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Measuring and Increasing Performance of a Materials Supply System

Master of Science Thesis in the Supply Chain Management Programme

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ABSTRACT

The performance of a production system in a manufacturing plant is highly affected by the performance of the materials supply system that provides the production system with materials. By measuring performance of the materials supply system, identification of potential performance increases is facilitated. However, knowledge of how materials supply systems should be designed should be acquired before aiming to increase the performance. The purpose of this thesis is to explore how materials supply system should be designed, how performance of the materials supply systems should be measured, and subsequently how the performance of the materials supply system can be increased. The materials supply system at Adient in Gothenburg is used in this thesis. Adient is a company providing car seats for the automotive industry. Four research questions are created in order to achieve the purpose:

1. *How should the areas in a materials supply systems be designed?*
2. *How is the current materials supply system designed?*
3. *How is the current materials supply system performing?*
4. *How can performance of the materials supply system in the target areas be increased?*

The answer to the first research question is a design model that can be used for designing materials supply systems. The design model encompasses the six areas of a materials supply system and aims to facilitate the selection of design aspects. To answer the second research question a current state that explores the existing design of the materials supply system at Adient is created. Four performance measurements from literature is used to answer research question three. Two measurements indicate potential for performance increase in the materials supply system at Adient. Three areas influencing these two measurements are targeted for performance increase; continuously supplied frames to first and third line, distance from materials presentation to assembly line, and materials presentation at assembly stations.

The suggestions for increased performance include implementation of sequential supply of frames. Reduction of platform length at the assembly lines to enable closer materials presentation and making adjustments in materials presentation at the assembly stations are the two additional suggestions for increased performance. The suggestions for increased performance eliminate two storage points of frames at the first and third line and thus also the space requirements for frames at the two lines. Sequential supply also reduce transport frequency to the two lines. Non-value adding time for operators at assembly stations is reduced by enabling closer materials presentation to eliminate walking. The elimination of walking is achieved by a reduction of the platform length at the assembly lines. By ensuring that only materials handlers open cardboard boxes and that reusable containers are used to a greater extent for materials presentation, non-value adding time is reduced for the operators.

Keywords: Materials supply systems, performance measurements, increase performance.

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1. INTRODUCTION

In this chapter the background for the thesis is provided which is followed by company profile, problem definition, purpose and research questions and scope of the thesis.

1.1 BACKGROUND

Increasing global competition contributes to that manufacturing companies are forced to find potential cost reductions, e.g. by adopting Lean with tools such as Just-In-Time (JIT) while still maintaining customer satisfaction (Danese et al., 2012). Adopting such philosophies or tools may require design adjustments in the supply chain. When supply chains are restructured, the prerequisites for *materials supply systems* will be changed (Johansson and Medbo, 2004). The materials supply system of a company is comprised by the materials- and its information flows inside a manufacturing plant, but also from suppliers to industrial buyers (Johansson, 2009).

Materials supply systems inside manufacturing plants encompass the arrival of goods at the plant, up until materials presentation at the assembly stations (Hanson, 2009). How the production system is designed influence how the materials supply system is designed and vice versa (Johansson and Johansson, 2006). The materials supply systems inside manufacturing plants can affect assembly operations in terms of time efficiency, flexibility and quality (Hanson, 2009). The materials supply system should ensure that non-value adding activities are not performed at the assembly stations, but by the materials handlers instead since the assembly time is more expensive compared to the time of materials handling (Baudin, 2002).

There is a limited knowledge of how materials supply inside manufacturing plants should be performed (Hanson, 2009). It is important that this knowledge is increased since Ellis et al. (2010) argue that reduced materials handling costs and increased productivity are the results from effective materials flows in manufacturing plants. In order to select the proper options in the design of materials supply systems, it is important to understand how the materials supply system ought to perform (Hanson, 2009). By measuring the materials supply system, selections of the proper options are facilitated which in turn increase performance of the materials supply system.

1.2 COMPANY PROFILE

Adient is a global supplier for the automotive industry and provides automotive seats and components to more than 25 million cars annually. With every third car seat produced globally each year and with 230 production plants spread across the globe in 33 countries, Adient is one of the biggest automotive suppliers in the world. The plants of Adient worldwide produce seats for different automotive manufacturers where the plant in Torslanda, Sweden, produces car seats for a Swedish car manufacturer.

