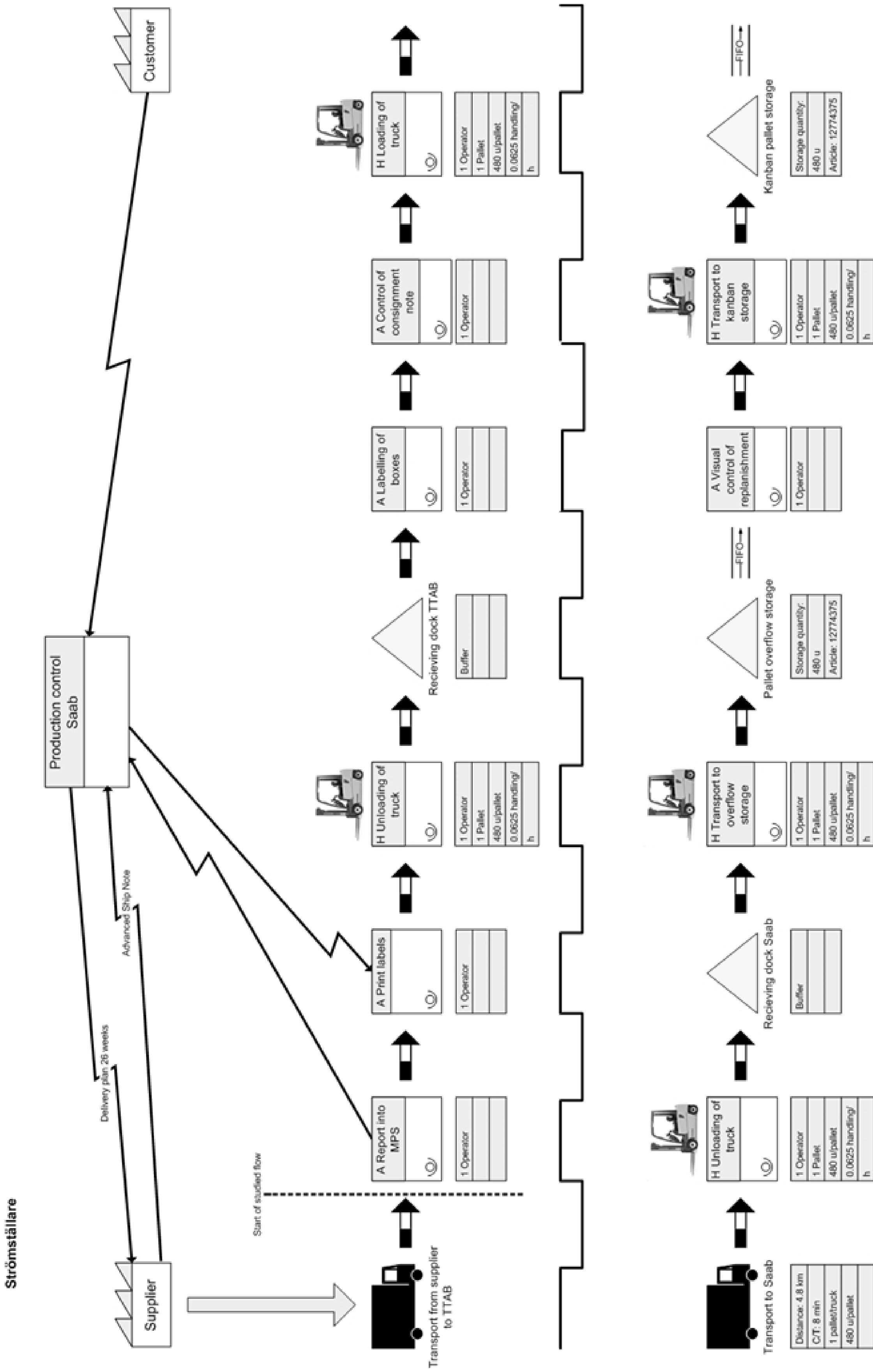
Appendix 5: MFM Dashboard panel

2/2



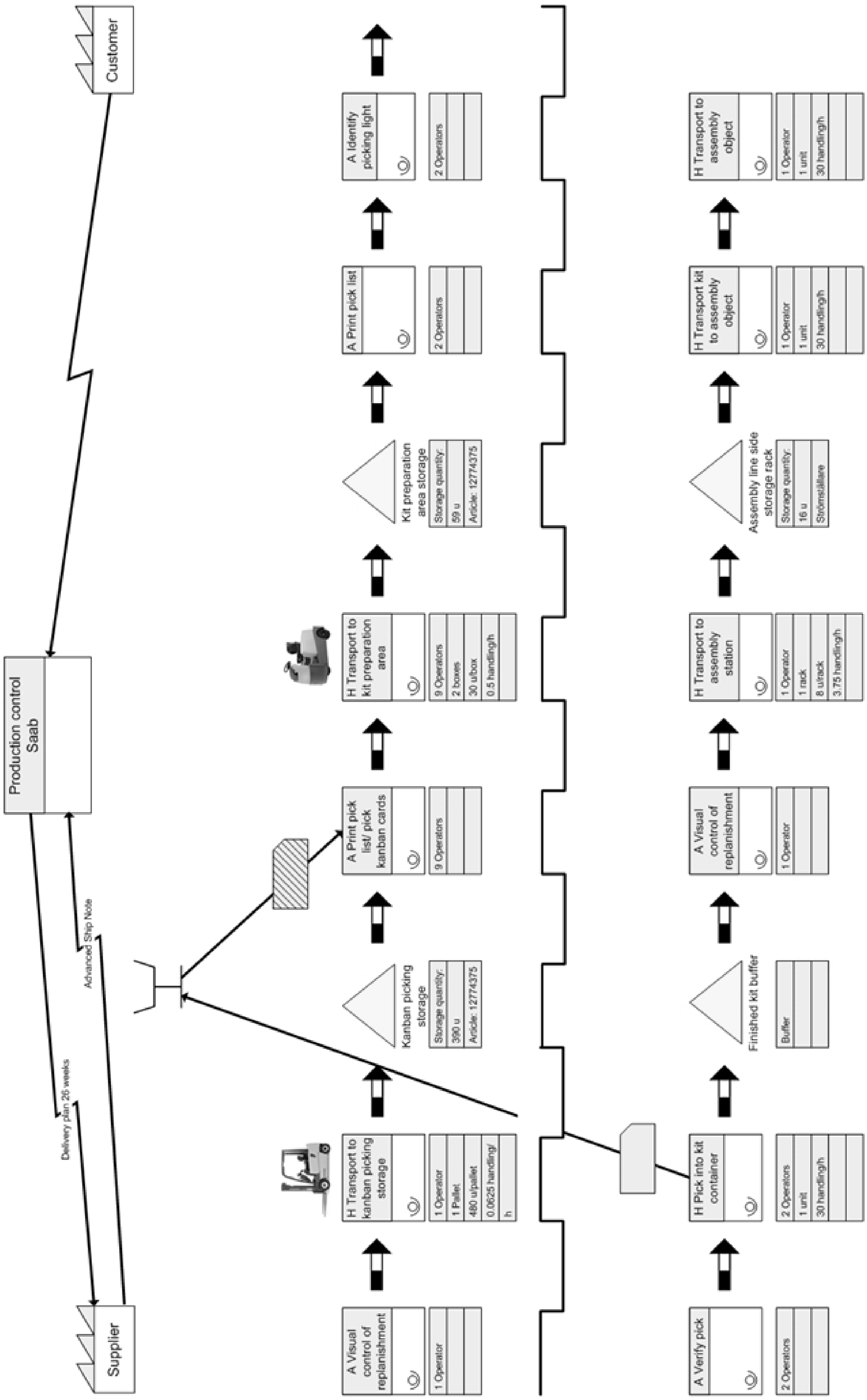
Appendix 6: MFM ESH

1/2



Appendix 6: MFM ESH

2/2



Appendix 7: Niosh lifting equation

The equation is a method to identify, evaluate and classify risks in tasks where lifting is involved. It consists of RWL (recommended weight limit). RWL is the recommended weight and it is constructed as a set of equations with limits so that 99 percent of all men and 75 percent of all the women can handle the task up to eight hours without risk of developing lifting related low back pain. The equation is calculated as a product of a weight of 23 kg, which is considered a safe lifting weight, multiplied with six weighted task variables, which are presented below (Bohgard et.al., 2008).

After each task variable the calculation for a maximum kitting container weight at Saab is presented. The handling which the calculation is based upon is where the operator in the kit preparation area put the finished kit on the rack. This is the handling of the kitting container where the operator handling the kit container is the most vulnerable for pain.

RWL = 23 x HM x VM x DM x AM x FM x CM

HM (horizontal multiplier) = 25/H where H is the horizontal distance from the feet to the grip of the load. IF H<25 cm then HM=1. At Saab H<25 cm which gives a value of HM=1

VM (vertical multiplier) = 1-(0.003IV-75I) where V is the height where the load is lifted from. At Saab V=120 cm, VM=0.87.

DM (distance multiplier) = 0.82+(4.5/D) where D is the vertical distance the load is lifted. At Saab D=55 cm, DM =0.90.

AM (asymmetric multiplier) =1-(0.0032A) where A is the angle if the lift is carried out in an angled position. At Saab A=15, AM=0.95.

FM (Frequency multiplier) a number between 0 and 1 obtained from table (Bohgard et. al., 2008). At Saab FM=0.81.

