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Material availability at point of use

Multiple-case study in the automotive industry

Master of Science Thesis in Supply Chain Management

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Abstract

Material availability at point of use can be a problem for many companies, i.e. parts are not always available at the assembly line exactly when needed. This can have a lot of consequences for the companies, like delays, rework, extra resources needed, increased work in process etc., which can all lead to extra costs. This problem is even more problematic for companies that are assembling customized products since they are dealing with larger number of parts and some of the parts have a very low turnover rate. Therefore, the purpose of the thesis is to increase the understanding of how material availability at point of use can be ensured at assembly stations.

In order to gain more knowledge about the topic three case companies were interviewed to gather information about how companies handle the problem when material is not available at point of use. It was realized that four things are important when trying to achieve high material availability at point of use. First of all there are two prerequisites that companies need to have in order to ensure the material availability, which are appropriate planning methods and material supply system. Secondly, companies need to respond to missing material in the right way by doing preventive activities, which are to perform root cause analysis on the problems that occur as well as improving the process by using effective problem solving methods. How these four elements affect the material availability at point of use was answered by looking both at literature and the information given by the case companies.

Key words: Material availability at point of use, material planning, material supply system, root cause analysis, problem solving.

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Rósa Dögg Gunnarsdóttir and Gréta María Valdimarsdóttir

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1 Introduction

This chapter will contain an introduction to the thesis and starts with a description of the background in section 1.1 where the importance of material availability at point of will be described. Then, the problem definition will be presented in section 1.2 and the purpose of the thesis as well as the research questions in section 1.3. In section 1.4 the structure of the thesis will be introduced where it is stated what can be found in each chapter of the thesis as well as how they are connected.

1.1 Background

Lean production was according to Liker (2004) invented by Toyota and has triggered a transformation in almost every industry around the world over the last decades. Lean production includes many goals such as Just-in-time (JIT) deliveries, low inventories, zero defects, flexible production in small batches as well as technical cooperation with suppliers (Levy, 1997). Lean production requires a focus on product flow, when applicape a one piece flow, through value adding processes without any interruptions (Liker, 2004). The products are “pulled” through the production from the point of customer demand and only leave the station when the following station needs them. But it can be very costly, especially when the distance is great, to achieve the rapid flow of products and information that is required of lean production (Levy, 1997).

As mentioned above JIT deliveries are one of the main goals with lean production. JIT is a Japanese-developed manufacturing philosophy for achieving excellence through continuous improvements and waste reduction (Fullerton & McWatters, 2001). This includes minimizing raw materials and work in process (WIP) inventories, controlling and eliminating defects, stabilizing production, continuously simplifying the production process, and creating a flexible, multi-skilled work force. JIT is getting more widely spread and according to Sugimori, et al. (1977) the efforts in JIT are to develop a production system for the entire material flow until the product is completed, with the aim of reducing lead time. By doing this, reduction of waste is needed, which highlights Pierce´s (1997) view of JIT, that it basically is a cost-reduction program that focuses on work efficiency and waste elimination. The consequences are that companies are decreasing their inventory and counting more on their suppliers to deliver only as soon as the parts are needed. This can increase the risk for companies to run out of stock if they do not apply JIT in the right way. This means that production companies have to contact the suppliers often and communicate with them in great details (Stank and Crum 1997), i.e. by implementing JIT it requires that production companies have to have closer relationships with the suppliers (Buvik & Halskau, 2001). As Spekman (1988) states, these close ties cannot work except if the number of suppliers is decreased. These relationships, according to Buvik & Halskau (2001), need to be long term and stable, and when they are, quality control at delivery becomes unnecessary since the production company can accept the quality of the products from the suppliers. In those kind of relationships the suppliers are expected to constantly improve their products both in quality and better features, but by doing so the production companies need to provide the suppliers with insight into their company in terms of demand, manufacturing schedules, etc. (Buvik & Halskau, 2001). Buvik & Halskau (2001) state that both parties need to perform as planned, because if one party does not the relationship will be interrupted greatly.

One other key to the success of JIT is the involvement of line workers, this is done by giving them more authority in designing and enriching their jobs as well as more responsibility in quality control

(Huson & Nanda, 1995). Hence, the amount of support and supervisory activity in the plant can be reduced. Instead of having the quality control or inspection at the end of the manufacturing process it is the responsibility of each person performing a task (Huson & Nanda, 1995). In JIT all inventory is placed near the person using it, and is replenished JIT by the supplier, so material handling also requires less manual effort (Huson & Nanda, 1995).

One of the most important things in order to achieve JIT is to have stability in the assembly and when this is the aim, companies need to have stable processes. Stable processes should give clear instructions of what should be done, how it is supposed to be done etc. This includes processes about how to make sure that all materials are available at point of use when needed. If the materials are not available when they are needed the assembly might be delayed because assemblers need to leave their station to look for the material or reschedule the plan if the material is not available in-house. The time wasted by assemblers leaving their station looking for material can be reduced by having extra people working at the factory to run and fetch the missing parts. However it is still a waste, which should be avoided. Thus, missing material at point of use can be a big problem for companies that want to decrease the assembly lead time, waste and cost. Although material availability seems to be very important for companies it is not a well covered area in the literature.

1.2 Problem definition

It is common for factories with long production lead-time to not have all needed materials available before releasing the work for production. According to Baudin (2004), companies should try to have all the needed materials on hand before releasing any work for production. If not, units that are 99% complete but cannot be shipped need to wait in a "final check" area until the missing components arrive. This may cause some disadvantages e.g. increased production lead time and WIP and more complicated logistics since the same parts need to be delivered for the same use to both production and to the "final check" area. When having to fix the product in the "final check" area it means that the production work is performed in a repair mode, away from the instructions, fixtures, and tools. This results in inefficient work and lower quality. Baudin (2004) states that the practice of continuing on the product without the missing material is not allowed in a lean environment, i.e. the production should always wait until all parts are available.

When the product is already on the line and the material is missing it can have great effects on the production. That is why material availability at point of use can be a problem for many companies since time needs to be spent looking for and getting the parts, while the product on the assembly line is waiting or is even forced to keep going down the assembly line without the missing part. Consequently, the finished product might be delayed. Even though the part can be picked in a short time without any big delays (by getting it from the internal stock etc.) it is still a problem because all instabilities in the process are bad, e.g. extra people are needed to pick the missing part. Both the delays and extra resources are an additional cost for the company and should therefore be avoided. Material availability problems can also lead to more work if the missing part cannot be picked within short time, e.g. the part can be at the suppliers. Then the product might need to be partly disassembled later in the process in order to fit the part in its right place. This is even more problematic for companies that are assembling customized products since they are dealing with larger number of parts and some of the parts have a very low demand.

1.3 Purpose

From the importance of material availability at point of use the purpose of this thesis was made and it is to increase the understanding of how material availability at point of use can be ensured at assembly stations. By doing so it can be showed how companies can be more proactive in increasing the material availability at point of use.

1.3.1 Research questions

According to Baudin (2002) part supply is the most important factor in assembly productivity since if all parts needed for the assembly are available then everything could be assembled according to plan. He also states that the most common complaint from assemblers, assembly supervisors, and assembly managers is that the parts are not available. The employees at the factory often blame the suppliers for problems regarding the material availability and suggest improvements at the supplier side, without taking into consideration the fact that they have control over the last link, i.e. how the parts are presented at the assembly line and physically get into the assemblers' hands. Baudin (2002) states that the internal operations should be looked at and improved before the improvements from the supplier can be successful. These improvement opportunities can be found in different tasks that the assemblers perform.

Baudin (2004) states that if not all material needed for the products are available when needed the product needs to wait in a "final check" area until the missing parts arrive. This indicates the importance of material planning, in order to have all material available before releasing any work for production. The first research question therefore is:

RQ1: How does material planning affect the material availability at point of use?

Material supply system within the plant is also important since it, according to Finnsgård, et al. (2011a), is the system that delivers the needed parts for the production to point of use. Control of the system is important since part supply to the assembler, according to Baudin (2002), is the most important thing in order to secure the productivity of the assembly operation. Therefore the second research question is:

RQ2: How does material supply system affect the material availability at point of use?

These two processes, material planning and material supply, need to work in order to achieve high material availability at point of use, but if availability problems occur, there is a need to eliminate them in order to improve these processes. Therefore, companies could benefit from root cause analysis, since the goal with root cause analysis is to find the real reasons for a problem in order to eliminate it completely (Wilson, et al., 1993). After finding the root cause there is a need to improve the whole process with the appropriate tools to be able to increase the material availability at point of use. The third research question is therefore:

RQ3: How do root cause analysis and process improvement activities affect the material availability at point of use?

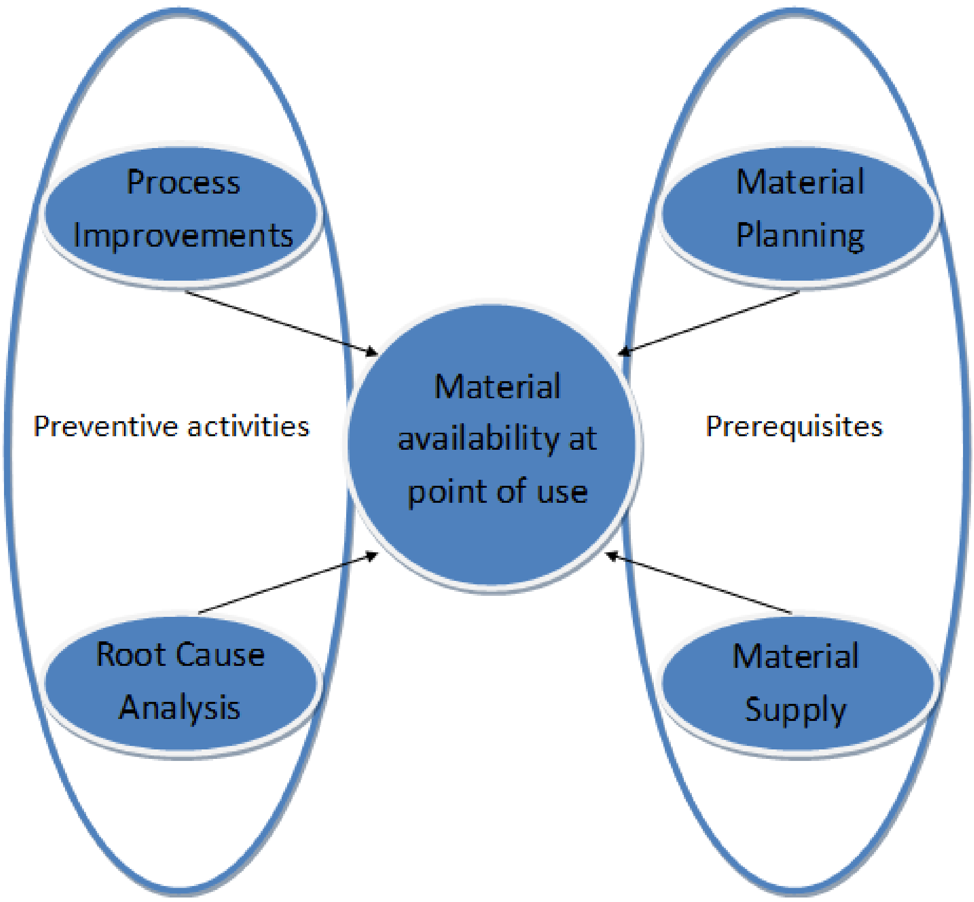

Figure 1: Four factors that affect the material availability at point of use

1.4 Structure

The thesis started with a brief introduction in section 1 with the background of the problem and the definition of it. The purpose and the three research questions were then introduced to highlight the objective of the thesis. In section 2 a theoretical framework will be presented with the base of prerequisites for high material availability and possible preventive activities to reach the desired level of availability. In the end of the theoretical framework an analytical framework will be introduced to point out the important factors when aiming for high material availability at point of use. In section 3 the method of the thesis is discussed to show how it was performed. Then the report moves on to the multiple-case study in section 4. In this section empirical data from the case companies is presented so the reader can get more understanding of the problem and see how companies are affected by it and how they deal with it today. In section 5 the analytical framework will be used to analyze the data by combining the theory behind it with the empirical data gathered in the case studies. In section 6 the research questions will be answered in discussion and conclusions. Finally in section 7 some recommendations for companies with assembly processes, especially Company A, can be found. The structure can be shown graphically in Figure 2.

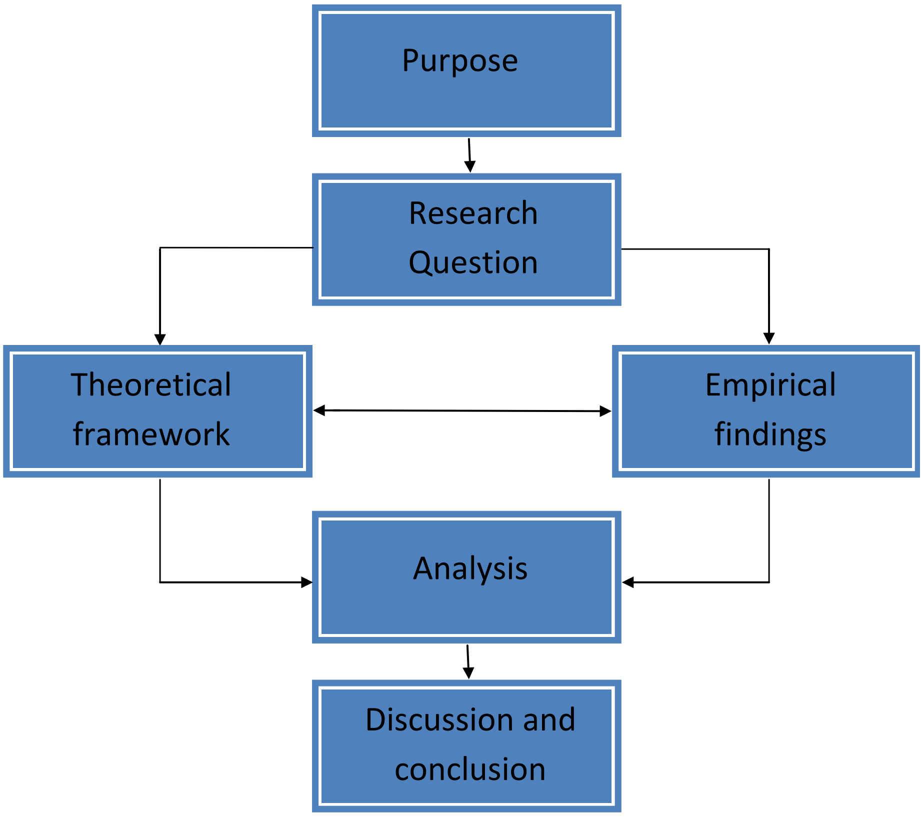

Figure 2: The structure of the thesis

2 Theoretical framework

This chapter contains a review of available literature about material availability and factors that affect the material availability at point of use. In section 2.1 material availability will be described and then the theoretical framework will go on into describing the prerequisites for material availability as well as what can be done to prevent the missing material problem to reoccur. In section 2.2 material planning will be introduced and material supply system will be introduced in section 2.3. In section 2.4 the importance of root cause analysis will be discussed and section 2.5 will go into how the process can be improved by solving the root causes of problems. Finally in section 2.6 an analytical framework will be introduced that shows which factors are most important in order to gain high material availability at point of use. In Appendix A more detailed information about how an assembly system works can be found.

2.1 Material availability

Availability is a way to measure the probability that a service is available to be used at any moment (Todd, et al., 2004). Material availability is therefore a measure of the probability that the material is available for use at any given instant. According to Lee and Billington (1993) the material availability at point of use depends on e.g. the supplier service performance for these materials. To characterize the availability level three measures are needed: fill rate (fraction on requirements met without delay), mean delay, and variance of delay when shortages occur. These measures together indicate the extent of material shortage delays that can occur at the company (Lee & Billington, 1993).

The material shortages can be the caused by suppliers being unreliable, for example there might be uncertainties in either their replenishment time or quantity (Graves, 1987). Therefore, Supply Chain Managers need to assess their risk to material availability and prepare for possible future problems by keeping track of existence of materials as well as the information exchange in order to ensure accuracy. To make the information exchange more efficient a good and accurate information system is helpful and it will also make the planning easier (Alonso, et al., 2007). According to Lee & Billington (1993) this risk of material availability problems can be due to different sources of uncertainties along the supply chain, that include demand (volume and mix), process (yield, machine downtimes, transportation reliabilities), and supply (part quality, delivery reliability). To protect the chain from these uncertainties inventories are often used. These inventories and associated costs need to be controlled by the Supply Chain Managers in order to maximize customer service performance since inventories stored at different points of the supply chain have different impact on the cost and service performance of the chain (Lee & Billington, 1993). For example, finished goods inventories have higher value than raw material inventories, inventories of raw materials have more flexibility than finished products because they can be turned into different alternative finished products, and finished goods inventories have more responsiveness since finished goods can be shipped to customers without delay, whereas some lead time is needed to transform raw materials into finished goods before shipments can be made. It is hard to tell how much of an inventory should be in a supply chain since different supply chains may differ in the network structure, product structure, transportation times, and degree of uncertainty. Therefore six weeks of supply may be just right for one supply chain, while two weeks of supply is too high for another (Lee & Billington, 1993).

According to Alonso, et al. (2007) companies tend to keep stock as well as using multiple suppliers to increase the flexibility, which helps them to secure material availability. This is however an opposite of what JIT requires, i.e. few suppliers and low inventory levels. Holding excess inventory also leads to a low return on investment (ROI) since inventories are the tangible assets of a company (Chen, 2007).

Cohen & Lee (1988) came up with a model for linking decisions and performance throughout the supply chain i.e. through material control, production and distribution. By this they wanted to show the impact different material and management strategies have on performance. They viewed each part of the supply chain separately and therefore introduced different sub-models: material control sub-model, production sub-model, stockpile inventory sub-model, and distribution sub-model. They also show how these models are connected and say that the performance of a company is dependent on the overall model. Since the material control is of most interest for this report the material control sub-model will be looked on in more detailes than the others.

Cohen & Lee (1988) state that in the material control sub-model, safety stocks of materials are necessary to prevent material shortage, which can lead to production delays. This is because of uncertainties in production and distribution. Even though the demand for finished goods and bill of material for each product are known the material requirements cannot be predicted 100% correctly in time. To simulate this they used the model for material control that results in service/availability levels for all raw materials used in the production by determining order policies for all the materials. Cohen & Lee (1988) emphasize how important these service/availability levels are because they affect the production lead times, i.e. material shortage can lead to delays in production. According to the authors material shortages can be backordered or the company can get the material from external supplier with shorter lead-times, but in both cases there is a risk of delayed production.

Delayed production affects the service level of finished goods and according to Cohen & Lee (1988) an increase in the service level can decrease distribution cost because the lead-time for replenishing the distribution network becomes smaller. They found that in order to improve the customer service, the inventory in the distribution network needs to be increased or the finished goods availability at the plant needs to be improved. This means that if a company wants to improve customer service but keep the same service level of finished goods, an increase in inventory in the distribution network is needed. On the other hand, if the service level of finished goods is improved the need for an increased inventory in the distribution network is reduced. Therefore the tradeoffs between investments in manufacturing versus distribution must be evaluated (Cohen & Lee, 1988).

By their model, Cohen & Lee (1988) have shown how important improvements in material availability are on customer service, especially in a lean environment where inventories should be kept at minimum.

As shown above material availability is really important in production companies since, obviously, if no material is available there will not be any production. In order to ensure high material availability at point of use companies need to use appropriate planning methods as well as material supply system, depending on the type of the materials. It is also important to take correct actions when material is missing in order to prevent the same problem to happen again. These prerequisites for high material availability as well as preventive activities can be seen in Figure 1 and will be discussed in more details in the following chapters.

2.2 Material planning

To ensure that all parts are available when needed companies need to have good material planning. According to Jonsson & Mattson (2009) production companies get materials, components and semi-finished items from external suppliers and use them as start-up materials for value-adding processes to make end products, which are then shipped to distribution warehouses or directly to customers. These flows, into, within and out of the company, need to be controlled on an operative level. Wilson (1992) further explains the importance to plan the assembly process well since a good assembly process can reduce assembly time, raise quality and reliability, allow greater flexibility, and reduce capital costs. According to Jonsson & Mattson (2009) these activities are carried out within the framework of the overall master production scheduling and are called order planning. Order planning can thus be seen as an execution of plans at the strategic and tactical level of the company. They say that the main task of order planning is to define, for every product, the quantity needed and the point in time when it is needed to satisfy existing requirements. This needs to be done as efficiently as possible with respect to tied-up capital, delivery service and utilization of resources. Current requirements of materials and capacity need to be considered in relation to supplies of materials and capacity. When only looking at the material perspective of the order planning, it is called material planning (Jonsson & Mattson, 2009).

Das & Bhambri (1994) talk about the material planning as a procurement process i.e. the process of ordering and receiving materials. They say that by redesigning this process, buffers of material between buyers and vendors that were traditionally used to protect themselves for each other's uncertainties can be avoided in order to reduce cost. They further say that improving the supplier relationship and installing quality checks at the supplier's end can also reduce these buffers.

According to Das & Bhambri (1994) the following three decisions must be made in the procurement process:

1. When to release the order (or deliver)?
2. What quantity to order?
3. Which vendor to choose?

Jonsson & Mattson (2009) agree with these decisions, but they do not say anything about the choice of vendor. According to them material planning is all about balancing demand for materials with supply of materials as cost-effectively as possible by answering the following four questions:

1. Which items need to be ordered?
2. How large quantity needs to be ordered?
3. When do we need to get the items delivered?
4. When do we need to place an order with the supplier or start internal production?

The first question is answered by material planning methods that are in use today. This is done by making proposals for planning new production orders or purchase orders to ensure materials supplies. Existing material planning methods also provide a basis for decisions regarding the other three questions (Jonsson & Mattson, 2009).

According to Jonsson & Mattson (2009) it is important to take decision about the three later questions as early as possible, especially when delivery lead times and throughput times in the company's own workshop are long. Sometimes, however, rescheduling is needed because of changes in demand and different forms of disruptions in material flows that are almost inevitable. If the supply is smaller than the demand, new production orders or purchasing orders need to be planned (Jonsson & Mattson, 2009). If, on the other hand, the supply is larger than the demand already planned orders need to be postponed or the demand influenced by e.g. sales campaigns. This needs to be done because otherwise large stocks will evolve if the supply is larger than the demand or a shortage situation if the supply is smaller than the demand. If, in the long run, there are imbalance between supply and demand the surplus stock needs to be sold at a discount prices or the company loses sales and customers (Jonsson & Mattson, 2009).

The supply of material consist of stock balance according to stock accounts and of information about purchase and production orders planned to be delivered, while the demand consist of forecasts, exploded requirements, customer allocation and allocation for production orders (Jonsson & Mattson, 2009). These types of demand differ in certainty and reliability, where forecasts are the least certain and reliable and allocation the most certain since the later are based on customers' decision or internal planning. Because of this, customer allocations are used for products in stock in near future, while forecasts are used further in the future (Jonsson & Mattson, 2009).

The balance between supply and demand has both a quantity dimension and a time dimension, which means that the supplies must not only be in a right quantity but also be available at the points in time when the demand arises. According to Jonsson & Mattson (2009) the time aspect is a much larger challenge than balancing the quantities; if a delivery is too late a shortage situation may occur with production disruptions and poor delivery service to customers, but if it is too early an unnecessary capital is tied up in the form of stock. It is therefore very important to plan the material to deliver as close in time to the demand as possible (Jonsson & Mattson, 2009). Synchronization is also a challenge because items are most often interdependent and therefore need to be planned in a holistic way (Jonsson & Mattson, 2009). This is the case for assembly where several incorporate items are required simultaneously and for a customer order with several order lines. When requirements change or some disruptions in material flow on the supply side occur, synchronization is restored if possible through rescheduling. It is, however, not always possible in practice. The stock that arises as a result of incomplete synchronization is called control stock (Jonsson & Mattson, 2009). This incomplete synchronization can be a result of functional drawbacks in material planning methods used, difficulties in completely predicting changes in demand and not making changes quickly enough as disruptions occur, or it can be deliberately created. There are many reasons for why to deliberately create incomplete synchronization, e.g. to co-ordinate deliveries of different items from the same supplier (Jonsson & Mattson, 2009). Then the delivery times for different items are chosen to coincide, even though the demand times do not coincide. The general rule is to let the item that needs to be delivered earliest define the delivery time.

When planning the material based on the demand, it is important to understand the division of demand into independent and dependent types (Jonsson & Mattson, 2009). Independent demand is when the demand for a product has no relation to the demand for other products, e.g. products stocked for delivery to customers (Jonsson & Mattson, 2009). On the other hand, dependent demand is when the demand for a product relies on the demand for another product, e.g. items that are a part of start-up materials. The dependent demand can therefore be calculated from the demand for the parent item instead of being forecasted (Jonsson & Mattson, 2009).

Material planning can be either of a pull or push type (Jonsson & Mattson, 2009). If materials movement only takes place on the initiative of the consuming unit in a form of an order it is of a pull type. On the other hand, if the consuming unit does not initiate a materials movement, but it is initiated by the supplying unit itself or by a central planning unit in the form of plans, the material planning is of a push type. Most material planning methods can be used for both a pull and a push type of planning, i.e. orders can be made either by orders from the consuming unit (pull) or to produce to stock (push) (Jonsson & Mattson, 2009).

2.2.1 Material planning methods

Different material planning methods are used in order to gain the balance between supply and demand and as synchronized material flow as possible. Das & Bhambri (1994) divide the material planning methods into three categories; demand based methods, reorder methods, and JIT/kanban methods. With demand based method each material is ordered solely in a required quantity (when there is a demand for it), thus no order lot size is used. One of the demand based methods that is used to identify the requirements is Material Requirement Planning (MRP). In reorder methods material is ordered when the stock goes below a predefined level. The order quantity in reorder methods is predetermined, usually by using Economic Order Quantity (EOQ) methods. With JIT/kanban methods the supplier is linked to the demand center for each material by a fixed number of kanban cards, and orders are released when the quantity on the kanban card is depleted. Different material planning methods differ in characteristics and are suitable in different planning environments, but they all answer the time questions, i.e. when to order and when delivery will take place. One goal with all of these methods is, according to Das & Bhambri (1994), to ensure that production is not disrupted, and that the associated inventory costs are minimized. The similarities and differences can be seen in Table 2 and Table 3.

Re-order point systems

According to Jonsson & Mattson (2009) Re-order point system is a system that compares the stock on hand with a reference volume (re-order point). When the stock on hand is lower than the reference volume an order is made, but otherwise not. The order quantity and the re-order point are a constant and are equal to the expected consumption during lead-time for replenishment plus a safety stock to protect against unpredictable variations in demand. According to Jonsson & Mattson (2009) kanban systems are an example of one variant of the re-order point system. To be able to apply this method information about consumption, stock volume and the re-order point is necessary.

According to Jonsson & Mattson (2009) two types of re-order point systems exist depending on when the comparison between the re-order point and the stock on hand takes place: continuous review system and periodic review system. The continuous review system makes the comparison after every stock transaction, while the periodic review system makes the comparison at given interval, e.g. weekly or daily. There are pros and cons with both methods, some of them can be seen in Table 1.

Table 1: Continuous review systems vs. periodic review systems

Continuous review system		Periodic review system	
Pros	**Cons**	**Pros**	**Cons**
Orders initiated directly when stock falls below the re-order point	New orders need to be planned per item	Planning can be carried out for a large number of items together, making administration more efficient	A larger safety stock is required because half the review interval becomes part of the uncertain time
Quick and flexible in initiating new material flows in supply chains	Work takes place more frequently and sporadically		
Planning is based on time of consumption rather than time of review			

Periodic ordering systems

Opposite to the re-order point system with a constant order quantity and varying ordering intervals, the periodic ordering systems has a constant ordering intervals with the order quantity varying (Jonsson & Mattson, 2009). The quantity depends on an order-up-to level, which is predefined. This is very beneficial when a number of items are ordered from the same supplier since the total ordering costs and transportation costs can then be reduced (Jonsson & Mattson, 2009). With reduced ordering cost and transportation cost orders can be made more frequently, which in turn decreases tied-up capital and increases flexibility. According to Jonsson & Mattson (2009) the order-up-to level is equal to the expected usage during the lead-time and the replenishment time plus a safety stock. The difference between the order-up-to level and stock on hand is then the order quantity. The replenishment frequency is fixed and is chosen so that the order quantity on average is as close to economic order quantity as possible. In order to use the periodic ordering system, information about stock on hand and demand from usage statistics, forecasts or requirement calculations is needed as well as the length of the re-ordering interval (Jonsson & Mattson, 2009).

Run-out time planning

According to Jonsson & Mattson (2009) the requirements can also be expressed in period of time instead of quantity, which is the case in the run-out time planning method. This method calculates how long the stock on hand plus scheduled receipts is expected to last, by dividing it by expected demand per time unit. Same information about expected demand is required as for the re-order point method based on usage statistics, forecasts or aggregated gross requirements through explosions of the master production schedule. A safety lead-time is used to protect against uncertainty in variations in demand during the replenishment lead-time (Jonsson & Mattson, 2009). The safety lead-time multiplied by demand per time unit equals the safety stock used in the re-order point system. The principle in the run-out time planning method is to order if the run-out time is less than the safety lead time plus the replenishment lead-time (Jonsson & Mattson, 2009).

As with the re-order point method, run-out time planning can be transaction oriented or periodic. When it is transaction oriented then the comparison is made when stock transaction takes place, while when it is periodic the comparison is made on a fixed time intervals. The pros and cons with those two alternatives are the same as for the re-order point method and can be seen in Table 1.

Material requirements planning (MRP)

According to Brennan, et al. (1994) the material requirements planning method is a set of procedures that transform the demand of a certain product into a schedule of components, subcomponents, and raw materials in order to produce the product. Jacobs, et al. (2011) describe this even easier by saying that the main objective of MRP is to provide "the right part at the right time" so that schedules for completed products are met. As Jonsson & Mattson (2009) state, this is done by calculating when requirements for each material arise, i.e. when the calculated stock becomes negative and estimating deliveries for that time. It means that no order is scheduled for delivery until there is a net requirement. The time to release an order is calculated as the delivery time minus lead-time for the order. If a conflict arises between manufacturing jobs, the order release function decides which jobs are released to the shop-floor and which need to wait for more material to arrive (Chen, 2007).

According to Jonsson & Mattson (2009) MRP is primarily designed for items with dependent demand and it uses the bills of materials (BOM) to find out which components need to be replenished and when. According to Jacobs, et al. (2011) MRP also requires information about the inventory status. The master production schedule (MPS) is the basis for MRP, it states when and in what quantities the end products are going to be delivered. The BOM file in the Enterprise resource planning (ERP) system then breaks the requirements down to when and in what quantities each component is needed. According to Jacobs, et al. (2011) this is a key element in MRP, i.e. the gross to net explosion. Only the product itself, with independent demand, needs to be forecasted. The requirements for all components, with dependent demand, are calculated using BOM. They also state that this can remove uncertainty from the requirement calculations. This gross to net explosion, however, only tells us what is needed, but not when it is needed. Each items' lead time is also important in order to know when the orders need to be placed in order to get the deliveries on time. Jacobs, et al. (2011) emphasize how important it is to use back scheduling instead of forward scheduling so that unnecessary WIP inventory will not be formed. According to Jonsson & Mattson (2009) this is one of the major strengths with MRP, i.e. its capability to synchronize the flow of materials at times when manufacturing orders for higher level items are planned to start. Jacobs, et al. (2011) agree on that saying that, the combination of back scheduling and gross to net explosion is the heart of MRP.