The seats that Adient produce are of high product mix, i.e. seats comes in a high amount of variants. A total of 4446 variants are possible to manufacture in the Torslanda plant. The high amount of variants creates high amounts of materials to be handled, which in turn creates high demands on the materials supply system to align with production.

1.2.1 The product

Each seat is comprised of three main sections: cushion, backrest and headrest. The included components in each section relevant for the thesis are explained more in detail in Appendix A. The seats are categorized into three rows in a car depending on where the seats are to be installed as illustrated in Figure 1.1.

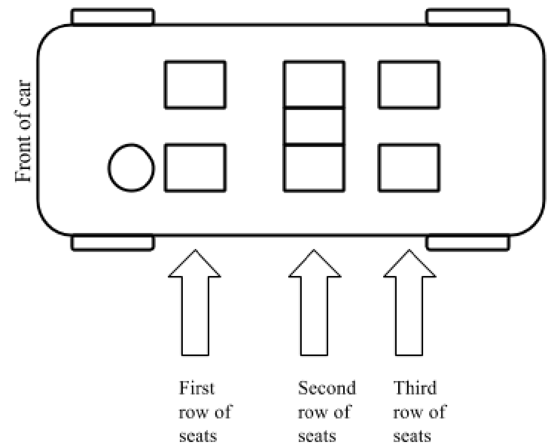


Figure 1.1. Illustration of seat rows.

The first row of seats is comprised of the driver seat and front passenger seat. The front row seats are the most advanced seats with the highest amount of components. The second row of seats is what traditionally is referred to as the "back seat" and the third row of seats is currently used in one car model only and is comprised of two foldable seats that are installed in the baggage of the car. In Figure 1.2, the three rows of seats are shown where "1" is first row, "2" is second row and "3" is third row.

Figure 1.2. The first row of seats (1), the second row of seats (2) and the third row of seats (3).

The three main components of all seats are trim, steel frames and foam. Trim is clothing of the seats which comes in textile and leather. Steel frames are the frames that is the basis of the seat and on which the other components are installed. The foam is the padding of the seats. A detailed explanation of all including parts and components is found in Appendix A.

1.2.2 The production system

Four production lines are used in the Adient Torslanda plant as illustrated in Figure 1.3 and are working in accordance with an assembly-to-order system (ATO). In an ATO system, inventory consists of components that are assembled into unique products according to customer demands (Song and Zipkin, 2003). First row of seats production line, from now on referred to as "*First line*", produces the driver seat and the passenger seat. The second row of seats is produced on two lines and the two lines are from here on referred to as "*Second line*" and "*Third line*". Third row of seats is only produced on one line since it is only available for one car model and is from here on referred to as "*Fourth line*".