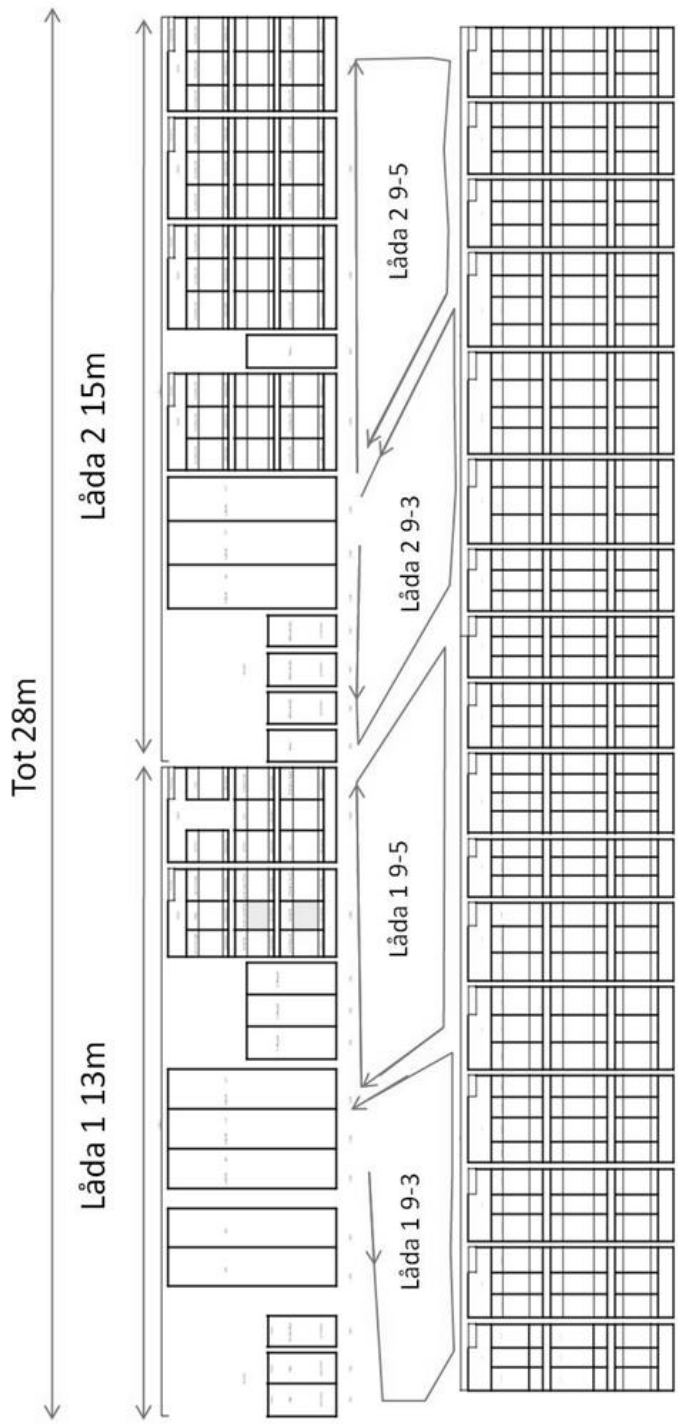
CM (coupling factor) a number between 0.9 and 1 obtained from table (Bohgard et. al., 2008). At Saab CM=1

RWL = 23 x 1 x 0.87 x 0.90 x 0.95 x 0.81 x 1 = 13.9 kg

From RWL the LI (lifting index) can be calculated. LI is the quote of the actual load and the RWL-value. A value smaller than 1 is considered a safe work and a value larger than 1 is resulted in the higher value the bigger is the risk for lifting related pain and work place should be restructured and designed to a lower value of LI. (Bohgard et.al., 2008)

LI at Saab (13.9 kg) = 0.60

Appendix 8: Running meters in kit preparation area



This picture acts as base for the assumption of 132 running meters in the kit preparation area. As can be seen in the picture three shelves can be placed on top of each other. The length required to store both empty and full racks of kits is excluded in the calculation.

Appendix 9: Cost for spaces within a simulated flow

High kanban storage of supplier pallets	Number of pallets	Square meters
At this storage location it is assumed to store 3 pallets above each other.		
Antenna	10	3,20
Instrument cluster	229	73,3
High kanban storage picking location		
At this storage location it is assumed that every variant has one pallet presented.		
Antenna	43	41,3
Instrument cluster	26	25,0
Kit preparation area	Number of boxes	Square meters
At this storage location it is assumed that 3 boxes of Antenna and 2 boxes for Instrument cluster can be stored above each other		
Antenna	99	7,08
Instrument cluster	104	18,5
Summarized square meters Antenna:		**51,6**
Summarized square meters Instrument cluster:		**116,7**
Number of produced car/year:		51000
Cost per square meter/year (SEK/year):		700
Cost/year Antenna (SEK):		36089,67
Cost/year Instrument cluster (SEK):		81718,00
Cost/assembled car Antenna (SEK):		**0,71**
Cost/assembled car Instrument cluster (SEK):		**1,60**