Guide & Srivastava (2000) state that even though, in theory, the use of MRP should avoid buffers, in reality, uncertainties exist in production systems, e.g. in forecasts and delivery times, and buffers are used to protect against these uncertainties. These buffers can be either in the form of safety stock or safety lead time. Safety stock is, according to Jacobs, et al. (2011: 197), "*a buffer of stock above and beyond that needed to satisfy the gross requirements"* and when used in MRP, the safety stock is subtracted from the stock on hand before the MRP calculations start. Safety lead time is, according to Jacobs, et al. (2011: 197) "*a procedure whereby shop orders or purchase orders are released and scheduled to arrive one or more periods before necessary to satisfy the gross requirements"* and when used in MRP, the safety lead time is subtracted from the net requirements and set as a delivery time for the planned order. A safety stock is used when there are uncertainties in quantities (scrap, spare part demand, or other unplanned usage) but a safety lead time is used when there are uncertainties in timing, like e.g. the delivery time from the supplier.

As mentioned above, the information needed for material requirements planning is gained from the master production schedule, BOM, stock on hand, lot sizing methods and lead times (Jonsson & Mattson, 2009). The parameters that also need to be defined are the length of time periods used, the length of the planning horizon, the planning frequency, different types of orders, handling of rescheduling and planning time fences. Like with the other methods, MRP can be grouped per day, week or any other time period, or it can be run for each stock transaction (Jonsson & Mattson, 2009). Shorter planning periods are preferred when making detailed plan for the short term, while longer time periods can be accepted closer to the planning horizon when information is to a large extent based on forecasts. The lead time along the critical path, i.e. the longest accumulated time for manufacturing and purchasing of all items included in the end product, defines the planning horizon; it must be at least as long as this critical path (Jonsson & Mattson, 2009). If the planning horizon is shorter than the critical path, the planning for some items at the lowest product structure will not be sufficient, i.e. it will not be planned sufficiently early which can have the consequences that problems arise in fulfilling the master production schedule. The frequency of material requirements planning differs between companies but it is most common to run the planning daily, while some companies run it weekly or at every transaction. Planned orders then cover the time from the present to the planning horizon (Jonsson & Mattson, 2009).

According to Jacobs, et al. (2011) the MRP processing can be in the form of either regeneration, where all part number records are completely reconstructed each time the records are processed, or the net change approach, where only those items that are affected by the new or changed information are reprocessed. Regeneration can generate very large processing demands on the system, while with the net change approach the computer time can be reduced enough to make daily or even real-time processing. With an increased computer cost the regeneration can be done more frequently with fewer unpleasant surprises.

According to Jonsson & Mattson (2009), planning time fences are used in MRP in order to minimize the cost associated with rescheduling since the consequences of rescheduling are more serious in near future than further away in time. Rescheduling may not only affect the product in focus, but also other products since items can be used in more than one products. The first planning time fence is the release time fence, which is equal to the throughput time of an order in the workshop (Jonsson & Mattson, 2009). Orders placed until the release time fence are frozen and rescheduling is not allowed. The planning time fence refers to the throughput time in the workshop plus the time from an order placement until delivery of materials. This period is half-frozen since rescheduling might cause problems because purchasing has already been made and capacity must be allocated in the workshop (Jonsson & Mattson, 2009). However, manufacturing orders have not been released so the consequences of rescheduling are not as serious as in the frozen period. The period after the planning time fence is a floating period which means that automatic rescheduling by the ERP system are allowed (Jonsson & Mattson, 2009).

Constraint-based material requirements planning

In order to not only consider the demand but also the supply, e.g. late deliveries from suppliers due to lack of capacity, constraint-based material requirements planning is used. According to Jonsson & Mattson (2009) the constraint-based material requirements planning can be looked at as a second generation of the MRP method and it uses the theory of constraints (TOC) as a basis. It means that all manufacturing orders are planned within available capacity. The traditional MRP only synchronizes the flow of materials with the demand and assumes infinite capacity, while constraint-based material requirements planning method synchronizes the material flow with both the demand side and the supply side (Jonsson & Mattson, 2009). By this capacity can be freed up for other higher priority manufacturing orders and tied-up capital can be reduced by avoiding too early deliveries.

Constraint-based material requirement planning needs information, according to Jonsson & Mattson (2009), from the master production schedules, BOM, stock on hand, lot sizing methods and lead times as well as routing information and work center information like available capacity. They also state that when using constraint-based material requirements planning, some kind of advanced planning and scheduling (APS) system, either parallel or integrated with an ERP system, is necessary. It is important to plan all workstations in front of the bottleneck station[1] according to the bottleneck's capacity because otherwise a lot of work-in-process will be stocked in front of the bottleneck since the bottleneck´s capacity limits the material flow. To do this a backward scheduling must be used from the requirements times in a bottleneck work stations, i.e. the last operation before the bottleneck is planned first according to when the items are needed at the bottleneck station to avoid shortages, then the preceding operation is planned and so on (Jonsson & Mattson, 2009). By doing this no operation starts until it is needed. Forward scheduling must then be used for work station after the bottleneck, i.e. first station after the bottleneck is planned first and as soon as possible, and then the following station is planned and so on. This is important since the bottlenecks limit the output from the system (Jonsson & Mattson, 2009).

Comparison of material planning methods

The methods mentioned above all have the same mission; to plan the material requirements. However, they are different in characteristics and it differs which method is best suited depending on the environment. The similarities and differences can be seen in Table 2 and Table 3.

According to Das & Bhambri (1994) in most cases a combination of material planning methods is used since materials vary greatly in size, cost, usage volume, etc. A buyer needs to decide which method to use and whether to use the same method for all materials or separately select a method for each material (Das & Bhambri, 1994). The overall objective of the procurement process is, according to Das & Bhambri (1994), to minimize the buyer's cost.

[1] The station that limits the capacity of the entire production system.

Table 2: The characteristics of different material planning methods

Characteristics	Re-order point system	Periodic ordering system	Run-out time planning	Materials requirements planning	Constraint-based material requirements planning
Complexity	Easy to understand, generally known in industry and most widely used	Easy to understand and apply	Easy to apply. Good understanding of the current need to order and how urgent it is	Complex and difficult to understand and master	Very complex and difficult to understand and master
Input	Accumulated future demand such as annual forecast or only historic consumption	Accumulated future demand such as annual forecast or only historic consumption	Accumulated future demand such as annual forecast or only historic consumption	Customer order demand, or demand from established master production schedules at the end-product level	Customer order demand, or demand from established master production schedules at the end-product level
Type of demand	Independent	Independent	Independent	Dependent, independent	Dependent, independent
Orientation	Component	Component	Component	Product	Product
Initiation	By past usage	By plan	By past usage	By demand	By demand
Capacity considered	No	No	No	No	Yes
Systems needed	Traditional ERP systems	Traditional ERP systems	Traditional ERP systems	Traditional ERP systems	Traditional ERP systems and an additional system of APS type
Planning	From time of review	From time of planning	From time of review	From time of requirement	From time of requirement or time of available capacity
Priority-basing information	No	No	Yes	Yes	Yes
Ordering time interval	Varying	Fixed	Varying	Varying	Varying

Table 3: Different material planning methods dependent on the environment

Environments	Re-order point system	Periodic ordering system	Run-out time planning	Materials requirements planning	Constraint-based material requirements planning
Type of products	Finished goods stock	Finished goods stock	Finished goods stock	Raw materials, purchased components and internally manufactured parts and semi-finished items	Raw materials, purchased components and internally manufactured parts and semi-finished items
Items' specifications	Low value items with even and predictable demand and items that usage cannot be planned, e.g. spare parts	Co-ordination of different items	Volume flexibility	Allocations and seasonal variation	
Demand	Frequent and continuous	Independent and frequent	Independent and frequent	Dependent	Dependent
Ordering	Small order sizes and short lead times	Small order sizes and short lead times	Small order sizes and short throughput times		
Data quality	Low demand	Low demand	Low demand	High demand	High demand

2.3 Material supply system

In a production company there is a need for a material supply system (MSS), which is used to deliver the components that are needed for the production to the destination where they are needed (Finnsgård, et al., 2011a). Finnsgård, et al. (2011b) also confirm this as well as extending the purpose of a MSS by saying that it has to both support the assembly system by supplying it with the components needed as well as maintaining and improving its efficiency. Supplying parts to the assembler is, according to Baudin (2002), the most important thing in order to secure the productivity of the assembly operation. Finnsgård (2009) describes this by saying that the MSS and the assembly system are connected at the workstation (the point of use) where materials are supplied by the MSS and are then assembled by the assemblers. Johansson & Johansson (2006) extend the definition of MSS as the system that supplies materials all the way from the suppliers to the buyers through the production company. They designed a model for MSS that is in four levels: supply chain, plant, sub-unit and utility, and which looks into six different areas: materials feeding, storage, transportation, handling, packaging, and manufacturing planning and control. Even though the authors are describing the MSS on an overall level they do believe that it is also relevant for in-plant material supply. Table 4 combines all the design areas and levels as well as the design issues that were found in the research by Johansson & Johansson (2006).

Table 4: The design issues connected to each design area and design level, Johansson and Johansson (2006)

Design area	Supply chain	Plant	Sub-unit	Utility
Materials feeding	Materials feeding principle		Material feeding principle Input store /output store	
Storage	Location within the supply chain	Level of centralization Location within the factory	Level of automation	Design of storage systems
Transportation	Incoterms Traffic mode	Level of automation		Choice of equipment Choice of transportation company Design of transportation networks
Handling	Location within the supply chain			Choice of equipment
Packaging	Returnable or non-returnable Standard/special Responsibility for packaging issues	Standard/special		Packaging design Number of components in each packaging unit
Manufacturing planning and control	Level of centralization Push/pull Volumes and frequencies	Level of centralization Push/pull	Volumes and frequencies	Choice of materials planning methods

The supply chain level has the material flows between companies in focus. The plant level has then the material flows within the company as a focus; storage location, internal transportation, capacity etc. The sub-unit level focuses the material flows to and from the subunits, which can be a single work station or a group of work stations. Finally the utility level has its focus on the detailed design issues like the type of equipment and packaging.

Material feeding design area is about choosing the method that fits the company best to feed the material to an assembly station or the company (Johansson & Johansson, 2006). Examples of that are kitting, batching, sequential, and continuous supply. Storage is about where and how the materials are to be stored, this involves all inventory (raw material, work in process etc.). Transportation is both handling the internal transportation as well as external (Johansson & Johansson, 2006). Handling is how and where the company chooses to handle the material, like how to package materials. Packaging, on the other hand, is about the packaging itself (Johansson & Johansson, 2006). Manufacturing and control is then about choosing the right method of manufacturing planning and control, if the company chooses push or pull systems, in what volume the products are produced, how often they are produced etc. (Johansson & Johansson, 2006).

According to Finnsgård (2009), planning and control is the most important in MSS processes and assembly processes. This means that it is important to have a good planning and control to be able to secure a correct flow between the MSS and the assembly processes. This is especially true when the production includes complex products with many different variants (Finnsgård, 2009).

Materials supply system is not only about delivering the material to the assembly station but also to do it in the condition that is the best fit for the assembly (Hanson, 2009). It should also be transported in a safe way so it will not be damaged, which makes the packaging and handling very important in order to be able to protect the parts to the fullest. This is not done in the same way for every part since not all parts have the same characteristics, which means that companies may have many different procedures to deliver and package the parts within the factory (Hanson, 2009).

The material supply system is then connected to the assembly system by material exposure (Finnsgård, 2009). The reason for this is that when material is exposed at the assembly station all work needed to be done by the material supply system is over and therefore the component has left the system and is then ready to be used by the assembly system (Finnsgård, 2009).

This report will take Finnsgård´s view on MSS, which is that the purpose of MSS is mainly to support the assembly system by supplying it with the material that it needs as well as improving its efficiency. This will be looked at, for the most part, from internal material supply point of view. The focus on the design areas will mainly be in terms of material feeding.

2.3.1 Stock necessity

According to Finnsgård (2009) there must be a fit between what the assembly process requires and what the materials supply system is serving to the process. This also means that materials delivered should not exceed the need from the assembly process. According to Baudin (2004) all excess inventory is a waste, which means that if there is no reason for why the materials supplied is more than what is required it is a waste. Having inventory has been known to decrease the quality of the production since companies then may be hiding their problems that otherwise would come up to the surface if the inventory was not there (Giust, 1993). However, there is sometimes need for inventory, e.g. when the transition between two stations cannot be done instantly (Finnsgård, 2009). Giust (1993) agrees with this and mentions that there are circumstances where keeping WIP inventory is necessary. These can be when two operations do not run on the same schedule or when operations that work in connection to each other do not have the same sequence. Having some WIP inventory between processes makes it possible to decrease the risk of the whole production process turning down when one process has a disruption (Hanson, 2009). But the WIP inventory should never reach a certain maximum level since there is no need to have inventory of items that are not going to be used in a short time (Giust, 1993).

Decreasing the inventory can though be hard when trying to keep high availability of the products and to be responsive to changing demand. But to achieve that, it is very important to have high flexibility, speed in production as well as capacity in supply, production, transportation and distribution to be able to respond to the changes in demand (Hales & Andersen, 2001). This is especially true for companies that produce customized products. This is because customization is, according to Fredriksson & Gadde (2005), where a customer can pick from a great amount of different features that will fit the customer's needs and thereby the companies will have a hard job in securing flexibility in all different variation of products. They also state that the greater the variety of features that the company offers the greater the likelihood will be of satisfactory customers. By having large variety of features creates the ability to produce great amount of different products by only changing few features in a product module. But companies that are highly customized have many different product variants and to be able to produce customer specific item in a cost efficient way they need to be flexible (Fredriksson & Gadde, 2005). This is why a customized company has to have a material supply system that is able to support the flexibility that the company needs to have to be able to decrease its cost (Hanson, 2009).

2.3.2 Part presentation

According to Hanson (2009) the design of the assembly system has great effect on the materials supply system. How the components are presented at the workstation and how much packaging is left for the assembler to take off before it is assembled are important factors when considering materials supply system. Baudin (2002: 171) states that *"parts should be presented to assemblers unpacked, within arm's reach, with their smallest dimensions facing out, and oriented for easy installation".* That is why it is important that the material handler[2] removes as much packaging as he/she can, so that the non-value adding time for the assembler is minimized as much as possible. This is important since the assembler's time is so expensive because they work in series of line (next assembler is waiting for the previous one to finish) (Wänström & Medbo, 2009). It can be very wasteful if the assembler has to use a lot of his/her assembling time to pick and prepare the components because the components are located far away, not in the most convenient position (too low or too high), etc. Another thing that can save the assembler's time is to have the components in small packaging at the station since then there can be more items close to the assembler than if the components are put in larger packaging (Wänström & Medbo, 2009).

2.3.3 Factors affecting materials supply

The design of the material supply system can be greatly affected, according to Hanson (2009), by the physical characteristics of the components. Characteristics like the shape, weight, size and sensitivity to damage need to be considered. This is because these characteristics can control what unit load is chosen to be used for the handling which then has an effect on what equipment is used (Hanson, 2009). This can be a choice between large equipment and a smaller one. For example smaller equipments are more fitted for milk run deliveries while larger units need larger equipments. Another thing Hanson (2009) mentions that affects the material supply system is how many different product variants the production company has as well as how many variants each product has. If a company has many different products it will include many part variants, this has the effect that the company needs to keep a lot of inventory (because of the wide variety of products) and the material handling will be increased. This can also affect the assembly operations, because having many different variants will cause problems when trying to fit all part variants at the station. Although this can be fixed by choosing a material feeding method that does not require much stock at the assembly station like kitting or sequencing (Hanson, 2009).

2.3.4 Material feeding options

According to Hanson (2009) the material feeding principles are the main element in the in-plant material supply system. There are many ways to present the components to the assembler. According to Hanson (2009) production companies can use e.g. kitting, sequencing, or continuous supply (line stocking). These different options can have different effect on how the materials supply system as well as the assembly stations perform. Therefore, it is very important to choose which material feeding principle is going to be used before the material supply system is put to use (Hanson, 2009). However, production companies often want to change from a principle they are already using to another. This is possible but it can be hard and costly to be able to achieve all

[2] Person that delivers the components to the assembly station.

benefits that the new principle can offer since the factory has, most often, been designed according to the prior principle. That is why there needs to be a careful consideration of the potential for the new material feeding method in the old layout (Hanson, 2009).

Kitting

Kitting is where a full kit with all the components and subassemblies that are needed for one (or more) assembly operation is prepared (Bozer & McGinnis, 1992). These kits, according to Hanson (2009), are presorted and they all contain components for only one assembly object. The kits are made prior to being delivered to the assembly line in a preparation area where components are picked from bigger unit loads into specific kits (Hanson, 2009). According to Caputo & Pelagagge (2011) the kits are prepared according to a picking list that is generated from the bill of materials and then delivered according to the production schedule. According to Brynzér & Johansson (1995) picking lists are the traditional way of informing the operator what to pick. In the list it is noted what component number is needed, the number of components, location of the components etc. After the kits are ready they are transported in a sequence to the assembly line with some kind of load carrier, so that the kit will match the correct assembly object (Hanson, 2009). If the kitting area is in direct connection with the assembly line the kit can simply be placed directly at the line.

There are, according to Bozer & McGinnis (1992), two types of kits, a stationary kit and a travelling kit. The stationary kits are where the kit is delivered at the station and does not leave the station until it is empty. The product then moves from one station to another but this stationary kit is meant for the operations that are done on only that station. Then, on the other hand, there are traveling kits where, as the name implies, the kit moves alongside the object through different stations until the kit is empty. It depends on the size and complexity of the assembly object how many kits are needed for that object (Bozer & McGinnis, 1992).

Kitting is very convenient in mixed-model assembly since then every assembly object has different components and therefore those components are all picked into a kit and delivered to the specific station and object (Hanson, 2009). According to Cheldelin & Ishii (2004) kitting is one of few techniques that can reduce the risk of errors in mixed-model assembly. Kitting, in their point of view, decreases the assembler´s need to make decisions when they are assembling. They simply asssemble the components that are presented to them in the kits and therefore do not need to choose the correct ones from racks located at the assembly line (Cheldelin & Ishii, 2004).

According to Hanson (2009) there are some kitting wagons that are standardized i.e. all kits have the same parts. However for customized production, which is most convenient for kitting, there are often varieties of kits depending on what they are supposed to hold. This is because it often varies greatly which parts are going in each kit in a customized production. However, this does decrease the flexibility factor that kitting provides. Medbo (2003) states that kitting wagons should be designed depended on the layout of the assembly system and should not be designed only once (in the beginning) and never changed. The kitting wagons should be able to change with the products and processes, i.e. if the assembly work is improved the kitting wagons might need to change as well in order to support those changes.

According to Bozer & McGinnis (1992), components are usually picked into the kitting wagons in a “walk-and-pick” order i.e. operators walk around the kitting area and pick the components into the kit. Then the kitting wagons are either delivered straight to the assembly line or to a stocking area where they stay until they are needed at the assembly line. When they are delivered straight to the assembly line they are delivered in a JIT approach which means that the kits are only made when there is demand for them. However, in the cases where the daily demand varies a lot already made kits are stored somewhere before they are delivered to the assembly line, so the JIT approach is hard to achieve (Bozer & McGinnis, 1992).

It seems to be at tendency to send the kits not fully completed to the assembly line (Ronen, 1992). Ronen (1992) strongly recommends that kits should always be fully prepared before they are sent to the assemblers to be assembled to the object. He mentions many things that are negative with delivering half prepared kits. When objects are only assembled partly and need to wait for the rest of the components to be delivered and assembled to it, it increases the WIP, i.e. near to finish items might pile up in the end station. He also mentions that when there is a need to put on components later in the process that should have been done at point of use it has the effect that double work on the object is needed. Ronen (1992) says that when WIP increases it in turn increases the lead time of the product, increases cost (holding cost, scrap, extra work, etc.) as well as decreases the quality e.g. kits have to wait for the components in a storage, double handling increases risk of mistakes, when things are put on afterwards it might be done wrongly, etc. Ronen (1992) also mentions that it hurts the motivation of the employees as well as the trust in the system when they are asked to do extra and unnecessary work.

Advantages of kitting

Advocates of the kitting method mention that the method gives a better control over WIP inventory as well as less space on the shop floor is needed since the components are stored at the kitting area instead of at the line (Bozer & McGinnis, 1992). Caputo & Pelagagge (2011) also mention this and say that kitting offers a cleaner shop floor since containers are not stored at the assembly line. However some components might be stored at the line and those components are the ones that are needed in most objects and are therefore not included in the kit and simply stored in bulk containers at the stations (this can e.g. be fasteners) (Bozer & McGinnis, 1992). More advantages that Caputo & Pelagagge (2011) mention are that with kitting less time is spent by the assemblers looking for the components at the assembly line as well as the assemblers do not need to be trained as much since the kit makes the work easier if the components are presented in the kitting wagon in a logical order. Medbo (2003) also mentions that the kitting method can serve as a work instruction for the assemblers by designing a structured kit since then there are special place for each component. This has the consequences that the risk of assembling the wrong components decreases since they should just assemble the components that are located in the kit and the assemblers are able to observe their own work. This also has the effect that fewer assemblers are needed at the line compared to continuous supply (Hanson, 2009). Antoher thing is, according to Hanson (2009), that since the assemblers are faster they can decrease the throughput time.

Cheldelin & Ishii (2004) discuss the improvement option for the kitting by having a so called "shadowbox"[3]. "Shadowbox" has the positive effect that it provides the operators with help in filling the kit (picking into it) at the kitting area as well as helping the assemblers in assembling the components since all the components have their own position[4] in the kitting wagon. This shadowbox makes it unnecessary for the operators and assemblers to make decisions and also makes it unlikely

[3] "Shadow box" is often used in automotive industry and considered a lean method.
[4] The form of the component drawed on the bord and a label with the component number and name.

to forget parts since all places in the kit should be filled as well as no parts should be left in the kit after assembly is done. However this does require that the kitting is done properly i.e. that the kits are not kitted with wrong parts, missing parts etc. (Cheldelin & Ishii, 2004).

According to Caputo & Pelagagge (2011) kitting offers a decrease in raw material (RM) and WIP inventory since the components have a centralized storage. They also say that this makes the control of the inventory easier. Caputo & Pelagagge (2011) also mention that kitting offers an easy product changeover since the only thing that needs to be changed is the picking list. More advantages with kitting are according to Bozer & McGinnis (1992):

- Better control and flexibility when only the kit containers are handled and routed through the assembly system instead of numbers of bulk containers
- Better control and visibility of components that are high in cost
- Increased productivity at the assembly stations
- Increased quality in assembly since parts are checked and pre-positioned and the kits can work as instructions for the assembler
- Provides better opportunity to assemble large variety of objects

Disadvantages of kitting

According to Caputo & Pelagagge (2011) the disadvantages with kitting can e.g. be that space is needed for the kit preparation area that was not needed before. They also mention that it can have great effects on the assembly line if the kits are not delivered in the correct manners; they can have wrong component, missing components, damaged components, etc. To come against these mistakes there is an option of having extra parts stored at the assembly line. Hanson (2009) also mentions this problem and says that the mistakes in kitting usually gets discovered at the assembly line and can then risk the quality of the product. Brynzér & Johansson (1995) mention that the picking lists might often be neglected by the kitting operator since they, in some cases, consider it for the beginners and they might think that they are experienced enough and start to pick without looking at the picking list, i.e. they are not precise enough and do mistakes. Kitting does also require much handling since it is often repacked and need to be handled first into a kit before it is taken to the assembly line. According to Corakci (2008) small components as well as sensitive ones are not convenient for kitting and should not be included in them. Extra handling of the components can increase the risk of quality problems which is even more for sensitive components (Corakci, 2008).

More disadvantages with kitting are mentioned by Bozer & McGinnis (1992):

- A lot of “non-value added” time added to the product (usually manual labor) when the kits are prepared
- Can increase storage requirements, especially with kits that are stored already made i.e. not JIT kits
- Shortage of components can decrease the efficiency of the material feeding since the kits are delivered with a shortage and then the product needs to be double handled
- Delivering wrong, damaged components (or other shortages) will affect the assembly since the material is not at point of use when needed
- Sensitive components (can fail in the assembly process) might need extra piece in each kit or at a storage location on the line

- If component is missing/wrong/defected assemblers might borrow the component from another kit that will complicate the shortage as well as extra handling is needed

Hanson (2009) mentions that the benefits of kitting might not be certain. He mentions e.g. that if kits are not correctly kitted it can affect the quality of the product.

Causes of picking errors

There can be many reasons why the kitting operators tend to do mistakes while putting together the kits for the assembly. Brynzér & Johansson (1995) mention examples of mistakes that are done in kitting in their report, which can be:

- Components for a product is located in the wrong kit
- Wrongly picked components
  - Operator disturbed because of radio, people talking to him/her etc.
  - Items picked wrong because components with similar item number are put next to each other
  - Operator uses experience to know which component to pick instead of looking at the picking list
  - Reading the list wrong, e.g. reading the item number for one component but taking the amount of it depending on another item number
  - Picking the same components as the picker in front of them

Solving picking mistakes in kitting

There are some solutions that can decrease the human effect on picking mistakes. For example, replacing the picking lists with the pick-to-light system. That type of system will also increase the productivity of the operators (Hanson, 2009). Pick-to-light is where a small lamp by the component lights up when it should be picked and a display that shows how many components should be picked (Brynzér & Johansson, 1995). But according to Brynzér & Johansson (1995) the pick-to-light system requires a lot of investment and can sometimes create idle time since the operators might have to wait in queues. Pick-to-voice[5] is also an option to increase the productivity, decreaseing the mistakes in picking as well as replacing the picking lists (Dallari, et al., 2009). Barcoding is also a solution to the picking lists mistakes (Brynzér & Johansson, 1995). Then the barcode at the location of the component is the same as on the picking list and when it is being picked the operator needs to scan the barcode on the picking list and the component and if it is correct they get a signal.

Sequencing

Sequencing is when the components are delivered to the assembly station, just before it is going to be assembled, in the sequence that they are going to be used. This method does not require a lot of space at the station but can include much handling because of repacking when achieving the correct sequence (Hanson, 2009). Sequencing also needs an additional work in terms of scheduling the sequence, which can either be done within the factory or outside it (Caputo & Pelagagge, 2011).

This method has similar advantages and disadvantages as kitting but is often used instead of kitting when each station only has few components to be assembled. That is, when each object can be

[5] Voice telling the operator which component to pick next through a headset that the operator has on.

assembled in great variety but still only few components are needed at each station so kitting is not convenient (Caputo & Pelagagge, 2011).

Continuous supply

According to Hanson (2009) continuous supply is when numbers of components are stored at the assembly station i.e. all components that are needed for the assembly at that station. The components are stored in bulk quantities (usually in the original packaging from the suppliers and therefore do not need any repacking) and are replenished periodically or when needed (Caputo & Pelagagge, 2011). This requires a lot of space at the station for storage, especially when producing variety of different objects since then magnitude of different components need to be stored at the assembly station (Hanson, 2009). Caputo & Pelagagge (2011) state that having high variation of components in continuous supply will lead to very high capital cost and the need for a lot of space at the assembly line. However, continuous supply does often need less handling since the components can be delivered in the packaging from the suppliers, i.e. no repacking is required. The material flow is also very direct since the components can be delivered straight to the assembly stations (Hanson, 2009).

Kanban

One type of continuous supply is kanban (Caputo & Pelagagge, 2011). In kanban the components are stocked at the assembly line in special containers. However, the containers do not hold components in bulk quantity as in normal continuous supply. The containers are smaller and are replenished more often with a pull method. How many containers are in the system depends on the balance between the holding cost and the desired service level, since having many containers will secure the service level but increase the stock level (Dub, et al., 2002). When each container is empty it is replaced with a full container. The difference between kanban and normal continuous supply is how often the components are replenished and the quantity it is replenished in (Caputo & Pelagagge, 2011).

Batch supply

Batch supply is another way of feeding material to the assembly line (Hanson, 2009). Then components are delivered to the line in batches for number of assembly objects and the content of the container by the line changes from batch to batch (Johansson, 1991 cited by Hanson, 2009). Then half full containers might be removed from the assembly line when the objects that were assembled with this component are not being assembled again until later. Instead of having to remove half full containers there is the possibility to keep count of the number of components that are going to be needed at the line and only feed them to the assembly line (Hanson, 2009).

Comparison of material feeding principles

The continuous supply method can be very wasteful in the case of customized products. In those cases the products can have many different part variants, which requires a lot of space at the assembly station which results in the assemblers having to walk long distances to pick components (Hanson, 2009). In this case kitting should be a better choice because then there is a special kit for each product produced so there is not nearly as many different components in each kit than would be needed at the station if the continuous supply would be used (Hanson, 2009). Caputo & Pelagagge (2011) confirm that by saying that kitting supports small batch sizes of products that are produced in wide variety. This means that kitting is most fitting in cases with high customization i.e. high numbers of components are needed in each assembly and great variation of different components (Caputo & Pelagagge, 2011). Everything above implies that kitting can offer greater flexibility than many other material feeding principles. However, in cases where only few components are assembled at each station or when the assembly job is very standardized then continuous supply is more advantageous than the kitting method since extra material handling would not save anything in other areas e.g. space (Caputo & Pelagagge, 2011).

Hanson (2009) states that one of his cases showed that it takes considerably less time to pick parts from the kit versus having to pick them from the racks since they are further away from the product being assembled. This implies the advantage of kitting over continuous supply.

Bozer & McGinnis (1992) state that continous supply does have its positive sides compared to kitting. Continuous supply uses considerably less handling since in kitting, as stated above, the components need to be handled extra when they are put into kits oposed to delivering them directly from storage to the assembly line. The kitting area also requires space for kitting operations that is not needed in the continuous supply material feeding method. According to Caputo & Pelagagge (2011) continuous supply needs less labor in terms of preparation and it has the positive side of always having the material at the assembly line. Having the components stocked at the assembly line will prevent any disturbanices if e.g. the component is damaged since the assemblers simply can pick the next item from the rack. This however needs a lot of space and holding cost, as stated before. One disadvantage with continuous supply is that if the same component is needed at different assembly stations it will have the effect that the same component will be stored at more than one place by the line (Caputo & Pelagagge, 2011).

Combination of methods

It does not always have to be a choice between one principle and another. There is, of course, the option of combining the principles in order to achieve as much benefits as possible. This is for example the case with the combination of kitting and continuous supply. According to Corakci (2008) kitting is usually not used on its own, but in combination with other methods, i.e. continuous supply, batching and sequencing, since putting all components in the kit is generally not considered a good idea. According to Hanson (2009) a reason why the combination is convenient is because the company can achieve the space efficiency at the assembly line and increase flexibility while not having to repack everything and then saving labor hours in repacking. Then the high variation components would be delivered by the kitting method while the more frequently used components are stored at the line. The reason for this split is that the high variation components are usually the ones that take the most space at the line. Another reason that Hanson (2009) mentions is that when components have high variation of different types then it can be hard for the assembler to identify which part should be assembled and it can increase the risk of assembling the wrong part. That is why it makes the assembler´s job easier if the high variant components are delivered in kits. However, it does not help them to have all components on the kit since the components that are very standard do not make it hard for the assemblers to identify which to put on the object. Hanson (2009) also mentions that it can be convenient to split the feeding method for the components by size. This would then mean that smaller parts are more convenient to be delivered in kits and consequently give more support on how to assemble them (e.g. with a structured kit).