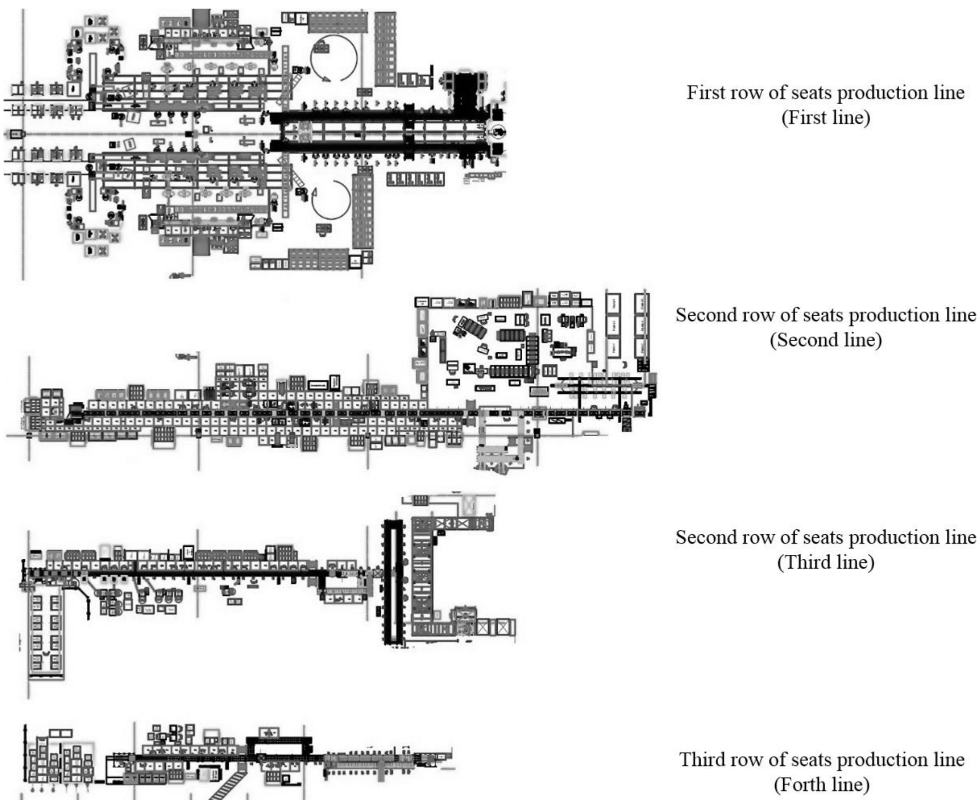


Figure 1.3. A layout displaying the lines at Adient Torslanda plant.

1.3 PROBLEM DEFINITION

The requirements on the production system at Adient are high since the customer demands short lead times. The requirements on the production system in turn puts high demands on the materials supply system to provide materials at short lead times. To maintain short lead times, the materials supply system must provide materials in a reliable and flexible way while still supporting assembly stations as much as possible. An additional demand on the materials supply system is to provide all this as efficiently as possible. The performance of the materials supply system is thus of importance in order to meet the requirements of the customer.

1.4 PURPOSE AND RESEARCH QUESTIONS

The purpose of the thesis is to investigate how performance of the materials supply system at Adient can be increased. In order to do so, four research questions are created.

To increase performance in a materials supply system, it should be known how the areas of a materials supply system should be designed:

RQ1: How should the areas in a materials supply system be designed?

Design of the current materials supply system at Adient should be mapped in order to make successful adjustments. The second research question is thus:

RQ2: How is the current materials supply system designed?

To increase performance, performance of the current materials supply system at Adient must be measured; hence the third research questions aims to understand how the current materials supply system is performing:

RQ3: How is the current materials supply system performing?

When performance of the materials supply system at Adient has been measured, areas are selected for performance increase. Research question 4 aims to answer how the target areas can be increased in terms of performance:

RQ4: How can the performance of the materials supply system in the target areas be increased?

1.5 SCOPE

The scope of this thesis is to investigate the materials supply system inside the manufacturing plant, i.e. the materials supply system within the manufacturing plant only. The system boundary is set to materials supply system design from the point of where materials enters the plant, up until storage at the assembly station. Materials supply system design upstream of the manufacturing plant and downstream of assembly will not be considered.

2. METHOD

The method chapter explains how the thesis is conducted. The chapter is divided into six sections; research approach, research strategy, project process, literature review, data collection and reliability and validity.

2.1 RESEARCH APPROACH

There are several ways to perform a research depending on what existing knowledge the prediction and purpose is based on. Bryman and Bell (2011) describe deductive theory approach as the most common way of working with empirical and theoretical data in research. The deductive theory approach entails creation of a hypothesis based on what is scientifically proven in theory, which in turn will be a driver for the data collection process (Bryman and Bell, 2011). In inductive theory approach, the findings from data collections are compared to the theoretical part to confirm or reject the created hypothesis (Bryman and Bell, 2011).

The theory approach used in this thesis is deductive approach, i.e. theoretical data was collected from literature reviews to create the research questions. Subsequently to creation of the research questions, empirical data was collected.