Hanson (2009) does though state that when using kitting combined with continuous supply much consideration needs to be given to which parts should be in the kit. This is because e.g. if the assembler always picks product A at the same time as it picks product B it will not save as much time to put product A in a kit compare to putting product B in there as well. This means that even though one component has many variants while another does not have any it might be most efficient to kit them both. Caputo & Pelagagge (2011) state that it can be convenient to use kitting for high value components or if only few components are customized while the rest of the components, that are low value or standardized, can be stored at the line. However, according to Hanson (2009), it is not always the case that kitting decreases the overall level of inventory so basing the decision on the value of the components can be tricky.

Since sequencing is like kitting except for that the volume of items being transported to the assembly line is much smaller, the combination of sequencing and continuous supply can also be achieved. Then, like with the combination of kitting and continuous supply, higher value components or high variation object would be fed to the line with the sequencing method and then the lower value or components used often are stored at the line (Hanson, 2009).

Some benefits with kitting, according to Hanson (2009), decrease when not all components are supplied in kits. This is because then the assemblers does need to spend some time thinking about which parts should be assembled opposed to only assemble the components that are in the kit. Also when kitting all components then there is a possibility to make a structured kit which provides the assemblers with directions of how to assemble the object.

There are though, according to Hanson (2009), more factors than just the product variation that can have impact on what option to choose. Examples of these factors are e.g. how much space there is at the assembly station and in other area of the factory (e.g. storage, kit preparation), space requirements for the production, transportation distance, the plant layout and the physical characteristics of the components (e.g. weight and dimension). According to Hanson (2009) there also needs to be consideration given to how frequent the transport needs to be, material handling locations, material handling equipment, etc. before choosing the principle. Every choice has its advantages and disadvantages so there is a need to have a deep knowledge about those to be able to make a sensible decision.

2.4 Root cause analysis

According to Wilson et al. (1993) root causes of problems are always negative and by fixing the root cause analysis the quality of the organization is increased and therefore the root cause analysis is one part that supports Total Quality Management (TQM). Toyota considers it very important to ensure the quality and to solve problems even if it takes time since they consider the long term benefits in eliminating the problems completely more important than short term goals (Toyota, 2006). The goal with root cause analysis is to find the real reasons for the problem in order to eliminate it completely (Wilson, et al., 1993). Bhaumik (2010) agrees with this by saying that root cause analysis both fixes the immediate problems as well as provides a solution on how to make sure that the problem does not come up again. According to Finlow-Bates (1998) there is not always just one root cause to a problem, there can be many potential root problems. It is then a question of how effective the solution for the root causes is which one is the best fitting and should be worked with.

According to Wilson, et al. (1993) root cause analysis can both be used in reactive mode i.e. to prevent problems from happening again and in a proactive mode where things are identified that can be improved. The techniques for root cause analysis are designed in order to identify and solve problems. Management can use this to decide on long term decisions regarding quality and productivity improvement (Wilson, et al., 1993). By doing the root cause analysis it offers a way to identify the root cause of the problem, which then makes it possible to find out how to fix the problem in order for it to never happen again.

2.4.1 Finding the real root cause

According to Arnheiter & Greenland (2008) root causes to problems are not always properly identified. The reason why the root cause analysis fails often lies in the differentiation between the apparent causes and the real root causes (Wilson, et al., 1993). Apparent causes are the causes that seem to be the reasons for the problem right away. That is why analysis of the causes is needed at all times to be able to find out the root cause of the problem. However, the apparent cause might be the root cause but it should always be confirmed by the analysis. Some actions might fix the apparent causes but it is not until the root causes are fixed that organizations can prevent the problems from recurring.

The people that are directly involved with the problem should not be the ones doing the analysis, however they should, of course, give input since their view is very important (Wilson, et al., 1993). Coming in with fresh eyes and not be blind sighted by the current process can give better results. According to Bhaumik (2010) the information that the people involved give is very important, if they do not give good enough information, by hiding or simply not giving correct information, the analysts will not be able to come up with the root causes of the problem. This can e.g. happen if the people are afraid of changes.

According to Finlow-Bates (1998) it is very hard to find a long-term solution that completely eliminates the problem. Finding the root causes can be very difficult and people tend to spend a lot of time and effort trying to find it. Sometimes they might even solve someone else’s problem instead of their own or they miss a better root cause than the one they decided on. A problem can also be the difficulties to distinguish between a cause and effect i.e. the same thing can be a cause of something and an effect of something else but the only difference is when in time it is looked at (Finlow-Bates, 1998).

2.4.2 Benefits of finding the root causes

There are many benefits of fixing the root causes rather than just “fighting fires”. Wilson et al. (1993) mention some advantages of finding the root causes. One is that by fixing the root cause the first time the problem comes up, it will have the effect that employees stop wasting time in repeatedly solving problems that are attributed by the same cause. Another example is that the solutions that come from the analysis are most often impartial since the analysts follow a prescriptive and well defined process to reach the solution. The root cause analysis can also predict other problems by looking at similar or related processes and operations. Finally root cause analysis focuses on preventing problems from reoccurring, finding solutions to fix the problems as well as identifying improvement opportunities (Wilson, et al., 1993).

2.4.3 Main tools

According to Finlow-Bates (1998) the two main tools that are used to find the root causes are the fishbone diagram and the 5 whys method. Uthiyakumar et al. (2010) also mention those two as the most commonly used tools for root cause analysis but to this they also add the interrelationship diagram (ID) and current reality tree (CRT). The methods 5 whys and fishbone diagram will be discussed in more details in this report.

5 whys method

The 5 whys method provides a structured approach to gather facts in order to find the root cause and how to correct it. It does not only focus on decreasing the problem but to completely eliminate it (Uthiyakumar, et al., 2010). The method of asking 'why' five times comes from Taiichi Ohno the pioneer of Toyota Production System (Toyota, 2006). He did not look at problems as a negative thing but rather as an opportunity for continuous improvements. Ohno would encourage the employees at Toyota to find out the root causes of the problems by observing the shop floor and asking 'why' for every matter five times. His most famous example of how to use 5 whys is about welding robot that stopped in the middle of the process (Toyota, 2006):

1. "Why did the robot stop?"
   -The circuit has overloaded, causing a fuse to blow.
2. "Why is the circuit overloaded?"
   -There was insufficient lubrication on the bearings, so they locked up.
3. "Why was there insufficient lubrication on the bearings?"
   -The oil pump on the robot is not circulating sufficient oil.
4. "Why is the pump not circulating sufficient oil?"
   -The pump intake is clogged with metal shavings.
5. "Why is the intake clogged with metal shavings?"
   -Because there is no filter on the pump.

Ohno also stressed the importance of "genchi genbutsu" (going to the source) in order to see for yourself what the problems are about. He emphasized that even though data is always important the most important are the facts (Toyota, 2006).

Fishbone diagram

The fishbone diagram (also known as "cause and effect diagram" and "Ishikawa diagram") is a systematic way to find the root causes of a problem (Bergman & Klefsjö, 2003). It is usually developed by a team in a brainstorming meeting with post-it notes. It was introduced by Dr. Kaoru Ishikawa in 1943 and looks like a fault tree (see Figure 3). This method starts with the main problem and then the possible causes of the problem are roughly described. Then the main causes are sorted out ("Cause" in Figure 3) and then one by one the causes are investigated in more detail to find out the contributors to the causes (detailed description of the causes) (Bergman & Klefsjö, 2003). There should be a lot of "bones" on the diagram in order to make it useful.

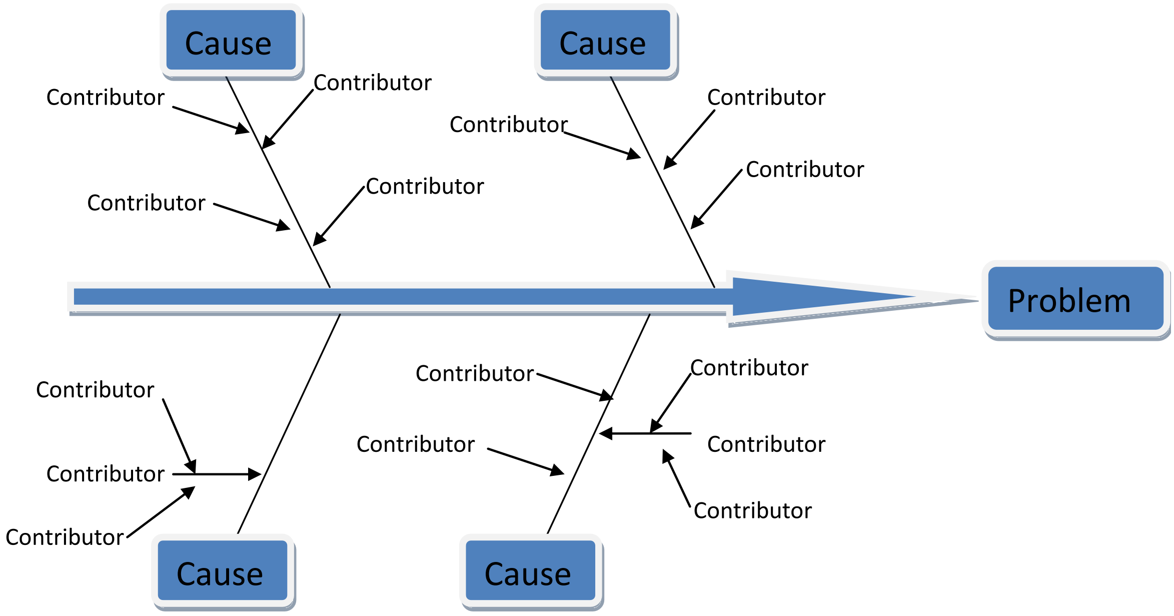

Figure 3: Fishbone diagram

2.5 Process improvements

After trying to find the root causes by using the fishbone diagram, 5 whys or other methods companies might feel that they have not been successful in finding a solution to the problem. If that is the case there are process improvement cycles that can help. Several different methods can be used but the methods Plan-Do-Check-Act (PDCA) and Define-Measure-Analyze-Improve-Control (DMAIC) will be discussed further. These methods not only help companies to realize their root causes to their problem but also they can start to figure out how to solve the problems in the best way.

2.5.1 PDCA

The PDCA cycle (see Figure 4) is a systematical way of solving problems (Bergman & Klefsjö, 2003; Eklund, 2000). The PDCA cycle *"emphasizes continuous improvements based on a circular and repeated pattern"* (Eklund, 2000: 643).

The process begins with the "Plan" stage where the problem is identified and a project team is assigned to the problem. This team should be put together with people with different background and skills to be able to achieve good brainstorming meetings (Bergman & Klefsjö, 2003). Each person in the team should participate in the whole cycle in order to achieve motivation, learning and improvements (Eklund, 2000). According to Eklund (2000), if only specialists do the problem solving the learning will not take place. Analysis of the problem, data collection and probable causes are identified (using root cause methods) as well as the results are evaluated in the planning phase (Bergman & Klefsjö, 2003).

The next stage is "Do" where the cause of the problem has been found and the team starts the improvement steps (Bergman & Klefsjö, 2003). According to Benneyan & Chute (1993) the plan made in the plan stage is tested in the do stage. This is done by performing the activities identified in the plan stage, training involved people in necessary skills, making changes, and collecting and analyzing data.

Next is the "Check" stage (sometimes called the "Study" stage) where the results from the improvement process are investigated to see if the improvements were successful. If it was successful the team needs to make sure that the improvements are maintained (Bergman & Klefsjö, 2003).

The last stage is the "Act" stage where the changes, if this was successful, are made permanent (Bergman & Klefsjö, 2003). If, on the other hand, the cycle was not successful the team needs to go through the cycle again. It is also good to go through the cycle once more even though it was successful the first time since it might be possible to improve even more and also in order to gain as much experience and learning from the improvement process (Bergman & Klefsjö, 2003). According to Eklund (2000) going several times through the cycle will give second-order learning, which is about learning how to learn and to improve the ability to reflect on the process itself.

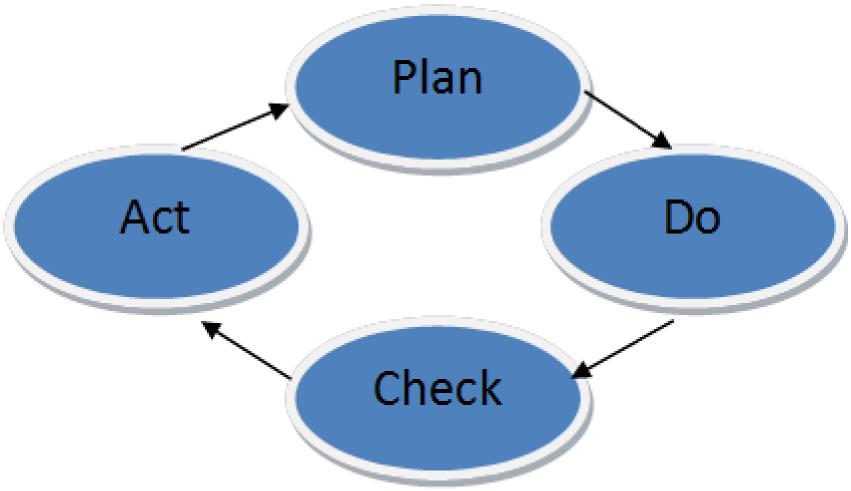

Figure 4: PDCA cycle

2.5.2 DMAIC

The DMAIC is, according to Bergman & Klefsjö (2003), the core of the Six Sigma philosophy, which is a systematical and statistical method used to bring about continuous improvements. DMAIC is used in order to improve the current process (Snee, 2004). It is an improvement cycle (like the PDCA) where the problem is defined (D), measured (M), analyzed (A), improved (I) and finally controlled (C) (see Figure 5) (Bergman & Klefsjö, 2003). Like in the PDCA there is a need for tools in order to identify the root causes of the problems.

The "Define" phase is where the project that should be worked on is chosen. The problem that needs to be solved is defined as well as the process that needs to be improved (Snee, 2004). There is a project charter used in this phase where the resulting project and its objectives are summarized. It needs to include the definition of the work that needs to be done, the process, problem statement, project goal, etc. (Snee, 2004). This needs to be done since it can be risky if all team members do not have the same understanding of what the project will do and accomplish.

The "Measure" phase is where the process is checked to ensure that the correct process is being worked on; it needs to be one that can be measured (Snee, 2004). This needs to be a process that is truly in need of improvements and is based on customer needs and the objectives of the project. The current performance is measured and appropriate performance identified. According to Snee (2004) the main tools that are used in this phase are process map, cause and effect diagram (fishbone), cause and effect matrix (C&E), measurement system analysis, capability analysis, and a control chart analysis.

In the "Analyze" phase, the root causes of defects and variations are identified by looking further into the current performance (Snee, 2004). It may be that additional information is needed for the analysis and then it is collected. The most popular tools that are used in the analyze phase, according to Snee (2004), are Multi-vari studies and Failure Models and Effect Analysis (FMEA)

The "Improve" phase is where changes are done to the process according to the root causes found in the analyze phase in order to improve the performance (Snee, 2004). These changes are verified by testing them with a confirmation study. To reach the desired performance it might be necessary to go through several rounds of improvements.

A system that ensures a sustainability of the performance is installed in the "Control" phase (Snee, 2004). According to Snee (2004) the Control Plan including control charts and long-term capability studies are the main tools used in this phase.

According to Bergman & Klefsjö (2003) the framework is not enough, there is a need for educated and trained people in improvements at different levels.

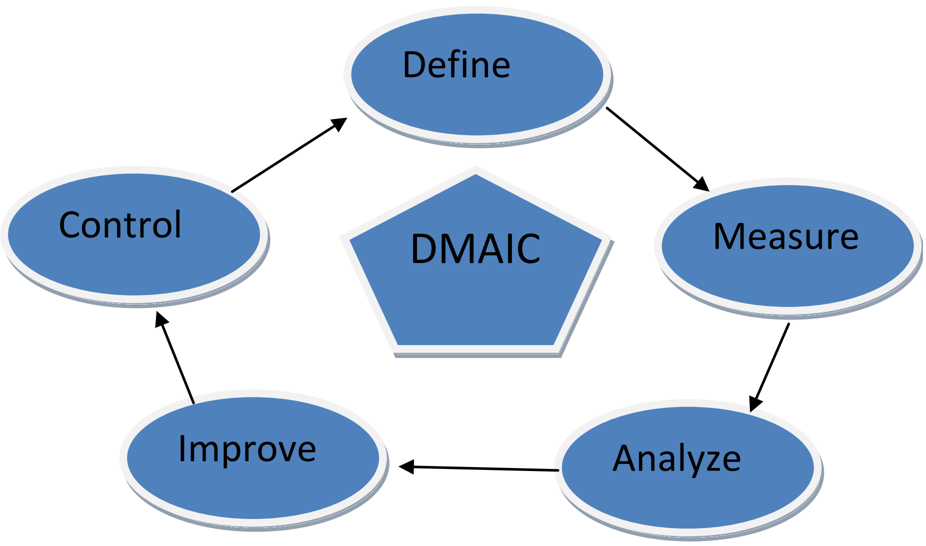

Figure 5: DMAIC method

2.6 Analytical framework

From the theory above an analytical framework has been developed by the authors. It was found that in order to obtain high material availability at point of use some prerequisites need to be in place. These prerequisites are good material planning, with appropriate planning methods, and good material supply system in the plant. It is also important to take the correct actions when the material is missing to prevent it from reoccurring. It could be with the help of a root cause analysis to find the root causes of the problem and then using some process improvement tools to solve the root causes, so they do not happen again. In order to analyze how companies can obtain and maintain a high material availability at point of use a list of important characteristics for companies was made. This list is presented in Table 5. The more of these characteristics a company has the greater is the potential for high material availability at point of use. This list will be kept in mind when studying the case companies to see how it works in reality.

Table 5: The analytical framework

	Characteristics
Material Planning	Appropriate material planning methods used
	Synchronized plans
	Multiple suppliers
	Good interaction with suppliers
	High supplier reliability
	Rescheduling to ensure that material will be available before releasing to production
Material Supply System	Appropriate material supply system used
	Support for picking
	Appropriate safety stock
Root Cause Analysis	Root Cause Analysis performed with appropriate tools
	Person not directly involved does the analysis
	Input from directly involved people
Process Improvement	Process Improvement tools used

There are many things connected to material planning that can affect the material availability at point of use. If a company has an appropriate material planning method is answered by looking into if a company uses the material planning methods best suited for each part since different planning methods suit different parts and environments. Using the best method for each part can increase the material availability at point of use. Synchronized plans are also important in order to gain high material availability at point of use, especially in companies where different parts need to be assembled at the same time. To have multiple suppliers can increase the material availability at point of use since then the company can order from another supplier when one fail to deliver or does not have the part in stock. By having good interaction with the supplier the material availability at point of use can also be increased since everyone is then on the same page. Good interaction means that the focal company and the supplier have close relationship with each other with frequent communication, the information flow between the companies is good, the supplier gets the production schedule long in advance, the supplier is informed of all changes in plans so the deliveries can be adjusted, etc. Supplier reliability is important for material availability at point of use since if the supplier does not deliver in time the material will not be available at point of use except if the focal company has a safety stock of that part. The supplier reliability is measured as delivery precision from suppliers and can be shown in the number of external missing parts at point of use. If the company does reschedule the products when it is known that a material will not be available when needed, the material availability at point of use can be increased since products can be scheduled according to the available material.

When considering the material supply system there are also many things that can affect the material availability at point of use. Using appropriate material supply system is important since these methods suit different types of parts depending on the characteristics of the part and the frequency of use. Choosing the right method for each part can increase the material availability at point of use since waste in form of extra walking, extra handling, etc. can be reduced. It has also been shown in the theory that support systems for picking, like pick-to-light, pick-to-voice, or barcoding can reduce picking errors and thereby increase material availability at point of use. Appropriate safety stock can also increase material availability at point of use, especially for parts with long lead times and unpredictable demand.

Root Cause Analysis can affect the material availability at point of use since the root causes of a problem can be identified which make the process improvement process easier. Companies can use many root cause analysis tools, e.g. 5 whys and fishbone diagram. These tools can help the company to identify the root causes. By letting a person not directly involved in the problem do the root cause analysis the material availability at point of use can be increased since fresh eyes can see some things and identify problems that people involved might not. It is also important to involve people that are directly involved since they can supply more knowledge about the problem and therefore the material availability can be increased.

By improving the process, i.e. fixing the root causes of the problem permanently, the material availability at point of use can be increased because the same causes should not come up again after they have been eliminated by the process improvement methods. Two main methods are used to improve the process; the PDCA cycle and the DMAIC cycle.

3 Methodology

This chapter will describe how the thesis was done in order to fulfill the purpose and answer the research questions. In section 3.1 it is described how the research method was chosen as well as description about the case study method. Then in section 3.2 it will be described and discussed why interviews are preferred. In section 3.3 it will be described how the literature for the thesis was gathered. Then in section 3.4 it will be described how the analysis was done. Finally in section 3.5 the reliability of the thesis will be discussed.

3.1 Choosing a research method

A research method had to be chosen for the thesis. Research method is according to Yin (2009: 21) "*a way of investigating an empirical topic by following a set of pre-specified procedures".* The research questions in this thesis are explanatory ones (since they are "how" questions) according to Yin (2009) and since there were not much literature on the subject it is good to have more of an explanatory study. Because an explanatory study is needed it is more likely to lead to a research method that is a case study, history or experiment. Case study is used to understand a real-life situation in details and is preferred when dealing with present events, as opposite to history, and the behaviors cannot be manipulated by the investigator. Case study uses the same techniques as history (relying on primary and secondary documents, and cultural and physical artifacts as the main source) but also adds the observation of the study as well as interviews with people of interests (Yin, 2009). With the case study methodology, the use of a variety of methods such as, documents, artifacts, interviews and observation is possible, which might not be available in historical studies. Experiments on the other hand are when manipulation can be done directly like in a laboratory.

Case study was, from the description above, the best choice in this thesis since it is dealing with a situation where we have no control over the event that is being studied and since the event is a contemporary one. Since it is of interest to know how a company can improve, which deals with links that need to be traced over time rather than incidences, it further supports the case study method (Yin, 2009). Multiple-case study is used when studying more than just a single case (Bryman & Bell, 2011). The purpose with multiple-case study, according to Bryman and Bell (2011), is to compare the cases involved to find out what is unique with each case and what is common across them. Multiple-case study was therefore suitable in this thesis since three companies were investigated to see the differences and similarities between them.

Interviews were conducted with people of interest to be able to gather data about the situation, collect documents from the companies, as well as observe the situation. All this also gave a clear hint that case study should be the method of choice.

Case study, which can involve single or multiple cases, is "*a research strategy which focuses on understanding the dynamics present within single settings"* (Eisenhardt, 1989: 534). Case studies are usually performed by using interviews, questionnaires, archives, and observations with the evidence being qualitative (e.g. words), quantitative (e.g. number) or a combination of both. Case study can involve multiple levels of analysis within a single study and there can be different reasons for performing a case study: to provide description, to test theory, or to generate theory (Eisenhardt, 1989). In this thesis case study was used to provide description of the situation as well as test available theory.

3.2 Interviews

Interviews were chosen because that method fits the case study the best. Another option could be to make a survey, but according to Yin (2009) even though it might be able to deal with the situation it is very limited in the ability to investigate. The reason that Yin mentions is that the survey needs to have limited number of variables that are supposed to be analyzed so that they can fit within the number of people that are surveyed. According to Flick (2009) interviews are also more likely to get the interviewee to openly discuss its viewpoint rather than surveys. Flick (2009) states that when conducting interviews it should be kept in mind that having the scope of the interview wide will make it possible to reveal the views of the interviewees but it should still be done in a structured way. The chosen structure of the interviews was semi-structured for the reason that the prepared questions are not written in stone and may change in each interview depending on how it evolves. The opportunity to develop each interview as it goes, as well as to give the interviewees the freedom to discuss their knowledge in as much detail as possible, was important during the interview process. The prepared questionnaires for the interviews can be found in Appendix B.

Interviews were conducted with people working with material availability at point of use in Company A both at the factory level as well as managers. This was done to see how different levels (white collar and blue collar) view the problem, how the problem is dealt with on those levels and how they are affected by it. This gave a view of how people within the company see the problem, what they think the root causes for material availability problems might be and the possible solutions that they might see. Five interviews were conducted at Company A and the people that were interviewed were the Material Handling Manager, one production leader, one andon person, kitting area representatives (group leader and a facilitator) and all group members of the Internal Material Controller (IMC) group. The IMC group is a group of andon people working in one specific area of the factory; they are working more with root cause analysis than the other andon people. All interviews were recorded as well as transcriptions were done afterwards in order to make the work easier when working with the data collected. Data in form of documents was also gathered from the company to get relevant information for the project.

To be able to look at the problem from other perspectives data was gathered by interviewing benchmarking companies. This gave a clearer view of how other companies are dealing with this problem and how their production works from material availability point of view. The benchmarking companies were chosen to be similar companies, i.e. large companies with assembly processes within the automotive industry. At Company C one interview was conducted where four people were interviewed at the same time. Those people were the Supply Chain Manager, a Supply Chain Coordinator that is responsible for all sequenced flows into the plant, an Incoming Material Handling Manager responsible for all pallets and blue boxes, and the Logistics Project Manager. At Company B two interviews were conducted. The first one was with the Logistics Development Manager responsible for the logistics development at the plant. The second one was with a former logistics andon person that works as a supervisor now.

3.3 Literature

Literature was gathered by reading articles from the Chalmers library database (e.g. Scopus, Emerald, and Business Source Premiere) and Google scholar as well as related books concerning the topic. This gave a clearer view of the problem, what the main causes are, how other companies deal with it, etc.

Keywords that were used were e.g. material availability at point of use, assembly planning problems, supply availability, root cause analysis, problem solving.

3.4 Analyzing the data

After gathering all the literature data an analytical framework was made to point out the important factors when aiming for high material availability at point of use. The data was analyzed with the purpose and research questions in mind by using the analytical framework i.e. by combining the theory behind it with the findings from the interviews in the empirical part. The data was analyzed in a qualitative way rather than in quantitative way. According to Kleining (1982) (cited by Flick (2009)) qualitative methods can stand for themselves but quantitative methods will need the qualitative method to explain the findings from the data. Since the data was collected through interviews and the findings were explained without graphs, statistics or other quantitative data, the qualitative method was a clear choice. According to Flick (2009) qualitative research features are:

- appropriateness of methods and theories
- perspectives of the participants and their diversity
- reflection of the researcher and the research
- variety of approaches and methods in qualitative research

3.5 Reliability

According to Bryman and Bell (2011: 158) reliability "*refers to the consistency of a measure of a concept".* Internal reliability can be achieved when more than one observer perform the case study and agree on what is heard and seen. In this thesis there are two authors taking all the interviews together at the companies so the case study is expected to have high internal reliability. Transcripts of all interviews were made in order to make the thesis more reliable. Apart from the interviews some observation of the assembly process and the kitting area was made at company A by both authors together. This helped to confirm that information gotten from the interviews were reliable. Unfortunately no observation was made at the benchmarking companies, so the data from the interviews needed to be enough in those cases. However, the authors have both seen the assembly process at Company C before but it was not in connection with this thesis. The empirical findings were then sent to the representatives for each case company for them to confirm that the information was correct. Therefore the information can be seen as highly reliable.

One thing that is worth noting is that since this research is done in English but both of the authors are Icelandic and most of the people interviewed are Swedish (one exception was an English person) some difficulties in communication and misunderstanding might have arisen.

4 Empirical findings

In order to see how companies are working with material availability at point of use three case companies were chosen to investigate. This chapter will go in detail into the cases, i.e. the situation in each company today. The data in this chapter is all gathered from the case companies, most of it in the form of interviews taken with representatives in the case companies.

4.1 Case A

Company A is a large assembly company in the automotive industry. The company has over 17.000 employees and it sells its products worldwide in more than 140 countries. It also has plants worldwide but the plant in Sweden will be in focus in this thesis. The plant has two main assembly lines.

4.1.1 Material planning

Every day Company A sends all suppliers delivery schedule with a forecast for the coming 12 months. There are 20-25 suppliers delivering in sequence according to this file, i.e. exact parts to every chassis number. These suppliers are e.g. suppliers for painted parts, cable harnesses, fuel tanks, etc. The plan is definite (firm plans and no turning back) around three weeks before the product enters the line and that helps the suppliers to send the exact call-off. Small parts, like nuts and bolts, are delivered directly to the assembly line from the supplier. More or less all these small parts are delivered from the same supplier. The replenishments for these parts are also made from the delivery schedule and are delivered every morning. All other parts are delivered in batches to the plant according to the delivery schedule with both firm call-off (4 days) and then forecast for a year. For the important parts Company A has a re-order point (ROP) system, but for materials that they have plenty of there is no special way of ordering; according to the andon person interviewed it sometimes seems that they just order those materials when they feel like it.

4.1.2 Material supply system

To supply material to the assembly line Company A uses kitting, external sequencing, internal sequencing, pallets, small boxes, two bin system, and line stocking. A material supply method is chosen for each part depending on the size of the part (or the cost) and the number of variants. To support their decision they have a process that they follow.

4.1.3 Material availability at point of use

Material availability at point of use is one of Company A's key performance indicators (KPIs) and is measured as the number of products that do not have any deviations of material, divided by the total products built, on a daily basis. It does not matter if the product has one deviation or ten; a product is marked as defected when the first material deviation happens. There are many products defected every day. Whether or not the material can be fetched before the product leaves the station, before it reaches the end station or if it is not fixed until after the product has left the assembly; it is all considered as a problem with material availability at point of use since the material is not at point of use when it should be assembled to the product. This KPI has been used for some time but they are still trying to work with the definition of it. They are still finding ways to actually see what is missing at point of use and what the logistic andon person[6] can handle before it becomes at point of use. Today there might be a situation where a whole kit, consisting of kits for e.g. six products, might all be wrong (like if the same part is missing in all of them). The andon person can see this when he/she

[6] A person that supports the assembly when material is missing which will be described in the next section.

is called for the first missing part and is then able to fix all of the kits. All of them will then be counted as missing parts at point of use even though they were able to fix it for some of the products before they were supposed to be assembled.

4.1.4 The andon concept

There are around fifteen andon people working with the logistic problems in the factory of Company A. They fix problems that concern the logistics e.g. if there is material missing at the assembly line. They have an in-house education i.e. the andon people teach the new andon people how they should work. The andon people are called to take care of different situations e.g. when parts are late, missing, wrongly kitted, if a kit arrives to the station for the wrong product (not in the right sequence), etc. These andon people also take care of other calls than those counted in the missing material at point of use KPI; they can fix situations where delivered items are scratched, broken, etc. There are also other andon people in the factory that take care of other things like the assembly (building the products), i.e. they are working for the assembly line itself in their specific area. Their job is to support the assembly when extra help is needed, it can be in a form of an assembly support or simply if an assembler needs to use the bathroom.