2.2 RESEARCH STRATEGY

In terms of research methodology there are two strategies when conducting research: qualitative and quantitative (Blaxter et al., 2006). In general, a qualitative research consists of data based on subjective forms while the quantitative research are raw data in forms of numbers and calculations (Blaxter et al., 2006). Qualitative data and quantitative data generate different outcomes, thus deciding on the suitable research strategy is important to achieve desired results (Blaxter et al., 2006). Quantitative research is commonly used to compare data of different variables and to review statistics (Hancock and Algozzine, 2015). Blaxter et al. (2006) further explain that quantitative research can be perceived as based on facts and thus considered as more objective than the qualitative research. The qualitative approach is beneficial to use if there is limited knowledge of an identified problem (Hancock and Algozzine, 2015) which aligns with Blaxter et al. (2006) claiming that the qualitative approach is more exploring than the quantitative study. The quantitative approach can be used to collect raw facts and to visualize patterns which can be used for testing and comparing data as well as generating hypotheses (Blaxter et al., 2006). Qualitative approach can be used in the same way, i.e. collecting data from employees at the company which is subsequently used for testing hypotheses and theories (Blaxter et al., 2006). Hancock and Algozzine (2015) describe qualitative and quantitative research from different perspectives, i.e. if the research is based on the perspective from researchers or on the perspective from participants. Qualitative approaches, e.g. by using interviews, provide the perspective of an insider while quantitative approaches, by collecting raw data, provide the perspective of the outsider (Hancock and Algozzine, 2015).

Furthermore, Blaxter et al. (2006) argue that qualitative and quantitative approaches do not necessarily need to be used in isolated contexts but can advantageously be combined. Since the four main data collection techniques, i.e. documents, interviews, observations, and questionnaires all can involve both qualitative and quantitative elements, the close relationship between the qualitative and qualitative approaches becomes evident (Blaxter et al., 2006).

The research approach used for this thesis is the combination of qualitative and quantitative approach as suggested by Blaxter et al. (2006) since both qualitative and quantitative elements were present in the data collection techniques.

2.3 Project process

In this section the process of the project is described in seven steps where the steps are illustrated in Figure 2.1. In step 1 the problem of the project was defined along with purpose and research questions. Four research questions were developed which the thesis aimed to answer. Step 2 of the project process was to conduct a literature review in order to create a theoretical framework. Step 3 of the project process was to create a design model from parts of the literature study in order to understand how materials supply systems should be designed. The design model was subsequently used in step 6 and 7. In step 4, all the areas of the current materials supply system at the company were mapped by observations and interviews. Step 5 of the project process was to measure the areas of the current materials supply system by using performance measurements from the literature study. Materials flow mapping was also conducted to further map the current performance. In step 6, areas from the performance measurements were targeted for performance increase. The areas were targeted by using the design model. Step 7 of the project process was performance increase of the target areas for performance increase identified in step 6. The increase in performance was achieved by using the design model.