Those fifteen logistics andon people are normal andon people taking care of the material availability at point of use and are mostly just firefighting since they do not have time to perform root cause analysis. These andon people take care of specific areas and specific processes. It was organized in this way in order to make the andon people responsible for their own processes. In one area e.g. there are two andon people taking care of different material flows. One has the responsibility for e.g. push pallets, kitting wagons, etc. and then the other andon person is responsible for paper boxes, blue boxes and pull articles.

The production at Company A was reduced recently because of a decreased demand. This affects the andon people's job but they do, in normal situations, get a lot of phone calls regarding different issues; one andon person mentions that in a normal situation there are at least 20 phone calls every day. They are constantly running errands, fetching missing parts that sometimes can be hard to find. This means that the andon people are running or driving the forklift all day fetching things for the assembly lines, the pre-assembly stations, the cab lines, etc.

Andon people, at least in the case of one andon person interviewed, do not only work with the internal issues but in some way they also look at the missing or late material from the suppliers. The external material controllers are not always aware of how much material is actually needed. This means that they are working a lot against the material controllers, but most often they work closely together with them in order to help each other. The external material controllers often use the andon people to count what material they have left and if it will last until the next delivery. The andon people also need to contact the external material controllers if they need to re-order sequenced material from the suppliers when there is something wrong with the delivered material. Since the material is not stored in-house, it is unloaded and driven directly to the assembly line, the andon people need to ask external material controller to make an extra order which is delivered outside the sequence as soon as possible. This is done since they cannot order it themselves in the current system. But this will be possible when they have implemented a new system which is in process.

Traditional material coordinators vs. the andon concept

The andon people are working in a better way now, compared to how they used to. Before, the andon people (then called material coordinators) were working like an umbrella over the whole organization. Each material coordinator was responsible for the whole line, every type of material, and every category of deliverance (re-packed, kitting, sequenced, paper boxes, blue boxes etc.). This had the consequences that the material coordinators spent around four hours a day in a forklift driving back and forth. In addition, they spent another four hours in the office trying to find out how to get the material to the stations. Consequently, they could not put so much effort into root cause analysis. This was also not popular with the employees because there were some material coordinator from somewhere else (not in their group) telling them they were doing something wrong. Now instead, an andon person is in their group and saying that the group as a whole did something wrong and they as a group need to fix it. Therefore, people got more defensive and felt more attacked before, but now it is a group effort. When they were suffering from a downturn, Company A changed to the system they have today. They divided the andon people so that they were responsible for their own processes and in a specific group.

Having a specific andon person working with a specific material flow, means that there is one andon person responsible for sequenced material from one part of the factory, another for blue boxes, another for sequenced material from another part of the factory, etc. Consequently, the assemblers have to call different numbers depending on what the problem is, if it is a problem concerning the repacking area, kanban, small boxes, etc. However, these andon people also only work in specific area which means that there are more than one andon person working with sequenced material but they are working in different areas of the plant.

In the beginning the idea behind the new setup was that the andon people would be able to work more proactive with their processes in order to eliminate the deviations so they would not re-occur. However, that has not been done enough, because the area that the andon people work in is very big, so they need to work more as firemen than anything else. It does not seem to be much time for them to sit down with problems that they know are frequently occurring. The reason is that they might start working with root cause analysis and while doing so the phone might call a number of times, which is an impossible situation for them to work in.

Working proactive

According to the andon person interviewed, in order for the andon people to work proactive, someone needs to take some of their workload, i.e. having more people working as andon people in each area in order to free them for a few hours a day so they can work on the root causes of problems. However, this does not mean that they do not work proactively, they try to do that but within their role, which is not as specific as the IMC role. However, if they are able to identify the causes without doing root cause analysis then they try to prevent the problems from occurring again.

White collar employees believe that after the andon people have logged the problmes into the quality system they should do root cause analysis on them to figure out the reason for the problem and if they have the time and it is possible they should try to make some actions that are needed to solve the problem. They say that they are both working with short term and long term thinking. The short term is by firefighting, which means that they are getting the material to the assemblers as soon as possible. The long term thinking is to consolidate the data, putting it together, seeing the trends and seeing what the main big issues are. However, the white collar employees do though realize that it does not always work this way. What the andon people actually do is logging the description of the problem into the quality system, what went wrong, etc. (first fact gathering) but they do not do the root cause analysis, the group leaders do it. The reason why the andon people do not do the investigation more thoroughly is that if the andon person gets a call about yet another problem he/she needs to go directly to work on that case. Hence, the andon person needs to be available for the assembly line at all times. This limits the ability to work on fact gathering, but the andon person needs to do as much of it as possible to make it easier for the group leader.

4.1.5 The missing parts process

It is a common understanding within the company that the assemblers call the andon person within logistics when they notice that the material is not available at point of use. This is because they do not have time to fix the problem themselves since the product is moving on the assembly line. The assemblers are not supposed to look a lot for the material, they only do a brief look and if they do not find it they call the andon person. The assemblers then explain to the andon person what part number is missing, description, what product is missing the part, which line it is missing at and so on. This andon person then looks into the computer to locate the missing part. The part might either be somewhere in the plant (internal missing material) or outside it (external missing material). The missing material process at Company A can be shown in Figure 6.

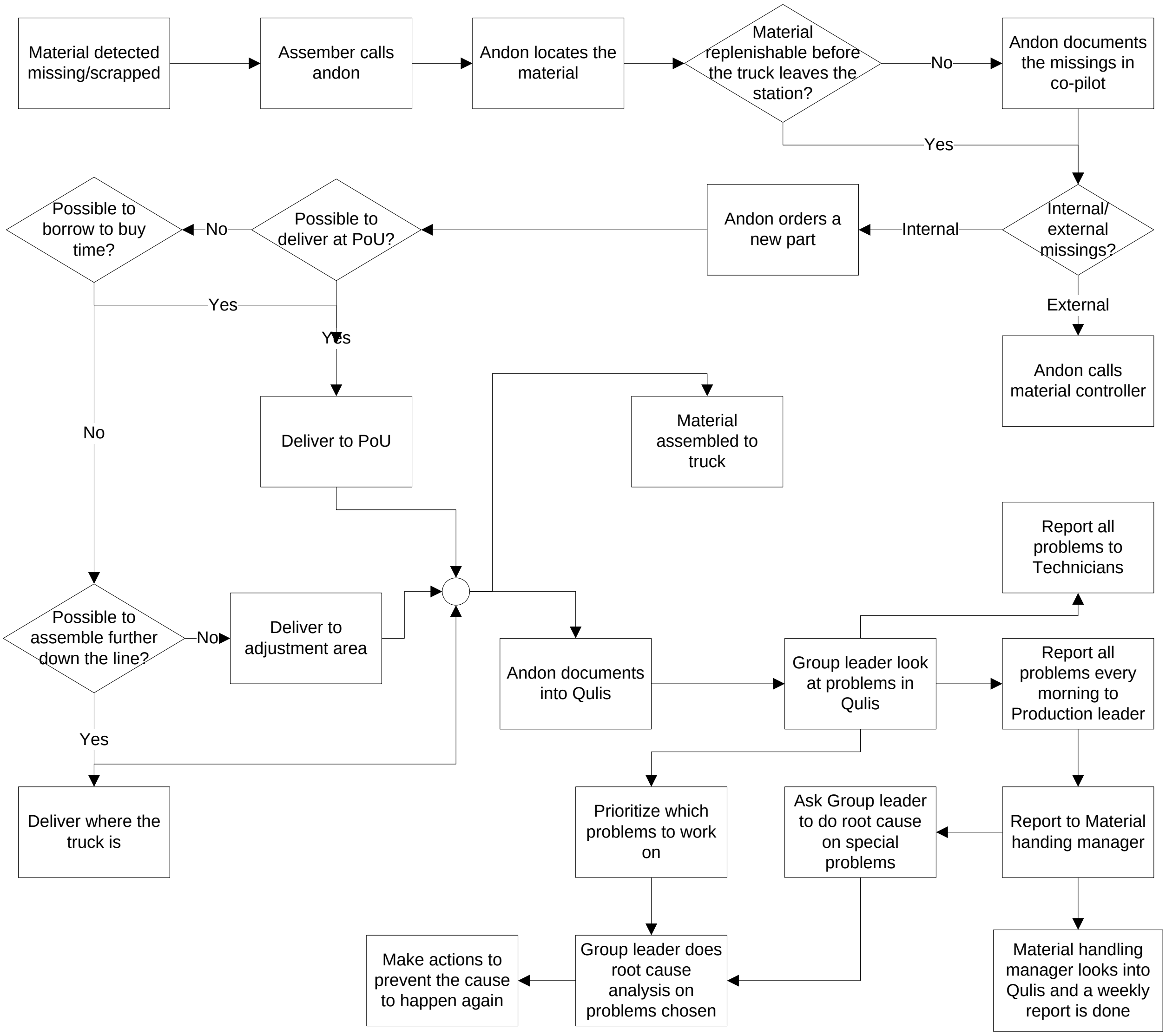

Figure 6: The process of internal missing material

External missing materials

If the cause for the missing material is external the andon person needs to call the material coordinator to notify that the part is not in the plant where it is supposed to be since the material coordinator is responsible for fixing the external missing material. It then depends on the location of the supplier, from where the external missing material is, how long it will take to replenish the part. Location in the same city as the factory should take within one day, even within an hour in some cases. But if the location is further away it can take at least one day. In some cases it can take many days to replenish the material. Material might need to be flown in from suppliers that have problems and are located in countries far away. However, this does not happen often but according to the andon person interviewed in the cases that it does it means that the material controller has not been on top of things since he/she could not get things to the plant in time. In these cases the material controller believes that they have enough material in the plant when they in fact do not. However, these problems are outside the andon people´s hands since they only handle internal missing materials.

It can take some time if the material is not repacked properly from the repacking area[7]. Because the truck that transports the material from the warehouse comes only three or four times a day, it may lead to two or three hours waiting time for the part. However, the company has not had a situation where they cannot wait for the next truck because in this warehouse only “insensitive” items are repacked, which means that the parts that can cause the line to stop (sensitive parts) are not repacked at that area. This means that it is considered in details which material can be stocked at the outside warehouse and which need to be stocked inside the factory. It can also take a very long time to replenish material that is missing in the sequenced material from outside the plant. There are though, in some cases, possibilities to use the stock at Company A´s parts warehouse, which means that the plant will get the part from them and then the parts warehouse needs to replenish that stock.

Internal missing materials

If it is, on the other hand, an internal missing material then it should only take a few minutes to replenish the part. Then, the andon person orders a new part that should be delivered to the assembly station. Most often it is the andon people themselves that go and pick up the part in order to ensure that it gets delivered as well as it is done quickly. If it is a kitting problem the andon people that are responsible for the kitting area get the description of the problem and go directly to the kitting area to get the material that is missing. On the way they look at the picking list to see if it is correct or not. Parts can often be borrowed from another kit at the line so they have time to do a little investigation at the kitting area before returning to the assembly station with the material. If, on the other hand, the missing material will cause the line to stop the andon people need to get the material directly to keep the line moving. In those cases they call the group leaders to ask them to check the picking list and all investigation is done afterwards.

The reason why the picking list is the first thing to check when doing the investigation is because it is often the source of the mistake. Since the material is stocked at the kitting area the andon look at the picking list on the way to get the material. Sometimes the part number is missing on the list and in those cases the group leaders need to bring it up with their technicians in their weekly meeting (they do though fill in the list temporarily). After checking the list, and if nothing is wrong with it, they talk to the operator to see if he/she has followed the repacking handbook (e.g. have to check the items in a certain way). If the same problem happens more than once the andon people talk to the group leaders. This can be e.g. if it is always the same operator doing mistakes.

Internal missing material can take very short time to replenish if it can be found. How long time it takes does, however, depend on from where in the plant the part is missing. If e.g. it is missing from the sequencing area it will only take few minutes. However, it depends on how much material is flowing in the sequential flow how quickly material can be taken out of sequence. Some material can be prioritized but that is not often a possibility, it depends on how much work they need to do to get the material, so the main thing is how important the missing material is. On the other hand, if it is a missing material from the warehouse it will take over 20 minutes. But if there is a problem of another kind, like stock accuracy, it will take even longer time. Most of the problems, however, only take within minutes to fix and can therefore be fixed before the product leaves the station where the part should be assembled.

[7] A warehouse several kilometers from the factory.

Delivery to the assembly line

The missing part should always, if possible, be delivered to point of use i.e. before the product moves out of the area where the part was missing. The replenishment of the parts is not always possible before the product leaves the desired station (where the part is needed) since the takt time[8] of the product is only nine minutes. If the andon person sees that he/she cannot deliver the missing material within the takt time of the station that is missing the part, the andon person will together with the assembler decide where the missing part should be delivered. It can be delivered at the following station, further down the line or even at the end of the line where the adjustment process will handle the part and assemble it to the product. It is up to the assemblers to tell the andon person if they are able to adjust the product at the station or if the product needs to be build incomplete. If the product is build incomplete the andon person needs to deliver the missing part to the "wolf cage" where all the missing parts (not assembled to the product) are gathered and then sent to the adjustment area (where the product is adjusted). Adjustment area is at the end of the line where every product is checked. They do a check to see if e.g. everything is tight enough, something is leaking, etc. They do not go through every part of the product, just the basic functionality.

Documentation

The missing part is documented by the andon person in a quality system. This system is used by everyone in the whole plant in order to keep track of all the quality issues that come up. It is a system for statistics that tells what kinds of deviations have occurred. The andon person needs to document the problems in great details because all the departments look at what problems they have had/caused at least once every day. However, it was mentioned that the quality system was made for the assembly line to document the problem and not the logistics, so the logistics have to work with it in another way.

The andon people log the problems into the quality system if they have time, but sometimes the problems are not even logged at all. This is a big problem since they do not see how great of a problem some issues are, since they just fix it and then forget it because it was not documented. Originally, when the andon people's role was created, they were supposed to log in every problem to the quality system. However, this was not possible from the beginning. According to an andon person interviewed, the andon people do not log in the missing material if they are able to catch the mistake before it is noticed at point of use. But, when they are fetching a part that the assembly line asked for then the assemblers themselves log it in (log in material deviation against the andon person's unit) since every assembly line zone has their own person that logs into the quality system. But even though it is not always documented it is most often done and especially if some items are missing at point of use. After the documentation the group leader tries to do root cause analysis from the logs that the andon people put in. They try to do their 5 whys but they feel that it often ends up with a temporarily solution.

White collar employees state that all group leaders look into the quality system every morning to see what happened the day before and decide what they are able to and need to work on. Sometimes the issues are so many that they need to prioritize which of them they are going to act upon during the day, but other days they are not that many issues so they can work on them all. However, people

[8] The time that must elapse between two successive unit completions in order to meet the demand if the line makes the product one unit at a time at a constant rate during the net available work time (Baudin, 2002).

working closer to the shop floor, blue collar, say that group leaders look at the problems many times a day depending on what was decided on the process meeting.

Although the group leaders do look into the quality system often per day to see what kind of actions are needed to be taken (if they have some extra minutes they look it up), they do not always see the logs until few hours later because the andon people often have a lot to do and then might not have time to log them until later. Even though the andon people do not have time to log into the quality system they do have a logbook where they always write everything they do. This means that when the group leader notices that there are not many deviations logged into the quality system (usually have many over a day) they go to the andon person to get his/her logbook so they can log it in themselves. However, the andon people need to contact the group leaders directly, not just by logging it into the quality system, when there are things that happen repeatedly.

For every missing part there also needs to be a missing part process in a missing parts system[9]. If there is an assembly part that is damaged and needs replenishment, then a missing part process also needs to be started. If, on the other hand, the andon people are able to replenish the part right away or they know they will be able to do it before the product passes their station then they do not have to make a missing part process for it in the system. This is because the missing part process is only needed for the adjustment area to know what parts are missing on the product. If a missing part is, for some reason, not in the missing part system then it is usually because assembly has not let the andon people know that it is missing and just let it pass through. Then they will not know about it until the people in the adjustment area notice that the part is missing and it does not have a missing part process on it. Then, the andon people need to start the missing part process and get the missing part. If they, on the other hand, are able to deliver the part right away there is no need to make a missing part process for it since the material is not missing anymore.

The andon people do not seem to consider the quality system as the main tool for having control over missing parts. They consider that the missing part process in the missing part system and the paper that is written on at the assembly line and follows the product are the tools that are most used for missing parts. The main reason for this view is that the adjustment department does not use the quality system at all; they look at the paper that comes with the product to see what is missing. The quality system is in their point of view more used to get the grip of how many things go wrong and to investigate why it occurred but not to be used as a tool when the product is adjusted. However, they do believe that the quality system could be used instead of the papers. The papers sometimes tend to disappear or are wrongly written on (missing part number etc.) so they might not be the best choice.

Root cause analysis process

There is a process meeting held every week with the production leader, group leaders, Quality Department, etc. where it is decided what actions need to be taken. There is also a morning meeting everyday where the deviations of material from the previous day are discussed. In those morning meetings the group leaders need to answer to the production leader what has happened (e.g. numbers of missing parts), what actions they are going to take, etc. The production leader will forward the report to the Material Handling Manager. The Material Handling Manager will then

[9] A system where the missing parts are logged and then taken out when it has been replaced, i.e. it tells what is specific with each product.

himself look into the quality system to see what happened the day before, to see how many defects they had. This information is then put together in order to see how many total products it has affected. Material Control also does a weekly report for their area, which shows all the issues that week and the trends for the past 16 weeks to see how they are doing, if they are decreasing or increasing in deviations, etc. In their weekly report, all issues are categorized into kitting, re-packing, sequenced, forklifts, etc. For each of those groups they have missing parts, wrong parts and so on, which is then measured. When root cause analysis is done they look at the whole to find patterns in order to find solutions.

The group leaders are the ones doing the root cause analysis of the problems that were reported against their stations by andon people or other people in the factory (like the assemblers). The group leaders are getting a lot of information about the deviations in their day-to-day work since they are both constantly going into the system to look at the deviations and are sitting next to the andon people. They have the possibility to go to the source and look at the problem (genchi genbutsu), talk to the operators to see why things happened and make root cause analysis. Since they are involved with the work they are able to realize the problems much easier than otherwise.

Company A is most often successful in fixing the root causes but of course they have had solutions that did not fix the problem. These solutions might reduce the problem even though they do not fix it completely. Some material deviations are hard to handle and they might simply not know how to handle them, but they do make actions that make the situation a little better every time. Most commonly they do deliver what they are expected to do, which is to take actions to bring them closer to their goal.

Prioritizing

The group leaders sometimes need to prioritize the deviations to work on because there is not always enough time to work on them all. They try to look at patterns and if they can find same causes that are reoccurring and therefore sticking out. Sometimes the production leader specifically asks them to do root cause analysis on a problem which they then do. They then make an investigation to try to see the sources of the problems and try to make actions in order to prevent the problems from reoccurring.

How problems are prioritized to work with depends on the seriousness of the problems. There are situations where root cause analysis has to be done right away e.g. if a product goes incomplete out of the assembly. Then it depends on how many disturbances they have and how serious they are, how many problems can be worked on. If there is only one deviation of material every week or every day they should be able to work on them all, but if there are e.g. ten or fifteen deviations they need to prioritize them. The way they prioritize is by, like stated above, finding patterns to find the ones that are happening more often, if there are some similar causes for many problems, etc. This can be that things are logged e.g. with the same part number, against the same station (maybe the same station but different operators which would mean that the station's design might be wrong) and others that have a common causes.

Root cause analysis tools

After going through the logs and deciding which problems to do root cause analysis on, the group leaders go to the source and talk to the operator. They go after a list of predefined questions like when the problem happened, what was the problem, who discovered it, etc. They then use 5 whys (which they consider very easy to use) to find the root causes of the problem. The 5 whys is used to find out what went wrong but it might not, in all cases, give them all the information that they need since they do not go into the problems that deeply with the 5 whys method. If they want to go deeper into the causes they do a PDCA cycle where they gather information, do root cause analysis and find a solution that fits all parties. PDCA cycle is therefore a tool that is used when they have a really big problem. When the PDCA cycle is done it is usually a big process with cross-functional work where engineers, re-pack personal, technicians, etc. from different business functions get together to solve problems. When working with the PDCA cycle they sit down and brainstorm different possibilities, solutions, take some actions as well as follow up to see if it has solved the problem. If it has not they need to start all over again. But in the end they will solve the problem; it might take a long time but in some cases they already know what the solution could be but the cycle is still done because a better idea can always surface.

Participation from other people

The production leaders do step in and work with problems if the problems are happening more frequently. They might do a PDCA cycle where they work cross-functionally with different departments and brainstorm, process analysis, root cause analysis, etc. In some cases, after looking at the pattern and doing the root cause analysis, they go with the group leaders to the source to look at it and to see why things are not working. By doing this they can often find a solution that was not obvious before. The problem can have effects all around the factory. Solutions to some problems might need the Logistics Department to make changes as well as the assembly line. In those cases they need to work together to find a solution that works well for all parts of the factory.

The logistics technicians need to get every fault reported to them and they often go to the group leaders, at the area investigated, to see what has happened. They do so because they also need to report the problems that occurred to their own manager. It is very good that they come to see what went wrong because often the group leaders realize what the problem is but they cannot fix it without the technicians´ help. This can be as simple as enlarging few numbers on the picking list, the ending of two products is too similar so one of them needs to be replaced with another part (not with similar ending) at the line, etc.

4.1.6 The IMC project

There is a new pilot project (started in August 2011) in Company A called IMC (Internal Material Controllers), with three andon people taking care of all logistics problems in a specific area of the assembly line. They work with all processes and problems that come up in their area, with the focus on working on the material availability at point of use by finding the root causes of the problems and eliminating them. By finding the root causes of the problems the group is able to make sure that the parts are at point of use when they are needed. Like with the other andon people, the IMC group is not responsible for looking into the external missing material, which is a problem for the external material controllers to deal with. The IMC group is only concerned with finding the root causes of the internal problems. Normally there would not be three andon people in one area but this project is aimed at fixing the root causes instead of just firefighting like before, so there is a need for more andon people. Later the IMC group will find out how many andon people will be needed to perform this work.

Since this is a new project the IMC group feels that there is no one that can teach them how to work, so that it is up to them to find a best practice. They are able to see material deviations that the other andon people might not be able to see, e.g. if the item was kitted right but the assembler took it for another kit. The IMC group gets the whole story since they are located at the area all the time e.g. if the assembler takes the wrong part from another kit the other andon people would get two different logs; one for wrong part number and another for missing part. What is seen as a positive thing from the assemblers' point of view (with the IMC project), is that they only need to call one number to get support from the andon people since they are taking care of all material processes in the area where they are located, then it is up to the andon people to take care of calling specific areas to locate the material.

The IMC process

The IMC people take care of the calls for missing parts and log the problem into the quality system where they categorize it on the spot if it is e.g. logistics problem, assembly problem, internal, external, etc. They then are responsible for facilitating the finding of the root causes of the problems and categorize it, e.g. human mistake, system mistake, method mistake, or environment mistake. The first thing they do after the call is to firefight (getting the missing material to the assemblers), and then they do the root cause analysis. After finding the root cause of the problem the IMC group will work with the group that caused the mistake to find a solution. This is done by going to that group, or person, and discuss the problem to see what happened and why. This can be to see if the preferred actions were followed e.g. if the part number was wrong on the list (which will then lead to discussion with the engineer to fix the description), if the wrong part was in the box, etc. So the IMC group is the first and last people to deal with the problem. Either it is something that only happened that one time, and they then do not have to look into it that much, or it reoccurs and they have to do something to fix the problem. That can either be an easy fix or something more complicated that needs to go through a PDCA cycle. Some people state that the IMC group might call the group leader of the station where the mistake came from and ask him/her to look into the problem briefly or get more detailed information of the situation. The reason for this is e.g. if there is a missing part or wrong part number from the kitting area, it can be very long way for the IMC group to go all the way to the kitting area to only look at the picking list.

Each person in the IMC group has only one PDCA running at a time. Having only one PDCA per person at a time can have the effect that, when there are no problems being reported and they are not able to work on the PDCA (e.g. waiting for input, meetings, etc.), they do not have that much to do. However, when they have expanded the area of the project they will not all three be located at the same spot so they will have a lot more to do. The reason why they only have one PDCA at a time is that they cannot handle more than that since they have other businesses to take care of that can take a lot of time. That is why it is hard to start something new (starting new alliances, etc.), because all their focus should be on that one PDCA case. Hence, too many PDCA cases can start taking time from day to day problems.

Since the IMC people are located at the assembly station they can have an ongoing conversation with the assemblers to find out the root causes as well as solutions. This is considered very important since they are always getting the information about the problem and can constantly get the input from the assemblers about issues and solutions.

Every assembly unit is working on what they consider the top five problems. These problems might not be the same things that the IMC group prioritizes because the IMC group can be working on problems that they want to prevent from becoming bigger problems for the units. It might be a lot easier for a person from the outside to see the problem rather than from the inside. But it is really important to work in cooperation with the production units in order to find a solution, it is not the group against the assemblers, the main focus is on the customer. That is why it is first and foremost the IMC group responsibility to collect as much data as possible so that they then can work together with the production units to find out the solution that prevents the problem from happening again.

The progress of the IMC project

People within the company feel like this project is the right way to go but there is still a lot of work to be done. Some people mentioned that they had a lot of starting issues mainly in terms of communication. There is not a lot of information about what they were going to do and who is a part of the IMC group and who is not. This has though gotten a lot better and the communication and cooperation is always progressing. Now the IMC group comes to morning meeting every week with the group leaders and other managers and they can find out ways that they can all work together in order to fix problems.

The IMC project has showed great results. In the beginning they got around 30 calls per day because of missing material but now they only get from five to ten calls per day. What is believed to be the reason for this is that they have been able to work out the root causes of the problems. A part of the reason for this progress can also be that the assemblers are now not panicking in the same way as they used to.

Next steps of the IMC project

The future of this project is not certain. If the IMC project will expand or not is still being decided upon, but it seems that it will. How far it will expand, in what direction, or if it will be in the whole factory is still a big question. If the expansion will be a reality then the IMC group will need to have more than just three andon people working on it in the beginning (when they have many problems), but then when they have reached a more stable situation they will not need as many andon people and in the end, after the project has been effective in the whole factory, there should hopefully only be need for one person at each area (in total they should have six people in the factory). The reason for why they believe there is a need for many in the beginning is that then they need to firefight a lot, do all the work descriptions (what they are doing, what they should do, etc.), work on the root cause analysis and so on. When, on the other hand, work descriptions are done and problems have been eliminated they believe it should be enough with only one. However, this all depends on the size of the expansion. The plan is, in the end, to have no IMC people in the factory at all, which is the case in their plant in France. There, the IMC people have moved outside the factory itself and are looking at the external materials that arrive to the factory, what condition it is in, etc. This was possible because they have been able to eliminate all the material availability problems in-plant, which they had a big problem with before they started the IMC project. This made them able to decrease the number of andon people from 30 or 40 in 2008 down to only six three years later.

4.1.7 Main reasons for missing materials

There are many reasons why material is not at point of use when it is needed at Company A. However, the kitting area is known throughout the company to be the main source of mistakes, which is mainly because of human errors. But other errors are also common in Company A. A list of the most common reasons can be shown in Table 6.

Kitting area

It is a common knowledge within Company A that the main reason for missing materials is the kitting area; operators can kit the wrong material, wrong number of parts, etc. The kitting has been a major cause of errors and has been a problem since the kitting procedures started; the reason is that there are humans that are operating it. One of the reasons is that people tend to go on an auto pilot when they are doing the same thing over and over again and when that happens the likelihood of mistakes increases. More reasons can be that the operator is stressed, products are heavy, and they try to hurry up to be able to get longer break so they can rest, chat, or do other things. Another thing that affects mistakes in kitting is when kits are being made; the operators might not read the picking list carefully because e.g. they think they know from experience that when one item is on the kit another usually follows. Problems reading the picking list are also a reason for mistakes since it offers a big possibility of picking the wrong things. There is too much information on the lists that the kitting operators do not need. However, this is currently being worked on by trying to clean the picking lists as well as planning the implementation of pick to light system were the picking lists are removed entirely. The mistakes concerning the kitting area have decreased a lot after they started cleaning the picking lists. Another thing causing the mistakes in the kitting area can be that the operators do not always follow the re-packing handbook. This can be as simple as not marking the part numbers that they have taken in the right way. The group leaders try to make the operators see the importance in doing the things right from the beginning. Picking errors can have such a great effects on the assembly because of the short takt time on the assembly line. This has the effect that if the operators do a mistake when they are preparing the kits for the assembly line the assembly can suffer a lot of disturbances since the assemblers only have nine minutes to assemble the parts.

Even more mistakes that can happen are that operators might deliver damaged goods, they might not pack sufficiently enough (materials get damaged during transportation), wrong wagons are delivered (the product number on the kit does not match the product being produced), etc. Having the wrong kits at point of use can have really bad effects since the assemblers may start to pick from the wrong kit even though it does not fit properly. This can be very difficult to correct later in the process.

The assemblers at the line can also do mistakes by e.g. picking parts from the wrong kit. This is usually noticed by the assemblers themselves in the end when they start to assemble parts to the product that they took parts from. The assemblers do not always realize that it is their own fault in the first place, that they took the wrong part. In the assemblers' point of view it has just messed up their sequence and they need to get that fixed. They then call the andon person that fixes the problem and he/she usually realizes what caused the problem.

Today, there is a lot of cooperation between the two kitting areas in the factory. They work together in order to eliminate the problems. They have a meeting to see if they can use the input from the other area. This is done because there might be a material deviation in one area that the other one has already dealt with before so they might have experience on how to deal with the problem. There is already a kitting standard so there should be no difference in how the two kitting areas work. They have a meeting where they present what they have done the past week, where they want to be in ten weeks and what actions they need to take to get there. Having fresh eyes looking at the problems can always lead to a solution that was not obvious before.

Connection between errors and specific person

There is often a connection between a specific person and the error, in other words some people do more mistakes than others. There have been really good kitting operators that almost never do mistakes, they focus and take it easy and even do checks on their own work. Those people usually have worked in the area for some time and know how to work with ergonomics and quality thinking. But then there have also been people that do mistakes more frequently and do not really care so much about their job. More training might help, but the attitude, that some people have, is what needs to be changed. The attitude problem is the reason why this is happening over and over again. The reason for the bad attitude could be that the operator might have been moved from one spot to another, which he/she might not be happy with. A reason for the connection can also be that the ergonomics at some station might be less favorable than others and therefore people there get tired, have decreased focus on their work, etc. The way that this is dealt with is to make it as easy as possible for people to do it the right way, by making e.g. the kitting as simple as it can be, try to make it easier to do it right from the start. A standard operating procedure[10] has been made to make it difficult to do mistakes. However, after the handbook was introduced they still had troubles and are working on ways to fix those e.g. by cleaning up the picking list, implementing the pick to light system, etc. Even though they are doing all this to fix the problems they still have people that do not follow the procedures. When there is a deviation and operators are not following the procedures then it is necessary to talk with the operators to find out why they are not doing so and try to show them the importance of following the procedures. However, in some cases they are not following it because there might be a better way of doing things, but then the procedures should be changed. There can be other reasons than not following the handbook that are causing the problems. It might e.g. be that the operator does not have the right training that is needed. This is up to the group leader to find out. If the operator is not following the handbook the group leader needs to emphasize the importance for the line to get the things right from the start. The problem is that minority of the kitting operators have worked at the assembly line so they might not realize the importance in getting the correct material. If, after all this, the person is still not getting better the group leaders need to ask the production leader to come and talk to the operator. If the person does not get better for a long time there might be a solution to the problem to have the operator moved to a station that is a better fit for that individual.

Making everything as easy as possible (fool proof) does sometimes make people feel like they are being treated in a way that they are considered stupid. Some people feel this way about the pick to light system that is about to be implemented. There is a need to show the operators that the implementation of the system is about more than just for them to pick correctly, but this can sometimes be hard. Some operators consider the pick to light system to be a way to make them do more work since it will take shorter time to pick the items. This is also the way some look at their kaizen projects that they run. With the kaizen projects they aim to get the operators, and not just the technicians, involved in making quality and ergonomics better. The projects are held at the station that is experiencing a lot of problems and then the people involved come up with solutions from

[10] Re-pack handbook where every kitting area is standardized through the factory; same paper, same work, same way of working, same kit carts etc.

brainstorming, but some people feel that they are getting increased workload with these changes and are therefore not content.

Connection between errors and specific material

There are often the same parts that are missing over and over again. That is the case for e.g. the fuel tank brackets. They have been a problem ever since the IMC group started this project and they do not know what is causing it. It can be a problem of getting the wrong brackets, too many or too few pieces, the wrong type of brackets, etc. They have done a PDCA cycle and have done a lot of changes in the repacking area and still it is not coming right at point of use. Other factories within Company A seem to have the same problem with the fuel tank brackets, according to Company A, and they are not sure why that is. However, it does vary which parts are missing. If there are parts that can be picked wrong in kitting they will be at some point.

Other errors

There are, of course, other things than the kitting area that create problems. One example is that the assemblers might not order the items in time. They do not scan the order soon enough which leads to that the forklift driver will not have enough time to deliver it. Then, the assembler might not think he/she caused it, but rather that someone else did not deliver the part in time. Another problem that was mentioned is that the factory is designed so there are several kilometers from where the goods come in until it reaches point of use. Consequently, it takes long time to get things to point of use and if things are late it can be very bad. If the goods receiving were closer to point of use then it would take shorter time to deliver the parts.

Missing material or wrong material is the biggest deviation when looking into material availability at point of use but when looking at all deviations in general then the most problematic is the scrapping of parts. Some stations have parts that are easily scratched or scrapped and are therefore a big concern. Material is often delivered to the assembly in a condition that is not acceptable because the operators are not educated enough, the material is already ruined when it arrives at the kitting station (from supplier or warehouse), etc. Another example of things getting scrapped is in the case of big pallets. If the pallets that are delivered are too big they need to be re-packed. In the process of re-packing the material it can happen that the parts get scratched and need to be scrapped. When material gets scrapped they do not get extra material instead of the scrapped ones so if they do not follow the routine of scrapped material it will cause them to be short of material after a while. Then they need to ask for the replenishment of the scrapped pallet to be put into the schedule as early as possible and then order extra pieces. A really bad example of scrapping is the fuel tanks transportation. The fuel tanks are transported long distances and the racks that they are put in are not designed well enough so the tanks are rubbing against each other during transportation and get scratched. The transportation racks are built by Company A itself and right now they are in the process of re-building them. Another scrapping problem example is when pallets disappear. It seems to be no explanation to this. The reason for this can e.g. be that the flags that are on the pallets might be wrong and then the pallet will end up somewhere else in the factory.

A big problem can be that when the assemblers or forklift drivers identify that something is wrong and do nothing about it, not even call the andon person. An example of that is if a forklift driver is missing a pallet and does not find it. The driver should always call the andon person before they get a red signal (meaning high risk of late delivery) but they do not always do that. Usually the andon person finds it fairly quickly so the forklift drivers could prevent problems by calling sooner. It does also sometimes happen, not often though, that the driver does not call the andon person at all. Then when it is noticed at the assembly line the forklift driver might respond to the questions from the andon person that he/she looked for it the day before and did not find it so he/she just skipped it.

The system that delivers materials to the assembly line produces problems itself because it is really complicated. This can e.g. be that things do not turn up on the forklifts drivers' screen, which has the effect that the drivers do not know that they are supposed to deliver certain things. Another problem can be wrong labels on the pallets.

Table 6: Main reasons for missing material at point of use in Company A

Main reasons for missing material
Operators not following the re-packing handbook
Difficulty reading the picking list
Kitting the wrong part number, quantity, etc.
Assemblers picking from the wrong kit
Kitting operators not familiar with the assembly line
Operators mentality e.g. easier to apologize afterwards
Assemblers do not order material in time
Other errors connecting to kits
Other human factors
Long distance between goods receiving and point of use
Material supply system itself produces problems

4.1.8 Seriousness of the problem

It is a common understanding within the entire company that material availability at point of use is seen as a big problem; people higher up in the organization are also looking into this problem. Today, managers at different levels are starting to put more effort to this problem; the managers want the IMC project to work and feel like they cannot keep going by only firefighting. Managers are aware of the seriousness of the problem and that reduction of faults can reduce cost. At the moment there is a lot of focus on the IMC project. All this focus (mainly from the Logistics Department) is because of their interest in seeing how the project works. If it works well, then they want to try to implement it in the whole organization.

The material availability at point of use is important for Company A since it is one of the company´s main KPI. That is why they are following it every day. However the problem with missing material is not considered to be as big by everyone. For example, the direct runners[11] are still not high enough. For people that have been working in the company for many years, i.e. when the direct runners were very low, the direct runners seem to be very high now compared to then. These people have seen the direct runners increase continuously so it is hard for them to understand why it is not considered high enough. It is not good enough to just be doing well when the possibility to do even better is still out there. The fact that not everyone perceives this as a big problem can e.g. be seen in that there

[11] Percentages of how many products go through the process without material deviations vs. all produced products.

are stations that do not follow the routine that is required. It may be because their managers do not make them do it, since they do not see this as a big problem either.

The material availability is really important for the assemblers and because the assemblers are the andon people´s first priority, it is important for them as well. If the andon people need to borrow things from other products then they will do that. Some other parts of the company, like forklift drivers, might not prioritize the assembly line and the reason can be that they have never worked at the line so they do not realize the consequences when the material is late.

Everyone in the plant gets a bonus onto their salaries depending, among other things, on the direct runners. The bonus system depends on the performance of the whole factory so in order to get this bonus everyone needs to do his/her job correctly. This means that delivering material to point of use on time can affect everyone's bonus. However, some people consider this unimportant because even though one group does everything right it does not mean that they will get the bonus since the next group can do a mistake that takes the bonus away. So each group itself might not see the importance that they have on the outcome of the factory.

When comparing the missing parts to the total parts that are delivered every day the percentage is not high. That, on the other hand, does not mean that it is not a big problem. Every time a person has to pick up the phone, because they cannot do their job because of someone else's mistake, is a huge problem and needs to be eliminated.

4.1.9 Delivery precision

Delivery precision at Company A is calculated as the percentage of products that are on time at agreed delivery point and date. They have a KPI that measures how many products get out of the end station unfinished (missing part, wrongly assembled, quality problem, scrapping, etc.). It is measured every day and every week. If the delay of the finished product is large enough it can affect the delivery of the product. However, there are only small percentages of the products delivered late to customers. But of course every product that is not delivered on time is a huge problem. Every week Company A has couple of products delivered late because of missing material. The bigger delays are mostly because of external issues but they do consider themselves to have a really good supplier dispatch precision[12], which is around 98%. This can be shown in the fact that over a two weeks period of time there was almost zero defected products due to external issues. That is not always the case though; there have been times where 60-70 percent of the products have been defected because of external missing material. The reason for that can vary; it can be because of supplier's bankruptcies, bad weather (e.g. snowstorm in central Europe), lack of raw material, strike in France, etc.

It is a common understanding that even though Company A is able to fix some of the material deviations its delivery precision is still not good. One of the reasons is the material availability at point of use, if that was not a problem the assemblers could concentrate on their work instead of focusing on getting material and fixing things after it should have been assembled.

Company A keeps track of the number of missing parts processes that are still in the system. One product might have many missing parts processes in the system. One example of the status of the missing parts in the system is that at one time there were 80 missing parts processes in the system, where the oldest was few weeks, still waiting for material from sub-suppliers, and the newest were

[12] How precise the suppliers are in delivering on time and in correct quantity according to schedule.

put into the system the same day. They therefore do have products waiting on the yard but it depends on the situation how many they can be. At one time there was a supplier that went bankrupt which resulted in over two hundred products waiting for parts on the yard (that number was only at the factory in Sweden, the total number was more when counting other factories as well).

There can also be smaller cases, e.g. once there was a bolt mounted on the product which should not have been there and when that was noticed the group that mounted the bolt did not have the time to fix the problem straight away. In that case the product needed to keep going without the necessary parts being assembled to it because the bolt prevented some of the following processes to be performed. Hence, in the end that product needed a lot of extra work to be done at the adjustment area.

4.1.10 Rescheduling

There is no rescheduling done in Company A when the parts are noticed missing, even though they notice it before it has entered the line. They do though sometimes have to do a “jump out” when the product is missing important materials (that prevents the product from being assembled), where the product is taken out of the schedule. This rescheduling will only happen if they cannot start the production, which is when they are missing a side member, axles or certain cross members. If there is more than one rear axle on the product it is sufficient to have only one ready at point of use to start the production. When those products are then put back into the sequence it needs to be done manually because the system does not know of that demand. Doing a “jump out” is a lot of work and causes a lot of material deviations, which is why it is more common to build an incomplete product to keep the already planned sequence.

4.1.11 Stock accuracy

Stock accuracy at Company A is measured as the percentage of total number of “good” counts vs. total parts counted. A good count is if the count is within the specific tolerance. The stock accuracy at Company A is high, around 98-99%, and most people feel that it is exactly right. With the implementation of the new system it should be more accurate. The current system only takes into consideration the material in the goods receiving and storage. The new system, on the other hand, will take into consideration the line-side stock that has not been taken into consideration before. This is e.g. the stock that is located by the assembly line (like kanban material). There are a lot of “use point” places for the material, i.e. each part has many different storage points at the line. This can, with the current system, have the effect that when many of those storage points are missing material at the same time they will suffer a shortage since the main storage does not have enough in stock to handle the replenishment of them all. However, this will not happen with the new system since it will consider each “use point” for the material from the start so they will have a clearer view of the status and can handle it a lot better.

The material availability issue does not seem to be affected by the stock accuracy; it does happen but not often. Although when it does happen it feels like it happens a lot because it causes so many problems. This is especially the case if there are missing external materials, then they will suffer serious problems since they might have to wait a long time to get the part replenished. Of course they might be able to send the missing material by air but that is also an extra cost that could have been avoided. However, they do have safety stock, which makes it easier for them to keep the material availability at point of use higher. To make sure the stock is accurate Company A has personnel that count some of the inventory every day to see if it is accurate. The stock is also counted yearly as well as when there is a need for it. These personnel will not be needed as much as now when they have started using the new system.

The main reason why Company A has stock accuracy issues is when they do not follow the routine of how they report the scrap. This can be e.g. if it is not labeled correctly or not put in the right place. Then it will affect the stock accuracy. It is also mentioned that the external material controllers do not have the right system to know when to order all the material. What the andon people notice as a problem, stock accuracy wise, is the long pallets storage which holds pallets that are too long for the automated storage. This storage is in their opinion the main source of the faults in terms of stock accuracy since things tend to disappear. They become "missing" in that sense that the flags (marking each pallet) can fall of the pallets, which has the effect that no one knows what is on the pallet. Another reason for the accuracy problem can be affected by manual labor since automation does not make the same faults as manual. An example of the difference between automatic and manual system can be seen with those "missing" pallets in the long pallets storage. There they have manual labor working so the "missing" pallets are not noticed until the material that is on them is needed and then the assemblers are desperately needing the material. The reason for this is that when the people working at the receiving area in the outside area see a pallet that has no flag on it, they might not do anything with it because they believe that it is not their problem. Since the andon people are aware of this problem then when they go out to the area, looking for material, and they see a pallet without a flag, then in 90% of the cases it is the item they are looking for.

4.2 Case B

Company B is a large assembly company in the automotive industry. It both produces some of the parts and does the final assembly. The assembly is performed on three lines and around 300 suppliers supply the lines with different material. The materials for the smaller products are quite similar between models, while the larger products are produced from much more unique parts. Company B assembles approximately 30 products per day and there is a four day lead time, which means one day at the assembly line, two days in WIP or on the yard waiting for missing material, and one day finished or in transition to the stock. There should also not be more than 90 products at the assembly line at a time.

4.2.1 Material planning

Company B uses different material planning methods depending on the type of the parts, but the MRP method is the baseline for the plans because they need to send out schedules depending on the MRP method to suppliers. Sometimes different methods are thenused when ordering, e.g. re-order point, sequenced, kanban, vendor managed inventory (VMI), etc. A decision model for which planning method to use can be seen in Figure 7. Company B single sources[13] almost all of their parts, there is one exception where they use more than one supplier.

[13] There is only one supplier for each part

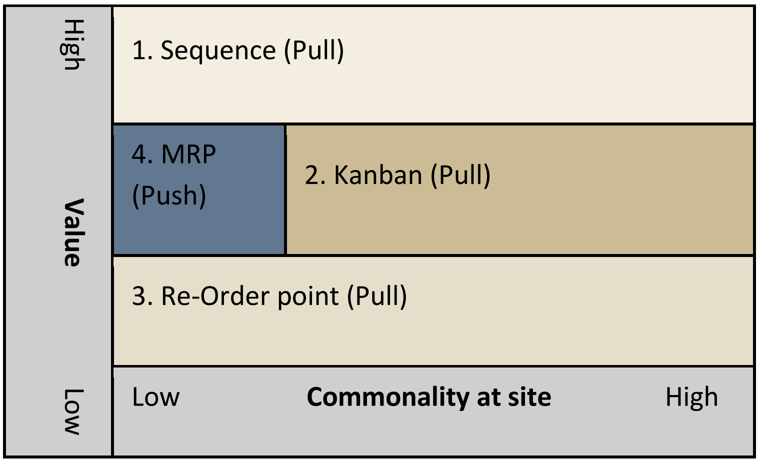

Figure 7: A decision model for planning method. Source Company B

4.2.2 The material supply system

Company B uses many different material supply methods. They keep a large stock of some parts while other parts are supplied directly to the assembly line in a sequence from the supplier. The parts that they keep stock of are then brought to the assembly line in kits, in blue boxes (two bin system), by using kanban or by using VMI where the supplier replenish the stock which is located by the assembly line (the supplier supplies directly to the line). VMI is used for smaller parts like bolts and screws, while kitting is more used for bigger parts. Different material supply methods can be seen in Figure 8 and a decision model that Company B uses to help them to choose a method can be seen in Figure 9. Company B has some safety stock of parts, which depends on the volume value (have an ABC categorizing).

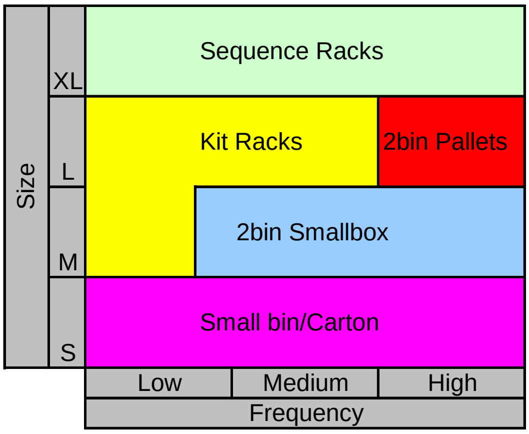

Figure 8: Material supply methods at Company B. Source company B

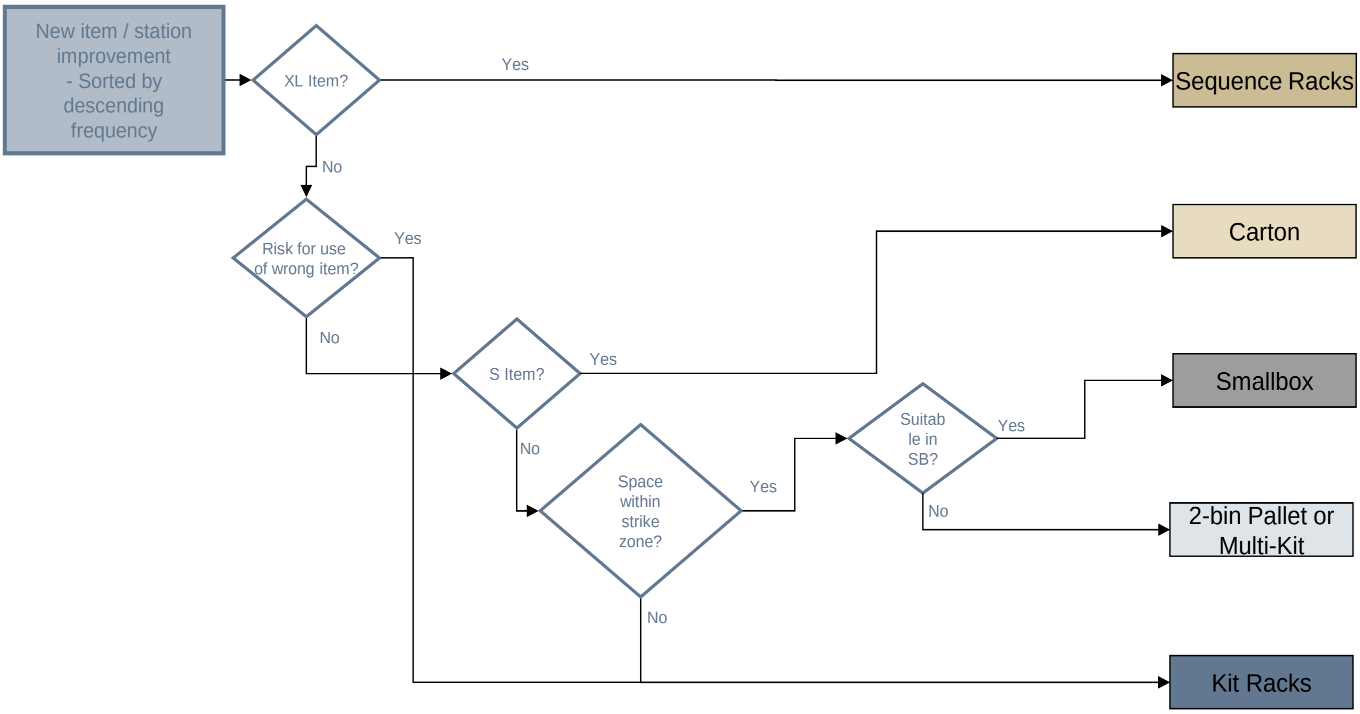

Figure 9: decision model at Company B. Source Company B

4.2.3 Material availability

The material availability at point of use within the factory is calculated as number of products with no shortage compared to all produced products. At the time the interviews were conducted the level was around 70% but it varies every day, can be from 30% up to 80% as it is best. This problem is, however, being worked on and a strategy with the goal of 98% material availability is followed. The material availability can affect the delivery of finished products to customers. Company B measures the delivery precision to customers as products that are not late according to promised delivery date compared to all products and it is normally around 98%. The reason for this high number is that they have small buffers and safety days in the plan, but it can go down to 70% when dealing with serious material issues.

There is a department within the company consisting of material controllers. They check the material availability in advance, i.e. if the material is available in-house. Normally when it can be foreseen that a part that should be assembled soon will be missing, a critical meeting is held with operators, supervisors, material controllers, and some other people depending on what kind of problem it is. On this meeting a decision is taken on what to do, if the production needs to be stopped or if the product can be produced with a shortage. If the product is produced with a shortage, the missing part will be installed at the adjustment area after the line. This is a decision that is taken on the crisis meeting, so it should be no surprise that the product needs to be finished in the adjustment area. However, this does not affect the delivery to customer greatly since it usually does not take that much time and they have safety lead time. In some cases though the missing material cannot be foreseen, e.g. when the stock accuracy is bad, i.e. the computer says that the part should be in stock but in reality it is not. Then it is difficult to foresee the problem and have a meeting in advance.

4.2.4 Rescheduling

If it can be foreseen, before the product goes on the assembly line, that some material will be missing then rescheduling of the plan is sometimes necessary. Company B does not like to change the sequence, but sometimes it needs to be done. Company B measures how often the sequence is changed. Now the schedules are made in the plant in Sweden so the planners can make the plans according to what materials are available and change the plans if it can be foreseen that the materials will not be available in time. This was not the case before when the plans were made by the management in another country and rescheduling was not allowed. Then it happened often that the materials were not available and the products needed to be produced with shortage or even worse; the line needed to be stopped. This means that today the material availability at point of use is much higher and it is much easier to get complete products out off the line, with no shortage of material.

Rescheduling is, however, only possible before the product enters the line. If the product is already on the line when a missing material is realized the product needs to continue with shortage or the line needs to be stopped.

4.2.5 The missing material process

Company B uses an andon system in the factory. There are three logistics andon people working in the factory at each shift. They take care of different assembly lines, including the adjustment area, but they also rotate so they are not working with the same line every day. The assemblers can push yellow, red or blue buttons depending on the problem. The blue button is pushed if material is missing and then the logistics andon person gets a signal to his/her telephone. The logistics andon people only take care of issues when the blue button is pushed, if the yellow or red ones are pushed then the line andon people will come. The signal only tells them on what assembly line the problem is. The logistics andon person goes to that assembly line and looks for an electronic signal (blue light) above the station where the button was pushed and goes there to get information about the problem. The andon person then gets the part number and looks it up in the system to see what is causing the problem. It can e.g. be that the employee that is supposed to order the material has missed an order. Sometimes the material is available in-house but for some reason it has not been delivered to the station, and then the andon person goes and finds the material and brings it to the assembly station. He then turns off the light and register that he has been there and taken care of the problem. If, on the other hand, the material is not in-house it is a big problem and a crisis meeting needs to be held with the material planners, supervisors and assembly andon people. On this meeting it is decided what to do, if the line should be stopped and wait for the material or if the production can continue without the missing part which would be installed later on when it arrives. After the andon person has taken care of the problem he/she turns off the light and register the problem. Other problems than missing material could be e.g. a quality problem, then the Quality Department is called to take care of that.

The takt time in Company B is 40 minutes so the andon person needs to get the material within this takt time; otherwise the product moves to the next station and the problem is marked as a shortage. Sometimes, however, the material is not available in-house and then the material needs to be ordered from supplier and if it can be installed later the product will continue down the line without the missing part. Products that finish the line before the missing part arrives wait for the part outside on the yard. If the part cannot be installed later in the process then the entire line needs to be stopped while waiting for the part from the supplier. Or at least, the products started after the one with the missing part need to be stopped; the ones in front of it can be finished. This means that a lot of assemblers need to stop their work. The Logistics Development Manager took the engines as an example, saying that, when the interview was taken, they had a shortage of engines. The engines are an example of part that cannot be installed later in the process. Consequently, the line stood still, i.e. they had no engines and could therefore not produce anything. The problem of missing engines has been on and off for many years and it is being worked on at the moment by the highest management.

Documentation and root cause analysis

All quality issues and material shortages are documented in a system within the shift. The Logistics Development Manager and his department get mail from the system every day with all shortages from the day before. Every morning there is a meeting where problems within logistics that caused shortages are highlighted. Attendants to this meeting are supervisors from different departments. On the meeting the production the day before is followed up, line stops and material shortage are discussed, and it is decided if a root cause analysis should be started and who is going to be responsible for doing it. The person who is chosen to be responsible for this can be anyone, an operator, an andon person, a supervisor, etc. All problems are categorized into safety related issues, quality related issues, delivery related issues, etc. In order to choose problems to do root cause analysis on a priority list is used. An example of priorities is that root cause analysis is always done on safety issues, repeated problems and if a lot of products are involved or affected. This priority list is used because there are so many deviations every day so the biggest and most serious ones need to be chosen. When root cause analysis is done, the person responsible follows a process called Quick Response Problem Solving (QRPS), which is used to find the root causes and fix the problems; it is e.g. checked if the method has been followed, if it is the right method, or if changes to the method are required. Most often the root cause analysis method 5 whys is used to find the causes of the problems. Company B also uses the problem solving cycle PDCA to improve the processes. In order to get the best information and results from the analysis the people that have the best knowledge about the problem are involved.

Root cause analysis is only done for material problems that are marked as a shortage, i.e. not when the andon person is able to get the material within the takt time so the production is not disrupted. The logistics andon people, however, have a logbook in which they register all the part numbers they are dealing with and should normally also do some analysis to improve the flow and fix what repeats itself to prevent it from happening again, but most often they do not manage to do it because of a high workload.

According to the logistics andon person the production engineers end up working with the root cause analysis in 90-95 % of occurrences, solving the problems, since the problems go back to the prototypes and follow the product in the production.

Company B is most often successful in finding the root causes to the material availability problems and implementing new methods. It is not 100% but a lot of problems have been eliminated and it is much better now than it was before. The Logistic Development Manager, however, states that they are not so good at the follow-up, i.e. following up a new method to see how it is working and if it is being worked after.

Special problems

The changes between shifts have been a problem for Company B because in the shift changes the logistics andon people can get maybe 10-20 calls at the same time; it seems like the assemblers gather many problems together and wait with pushing the blue button until in the end of the shift. This is a big problem since there are only three logistics andon people working in the factory at a time taking care of these problems.

In the mornings, maybe between 7 and 8, there are also more andon calls than usually, so the workload is not so even during the day, it has peaks in the mornings and again in the shifts changes. In a normal day there are maybe 30-40 alarms concerning logistics problems from two of the assembly lines, but in the worst case it could go up to 120 alarms.

4.2.6 The main reasons for missing material

When doing the root cause analysis the causes are analyzed by using the 4M method to see if the cause is connected to method, man, material or machine. Most of the material availability problems are external problems or at least what causes the company to reduce production is most often caused by external things. A list of the most common reasons for missing material at point of use can be seen in Table 7.

The main reasons for the material availability problem to occur are late deliveries from suppliers (like with the engines mentioned earlier) and bad stock accuracy. Suppliers can have a lot of different problems that cause them to deliver late. The stock accuracy is also a big problem, i.e. the system says that the part is in stock but in reality it is not. When doing the root cause analysis, one needs to ask questions like "why is the supplier late?" and "why is the stock accuracy low?", and then lot of other causes appear. The same suppliers are causing problems for Company B over and over again, and also the same part numbers are causing stock accuracy problems over and over again. The Logistics Development Manager says that maybe some new ordering method, like re-order point, should be used for these part numbers to decrease the problems. The stock accuracy is being worked on at the moment, they are trying to fix all the root causes to that problem, so hopefully that will not be as big problem in the future. However, the stock accuracy is also bad because sometimes the operations are not reported in time, like e.g. when material arrives late and it is taken into the assembly faster than it is reported into the system or when the truck driver's computer does not work so he/she does not report the arriving pallet into the system. The logistics andon people often need to work with this kind of problems, to look for the missing pallets and correct it in the system. There is an ongoing project to educate the truck drivers in the system so they should do it right.

These two causes are suggested as the main ones because of how serious they are. Like with the engines, even though they are only missing couple times a month they are the main causes of missing material since it is so serious. However, there are also some smaller parts like hoses missing every day, but because that can most often be fixed they do not categorize that as the main causes.

If the same part is missing over and over again there is a signal that indicates that something is wrong. Then it is most likely that the system is wrong and then the production engineers need to fix it. It can, however, also be that the assemblers are not following the assembly procedure, e.g. using the wrong screw, then the production engineers cannot do anything about that, someone needs to talk to the assemblers and make them realize how important it is to follow the procedures. This has been done by using standardized work, so these problems have been reduced a lot.

Table 7: Main reasons for missing material at point of use in Company B

Main reasons for missing material at point of use
Late delivery from supplier
Bad stock accuracy

The kitting area

The kitting area is not considered as a serious problem since it does not happen that often that wrong parts are kitted. When it happens the feedback goes back to the kitting personnel and they look into it and do a root cause analysis to see why this happened and so on. In the beginning some small problems arose, but now it has all been fixed and the kitting has turned out very well. If problems come up regarding kitting then it is usually because the kitting operator did not follow the procedures and kitted the wrong part; it is seldom that a wrong part arrives to the plant from suppliers. The work instructions are, however, very good with photos showing exactly how the kit should be, so it should be very easy to do.

4.2.7 The seriousness of the problem

It is a common understanding within the company that the problem of missing materials is very serious, it is a big problem for the company since sometimes it is not possible to run the machines according to plan because of missing materials. The Logistics Development Manager thinks that everyone is aware of this problem and how serious it is.

4.3 Case C

Company C is a large assembly company in the automotive industry and its plant in Sweden will be in focus in this thesis. It produces approximately 870 products per day in 6 models. Products are assembled on one assembly line in two shifts five days a week.

4.3.1 Material planning

Company C uses a long term plan that is sent out to the suppliers so they can see what Company C is planning to build for next 300 working days, i.e. 60 weeks. Then within eight weeks it is firmed up a little bit, but not that much, but 48 hours before the parts are to go on the line then the plan is frozen. The plan for the factory is actually frozen 8 days before and what is needed from suppliers is frozen 2 days before. Company C therefore needs to keep a higher safety stock for parts from suppliers located more than two days lead time away. The suppliers also need to have safety stock to be sure to have the parts when company C orders them. After the pressure of the downturn in 2008, Company C has also in-sourced several of the sequenced supplies where no value adding activities were done. Since late 2011 the inventory is in-house at Company C. The utilization of the plant does not allow much space for safety stock so sometimes the safety stock is smaller than the calculated recommended amount and therefore in some cases they need to speed up the transportations of the material or the material needs to be flown in to the plant and products waiting for the material need to be blocked in a buffer before the main line until the material arrives.

Company C only uses single sourcing. From most of those suppliers the parts arrive to Company C once a week, but some come twice a week, every day or even few times a day like is the case for the engines; they arrive three times a day since the safety stock is only 8 hours or one shift. A lot of parts are also transported with a full trailer flow, which means that if the truck is not full it is filled up with material that Company C might need in the near future. This means that Company C might end up with some stock of parts that they are not going to use right away. Company C has racks of smaller parts like screws and bolts that is controlled with a kanban system, i.e. when one box is empty another is ordered.

4.3.2 Material supply system

For internal material supply Company C uses kitting, line stocking and sequenced material. The ambition with the line stocking principle is to have no more than 2 hours of material on the line side. The items that are stocked at the line are mostly small parts like screws, fixings, etc. while the demand for kitting and sequencing comes from the production to enable the assemblers to do their job efficiently. Option specified parts where different options are used for each product are often sequenced, while common parts for every product are more often stocked at the line.