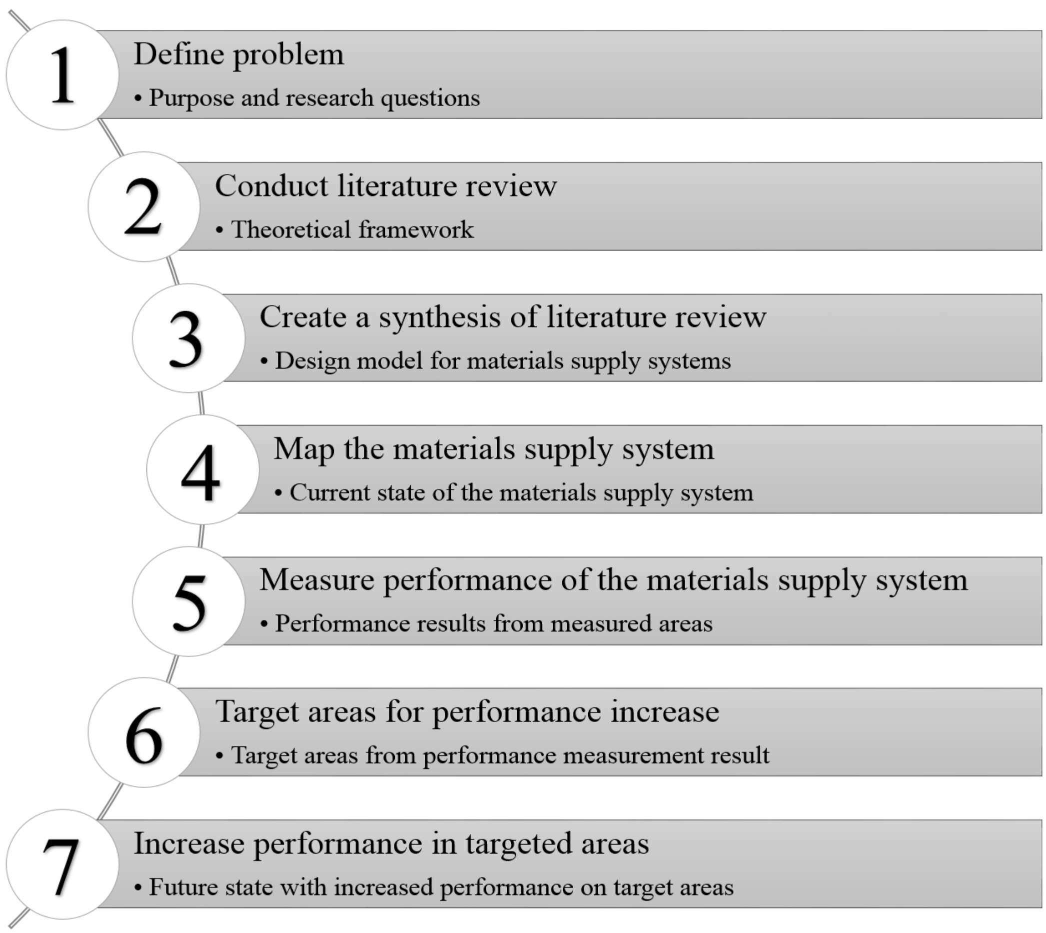


Figure 2.1. The seven steps of the project process.

After the seven steps were conducted, three suggestions that could increase performance in the materials supply system were provided to the company.

2.4 Literature review

The literature review is important since it constitutes the basis on which the research questions are justified and for building the research design (Bryman and Bell, 2011). Furthermore, the use of literature for the selected topic is a way of "developing an argument about the significance of your research and where it leads" (Bryman and Bell, 2011, p. 91).

The literature review conducted is based upon existing literature with different degree of influence on this thesis. The framework for what areas that are included in a materials supply system by Johansson and Johansson (2006) is the basis for the section of materials supply system in the theoretical framework. The work by Hanson (2009) on in-plant materials supply system highly influences the content of the thesis as well, partly due to the "in-plant" delimitation that aligns with this thesis, but also due to the suggested performance measurements for materials supply systems. The performance measurements are used to measure performance of the materials supply system in this thesis. Additional literature also contributed to the thesis but to a lower extent.

2.5 Data collection

There are several ways of conducting data collection. The four main sources of data are: documents, interviews, observations, and questionnaires (Blaxter et al., 2006). In this thesis the data collections methods used were interviews and observations.

2.5.1 Interviews

There are in general three types of interviews; structured, semi-structured and unstructured (Bryman and Bell, 2015). The structured interview, also referred to as standardized interview, is comprised of specific questions and provides fixed answers for the interviewee (Bryman and Bell, 2015). Structured interviews are commonly used in quantitative studies with standardization of questions and answers, thus the variations in this type of interviews are due to real variation and not depending on the context of the question (Bryman and Bell, 2015).

Qualitative interviews are advantageous compared to quantitative interviews in terms of flexibility since the possibility of departing from expected answers is provided (Bryman and Bell, 2011). This enables redirection of focus by asking follow-up questions if the answer provided is not as initially expected (Bryman and Bell, 2011). In qualitative interviewing, there are two types of interviews: unstructured interviews and semi-structured interviews (Bryman and Bell, 2011). In unstructured interviews the interviewer has a topic for the interviewee which may include only one single question for the interviewee to answer and subsequently speak freely about the topic (Bryman and Bell, 2011).

In semi-structured interviews the interviewer has an interview guide with a set of topics and questions for the interviewee (Bryman and Bell, 2011). However, the interviewer is not compelled to follow the interview guide precisely and is allowed to add follow-up questions depending on the answers to obtain as much information as possible (Bryman and Bell, 2011).