4.3.3 Material availability at point of use

Material availability at point of use is measured at Company C in terms of missing parts, i.e. the number of missing parts. A percentage is not used; it is just reported as a number. There have been a lot of discussions between plants connected to Company C since they document the missing parts on scorecards in different ways (either as a percentage or as number of parts). Company C argues that by using number you actually see the real issues when you look at the scorecard. This, however, is difficult since people do not know how serious it in form of the effect it has on the product, if it is 5 issues out of 50 or if it is 5 issues out of maybe 50.000, it is a lot of difference.

This measurement only takes missing parts, i.e. not parts that are delivered late, parts that are delivered to the assembly line broken, etc. An example of a bad day was when Company C had four missing parts, including one that was not adjusted until at the end of line. These parts, however, did not stop the line; there was a decision made to continue the production and install the missing parts later on. Managers at Company C describe this as a bad day, even though the line was not stopped, because the ambition is zero missing materials so any issue that comes up is big since the logistics should deliver the right parts to the right place on time and they should not have any negative effect on the quality of the product.

Another measurement Company C is using for material availability is late deliveries. It is measured in minutes, i.e. how many minutes the assembly line needs to stop because of late deliveries. The goal is zero minutes lost and reporting root causes and containment actions for issues that cause the line to stop for more than 10 minutes. This is a very ambitious goal compared to the overall issues in production that results in around 600 stop minutes daily on all lines. So it can be seen that the logistics causes just a minor part of the total disturbances. During the same day, as mentioned above, the total disturbances because of logistics were seven; for missed parts, late deliveries, and broken parts all together. It resulted in 15 stop minutes, but the total stop minutes in the factory that day were 624. In these total minutes are also minutes where the feeder lines are stopped because they have filled up the buffers at the end of their lines, but that is not affecting the main line.

4.3.4 The andon concept and the missing material process

Company C is introducing an andon system to their plant. At the moment it is only used at the door-line since that is a pilot project which they are trying out. However, there will be no specific andon people working in Company C, instead the group leaders take care of the andon calls. Their responsibility is to offer support to the assembly line so the products can be built in the right quality at the right time. When a material is missing or something else is wrong and the assemblers cannot build the product they pull a cord at their station and then a light will flash and a melody starts to play. The group leader then sees that there is a problem and goes to the line and tries to solve the problem or takes a decision on what to do. If the product reaches the end of the station before the group leader arrives, the line will stop. The takt time is only one minute and six seconds so the group leader needs to be fast. Because of this it is very important that the group leader is not working with something else that he/she cannot run away from. If the group leader needs to leave for more than a minute then he/she needs to let the production supervisor know so that person can take over. If the group leader decides that it is possible to solve the problem at the next station he/she pulls the cord again and the line continues. In some cases it is not possible to solve the problem at the next station, e.g. if the assemblers at next station build over the problem in that way that the missing part cannot be installed later on, and then the group leader needs to let the line stop while the problem is solved. If the product continues down the line without the missing part then it is documented in a system so it is known that this product cannot be shipped to the yard before this failure is fixed. When a material is missing at the assembly line the group leader calls logistics to get the material. If it is a quality problem he/she also needs to call the Quality Department, but it is logistics that bring new material to the line.

The employees at higher levels think the andon concept is bringing the problems more to the surface. The reason is that now, without the andon concept, the assemblers can fix problems one meter into the next station, while with the andon concept the line is stopped as soon as the products reaches the end of the station. This means that where the andon concept is not used in the factory the small problems that can be solved at the current station or the next one are not documented. Therefore, there are probably more problems than can be seen because they can be solved without stopping the line. By this, the goal of the andon concept is to identify and eliminate problems and should not be seen to stop the production. It gives the opportunity to produce quality and makes the environment supportive to work standardized and avoid disturbances that are negative for the quality. If the issues are not put to the surface then they cannot be solved. But in order for this to work the logistics people need to work fast and help others to solve problems. Company C has started up a project to manage the sequence rack from internal sequence because today there is just one man working there putting out all the extra material in the factory and he does not manage that in one minute (the takt time).

It happens every day that the assembly does not have the material at the right time. This happens e.g. if the system for the forklifts, boxes, or the forklift-free transportation breaks down and the transport therefore becomes late. Although the main line stops it is not necessary for the feeder lines, like the door line where the andon concept is used, to stop immediately because they can build up buffers, but when the buffer is full they need to stop as well.

The stop minutes are the biggest issue for the logistics, each stop minute costs the company a great deal of money. If the stop for one disturbance goes over 10 minutes the managers need to go to the Production Manager and explain why this happened and what caused the plant to stop for more than 10 minutes. Obviously the ambition is to have no stop minutes at all, but if it goes over 10 minutes it is a serious issue. When the line stops the assemblers log in the minutes to a system and categorize it; if it is caused by logistics, production, IT, etc. They then also call the supervisors to inform them about the stop.

Each day there is a report made by the day and the night shift to see the scores from different lines. The current target is that 71% of products are supposed to go down the entire line without any disturbances. For the other 30% explanations for why the disturbances occurred are constantly being asked. With this new system (andon concept) they are not letting the product go until they get proper answers for when the material will be available or the issue is solved. The group leader will therefore ask the production leader what to do and the production leader will then ask the responsible manager where the material is. By documenting all issues and working with them (doing a root cause analysis), regardless of how small they are, this 71% goal can easily be reached and then it can be increased.

There is a morning meeting every day with the whole Supply Chain Department. Supply Chain goes through how many products were assembled the day before, how many stop minutes, how many missing parts, how many end-of-line, how many wrong labeled pallets, etc. Similar meetings are held by other departments in the plant, e.g. the incoming material handling.

4.3.5 Root cause analysis

To solve the problems with material availability, both missing parts and late deliveries, a root cause analysis is performed right away. This is logistics´ biggest problems so the supervisors work a lot with this on the shifts. Today Company C is working with a rather heavy analysis tool that takes a lot of time to work with. It is a tool used for the root cause analysis and for coming up with temporarily and permanent containment actions and to make sure that the correction actions are implemented as well. The analysis starts with the group leaders but since they need to be so much at the line they do not have so much time to do this analysis. To solve this issue the Logistics Project Manager suggests that the group leaders can do a short checklist at the line and mark “ok” or “not ok”. Then the issues that are marked as “not ok” are looked into with the 5 whys method. The analysis then escalates further in the organization with respective managers finishing it. The managers often try to get somebody that was actually involved, like coordinator, to help them with the root cause analysis process. For example, when a material is missing at point of use the Logistics Project Manager does the analysis and finds out what was the problem, if the truck driver was late, if the system broke, if the stock accuracy was bad, etc. The aim is to always try to complete the analysis within one day, which is an industry standard. An important part of the analysis is the 5 whys method. It is used to get people to think deeply, and if they have not completed the 5 whys then they need to explain why they only have filled in e.g. 3 whys. Fishbone diagram is also used when it is needed to go deeper into the problem to understand why it happened. Then DMAIC tool from the Six Sigma philosophy is used to try to solve the issues. Company C has one person with a Six Sigma black belt (sansei) working solely with Six Sigma and kaizen. He tries to find answers to the problems and see if the analysis has been done properly.

The root cause analysis is always done in some form, even though the problem did not result in a long line stop. The rule, however, is that a real root cause analysis must always be done if the line is stopped for more than 5 minutes and also for the three top disturbances in logistics each week. These can be disturbances that cause only short stops but they happen over and over again, then root cause analysis is needed to try to eliminate them. That is why top three disturbances are chosen to work with every week.

The Supply Chain Manager stated that the production does not demand a follow up of a missing material if it did not stop the line because then there is no problem, the logistics has done their job by ensuring that the material is at the line before it is needed to stop the line. The logistics does their own follow up at logistics level for their own understanding and continuous improvements.

The logistics department is successful in fixing the problems when they are caused by themselves, e.g. the forklift driver is late. In those cases a root cause analysis is performed and the managers talk to the personnel causing the problem. If the root cause analysis will not result in a conclusion then a kaizen workshop is started. A kaizen workshop is when a project is started and a detailed investigation of the problem is done by working with DMAIC for about one week. But the problems are often due to poor and unsafe IT tools and then it is more problematic to solve, it needs a support from outside the logistics.

4.3.6 Main reasons for missing materials

There are three big issues connected to material availability at point of use; wrongly labeled parts, missing parts, and late deliveries to the assembly line. When a part is wrongly labeled it means that wrong part is delivered to the assembly line so the right part is missing. When the material is delivered late to the assembly line then it is the sequenced supplier or the forklift driver that is late and that also means that there is missing part at point of use because it is not available when it is needed. This fault is most common when there are new people at work that tend to do some mistakes and prioritize the wrong material and so on. The main reasons for late deliveries, however, are bad stock accuracy or problems at the redistribution center (RDC[14]) that cause them to deliver late to the plant. It is not that often that the forklift drivers are late themselves because they have a slack. Late deliveries can also occur when the IT system breaks down, for example when the line needed to be stopped for 70 minutes because of an IT issue at the supplier for sequenced parts. In this case it was a part that needed to be put on the product on the main line so it affected the whole factory. The feeder lines could continue for some time but once the buffers were filled up, after maybe 10 minutes, they needed to stop as well. In the internal sequence the most common problem is that the part is broken or there is something wrong with the part, but where the material is not sequenced the main reason is probably that the logistics are late to deliver. A list of the most common reasons for missing material at point of use can be seen in Table 8.

Last year the stock was moved from in-house to the RDC approximately 800m away from the company, the stock is still owned by Company C but it is just located at the RDC. Transports from the RDC go to Company C regularly during the day and it has happened that these transportations are late. That is another reason for missing material at the assembly line. This has, however, been worked on and is much better now than it used to be. Before the issues were bigger than today, the transports were late and nobody knew why. Then it was realized that the signal was sent too late to the RDC, so it was a failure in the IT system. This was very bad for the JIT principle that Company C works after since they are always chasing time, they cannot lose 20 minutes because the material is stuck in transportation. Today IT has updated some things in the system so it works better.

It is a common understanding that most of the reasons for missing material are external causes. The managers say they are doing pretty well internally. The biggest issues are wrong labels and things like that from suppliers. It can also happen that wrong labels are put on in-house, but that is not as

[14] Off site manual warehouse run by an external company.

common. Wrong labels are a big issue because it can then cause other issues because the assemblers at the line get confused if this is the right part, the right box, etc. and the line needs to be stopped while figuring out.

If the same cause, like a human mistake, is happening repeatedly the managers need to talk to the person. Then if it happens often they give them a warning because they are not doing what they are told to. If it is some other cause that is happening repeatedly, not a human mistake, then an analysis is done by following a DMAIC process. This analysis is a little bit ambitious and complicated to fill out and it also demands a lot of information as mentioned earlier.

The kitting area

Of course the kitting area can also be a problem sometimes, the operators can kit wrong. They use barcoding when possible i.e. if the parts are barcoded. They also work with pick by voice system and they sometimes have disturbances in that system that causes them a lot of problems. The system itself is good, but when there are some internal issues causing the system to not work the kitting operators have a backup plan. They can, however, do some errors when they switch from using the system over to the backup plan because they need to calculate back from the line and that is a lot of work.

Stock accuracy

Stock deviation is also a big problem because it is often not realized until the product is already on the main line. The computer system may say that one piece of a certain part should be in stock but in reality it is not because somebody has taken the part without reporting it to the system. This is a big problem for all departments.

Table 8: Main reasons for missing material at point of use in Company C.

Main reasons for missing material at point of use
Wrongly labeled parts from suppliers
Late delivery from sequenced supplier
Late delivery from the forklift driver because of bad stock accuracy
Broken parts delivered to the assembly line
Late delivery from the RDC
Disturbances in the pick-to-voice system
Stock deviation

4.3.7 Seriousness of the problem

The Supply Chain Manager sees the problem with material availability at point of use as very serious since his department's job is to support and enable internal material handling to be able to deliver material to the line on time. So if there is any missing material then they have failed what they are supposed to do. The focus in the plant is extremely high and everybody in the company looks at this as a serious problem and knows that if the line stops more than 10 minutes they need to go and report it to the Production Manager.

4.3.8 Rescheduling

If the product is already on the main line when it is realized that a material is going to be missing, like e.g. sequenced material that is just ordered a short time before it is needed, nothing can be done to prevent a line stop except if a decision is made to continue building the product without the missing part and then install it later on. However, if the product has not reached the main line when it is realized that some part is missing, which is most likely a batched item, then the product can be blocked which means that it is taken out of the sequence and other products are taken ahead of it. This most often happens after the body shop or after the paint shop, so the product has already gone through these steps and just waits in a buffer to get on the main line.

4.3.9 Almost finished products

It is rare that a product is put on the yard after assembly to wait for a missing material; it has only happened once or twice last two years. Instead they are put on the side at end of line before they finish the line while waiting for the material, which usually does not take that much time. However, around 80 products are waiting on the yard because of some production errors. This amount has though decreased a lot as some years ago there were hundreds or even thousands of products on the yard. This decrease is very good since every time somebody touches the product or goes into it the likelihood of damaging it increases, so the extra handling afterwards can increase the risk. The target today is to have less than 50 products on the yard.

The products that are put on the side at end of line waiting for some missing material do usually not affect the delivery of the product since it is fixed fast, as soon as the material arrives. There is a lot of pressure to get the products out in time. This is one of the ambitions with the andon concept, to reduce the products in the repair area, to solve the issues straight away on the station rather than letting it go and let it end up in the repair area or on the yard.

5 Analysis

In this chapter the theoretical framework is applied to the empirical findings to see how the situation today at the case companies tie in with the theory about these subjects. In section 5.1 different measurements for material availability are analyzed and in section 5.2 it is looked at how serious the case companies see this problem. Different ways of planning the material are analyzed in section 5.3 and different material supply systems are analyzed in section 5.4. Root cause analysis is then analyzed in section 5.5 and process improvements in section 5.6. Finally in section 5.7 the findings are put into the analytical framework to see if the case companies have the main characteristics in place.

5.1 Measurement of material availability at point of use

As stated by Todd, et al. (2004) the material availability at point of use should be measured as the probability of the material being available when it is needed. However, this can be looked at from many different perspectives as can be seen in the empirical part of this report where the case companies do not use the same definition to measure the material availability. Company A measures this as a number of products with no deviation compared to the total number of products produced. Company B uses similar measurement as Company A with the difference that the machines are only considered with deviation if the problem cannot be fixed within the takt time. This means that Company A are much stricter when measuring the material availability since they consider all products, for which the material is not available when it should be assembled, that have a deviation; it does not matter if it can be fixed within the takt time or not. Company C, on the other hand, has two measurements for material availability at point of use. First it measures the number of missing parts. For people outside the company this measure does not say much about the seriousness of the problem since they do not have the comparison, i.e. out of how many parts the missing parts are. But as managers at Company C pointed out each missing part becomes more obvious for people in-house since you can actually see them on the information board. This also means that if the same car has two missing parts it is measured as two deviations, while in the other companies it would only be measured as one deviation in the material availability measurement. Then Company C also measures late deliveries (it is not counted in the missing parts measurement). Late deliveries are measured in terms of stop minutes, i.e. how many minutes the assembly line needs to stop because of a late delivery of material. Because of these differences in the measurements it is hard to compare the companies' performance to each other.

5.2 Seriousness of the problem

As written in the theoretical framework Cohen & Lee (1988) emphasize how important the material availability is because it affects the production lead times, i.e. material shortage can lead to delays in production which can then lead to delayed delivery to customers. It can be seen from the empirical findings that all the companies agree with this and perceive this problem as serious. People at all levels in the companies are aware of this problem and the importance of preventing the failures. They realize that it can save a lot of time if the number of failures can be reduced. Company C makes the importance of material availability at point of use obvious for everyone by letting them report to the Production Manager if the line needs to stop for more than 10 minutes. However, there are always some people in the case companies that do not see the importance in this. It can be because they look at the material availability problem as owned by the logistics department and they should be the ones looking into it. Some people that have not worked at the assembly line do not realize how important it is for the assembly that the material is available on time.

It seems to be a common understanding between the companies that even though the number of missing parts is not so high compared to all parts used, every fault is a big problem since then something has gone wrong, which should not have happened.

5.3 Material planning

According to Wilson (1992) it is really important to plan the assembly process well since a good assembly process can reduce assembly time, raise quality and reliability, allow greater flexibility, and reduce capital cost. One part of this planning is the material planning, which is according to Jonsson & Mattson (2009) to define, for every product, the quantity needed and the point in time when it is needed in order to satisfy the requirements. All the case companies are planning the deliveries of the materials by defining the quantities needed and when they are needed. This needs to be done in a cost efficient way, since that is the overall objective according to Das & Bhambri (1994) and they mention that it can be achieved by redesigning the process and improving suppliers' relationships and thereby reduce the buffers that were traditionally between suppliers and buyers. This is the case at all of the case companies since they do not keep a lot of material in stock, but rather send a schedule to the suppliers so they can deliver just when the material is needed. According to Jonsson & Mattson (2009) the most important thing is not just to plan the amount needed, but also the point in time when it is needed since late deliveries may cause shortages and too early deliveries cause extra inventory. They also emphasize on how important it is to plan the synchronization in a good way, i.e. so parts that are going to be assembled together arrive at similar time. Since all of the studied companies are companies with the demand for the parts being dependent on the demand for the end product, synchronization is very important. It seems like they are all thinking about that, i.e. ordering material so that parts that are going to be assembled together are all available at the same time. This is e.g. done by using kits that contain all parts for certain product.

All the case companies use a combination of material planning methods in order to plan the material so the production will not be disrupted and the associated inventory costs are minimized, which is, according to Das & Bhambri (1994), the goal with all material planning methods. They all seem to have close relationships with their main suppliers and it seems like they are having some kind of VMI, i.e. the suppliers replenish the stock (or sequenced material) according to the production schedules they get from the companies.

Company A uses re-order point system for the most important parts. According to Jonsson & Mattson (2009) re-order point system is a system that compares the stock on hand with a reference volume (re-order point). When the stock on hand is lower than the reference volume an order is made, but otherwise not. According to Jonsson & Mattson (2009) re-order point method is best suited for finished goods stock, low value items, items that usage cannot be planned, with frequent and continuous demand, small order sizes and short lead times. Company A might be using this method for the most important parts so they always have a small stock of these items to secure against shortage.

Company B uses MRP as the base for all material planning since they use MRP to make the schedules they send out to suppliers. This matches with how Jacobs, et al. (2011) describe MRP by saying that the main objective of it is to provide the right part at the right time so that schedules for completed products are met. Company B then sometimes uses other methods when ordering, e.g. re-order point, sequenced, kanban, VMI, etc. By using different methods depending on the characteristics of the parts Company B is securing material availability at point of use since different planning methods are best suited for different products and environments.

Since the frozen plan at Company C is only two days, they need to keep stock of some parts (when the suppliers are located more than two days away) so the suppliers are not completely able to replenish the stock for all materials by themselves. Company C then uses kanban system for replenishment of the small parts like screws and bolts. By keeping stock of the parts from suppliers located far away Company C is securing material availability at point of use. According to Jonsson & Mattson (2009) Kanban is one type of re-order point systems and is well suited for low value items so using it for small parts like screws and bolts like Company C is doing is good.

5.3.1 Supplier relationship

Alonso et al. (2007) believe that by using multiple suppliers companies are able to increase the flexibility and by doing that securing the material availability. However, none of the case companies uses more than one supplier for their parts. Lee and Billington (1993) then talk about supplier service performance as one factor that affects the material availability at point of use. Of course this is true since in order to have high material availability at point of use the suppliers need to be reliable. Both Company B and Company C consider the suppliers one of the main causes for missing material at point of use, i.e. the suppliers deliver late or wrongly labeled material. The reason why this is seen as one of the main causes can be because of the effects it can have. It can be very serious when the suppliers do not deliver in time, especially when they are located far away and it therefore takes a lot of time to get the missing material. Company A though does not see this as the supplier’s fault, but rather that the material controller has not been on top of things. After the pressure of the downturn in 2008 Company C has also in-sourced several of the sequenced supplies where no value adding activities were done and thereby decreased the number of suppliers they are dealing with. On the other hand, when the issue is internal it should only take few minutes to replenish the part.

According to Graves (1987) it is important to have a good information exchange between the company in focus and the suppliers as well as keeping track of existing material in order to prepare for possible future problems. The information flow between the case companies and their suppliers seems to be pretty good and the suppliers are informed about the schedules and what is needed to be delivered long in advance. These schedules then become more detailed and reliable close before the assembly will take place.

5.3.2 Rescheduling

According to Baudin (2004) it is very important to have all the material available before releasing for production because otherwise the product might need to wait 99% ready in the “final check” area until the missing material arrives. This, in fact, increases production lead time and WIP as well as it complicates the logistics since the same parts need to be delivered to two or more places. The repair work is also done away from the tools, fixtures and instructions so the quality may be reduced. However, waiting with releasing the product to the shop floor until all material is available is not the rule at the case companies. This is because they do not reschedule the plan if a material is known to be missing, except if it is a really important material that will stop the line. At Company A they do a “jump-out” and the product is taken out of the schedule if the production cannot be started because of a missing material. This, however, is a lot of work and causes a lot of deviations so it is more common to build incomplete products to keep the sequence already planned. In Company B rescheduling is sometimes done when it can be foreseen before the product enters the assembly line that the material will not be available. This is however only possible when the product has not entered the line. If the product is already on the assembly line it needs to be produced with shortage or the line needs to be stopped. After Company B started to allow rescheduling the material availability at point of use has increased since they can plan the assembly according to available material. Company C has the same situation, i.e. if the product is already on the main line when it is realized that the material will be missing the line needs to be stopped or the product produced with shortage. This is often the case with sequenced material since it arrives only few hours before it will be installed. On the other hand, if the product has not entered the main line when it is realized then it is taken out of the schedule for that day.

5.4 Material supply system

Companies should have a solid material supply system since, according to Baudin (2002), it is the most important thing in the productivity of the assembly because it makes sure that all parts are available. This can explain why the case companies have very clearly defined guidelines on how to choose which material supply method to use in certain situations. Each company chooses from few material feeding principles to supply the assembly line with parts. According to Johansson and Johansson (2006) it depends on which method fits the company the best which method is chosen. The most common material feeding principles are kitting, batching, sequencing and continuous supply. According to Corakci (2008) even though kitting is the most convenient for mixed-model assembly it is usually not used by itself; it is usually used in a combination with continuous supply, batching and sequencing.

According Hanson (2009), by combining the methods companies are able to gain more advantages than if they would only have one method. However, some advantages of kitting might decrease when combined with other methods. All of the three case companies use a mix of those methods. Company A uses kitting, external sequencing, internal sequencing, pallets, small boxes, two bin system, and continuous supply as their material feeding principles. How they choose between them depends on the size of the part and the number of variants and to help them to choose they also have a process to follow. Company B uses kitting, sequencing and kanban (continuous supply). Company B also has their guidelines of how they choose the methods and in their case it depends on the size of the part and how frequently they are used (see Figure 8). To help them choose which method a new part should use they also have a process to follow (see Figure 9). Company C uses kitting, line stocking and sequencing as their material feeding principles. Small parts and more common ones are often stocked at the line while option specific parts are usually fed with the sequencing method.

When companies combine methods they are able to achieve a more efficient part presentation. According to Hanson (2009) the part presentation at the assembly line and how much packaging is left for the assembler to take off are important factors when considering material supply system. The material should be, according to Baudin (2002), presented to the assembler unpacked, within arm´s reach and oriented for easy installation. This is one of the reasons why the case companies have combined the material feeding methods. According to Hanson (2009) companies should choose the material supply system dependent on the physical characteristics of the parts which is what the case companies are doing. All three case companies are basing their decision on the size of the part. Another thing that Hanson (2009) mentions as a decision factor is how many different product variants the company has as well as how many different part variants each product has. Company A and Company C consider this when they choose the material feeding method. By having the smallest and most common parts, e.g. bolts, screws, located at the assembly line but the larger and more customized ones with kitting and sequencing they are able to achieve more efficient part presentation. The assemblers are not wasting time looking for parts and having to walk around the assembly line when fetching them. By having the parts located in kits or in one piece sequenced flow the parts can be located very close to the assemblers and in as little packaging as possible to deliver in. In order to save the most time for the assembler, according to Wänström & Medbo (2009), is to have the parts in smaller batches since then more parts can be stored close to the assemblers and less time is spent looking for the items. This is what the case companies are achieving by using blue boxes. The parts are repacked from the original packaging into blue boxes to achieve the space efficiency at the assembly line.

5.4.1 Missing material caused by the kitting area

Kitting is, according to Hanson (2009), very convenient in mixed-model assembly, which is the case in all the three cases in this report. Kitting reduces, according to Cheldelin & Ishii (2004), the risk of errors in the mixed-model assembly since it does not require the assemblers to make decisions when assembling. Kits are only prepared when they are needed which is a JIT approach. Because of this it is really important that the kits are made right first time; otherwise it can delay the assembly. According to Caputo & Pelagagge (2011) it can have a great effect if the kits are not delivered in the correct manner e.g. wrong parts, missing parts, damaged parts. In Case A it is mentioned that, because of how short takt time the assembly has, picking errors can have serious effects. This is because if the operators do a mistake when they are preparing the kits for the assembly line the assembly can suffer a lot of disturbances since the assemblers only have nine minutes to assemble the parts.

According to Ronen (1992) it is strongly recommended to not send the kits to the assembly line if they are not fully prepared. This was mentioned in Case A where it was noted that some kitting operators feel like it is better to apologize to the group leader afterwards rather than ask the forklift driver to wait or ask for help. Ronen (1992) mentions that if kits are not fully completed it will cause WIP were products need to wait for the remaining parts to arrive. The WIP can be seen in Case A as there are often products waiting in the yard for parts that are missing. This also causes extra handling since the parts that were not kitted need to be delivered separately to the line and might need extra work when assembling. This, according to Ronen (1992), causes increased lead time, increased cost (holding cost, scrap, extra work, etc.) as well as the quality can be decreased.

There are many mistakes that can be done in kitting. According to Brynzér & Johansson (1995) it can be that components are located in the wrong kitting wagon, the wrong part is picked (e.g. because kitting operators get disturbed), operators use experience rather than looking at the list, operators read the list wrong e.g. read the part number for one item but the amount for the next one, etc. All of these errors (and more) were mentioned in Case A as examples of what can go wrong in their kitting area. For Case A the kitting area was the greatest source of mistakes and has been since they started kitting. In Case A it was mentioned that the reason for many of the mistakes is that humans are working on it. They tend to go on autopilot, can be stressed, ergonomics can be bad, operators can be distracted because of chatting, etc. Even though operators might be the ones doing most of the mistakes e.g. by not reading the picking list, because they feel they have good enough knowledge, the picking lists themselves might cause problems because they are not clear enough. This has been the case for Company A, which is why they have started cleaning the picking lists and it has had the effect that a lot of errors have disappeared. In Case A it was mentioned that it is not always the kitting operators that do the mistakes; it can also be that the assemblers assemble part from the wrong kit.

It is a common understanding among all the case companies that some people do more mistakes than others. Then there is a need to talk to the respective people and try to solve the problem. In Company A they are trying to do the work as easy as possible to do right in order to reduce the human errors. To do that they use standard operating procedures to make it difficult to do mistakes. If the operators are not following these procedures then it is necessary to talk to the operators to show them the importance in following them. If this is not enough, the production leader is called to talk to the operator. If that does not fix the problem the operator is sometimes moved to another station that fits him/her better. In Company C the managers also talk to the operators that are causing the same mistakes repeatedly. If the problem continues the operators get a warning because they are not doing what they are told to do.

Decreasing the human errors

Cheldeling & Ishii (2004) mention a so called “shadowbox” were each part has a well defined spot in the kitting wagon. Hanson (2009) also mention that mixed-model assembly often uses customized kitting wagons to help the kitting operators and the assemblers even more to decrease the risk of assembling and kitting the wrong parts. However, this does decrease the flexibility, which is also important in mixed-model assembly. This can be seen in Case A where they have, for some kits, special places for each part e.g. the kit wagon that holds the petals for the product have a special design so that you cannot put two right petals or two left. Having a well defined kitting station with photos showing exactly how the kit should look like, like in Case B, makes it easy for the kitting operators to kit correctly. In Case A they have also made a repacking handbook in order to make the kitting more standardized and flawless. However, not everyone follows it which has caused mistakes.

There are further ways that can be done to decrease the human factor in kitting. Hanson (2009) mentions the pick-to-light system that can replace the picking list completely and increase the productivity of the operators. The pick-to-light system is being implemented in Case A in order to fix the human mistakes that is done in kitting. Dallari, et al. (2009) mention the pick-to-voice system, which can have the same effect as the pick-to-light system. The pick-to-voice system is used in company C. They say that there are not many mistakes done in the kitting area, but when it happens it is usually when the pick-to-voice system breaks down and they need to turn to plan B. According to Brynzér & Johansson (1995) these systems, however, are expensive and can create idle time, especially pick-to-light since operators might need to wait in queue. Brynzér & Johansson (1995) mention that barcoding can also decrease the mistakes done in kitting. However, barcoding is only used by Company C and only for the parts that already have barcodes on them.

5.4.2 Inventory

According to Finnsgård (2009), Giust (1993) and Hanson (2009) it depends on the necessity of the inventory if it is considered a waste or not. Inventory can be necessary in order to keep high availability and to be responsive to changing demand but it can also decrease the quality if it is too much. It is therefore up to the company to define what kind of inventory is needed and how much.

Guide & Srivastava (2000) also mention that buffers are often necessary to handle uncertainties in the production. According to Hales & Andersen (2001) companies, especially companies with customized products, need to have high flexibility and speed in production as well as capacity in supply, production, transportation and distribution in order to respond to changing demand. Since the three case companies all have customized production this should be very important to them and they need to choose a material supply system that supports the flexibility that the company needs. Alonso, et al. (2007) state keeping safety stock can increase the flexibility and therefore secure the material availability. Cohen & Lee (1988) also say that safety stocks of material are necessary to prevent material shortage. All three case companies are keeping some safety stock to secure the material availability. It does though depend for which part safety stock is kept e.g. Company B uses ABC categorizing in order to decide which parts to keep safety stock for. Company C depend their safety stock on the lead time and frequency of the suppliers´ deliveries.

The three case companies all believe that having high stock accuracy is very important. If the stock is not accurate enough it can be very serious since these problems do not appear until shortly before the material is needed in the assembly. If the stock is not accurate it can cause a lot of deviations like line stoppage. This is especially the case if there is any inaccuracy in the stock for parts that take long time to replenish and sensitive parts that will cause the line to stop because the production cannot be completed without the part, as happens sometimes in Case B. Case B has though some safety days (safety lead time) in the plan and therefore it does not affect the delivery to customers that much when a shortage occur. Safety lead time is according to Guide & Srivastava (2000) a way of coming up against uncertainties in timing e.g. delivery time from the supplier. Case A has planned the inventory in the way that all sensitive parts are stocked in-house so it will not take long time to reach it if it is missing at point of use. Other parts might be stocked at a warehouse located some distance away from the factory. In case C they have buffers at certain places before the main line where they can keep products that they know will stop the line if they keep going because there are parts missing for the product. There are not many places but it offers them the opportunity to prevent the line from stopping. The stock accuracy does, however, not seem to be as big problem at Company A as it is in the other companies, of course it happens but not that often. The main cause for the stock accuracy problems seems not to be an error in the system, it is rather that not all transactions are reported in the system, e.g. when parts are scrapped or a newly received part is taken into production before it is reported into the system.

5.5 Root cause analysis

According to Wilson, et al. (1993) root causes of problems are always negative. This shows the importance for companies to find the real reason for the problem and to eliminate it to ensure the quality of the organization. The aim with root cause analysis is to find the long term solution to the problem and according to Toyota (2006) it is very important to ensure the quality as well as to solve problems, even if it takes time. Root cause analysis techniques are designed to identify and solve problems. All three case companies are fully aware of how important it is to find the root cause of the problem and not only do a quick fix. They see that the organization cannot achieve the same quality and potential that they aim for without figuring out the root causes in order to prevent the problems from happening again. However, according to Arnheiter & Greenland (2008) it is not always easy to identify the root causes and it can be easy to mistake them for apparent causes by not going deep enough into the problem. All the companies mention that they most often are able to find a solution that fixes the problem but it still does happen that they are not completely successful e.g. the problem decreases but is not completely eliminated.

According to Wilson, et al. (1993) the root cause analysis can both be used to prevent problems from happening again and to identify potential problems, i.e. it can be used both reactive and proactive. All three case companies work reactive by trying to figure out the root causes of the problems that occur. They also have, to some degree, a proactive policy in the way that they encourage the people involved to improve the existing system. Fixing the root causes can have many advantages like, according to Wilson, et al. (1993), not having to waste the employees' time to keep solving the same problems or similar problems with the same root cause.

5.5.1 Andon and problem solving

All the case companies are working with the andon concept in some way, which is very good since by using an andon concept the products in the repair area can be reduced by solving the issues straight away on the station. In Case A there are fifteen andon people that work with fixing the logistics problem in the factory. The andon people are called when there is a problem with the material; they are then informed about the problem, i.e. what is wrong, the part number, the product number, etc. They mostly only firefight because they do not have time to do root cause analysis since the area they are in control of is very big and they always need to be available for the assembly line. That has the consequences that they are constantly running errands so if they start on root cause analysis they can get many calls about a problem and need to run right away. The andon person does though log in the problems in details (as much as they can) in order to make it easier for the analyzer to work with the problem (most often the group leaders). The andon person also tries to do some kind of problem solving if it is obvious what is causing the problem. Case B has the same idea of fixing the missing material problem, they have the andon concept but they only have three andon people working in the whole factory and like with Company A they mostly firefight and register the problem. When there is a problem with the material these andon people are not called, like in Case A, instead a button is pushed and they get information in their phones telling them on which assembly line the problem is. They then need to go to that line to get more information about the problem. The difference between Company A and Company B is that with the later one, root cause analysis are not done on the problems that can be fixed within the takt time, which means that many problems could go by without any actions taken to fix the causes of them. However, the andon people are supposed to keep all problems in their book and do some work to improve it but, as in Case A, they have a lot to do so the time to work on preventive activities is limited. With Case B the production engineers are the once that most often end up working with the root cause analysis since it most often is a problem that goes back to the prototypes. Company C states that they do root cause analysis right away to be able to solve the problems and they have the aim to complete the analysis within one day. They are though not that far as the other two in terms of the andon concept. They have group leaders that take care of the problems and support the assembly line. When there is a problem with the material a light start to blink and some melody starts to play, so the group leader goes to the light and gets more information. Because the group leaders do not get the information needed in their phones, it is important for them to be located at or very close to the assembly line, as opposed to the other cases where the andon people do not need to be at the line since they get a phone call or information sent to their phones. The group leaders are the ones that start the root cause analysis but since they need to be constantly available for the line, because of the short takt time, they do not have much time to do it and the managers continue the work.

In order to eliminate the problems Company A has implemented an IMC group in part of the factory that has the same job as the other andon people except they are also doing the root cause analysis, i.e. they are following the problems all the way. They have seen great improvements after the implementation of the project which is believed to be the results from solving the root causes. Company C is also trying new things in order to eliminate the root causes of the problems and that is by implementing the andon concept. This is though only in the beginning stage and now they only have it in part of their factory. For Company C they believe that by implementing the andon system they will be able to bring more problems to the surface (now smaller problems that can be fixed quickly are not documented) and by that have more chance to eliminate them and increase the quality of the organization. They say that then the target for total disturbances can be a lot higher.

According to Wilson, et al. (1993) people that are directly involved with the problem should not be the ones doing the root cause analysis. Hence, it is good that the group leaders, andon people, etc. are doing the root cause analysis since they are not as involved as the kitting operators, forklift drivers, assemblers, etc. This is what they are doing in all the case companies. It can be good to come in with fresh eyes so when the analysis goes to a higher level, e.g. PDCA or DMAIC, then even more cross-functional and fresh minds come together. In Case C it was stated that it might be a lot easier for a person from the outside to look at the problem, but they should work in cooperation with the people that are involved to find a solution. Bhaumick (2010) states the importance of getting the input from the people involved. This can be seen in Case A where they involve the operators in the kaizen projects and in the PDCA process improvement cycles. Company B and Company C also include the people directly involved and believe that it is very important. Fresh eyes as well as analysis that follow prescriptive and well defined process will give impartial solution according to Wilson, et al. (1993) which is what all the case companies do e.g. Company C uses QRPS process to find the root causes and Case A has a predefined questionnaire.

5.5.2 Prioritization

Prioritization is important when there are many problems that need to be worked with. This is the case in all of the case companies. How Company A prioritizes depends on the situation, the seriousness and the pattern of the problems. When the problems have been chosen the group leader investigates it and tries to find the root cause and makes actions to prevent the problem from happening again. Company C also has rules on which problem to do root cause analysis on. They work for example on top three disturbances each week and also the problems that cause longer than five minutes stoppages. In Case B the problems that are going to be worked on as well as the person that should do the analysis (which can be anyone) are chosen on a meeting. They also have priorities for the problems e.g. if there is a safety issue root cause analysis is always done.

5.5.3 Main tools

There are many tools that can be used to do root cause analysis. Company B for example uses the 4M method to see if the cause is connected to method, man, material or machine. According to Finlow-Bates (1998) and Uthiyakumar et al (2010) fishbone diagram and 5 whys are though the main tools. The 5 whys method is used in both at company A and at company C where they ask the question “why” five times in order to reach the root cause. Company C believes that the 5 whys method offers the opportunity to go deeper into the causes. Company A does though mention that after finding a solution it often ends up with a temporarily one. They feel that this method does not go into as much detail as is needed. However, they mention that the 5 whys method offers the opportunity to go to the source where they ask the operators the questions. This is, according to Toyota (2006), what Ohno stressed as being very important, i.e. genchi genbutsu. By this you are able to see the problems for yourself as well as talking to the people that are dealing with it. Company A mentions that by doing this solutions that were not obvious before can be found. This is what the IMC group in Case A is doing, i.e. they are located by the assembly line which gives them the opportunity to constantly receive information about problems and the input from the assemblers. Company B also uses the 5 whys method to help them figuring out the root causes of the problems.

The fishbone diagram is according to, Bergman & Klefsjö (2003), a systematical way of finding root causes of a problem and it is a tool that Company C uses to go deeper into the problem to understand why the problem occur.

5.6 Process improvements

In order to improve the process all the case companies work with some kind of problem solving processes for serious problems that are repeating and need to be eliminated. These processes help them to find the root causes as well as figure out how to solve the problem in the most successful way. The most common processes were mentioned in the theoretical framework of this thesis, i.e. the PDCA cycle and the DMAIC cycle. Company A and Company B use the PDCA process for this purpose, but Company C uses DMAIC.

5.6.1 PDCA

According to Bergman & Klefsjö (2003) and Eklund (2000) the PDCA cycle is a systematical way for solving problems that have repeated patterns and therefore emphasizes continues improvements. Company A uses this process when they want to dig deeper into some causes of material availability problems. This is especially done when they have really big problems. They then form cross functional groups with employees from different departments of the company and brainstorm in order to come up with possible solutions. Bergman & Klefsjö (2003) emphasize that it is important to have groups with people with different background and skills to be able to achieve good brainstorming meetings. Eklund (2000) agrees with this by saying that if the problem solving is only done by specialists the learning will not take place. He also states that all participants should participate in the whole cycle in order to achieve motivation, learning, and improvements.

According to Bergman & Klefsjö (2003) the PDCA is done in four stages; plan, do, check, and act. In the plan stage the problem is analyzed, data collected, and probable causes are identified. In the do stage the improvement steps are started. In the check stage the improvements are checked to see if it was successful. The act stage is where the changes are made permanent. Company A follows all these stages by gathering information, doing root cause analysis, finding solutions that fit all parties, taking some actions, and following them up to see if they have solved the problems. If the problems are not solved they start over with the PDCA process which is according to Bergman & Klefsjö (2003) what is needed to be done. They also state that even though the changes made were successful it is good to go through the cycle again because the process it could maybe be improved even more and also to gain more experience and learning from the process.

5.6.2 DMAIC

DMAIC is used, according to Snee (2004), to improve the current process. This process is similar to the PDCA process and is used to identify root causes of a problem and find possible solutions. This is exactly what Company C is doing; they use DMAIC to try to find solutions to problems. The DMAIC process has five stages: define, measure, analyze, improve, and control. In the define stage the project to work on in chosen; the problem and the process are defined. In the measure phase it is ensured that the process chosen is measureable and truly in need for improvements. The analyze stage is where the root causes are identified. Changes are done to the process in the improve stage in order to improve the process. Finally in the control stage a system is installed that ensures a sustainability of the performance.

Bergman & Klefsjö (2003) state that educated and trained people in improvements are needed in order to make the DMAIC process successful. In Company C there is one employee that has the black belt in six sigma and kaizen that looks after if the analysis has been done properly. The DMAIC process is often done in a kaizen workshop at Company C, and then they work with the problem for maybe one week.

5.7 Analytical framework

After looking at the three case companies and investigating how they are working with the material availability at point of use the information from each company can be put into the analytical framework.

Table 9: The analytical framework applied on the cases

	Characteristics	Company A	Company B	Company C
Material Planning	Appropriate material planning methods used	X	X	X
	Synchronized plans	X	X	X
	Multiple suppliers			
	Good interaction with suppliers	X	X	X
	High supplier reliability	X		
	Rescheduling to ensure that material will be available before releasing to production		X	X
Material Supply System	Appropriate material supply system used	X	X	X
	Support for picking			X
	Appropriate safety stock	X	X	X
Root Cause Analysis	Root Cause Analysis performed with appropriate tools	X	X	X
	Person not directly involved does the analysis	X	X	X
	Input from directly involved people	X	X	X
Process Improvement	Process Improvement tools used	X	X	X

6 Discussion and conclusions

In this chapter the findings are discussed further. It begins with some introduction in Section 6.1 where it is discussed how material availability at point of use can be increased by using proactive actions. The research questions are then answered in sections 6.2 to 6.4*. In section 6.5 additional findings are discussed. Finally some future research is brought up in section 6.6.*

6.1 Proactive actions in increasing the material availability at point of use

It is very important to have high material availability at point of use since if there were no problems the assemblers could concentrate on their work instead of having to focus on getting material and repairing things after it should be assembled.

It has been showed in this thesis that the four most important things for ensuring high material availability at point of use are material planning, material supply system, root cause analysis and process improvements. These things all affect the material availability at point of use since if the material planning and material supply system is controlled in a good way and the root cause analysis and improvements of the processes are done, the material availability at point of use can be increased.

In order for this all to work as planned everyone at the company needs to see the seriousness of the problem and be willing to make the actions needed. At Company A it sometimes happens that the assemblers do not care about this because their managers do not see the importance of material availability at point of use. They look at this problem as something that just the logistics department should be working on with no help from other departments. The assemblers take this attitude from their managers, and the result is that they do not follow the routines. The managers and the assemblers need to see the importance in sending the product from their station in time and for that to be possible they need to receive the material in time. Managers should feel the need in; getting the right material on time, measuring the material availability on time, measuring if they have the right staff with the right competence, having the tools and equipment working properly, etc. They should also realize that if this is not fulfilled they will have problems with sending the product in the required condition. This is why the way people are thinking about their stations needs to change, and to turn their stations into processes. Managers need to realize that they should be working more proactive, especially with material availability issues, so they can assure deliveries on right time and in right condition. It can also be that some people in the factory, e.g. forklift drivers and kitting operators, have never worked at the assembly line so they do not see the importance in having high material availability. This needs then to be introduced to them to show them how important this is.

To summarize, in order for companies to be more proactive in increasing the material availability at point of use they need to have good material planning as well as good material supply system within the plant. When a problem with the material availability occurs they also need to do root cause analysis and improve the process in order to prevent the problem from reoccurring.

6.2 How material planning affects the material availability at point of use

It has been showed in this thesis that a good material planning is a prerequisite for high material availability at point of use since without a good material planning it is difficult to ensure that the parts will arrive to the plant in time. It is important to use appropriate planning methods to plan the material depending on the characteristics of the parts and the demand for them. This needs to be done both in quantity and time in order to meet the requirements. It is also very important to use synchronized planning, especially for companies where more than one part needs to be assembled at the same time. This is important since if the parts, that are supposed to be assembled at the same time, will not arrive at the same time it will have the effect that the part that has arrived needs to wait for the other one. This might also cause the line to stop. As has been showed in the study this can be achieved by using sequenced deliveries from suppliers which all the case companies use. All the case companies have good interactions with their suppliers by sending the schedules to them and informing them of all changes. However, an interesting finding was that none of the case companies uses multiple suppliers for their parts. It has been showed that using multiple suppliers might increase the material availability at point of use because of the possibility to order from another supplier when it can be foreseen that the main supplier will not be able to deliver in time. Having only one supplier for each part, however, can have the effects that closer relationships with the suppliers will evolve which can result in more trust and better deals. This means that companies can achieve the same benefits, and even more, by having a good relationship with this one supplier instead of having multiple suppliers. Therefore a precise evaluation needs to be done when choosing to use single or multiple sourcing strategies.

The supplier reliability is important since it has direct effects on the material availability at point of use, i.e. if the supplier cannot deliver in time the material will not be available at point of use when needed. As mentioned before, Company B and Company C do both have some problems with the suppliers in the sense that they sometimes deliver late. Company A does not have as much problem with this, but when it happens some people feel that it is rather that the material controllers have not been on top of things, they might have thought that they had more parts in stock than they had in reality. This is an interesting finding and could be interesting to investigate this more to see what it is that is causing the material controllers to not be on top of things. It can be that they are lacking some procedures to work after when checking what material needs to be ordered or even that the system they are using is not detailed enough.

In order to have high material availability at point of use rescheduling might be important when it can be foreseen that the material will not be available in time. This means that companies could take that product out of the sequence and rather assemble the products that do not have any missing parts. Even though this can increase the material availability at point of use, it can have negative effects on the delivery to customers since the products can be ready too late if they are not started until all materials are available.

To summarize, material planning is very important for the material availability at point of use. It is important to use appropriate material planning methods depending on the parts as well as synchronizing the plans. The material availability can also be increased by using high reliable suppliers and have good interaction with them. Multiple suppliers can also help since then the material can be ordered from another supplier when the main one cannot deliver in time. Finally in order to increase the material availability at point of use rescheduling of plans can be necessary.

6.3 How material supply system affects the material availability at point of use

It has been showed that the material supply system can have great effects on the material availability at point of use. This is because if the system that supplies the assembly line with parts is not efficient and has flaws in it, it will have negative effect on the assembly line´s productivity. Therefore it is important to secure that all sections of the supply system are working as good as possible in order to ensure that material is available at point of use when it is needed. This is done with different material feeding options where the most common ones are kitting, sequencing and continuous supply. Which one of them is best fitting depends on each company, e.g. physical characteristics of the parts, space at the line. But usually it seems to be most efficient to combine the methods to achieve the greatest advantages. Kitting has proved to be the best method for mixed-model assembly but is usually used with the combination of the other methods.

The importance of having a completed kit going to the assembly line cannot be stated enough. When the kit is sent to the assembly unfinished (wrongly kitted, missing parts etc.) it will cause a lot of extra work that would be unnecessary if it had been done in the right way from the beginning. It also increases WIP since the product might have to wait for the parts that were missing in the kits further down the line. The kitting operators should see the importance in sending away fully completed kits. Operators need to feel comfortable enough in asking for help to finish the kits, double checking their work, asking the forklift drivers to wait while finishing the kit, etc. An example of this is that in Company A the operators seem to be more comfortable with apologizing to the group leader that comes to investigate the wrongly kitted kit instead of simply asking the fork lift driver to wait while he/she finishes the kit. The operators need to get more ownership of their work so that they feel proud of their work and want to send it away in a perfect condition. One way could be to decrease the number of people in each group so that it will increase the teambuilding.

The kitting area has been found to be the cause of many mistakes because of different reasons. The human factor is for example the cause of many problems. This can especially be in terms of the picking list. Many operators are neglecting the picking list because they think they know the work too well to have to go after the list or they might go on auto pilot since they are doing the same thing over and over again. Companies can decrease this human factor by replacing the picking list with a system like pick-to-light or pick-to-voice. With this system the operators only need to follow the system that gives a signal about what part to pick, which gives them more support in kitting. Company A is about to implement the pick-to-light system and they believe that the deviations in the kitting area will be decrease a lot and that is definitely a possibility since the system decreases the human factor drastically. The pick-to-voice and pick-to-light are not the only things that can decrease the human factor. Options like “shadowbox” and barcoding can decrease the human factor as well. They might not have the same effect as the picking systems but they do support the operator in picking the right products.

The kitting area does not have to be a big problem for all companies. This was found out in the case studies where Companies B and C did not seem to have as much problem with the kitting area as Company A. The reason can be that Company C already has the pick-to-voice system that eliminates, for the most part, the human factor in the kitting area. The reason why Company B does not consider the kitting area as much of a problem as for example the suppliers can be because they do not note down the mistakes except if it causes the line to stop. Since they have a takt time of 40 minutes they are able to fix most in-house problems before they stop the line.

The transportation can have a great effect on the quality of the product and companies need to have a system and equipment that secure the products so that they do not get scratched in transportation. It can cost a lot if the items need to be scrapped if it is only because of bad equipment. This is an example where the employees can come with input on how they see that the quality can be increased as well as coming with ideas about how the equipment should be designed in order to better support their work.

Keeping safety stock can be very helpful in order to make sure that the material will be available when needed at point of use since it prevents material shortage. Some inventory is known to increase the availability and responsiveness to changing demand. However, there needs to be a careful consideration to how much inventory is necessary since too much of it can decrease the quality of the production. The most important thing concerning the inventory is to have the information about the stock level accurate. Inaccuracy in the stock level can lead to considerable amount of delays in production. This is especially the case if the supplier of the missing material is located far away so the lead time for it is long. That is why all companies need to have an inventory system that provides the accuracy that the company needs. This inventory system needs to take into consideration all inventory located at different places in the factory. This can be seen in Company A since the current inventory system only considers the stock in the warehouse and therefore shows high accuracy levels. But in reality if they would include all stock areas, e.g. line stock and the stock in the kitting area, then the accuracy level would be a lot lower.

To summarize, the most important thing with material supply system in order to secure high material availability at point of use is to pick the right material feeding method (or combinations of methods) that fits the company and decrease the human factor of mistakes by training people or using picking systems that supports the picking operators. Having a good and accurate inventory system and keeping some level of safety stock is also important to be able to achieve high material availability at point of use. All these things show that having a good material supply system as well as managing it right is very important in order to achieve high material availability at point of use.

6.4 How root cause analysis and process improvement activities affect the material availability at point of use

It has been showed in this thesis that root cause analysis and process improvements activities are very important in order to increase the material availability at point of use. This is true because if the root causes of the problems are not identified then the problems cannot be eliminated and will reoccur. It has the result that extra time is wasted in fixing similar problems.

When problems with material availability at point of use come up it is very important to log them into a database. This database can then be useful to find patterns and see which problems are reoccurring. By this, the prioritization of problems to do root cause analysis on becomes more efficient since it can be seen which problems are most common as well as which are the most serious ones. If not all problems are logged in it cannot be seen how great of a problem some issues are. This can be the case when it takes short time to fix the problem and the one fixing the problem does not see the point in logging it in when the problem is already fixed. This means that these “small” problems will be forgotten and because they are not eliminated they keep coming up again and again. This is bad because even though the problems are not affecting the line it is still causing extra cost e.g. in terms of having people running errands picking up the missing material.

It is also very important that everybody is using the same system and has a good knowledge of that system. In Case A, two different systems are used to log in the material availability problems, one for the group leaders and another for the adjustment area. This increases the workload for the people logging the problems and is doomed to increase confusion. A much better way would be to use the same system for both the group leaders and the adjustment area. Of course different systems may have different functionalities, but it should be worth trying to find one that suits everybody or maybe even create one.

When doing the root cause analysis it is important to choose the right problems to work on, i.e. the problems that are causing the most serious effects and problems that are most common even though they do not have so serious effects. In Case B root cause analysis is only done for problems that cause the product to be continued to next station with a shortage causes the line to stop, i.e. not the problems that can be fixed within the takt time. Since the takt time in Company B is so long (40 minutes) there are a lot of problems that can be fixed without stopping the line or pushing the product down the line with a shortage. If root cause analysis is not done on these problems they will continue. This can be the reason why Company B considers most of their material availability problems to be external, i.e. because the internal ones might be fixable within the 40 minutes takt time and are therefore not considered serious.

Root cause analysis methods are important in order to do the analysis in a structured way to not forget anything. The most common methods used are the 5 whys method and the fishbone diagram method. The root cause analysis, however, is not enough by itself. The analysis must be followed up by improving the process in order to eliminate the problems. There is no point in finding the root causes if they are not used to eliminate the problem. There are methods that can help with doing the process improvements, e.g. PDCA and DMAIC cycles, are useful. In these methods the root causes are identified and solutions to fix them and improve the process introduced.

It is very important to let people not directly involved with the process do the root cause analysis and process improvements since fresh eyes can see other things than the people directly involved with the process, i.e. they may spot some issues that the people directly involved could not see. However, it is very important to involve people that are working with the process. This is important because they are the ones that know the process the best since they work with it every day.

To summarize, the most important things connected to root cause analysis and process improvements that can affect the material availability at point of use are to document all problems, use one good system for documenting, choose the right problems to work on, use appropriate methods and involve both people directly involved with the process and people not directly involved. All these things can increase the material availability as well as not having a good management of these things is likely to result in lower material availability at point of use.

6.5 Additional findings

Apart from the four important factors that have been discussed in order to ensure high material availability at point of use few other things were found to affect the material availability at point of use. These additional findings will be discussed in this chapter.

6.5.1 Measurement

It is very important to measure the material availability at point of use to be able to improve it. It is also important to use an appropriate measurement and the more disturbances that are included in the measurement the more can be improved. An example of this is the difference between when Company A and Company B mark their products as defected; Company A marks all products as defected that have any part missing at point of use while Company B only mark the product as defected if the missing part cannot be brought to the station within the takt time. Because of this, it is obvious that, in the same situation, Company A should have more deviations connected to material, but at the same time they see all issues, does not matter how small they are, and therefore have greater opportunities to improve the process. This is important because even though the missing material does not stop the line it is causing a lot of extra work and cost in terms of e.g. extra people picking the missing material up from stock. When Company C measures late deliveries they also only measure it when the line is stopped since it is measured in stopped minutes of the line.

Today at Company A all parts are measured as missing if the andon people are called to fix the problem even though they can fix it before it comes at point of use. These missing parts can e.g. be when three kits are prepared in the same kit chart and when the first one is at point of use it is realized that one part is wrong in all the kits, then it might be fixed while the first product is still at the station, i.e. before the other kits become at point of use. In the future, they want to exclude these parts from the material availability at point of use KPI since they never become a problem at point of use, they are fixed before. However, it is still causing extra work so it should be measured in some way in order to eliminate it.

6.5.2 The andon concept

Having an andon concept in the plant can increase the material availability at point of use since then certain people are responsible for fixing the problems and document them into a system. This means that e.g. the documentation is always done in the same way which makes it easier to choose the problems as well as working with them, i.e. doing root cause analysis and improve the process. As in the case companies today, the andon people do not have much time to do anything else than just running errands to fix problems. It would be best if the andon people would have time to do a root cause analysis when needed and improve the process with appropriate tools, but to enable that, more andon people are needed or their work needs to be done more efficiently e.g. with standard operating procedures (SOPs). Then, when some of the problems have been eliminated the need for andon people will be reduced. It is also really important that everybody understands that the goal with the andon concept is not to stop the line, but to identify the problems to be able to eliminate them. Therefore it is very important that the andon people have time to do root cause analysis and try to eliminate problems instead of constantly running errands to fix things. The andon concept is also important since there is certain person within the group pointing out that the whole group did something wrong and they as a group need to fix it. When companies do not use an andon concept it is usually someone outside the group telling them they are doing something wrong, and that is not popular with the employees. In Company B there is sometimes a problem that all issues seem to accumulate to shift changes. This is not good and is an indicator that the andon concept is not working like it should, i.e. the assemblers should be the trigger as soon as something happens.

To be proactive the andon people need to think about what they can do to help others. This can e.g. be how they log the problems. Other people should also think what they can do to help the andon people doing their work. It is important that this help is two-sided and that people are not just thinking about themselves in isolation. It is also important to have the andon people on the shop floor where the assemblers can see them and easily contact them because that can relax the assemblers.

At Company B the andon people get a message to their telephone when there is a problem at a a station. Howeve, it only shows which assembly line the problem occurred. It would maybe be better if they would also get the station number as well as the part number of the defected part. This would shorten the time it takes for the andon people to fix the problems since they do not need to go to the line first, find the station before being able to figure out what the problem is. This change would be rationalized by the fact that around 90% of all andon calls are because of a missing material.

6.5.3 Reoccurring problems connected to people

When the same operators are causing problems with material availability over and over again it often seems to be because they are not satisfied with their job, maybe they have been moved to another station or the work ergonomics are not good so people get tired, less focused, etc. It can also be that they need more training in the tasks they are performing. Companies could try to fix this by talking to the operators and find out what is the problem, why they do not like the work. The attitude that some people within organizations have can be what is breaking down the process of improvement. If people are not happy they will not give all they can to their work. That is why the attitude and moral of the employees need to be good if companies want to make the improvement possibilities become a reality. The solution might be more training, change of the tasks or to move the operator to another area that suits him/her better.

Another thing that is connected to human factor is when companies try to make things “fool proof” (as easy as possible) to prevent things from going wrong so that they are able to do it right from the beginning. This, however, can make people feel that they are not being trusted to do things in the right way. Therefore, all changes need to be done by involving the workers so that they see the benefits from it. This shows that the human factor is a big part to consider before going into any changes; the employees need to be on board and see the opportunities in the changes and see how their participation to the work will make it even better, i.e. get a sense of ownership of the product. It has also been noticed that the assemblers are more willing to fix the problems if they feel that they are a part of the process. They become more proud of their work and feel that it is really crucial to fix the problems before the product leaves their production unit.

6.5.4 Stability

Stability is also a prerequisite for high material availability at point of use. When companies lack a stable process or the ability to follow a set process, it increases the problem of parts missing at point of use. This is because when people do not follow set working instructions or if the instructions are not in place, it may cause things to be in chaos; people do what they think is best and no one has a control over the situation. It is not until stability has been reached that companies can go into more improvements in the assembly. This can e.g. be seen in the kitting area in Company A because when kitting errors happen it is often because people do not follow the set processes. If all processes were stable then there would not be as much need for people like the andon people to fix problems that occur.

6.6 Future research

One thing that was noticed in the thesis is that stability has shown to be one of the prerequisites for high material availability at point of use. This could be achieved by focusing on the processes and try to keep things more standardized. This would be very interesting to research further to see how it actually affects the material availability at point of use.

However, it is not enough to have the right systems and methods in use, people involved also play a big part in the organization and need to be considered. It is very important that people understand the system and the processes in order for it to work as it is supposed to. That is why it would be of an interest to see in more details how the human factor affects the material availability at point of use and how it can be reduced.

In general the material availability at point of use subject has not been researched much, but since this seems to be a high importance for companies it would be interesting to go into more detailed research about it. This could be to see how more companies are affected by this, what the main problems seem to be, how the problems could be reduced or eliminated, how the human factor can make or break the improvements, etc.

7 Recommendations

In this chapter some recommendations that the authors want to point out will be discussed. These recommendations are mainly for company A but can also be considered for other companies that are dealing with material availability at point of use problems.

7.1 Proactive work

It is recommended for companies to document and measure all deviations, it does not matter how small they are or if they are fixed right away or not. By doing this all problems are brought to the surface and more potential for improvements arise.

It is very important that everyone in the company sees the material availability at point of use as a serious problem so that companies can make all the improvements needed. Sometime stations do not follow the routines that are required because their managers do not make them do it since they do not see this as a big problem either. The reason for this might be that some of the managers believe that the material availability problem is something that the Logistic Department should be taking care of, so that is something they themselves should not be putting any energy towards. Consequently, this is the signal that they are sending to their assemblers which has the effect that they do not follow the routine. This needs to be changed because without everyone on board it can be difficult to make all the improvements needed. It can also be that some people in the factory, e.g. forklift drivers and kitting operators, have never worked at the assembly line so they do not see the importance in having high material availability. They might not prioritize the assembly line because they do not know the consequences of not having the material available at point of use when needed. This then needs to be explained to them to show them how important it is.

An important thing when considering material availability at point of use is that employees need to feel proud of what they are doing and the product they send to the next station. If they are not, it can have negative effect on the material availability since then the employees might not send the product forward in the best condition possible. This is why it is important to build up the moral of the employees and one way could be by not having too many people in each group since smaller groups can increase teambuilding.

7.2 Material planning

In the case study it was found that Company A does not have as much problem with the suppliers delivering late as the other case companies. Of course this happens sometimes but the feeling from the andon person interviewed is that then it is not the supplier‘s fault, it is rather that the material controllers have not been on top of things, they did not order because they thought they had enough material in stock. This is an interesting finding and could be interesting to investigate more to see if it is true and if it is, then it would be interesting to see what it is that is causing the material controllers to not be on top of things. It can be that they are lacking some work procedures when checking what material needs to be ordered or even that the system they are using is not detailed enough.

7.3 Material supply system

Having an inventory system that provides the companies with the needed accuracy is very important and it should take into consideration all inventory at different places in the factory in order to be more accurate. The material availability issue does not seem to be affected by the stock accuracy in Company A according to the interviewees. The fact that their inventory system only shows inventory in the warehouse, but not the inventory in e.g. the preparation area, can however be the reason for this high stock accuracy. If all stock in-house would be considered the stock accuracy would probably be much lower and people would consider this as one cause to the material availability problem. This will, however, hopefully be better with the new inventory system they are about to implement.

Support for picking

It has been showed, both in theory but also in the case study we performed, that a support for picking, like pick-to-light or pick-to-voice systems, can have very great effects on the material availability at point of use since the human factor is reduced. Hence, it is very good that Company A is starting to implement the pick-to-light system in the kitting area in their factory. But this needs to be done carefully and it is important to make sure that the benefits are explained for the kitting people in a good way and they are involved as much as possible to try to create positive thinking about the system. This is because when "fool-proofing" the employee's work, like with pick-to-light system, the employees might feel that they are treated as a stupid person and not able to do their job without a support from a blinking light. Barcoding and "Shadowbox" are also methods that can support the kitting operators to pick right. This does not need as much investment but can decrease the human factor and can therefore be good for companies to use.