Since a combination of quantitative and qualitative research strategies is used in this thesis, semi-structured or unstructured interviews should be selected. Semi-structured interviews were selected to provide a certain degree of structure since some questions were used for multiple interviews, thus allowing comparison of answers for the same question. This would be hard if unstructured interviews were used. The interview guides used for the interviews were customized for each interviewee in order to capture desired information. The relevant stakeholders were interviewed face to face at the company while the interviews were recorded to ensure that all information were captured. The interviewees and the date for interviews are presented in Table 2.1.

Table 2.1. Interviewee and date of the interview.

Interviewee	**Date of interview**
Operations Manager	11th of May
Logistics Manager	3rd of May
Production Manager	24th of April
Packaging Engineer	24th of May
Material Requirements Planner	12th of April

2.5.2 Observations

One of the principles of Lean is that you should go out and see things on your own in order to thoroughly understand the situation (Liker and Meier, 2006). The thesis work was conducted at the company in order to have the possibility of own observations. Since a materials supply system is encompassing and challenging to map without observations, this was a crucial data collection method in the thesis.

2.6 RELIABILITY AND VALIDITY

Reliability and validity are two central aspects for measurements in research studies. Reliability is closely connected to repeatability in research studies, i.e. reliability is achieved if empirical measurements are repeated while providing the same results (Bryman and Bell, 2011). Repeatability and reliability are strongly connected to quantitative research since they are characterized by measures and questioned in terms of stability (Bryman and Bell, 2011). In order for a research study to be reliable, the study must be replicable, i.e. the study process should be explained in great detail and be possible to replicate by someone else (Bryman and Bell, 2011).

Validity concerns the integrity of the generated conclusions from a study and there are several different variants of validity; Measurement, Internal, External and Ecological (Bryman and Bell, 2011). Validity in terms of measurements mainly applies to quantitative research and involves the adequacy of measures. Internal is also commonly applied to quantitative research and concerns the correctness of a causal connection and ecological validity can be applied in both qualitative and quantitative research and concerns the naturalness of the research. External validity is applied in qualitative research and is concerned with if the results of the study can be generalized outside of the context in question. External validity parallels transferability which is a more commonly used term when doing qualitative studies and it represents that the specific findings should be applicable in other contexts (Bryman and Bell, 2011).

In this thesis, measurement validity and external validity is prioritized. Measurement validity is important to assess the adequacy of the measures conducted, e.g. material flow mapping measures. Employees with insight in the areas to be measured were consulted before the measurements were conducted to increase the degree of adequacy. External validity is also prioritized in order to ensure that the results are relevant in other contexts, e.g. other companies. Regarding the external validity, this study is considered as valuable outside this specific context since all manufacturing companies are concerned with performance of their materials supply system in some way.

3. THEORETICAL FRAMEWORK

The theoretical framework starts with an investigation of definitions of materials supply systems, which is followed by an exploration of the areas included in materials supply systems. This is followed by materials presentation at assembly stations, performance of materials supply systems, and materials flow mapping.

3.1 MATERIALS SUPPLY SYSTEM

This section aims to define a materials supply system. There is no unanimous definition of a materials supply system, and its areas are hence not unanimously defined either. Furthermore, the systems that are used in literature to describe material flows in companies are sometimes overlapping thus making it hard to distinguish materials supply systems from other systems.

Jonsson and Mattsson (2009) claim that, as a part of a company's logistics system, the materials supply system is the flow of inbound materials to a company from suppliers. The production system is comprised by the flow of materials inside the company, i.e. during value adding processes and the distribution system is the outbound flow of materials from the company to customers (Jonsson and Mattsson, 2009). This definition provided by Jonsson and Mattsson (2009) is illustrated in Figure 3.1.

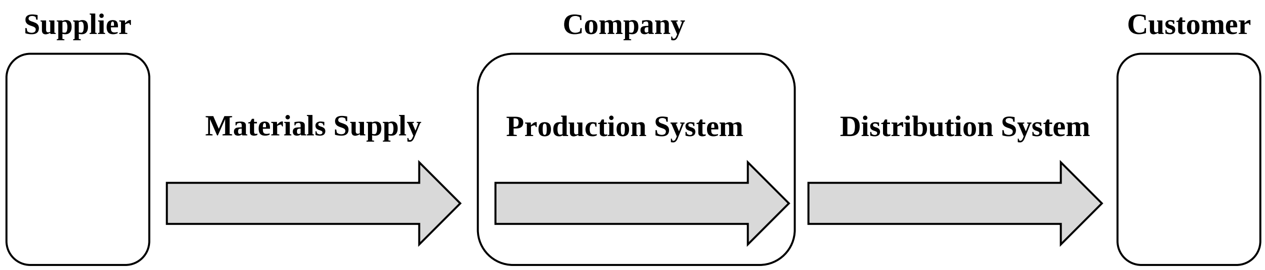


Figure 3.1. Materials Supply System as seen by Jonsson and Mattsson (2009).

Johansson (2007, pp. 390) defines the materials supply system as "… the system that supplies materials from suppliers through the focal company's production to industrial buyers". The flows between and inside plants are included in terms of material and planning and control (Johansson, 2007). The illustrated definition of Johansson (2007) is seen in Figure 3.2. Furthermore, the definition by Johansson (2007) aligns with Johansson and Johansson (2006, pp. 373) claiming that "The MSS comprises activities related to materials flows within as well as between plants, including both the physical flows and the planning and control of the flows".

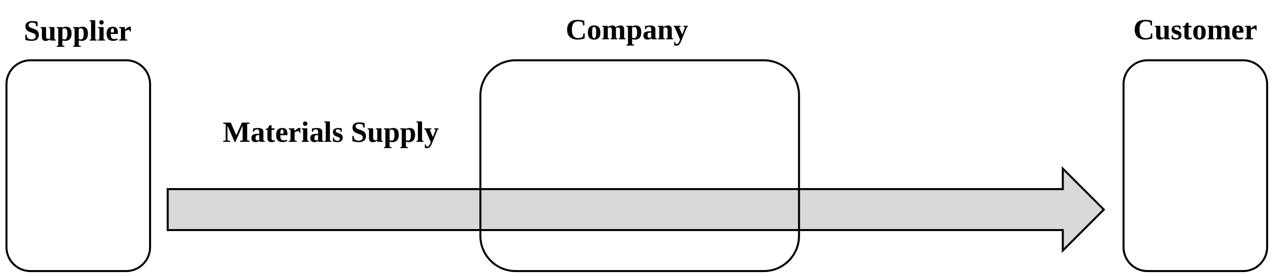


Figure 3.2. Materials supply system according to Johansson (2007).

Hanson (2009, p. 5) refers to in-plant materials supply systems as “the equipment, operations, and principles used for supplying parts to assembly”. This involves the physical handling of parts and packaging, planning and controlling supply, and presentation at assembly stations (Hanson, 2009).

The “in-plant” delimitation is added by Hanson (2009) to emphasize that only the materials supply system inside the plant is considered. Part deliveries from external suppliers are considered as inputs to the material supply system and assembly inside the plant is considered as the customer which the materials supply system is to serve (Hanson, 2009). Illustration of this definition is seen in Figure 3.3.