7.4 Root cause analysis and process improvements

It is great to do root cause analysis and improve the process for the most serious and common issues. Of course it would be best if root cause analysis could be done for all issues, but by starting with the most serious ones and most common ones, more time will be available later to eliminate the smaller issues.

One drawback was seen with the documentation at the factory in Company A. They use two different systems to log in the missing material, one for the group leaders (quality system) to see which project to do a root cause analysis on, and one for the adjustment area. It would probably be better if they could combine these systems so the people involved only need to log the missing material into one system. This system should be designed to fit everyone since it was mentioned that the quality system was not made to fit logistics. That would ease the process for the people logging the problems in as well as decrease the possibility that they forget to log it into one of the system. Of course this means that some investment is necessary, but the authors believe it will increase the quality of the processes which can save time and money in many different areas.

The andon people do sometimes not log in the problem at all. This is a big problem since they then do not see how great of a problem some issues are since they just fix it and then forget it because it was not documented. Furthermore, sometimes the andon people catch the mistake before it is at point of use and then they do not always log it into the system. This must be logged in as well since it is a problem and should be eliminated, even though the line was not affected by it. Sometimes, however, the assembly operators log in the problems that the andon people do not log in, like when the andon person is fetching a part that the assembly line asked for.

An additional problem is that the blue collar employees seem to not always realize exactly how things work; they have an opinion about it but might not realize the process and what is actually lying behind it. The andon person interviewed said that it is not always time for them to do root cause analysis and that more people are needed to take some of their workload so they can work on root cause analysis for a longer time. Maybe this is the case, but it could also be that the andon people´s work might not be structured in a good way. If they had standardized procedures to work after the work would maybe take less time and they would have extra time to work on root cause analysis. It was also mentioned in the interviews that it is hard for the andon people to do root cause analysis since they might be called to take care of different problems when they are in middle of the analysis. This might also be solved by having the analysis work more standardized so that the andon person feels confident enough to start the work, even though they might be called away from it, since it would be easy for them to start from where they left. One more thing mentioned was that the IMC group thinks that they do not have any training and that they need to learn from their own experience. This might not be totally true since the managers have said that they give the IMC group a lot of help. This could be because the people might not have a process mindset, they do not have the knowledge or they might not see the problems that are there, they need to learn to use more logic.

The fact that the andon people are spending so much time fetching parts means that it decreases the time they could spend on root cause analysis. A solution to this could be to relieve the andon people from the job of actually fetching the parts. They should be able to order the parts from the Logistic Department and the Logistic Department should deliver them as quickly as possible. This would then give the andon people a lot more time to work on root cause analysis. However, the andon people do not think this is quick enough and therefore fetch the parts themselves.

7.4.1 The IMC project

The IMC project in Company A is really good in order to increase the material availability at point of use since more time is spent doing root cause analysis and improving the processes. The people interviewed said that it has been a lot of starting issues, mainly in terms of communication, and it is still a lot of work to be done. They mentioned that there needs to be clearer instructions about how the IMC group works and who is a part of the team and who is not. They also mention that the help should not just be one sided, the IMC group needs to ask themselves more what they can do to help others as well as other people need to ask themselves what they can do to help the IMC group. The communication and cooperation is, however, much better today. Now the IMC group comes to morning meetings with the group leaders and other managers every week where they can find out ways to work together in order to fix problems.

This project should be expanded to the entire factory because this group has been very successful in fixing the root causes of the problems. This could mean that more andon people are needed in the beginning while the project is starting up, but after it has reached a stability there will not be as much need for the andon people and hopefully it will be enough to have just one in each area. The reason for why many andon people are needed in the beginning is that then they need to firefight a lot, do all the work description, work on root cause analysis and so on.

7.5 Summary of recommendations

To summarize, the most important things that are recommended for companies, especially company A, are the following:

- Document and measure all deviations, no matter how small they are or if they can be fixed right away or not
- Everyone in the company should look at the problem as a serious one
- Make employees feel that they are a part of the process and proud of their work

- Investigate if the material controllers are not on top of things and if so then why not
- Have an accurate inventory system that takes all stock into consideration
- Have a good support for kitting, e.g. with a pick to light or pick to voice system
- Do root cause analysis for as many problems as possible
- Have one system for documenting the missing material
- Make the work more standardized so the people’s mindset is more on the processes
- Get more support from logistics so that the andon people do not need to fetch the material as much
- Expand the IMC project to the entire factory

References

Alonso, E., Gregory, J., Field, F. & Kirchain, R., 2007. Material availability and the supply chain: Risks, effects, and responses. *Environmental science & technology,* 41(19), p. 6649.

Arnheiter, E. D. & Greenland, J. E., 2008. Looking for root cause: a comparative analysis. *The TQM Journal,* 20(1), pp. 18-30.

Baudin, M., 2002. *Lean Assembly: The Nuts and Bolts of Making Assembly Operations Flow.* New York: Productivity Press.

Baudin, M., 2004. *Lean Logistics: The nuts and bolts of delivering materials and goods.* New York: Productivity Press.

Belgran, M. & Johansson, C., 1994. A method for the design of flexible assembly systems. *International Journal Production Economics,* Volume 41, pp. 93-102.

Benneyan, J. C. & Chute, A. D., 1993. SPC, process improvement, and the Deming PDCA circle in freight administration. *Production and Inventory Management Journal,* 34(1), p. 35.

Bergman, B. & Klefsjö, B., 2003. *Quality from Customer Needs to Customer Satisfaction.* 3rd ed. Lund: London and Studentlitteratur.

Bhaumik, S. K., 2010. Root cause analysis in engineering failures. *Transactions of The Indian Institute of Metals,* 63(2-3), pp. 297-299.

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

Brennan, L., Gupta, S. M. & Taleb, K. N., 1994. Operations Planning Issues in Assembly/Disassembly Environments. *International Journal of Operation & Production Management,* 14(9), pp. 57-67.

Bryman, A. & Bell, E., 2011. *Business Research Methods, 3rd Edition.* New York: Oxford Universtiy Press Inc..

Brynzér, H. & Johansson, M., 1995. Design and performance of kitting and order picking systems. *International journal of production economics,* 41(1-3), pp. 115-125.

Bukchin, J., Darel, E. & Rubinovitz, J., 1997. Team-oriented assembly system design: A new approach. *International Journal of Production Economics,* Volume 51, pp. 47-57.

Buvik, A. & Halskau, Ø., 2001. Relationship duration and buyer influence in just-in-time relationships. *European Journal of Purchasing & Supply Management,* 7(2), pp. 111-119.

Caputo, A. C. & Pelagagge, P. M., 2011. A methodology for selecting assembly systems feeding. *Industrial Management & Data Systems,,* 111(1), pp. 84-112.

Cheldelin, B. & Ishii, K., 2004. *Mixed model assembly quality: An approach to prevent human errors.* Anaheim, CA, Proceedings of ASME IMECE.

Chen, K.-P., 2007. *Assembly job shop scheduling problems with component availability constraints.* Norman, Oklahoma: University of Oklahoma.

Cohen, M. A. & Lee, H. L., 1988. Strategic analysis of integrated production distribution systems: models and methods. *Operation Research,* 36(2), pp. 216-228.

Corakci, A. M., 2008. *An Evaluation of Kitting Systems,* Master´s thesis. University of Borås, Sweden.

Daganzo, C. F. & Blumenfeld, D. E., 1994. Assembly system design principles and tradeoffs. *International Journal of Production Research,* 32(3), pp. 669-681.

Dallari, F., Marchet, G. & Melacini, M., 2009. Design of order picking system. *International Journal of Advanced Manufacturing Technology,* Volume 42, pp. 1-12.

Das, S. K. & Bhambri, S., 1994. A decision tree approach for selecting between demand based, reorder, and JIT/kanban methods for material procurement. *Production Planning & Control,* 5(4), pp. 342-348.

Dub, M., Pipan, G. & Hanzálek, Z., 2002. Stock Optimization of a Kanban-based Assembly Line. *Proceedings of the 12th International Conference on Flexible Automation and Intelligent Manufacturing,* pp. 258-267.

Edmondson, N. F. & Redford, A. H., 2002. Generic flexible assembly system design. *Assembly Automation,* 22(2), pp. 139-152.

Eisenhardt, K. M., 1989. Building Theories from Case Study Research. *The Academy of Management Review,* October, 14(4), pp. 532-550.

Eklund, J., 2000. Development work for quality and ergonomics. *Applied Ergonomics,* Volume 31, pp. 641-648.

Finlow-Bates, T., 1998. Perspectives - The root cause myth. *The TQM Magazine,* 10(1), pp. 10-15.

Finnsgård, C., 2009. *Assembly processes and materials supply systems design ,* Gothenburg: Chalmers University of Technology.

Finnsgård, C., Medbo, L., Johansson, M. I. & Wänström, C., 2011b. *Materials flow mapping: a tool for describing and assessing performance of material flows in supply chains,* Gothenburg: Chalmers University of Technology, Division of Logistics and Transportation.

Finnsgård, C., Wänström, C., Medbo, L. & Neumann, W. P., 2011a. Impact of materials exposure on assembly workstation performance. *International Journal of Production Research,* 49(24), pp. 7253-7274.

Flick, U., 2009. *An Introduction to Qualitative Research.* 4 ed. London: SAGE Publications .

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

Fullerton, R. R. & McWatters, C. S., 2001. The production performance benefits from JIT implementation. *Journal of Operations Management,* 19(1), p. 81–96.

Giust, L., 1993. Just-in-Time Manufacturing and Material Handling Trends. *Industrial Management & Data Systems,* 93(1), pp. 3-9.

Graves, S. C., 1987. *SAFETY STOCKS IN MANUFACTURING SYSTEMS.* Cambridge: A. P. Sloan School of Management, Massachusetts Institute of Technology.

Guide, V. D. R. J. & Srivastava, R., 2000. A review of techniques for buffering against uncertainty with MRP systems. *Production Planning and Control,* 11(3), pp. 223-233.

Hales, H. & Andersen, B., 2001. Industrial engineering support for materials management. In: K. Zandin, ed. *Maynard´s industrial engineering handbook.* New York: McGraw-Hill, p. 10.1.

Hanson, R., 2009. *On the options available in the design of in-plant materials supply systems,* Gothenburg: Chalmers University of Technology, Department of Technology Management and Economics, Division of Logistics and Transportation.

Huson, M. & Nanda, D., 1995. The impact of just-in-time manufacturing on firm performance in the US. *Journal of operations management,* 12(3-4), p. 297.

Jacobs, R. F., Berry, W. L., Whybark, C. D. & Vollmann, T. E., 2011. *Manufacturing Planning & Control - For Supply Chain Management.* sixth ed. New York: McGraw-Hill.

Johansson, E. & Johansson, M. I., 2006. Materials supply systems design in product development projects. *International Journal of Operations & Production Management,* 26(4), pp. 371-393.

Jonsson, P. & Mattson, S.-A., 2009. *Manufacturing planning and control.* London: McGraw-Hill Education.

Lee, H. L. & Billington, C., 1993. Material Management in Decentralized Supply Chains. *Operations Research,* 41(5), pp. 835-847.

Levy, D. L., 1997. Lean Production in an i-International Supply Chain. *Sloan Management Review,* 38(2), pp. 94-102.

Liker, J. K., 2004. *The Toyota Way.* New York: McGraw-Hill.

Medbo, L., 2003. Assembly workexecution and materials kit functionality in parallel flow assembly systems. *International Journal of Industrial Ergonomics,* Volume 31, pp. 263-281.

Pierce, F. D., 1997. Applying Just in Time to safety and health. *Occupational health & safety,* 66(4), p. 65.

Ronen, B., 1992. The complete kit concept. *International Journal of Production Research,* 30(10), pp. 2457-2466.

Snee, R. D., 2004. Six Sigma: the evolution of 100 years of business improvement methology. *International Journal of Six Sigma and Competitive Advantage,* september, 1(1), pp. 4-20.

Spekman, R. E., 1988. Strategic supplier selection: understanding long-term buyer relationships. *Business horizons,* 31(4), p. 75.

Stank, T. P. & Crum, M. R., 1997. Just-in-time management and transportation service performance in a cross-border setting. *Transportation journal,* 36(3), p. 31.

Sugimori, Y., Kusunoki, K., Cho, F. & Uchikawa, S., 1977. Toyota Production system and Kanban system Materialization of just-in-time and respect-for-human system. *International Journal of Production Research,* nov, 15(6), pp. 553-564.

Todd, C. J., Leasher, T. R. & Ramirez, N., 2004. *Component management framework for high availability and related methods.* United States, Patent No. 183894.

Toyota, 2006. *Toyota Traditions: Ask 'why' 5 times about every matter.* [Online]
Available at: http://www.toyota-global.com/company/toyota_traditions/quality/mar_apr_2006.html
[Accessed 24 April 2012].

Uthiyakumar, M., Samuel, B. J., M. Strikamaladevi, M. & Saravanan, M., 2010. Scrap loss reduction using the 5-whys analysis. *International Journal of Quality & Reliability Management,* 27(5), pp. 527-540.

Wänström, C. & Medbo, L., 2009. The impact of materials feeding design on assembly process performance. *Journal of Manufacturing Technology Management,* 20(1), pp. 30-51.

Wilson, P. F., Dell, L. F. & Anderson, G. F., 1993. *Root Cause Analysis: A Tool for Total Quality Management.* Miwaukee: ASQC Quality Press.

Wilson, R. H., 1992. *On Geometric Assembly Planning.* Stanford, Stanford University.

Yin, R. K., 2009. *Case Study Research: Design and Methods, 4th edn.* Thousand Oaks, CA: Sage Publications.

Appendix A – Assembly system

Assembly system is, according to Finnsgård (2009), the system where products are assembled. He also defines assembly process as the process where the products are assembled. The assembly process is, according to Belgran & Johansson (1994), an essential part of the total production process since it often constitute the last stage of the production process and therefore the processing value is higher than in previous stages. After series of assembly operations the final product is ready, which is only when there is no more work needed on the product in the current facility (Bozer & McGinnis, 1992). The subassembly is, according to Finnsgård (2009), not included in the assembly system or assembly process, but is rather a part of the materials supply system. On the other hand, Bozer & McGinnis (1992: 3) define subassembly as "*the aggregation of two or more components and/or subassemblies through an assembly process*" which means that they consider the subassembly as a part of the assembly process. According to Baudin (2002: 6) assembly "*consists of putting or fitting together different parts into a product*". The assembly can take place on a single assembly line, in one or series of assembly cells, or in bench assembly. The work of assembly is often repetitive, especially at the component and subassembly level, but also at the finished product level. The main goal, according to Baudin (2002), is to make sure that all product units flow to the next station at takt intervals. Bukchin, et al. (1997) also state that the main objective when designing an assembly system is to maximize the ratio between throughput and required costs, i.e. increase efficiency.

This report will look at subassembly as Finnsgård defines it; that it is not a part of the assembly system but as a part of the material supply system. It further will use Baudin´s definition of assembly; that assembly consist of putting and fitting together different parts into a product.

Assembly line

According to Baudin (2002) an assembly line is a system with a sequence of stations that each item moves through and is processed as it passes. All materials, machines, tools, fixtures, instructions, and assemblers needed for the operation are available at each station. In mass production environment an assembly line is the most common setup according to Bukchin, et al. (1997) since with that setup complex products can be assembled by workers with limited training. An assembly line can consist of a single line or a line with feeder lines, either with small components assembled in these feeder lines or major modules that are then fed to a short final assembly line. When only small part of the product is being worked on and the rest of the product just waits, it should, according to Baudin (2002), be considered to make the subassembly into a feeder line so that the assembly and the subassembly can be done simultaneously. A small buffer can then be used at the end of the subassembly feeder line so the main line can pull the subassembly from it. He also states that It is common today, especially in the electronics industry but also recently in the automotive industry, to make the main suppliers assemble the main subassemblies and thereby cut down the amount of work in final assembly by about 90%. Assembly lines have the characteristics that the flow of units down the line is one piece at a time, the direction of flow is not specified, and backtracking is not allowed.

While straight assembly lines live on in airplane assembly, car assembly lines are today usually formed like a snake since they are so long (Baudin, 2002). By this, material can be supplied into the folds of the snake to two linear feet of the assembly line and to both sides of the line. This setup, however, also complicates the material supply since each supplier needs to deliver to two folds of the snake to be able to feed both sides of the car with similar parts (one right and one left) (Baudin, 2002).

Conveyance system

The way the parts are moved in an assembly line is by conveyance systems (Baudin, 2002). The goals with conveyance systems are to get a one-piece-flow with First-in-First-out (FIFO) philosophy. If total synchronization between stations is impossible a one-piece buffer between stations can be used, but a bigger WIP buffer should be avoided. Conveyance systems should also not be shared among multiple conveyance tasks and it should not lose product orientation. The takt time can be enforced with conveyance systems (Baudin, 2002).

Conveyance systems can be of a different size and complexity, the easiest one is pure hand-to-hand pull system, where the operator picks the parts from the upstream operator. When the parts get bigger and heavier then conveyance belts or pushcarts can be used. According to Baudin (2002) two different types of conveyors can be used; continuously moving conveyors and stop/start conveyors. Assembly takes place over the entire takt time with continuously moving conveyors, while start/stop conveyors lose time because of transfers between stations, but instead the assemblers can work on a fixed object. He also emphasizes that it is important that the work is done on the conveyor, instead of moving it away from the conveyor and by that lose time and risk damage.

Edmondson & Redford (2002) agree with these two types of conveyors but they call them indexing system and free transfer, respectively. They emphasize that if one operation in the indexing system fails the whole system stops. They also mention that when working with free transfer it is good to have small buffers between stations to be able to continue the remaining operations even though one fails. To avoid the buffers, according to them, it is really important to balance the line so that all stations have similar workload that takes the same time, the takt time. This is because otherwise buffers will start to evolve in front of the stations with the longest cycle time and the output will still never be more than the output of slowest station.

Traditional vs. modern assembly setup

The traditional assembly setup, according to Daganzo and Blumenfeld (1994), is a system with workstation arranged in series, but newer assembly systems are more flexible with some workstation arranged in parallel. In a serial system the labor cost tends to be higher because of imbalances between task times, i.e. workers tend to be idle when waiting for next job to work on. In order to decrease the labor cost, according to Daganzo and Blumenfeld (1994), the line can be balanced and transfer time reduced by combining tasks in the same station. This, however, results in longer time for each job at each station so they state that in order to maintain the same throughput more than one station must be operated in parallel; the number of stations depends on the number of tasks that are combined and the times they take. This can also decrease the operating time since tasks can be worked on simultaneously instead of sequentially. Even though the labor cost is lower in a parallel system the capital equipment cost may be higher because of duplicated machines. The trade-off between the labor cost and the capital equipment cost needs to be evaluated in order to choose an appropriate system. In general, where the labor cost is relatively larger than the machine cost a parallel system is a better choice, whereas a relatively larger machine cost favors a serial system (Daganzo & Blumenfeld, 1994).

Bukchin, et al. (1997) also talk about the traditional assembly line as an assembly line with workers standing by the line and the product being worked on flows between them. The main drawbacks of traditional assembly lines, according to them, are low flexibility, high balance loss, poor quality, poor working environment, high work-in-process, and high costs of material handling. They measure this traditional assembly line against a newer setup of team-oriented assembly (TOA) which they think is a better setup. Bukchin (1997) describe a TOA as an assembly where a group of workers work together at the same territory and complete assemblies in a continuous flow (batch equal to one item, i.e. is one piece flow). According to them the main characteristics of TOA are semi-autonomous teams, orientation to the product structure, worker expertise, short flow times, continuous flow, and high motivation. They mention that the main benefits with TOA are the increased flexibility of the system and increased quality of the products.

Assembly cell

An assembly cell is a special type of an assembly line where a team of no more than eight to ten operators works. The cells are most often designed so that the stations are arranged in a U-shape where the parts are fed from outside and the operators work inside the U (Baudin, 2002). According to Baudin (2002) parts can be fed directly to the cell from the warehouse through milk runs, by water spider from a supermarket to each station, or as kits to the first station of the cell. U-shaped assembly cells are suitable for products that are small enough in at least two dimensions and that do not need assembly on two or more sides simultaneously. The products need to be small enough in at least two dimensions so that material feeding from outside works, i.e. that the assemblers are able to reach the materials across the assembly station. The main benefits with this setup, according to Baudin (2002), are staffing flexibility when volume changes, easy communication between operators, and no interference between production and part supply. In U-shaped cells the assembler's work can be designed as a loop through multiple stations so the assemblers do not need to be as many as the stations. The input and output buffers are also side by side, making all logistics easier.

An assembly process is sometimes set up as a series of assembly cells (Baudin, 2002). Then it is easier to stop the assembly because only one cell needs to be stopped, instead of the entire assembly line. This means that the output of the plant is not affected if one cell needs to be stopped for a few minutes. By having quality station at the end of each cell also improves quality since the failures are detected at the cell and can therefore be fixed within the cell by operators from the group, providing faster and better feedback (Baudin, 2002).

According to Baudin (2002) the assembly lines have been more popular through the years, and assembly cells are only used when they can cover a complete assembly or subassembly process.

Assembly station

According to Baudin assembly station is the spot where assemblers, materials, fixtures, tools, machines, gauges and methods make an assembly operation happen. Assembly work is usually performed standing without platforms to ensure assemblers' mobility. Assemblers also move and rotate between stations. According to Baudin (2002) it is most common to have the handheld tools attached to each station rather than the assemblers, but on large products sometimes fixtures are used to keep the tools aligned with the moving products. It is also important to have assembly instructions, with drawings or photographs and text with sequence of operations, safety rules, quality checks and other information, available at each station.

Where small products are assembled the assembly usually takes place only on one side of the line and the parts are presented on the other side (Baudin, 2002). These products are usually light so they can be passed between assemblers without conveyors. Large products, on the other hand, are usually worked on from both sides of the station and parts are presented behind or on the side of the assemblers. These products usually move on conveyors or carts. If the products must be worked on from underneath fixtures should be invented to rotate the product to make the work easier for the assembler (Baudin, 2002).

Bench assembly

As opposed to assembly lines, bench assembly is where the product itself does not move, but the assemblers work around it and all the equipments and parts needed are brought to it, usually in kits (Baudin, 2002). The assembly in bench assembly can be done by one operator or a team of operators.

According to Baudin (2002), the most common reasons for using bench assembly instead of an assembly line are that the volume is too low, no repetition due to customization, or the assembly line work is unbearable for operators. Higher job satisfaction usually also goes along with bench assembly. He states, however, that assembly lines most often outperform bench assembly, both in high- and low- volume production.

Assembly productivity

Edmondson & Redford (2002) explain the assembly process as twofold; the manipulator which performs the actual assembly task (the assembler) and the material handling equipment which ensures that the correct parts, fixtures, and tools are brought to the right place at a correct time. According to Baudin (2002) part supply is the most important factor in assembly productivity since if all the parts that are needed for the assembly are available then everything could be assembled without any problems. He also states that the most common complaint from assemblers, assembly supervisors, and assembly managers is that the parts are not available. The employees at the factory often blame the suppliers for problems regarding the material availability and suggest improvements at the supplier, without thinking about the fact that they have control over the last link, i.e. how the parts are presented at the assembly line and physically get into the assemblers' hands. According to Baudin (2002) the design of the assembly work is the second major factor in assembly productivity. This includes the subassembly structure, the sequencing of assembly steps, the allocation of assembly steps among assembly stations, the size, fixtures, and tools of assembly stations, the design of assembly procedures, and the means of controlling the quality of assembly work. He states that the internal operations should be looked at and improved before the support from the supplier can be successful. These improvement opportunities can be found all around the assemblers. Some examples are that by designing jobs that keep operators busy doing useful tasks can save them from making extra parts, by eliminating shortages and imbalances between stations the waiting time for the operators can be reduced, by sequencing the steps in a good way some extra work can be avoided, and by presenting parts in a good way multiple handling can be avoided. The factory needs to use more people if the assembly work design is ignored. That can have the following consequences, Baudin (2002) mentions; people fight over the work instead of simply doing it, production numbers go down and lead times go up because people are in each other's way, responsibilities get weak and quality suffers because problems are always somebody else's, employees feel insecure in their jobs, and the only way to obtain price concessions is by pressuring suppliers into giving up some of their own profits. It is also a common mistake, according to Baudin

(2002), to assume that because the direct labor cost is low compared to materials and overhead costs then improvements on the assembly work design are not important.

Appendix B – Prepared questionnaire

Meeting with the Material Handling Manager at Company A, on March 7th

1. How does the material flow to the assembly line look today? (Discussion, drawings and/or process map)
    a. What kind of material flow are you using? Kitting/sequenced delivery/ continuous supply/batch supply?
2. How big of a problem is missing material at point-or-use? How often does it happen?
3. How serious do you think this problem is?
4. Is rescheduling often required because of missing materials?
    a. Does it sometimes happen when the product is already on the line?
5. Are finished products often delayed because of missing materials?
6. How does the process for material availability problems look today? (Discussion, drawings and/or process map)
    a. What does the assembler do when the material needed is not available?
    b. Are there any guidelines for what to do when the material is missing?
    c. How is it documented?
    d. What do you think are the most common causes of this problem?
    e. Are you grouping the causes in some way?
    f. Are you working on any improvements regarding this problem?
7. Stock accuracy
    a. How is the situation today?
    b. How is it measured?
    c. Are there any projects today aimed at increasing this accuracy?
    d. What do you think are the most common causes of this problem?
8. Can we interview some of the assemblers?
9. Who do you think are of interest for us to interview?

Meeting with andon personnel at Company A, on March 12th and 14th

1. How often are you, as an andon person, called because of material availability problems?
2. What is the first thing you do when you get the call?
3. Do you solve the problem temporary, i.e. get the material to the product?
    a. How long time does it usually take to get the material? Is it often in-house or is it often still at the suppliers?
4. Do you document the problem somewhere?
5. Do you group the problems in some way?
    a. What do you think are the main causes of the problem?
    b. Do you think the same parts are missing over and over again?
    c. Do you think the same causes over and over again?
6. Who continues looking at the problem after you have done your part?
7. How serious do you think the problem is?
8. Do you think everybody looks at this as a serious problem?
9. Do you think the stock accuracy is bad, i.e. the material is not in stock even though the system says it is?
10. How many andon people are working in the factory?

a. Are they responsible for different areas?

Meeting with the production leader at Company A, on March 22nd

1. What is your position?
    a. What do you do in every day work?
2. What is your job within in this material availability at point of use?
3. What happens when the material is missing?
    a. What is done and who is responsible for it?
    b. How often does it happen?
    c. Are there any guidelines for what to do when the material is missing?
    d. How is it documented?
4. Do you group the problems in some way?
    a. What do you think are the main causes of the problem?
    b. Do you think the same parts are missing over and over again?
    c. The same causes over and over again?
    d. The same person over and over again?
5. How often do you look at the problem?
    a. Periodically, continuously, etc.?
6. Do you work proactive to reduce the problem?
    a. Like do root cause analysis
7. How do you choose the problems that you will do root cause analysis to?
    a. Do you do it yourself or do you delegate it to someone else?
        i. If you delegate then to whom?
    b. How often do you choose the problems and delegate it to someone (if you delegate it)?
8. Are you successful in fixing all the problems or does it often happens that you work on a problem and are not able to eliminate it?
9. How serious do you think this problem is?
    a. Do you think everybody looks at this as a serious problem?
10. How many andon people are working in the factory?
    a. Are they responsible for different areas?
11. What is your view on the IMC project?
    a. Do you think it should be expanded throughout the whole factory?
12. Are finished products often delayed because of missing materials?
13. Is rescheduling often required because of missing materials?
    a. Does it sometimes happen when the product is already on the line?
14. Do you think the stock accuracy is bad, i.e. the material is not in stock even though the system says it is?

Meeting with group leader at Company A, on March 27th

1. What is your position?
    a. What do you do in every day work?
2. What is your job within in this material availability at point of use?
3. What happens when the material is missing?
    a. What is done and who is responsible for it?

        b. How often does it happen?
        c. Are there any guidelines for what to do when the material is missing?
        d. How is it documented?
            i. Is it always documented?
                1. By whom?
4. Do you group the problems in some way?
    a. What do you think are the main causes of the problem?
    b. Do you think the same parts are missing over and over again?
    c. The same causes over and over again?
        i. What do you do about that?
        ii. What do you believe is the reason for that?
    d. The same person over and over again?
        i. What do you do about that?
        ii. What do you believe is the reason for that?
5. How often do you look at the problem?
    a. Periodically, continuously, etc.?
6. Do you work proactive to reduce the problem?
    a. Like do root cause analysis
7. Do you choose the problems to do root cause analysis on?
    a. How are they chosen?
    b. Do you do the root causes yourself or do you delegate it to someone else?
        i. If you delegate then to whom?
    c. How often are the problems chosen and delegated (if you delegate it)?
8. Are you successful in fixing all the problems or does it often happens that you work on a problem and are not able to eliminate it?
9. How serious do you think this problem is?
10. Do you think everybody looks at this as a serious problem?
11. What is your view on the IMC project?
    a. Do you think it should be expanded throughout the whole factory?
12. Are finished products often delayed because of missing materials?
13. Is rescheduling often required because of missing materials?
    a. Does it sometimes happen when the product is already on the line?
14. Do you think the stock accuracy is bad, i.e. the material is not in stock even though the system says it is?

Meeting with the benchmarking companies, on April 12th, 13th and May 8th

1. How is the assembly setup at you factory, i.e. do you use assembly line, assembly cell, bench assembly, etc.
    a. How is the in-house logistics in the factory, do you use kitting, sequencing, line stocking, etc. Does it differ with different parts?
2. What is your position within the company?
3. Are you familiar with material availability at point of use?
    a. How is it measured?
    b. What is your job within material availability at point of use?
4. How good or bad is the material availability at point of use at your factory?

5. What happens when the material is missing?
    a. What is done and who is responsible for it?
    b. How often does it happen?
    c. Are there any guidelines for what to do when the material is missing?
    d. How is it documented?
        i. Is it always documented?
            1. By whom?
6. Do you categorize the causes of the problem in some way?
    a. What do you think are the main causes?
        i. Does inaccuracy in stock have any effect on the material availability?
    b. Do you think the same parts are missing over and over again?
    c. The same causes over and over again?
        i. What do you do about that?
        ii. What do you believe is the reason for that?
    d. The same person over and over again?
        i. What do you do about that?
        ii. What do you believe is the reason for that?
7. How often is the problem looked at?
    a. Periodically, continuously, etc.?
8. Do you work proactive to reduce the problem?
    a. Like do root cause analysis
9. Do you choose the problems to do root cause analysis on?
    a. How are they chosen?
    b. Who is responsible for doing the root cause analysis?
    c. How often are the problems chosen and delegated (if you delegate it)?
10. Are you successful in fixing all the problems or does it often happens that you work on a problem and are not able to eliminate it?
11. How serious do you think this problem is?
    a. Do you think everybody looks at this as a serious problem?
12. If you know the material is missing before the product enters the line do you reschedule the plan?
    a. What if the product is already on the line?
13. Does it often happen that products finish the assembly line not completely ready because of a missing material?
    a. Is the delivery of finished products often delayed because of this?
14. What material planning methods do you use? Re-order point, run-out time, MRP, etc.