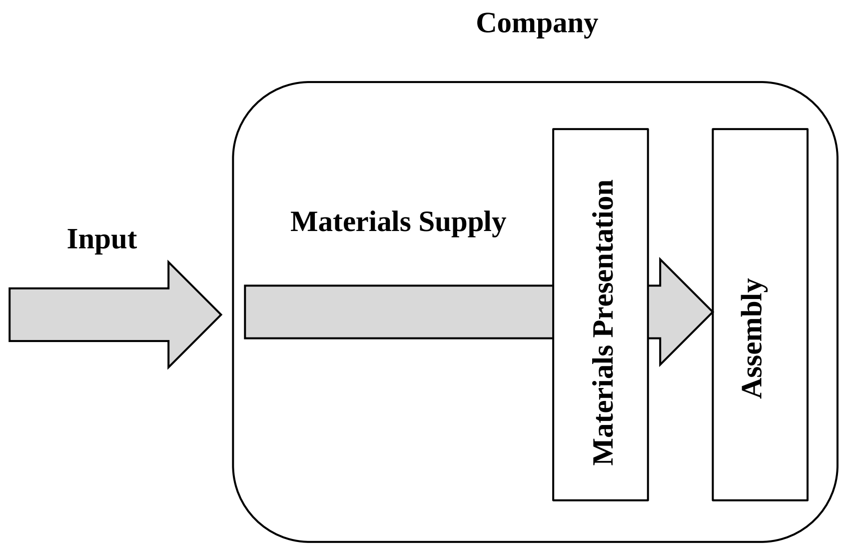


Figure 3.3. Illustration of Materials Supply System definition from Hanson (2009).

As noted, assembly itself is not included in the materials supply system but the presentation of materials at stations are included and is considered as the interface with the customer (assembly is considered as the customer) according to Hanson (2009). To further define the in-plant materials supply system, Hanson (2009) distinguishes it from in-plant logistics and in-plant materials handling. In-plant logistics is considered as more encompassing by including in-plant materials supply, but also planning and control linked to the main product flow and assembly sequence (Hanson, 2009). In-plant materials handling is referring to the physical handling of materials, excluding planning and control, and parts presentation at assembly stations. To clarify, in-plant materials handling is a part of in-plant materials supply, which in turn is a part of in-plant logistics.

The definitions of materials supply system by Hanson (2009), Johansson and Johansson (2006) and Johansson (2007) include the in-plant perspective. The definition by Hanson (2009) is selected for this thesis since it is limited to in-plant perspective and is also distinguished from in-plant logistics and in-plant materials handling, which aligns with the thesis. However, this implies that the definitions by Johansson and Johansson (2006) and Johansson (2007) also will be used since they cover the definition of Hanson (2009) as well due to their broader definition.

3.2 AREAS OF THE MATERIALS SUPPLY SYSTEM

Johansson and Johansson (2006) present a model for materials supply systems containing six areas: materials feeding principles, materials handling, storage, transport, packaging, and manufacturing planning and control.

3.2.1 Materials feeding principles

Materials feeding principle denotes "how the parts are arranged as they are fed and presented to assembly" (Hanson, 2012, p. 2). The entire in-plant materials supply system is integrated with materials feeding principles, i.e. adjustments in these principles will likely alter all areas related to in-plant materials supply (Hanson, 2012). Materials supply operations and receiving assembly operations are examples of operations that can be impacted by the materials supply system (Hanson, 2012). Johansson (1991) presents a definition of three materials feeding principles: continuous supply, batch supply and kitting (see Figure 3.4). The division of these three materials feeding principles by Johansson (1991) is based upon the selection of materials exposure at the assembly station and how the materials are sorted at the station.

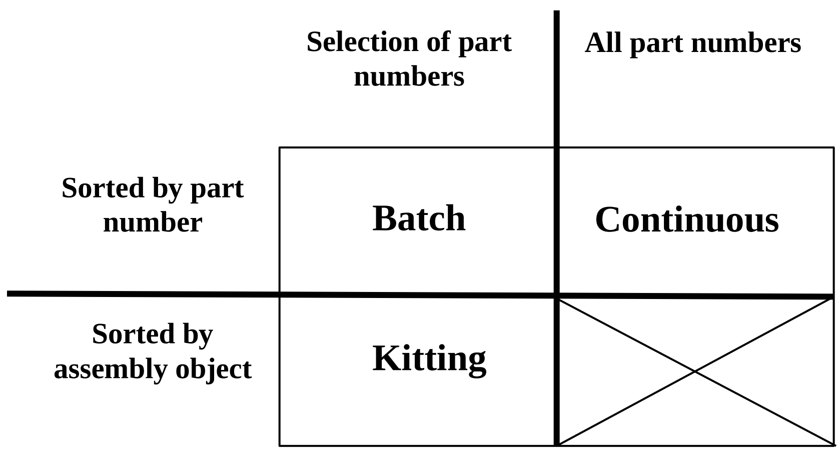


Figure 3.4. Materials feeding principles from Johansson (1991).

3.2.1.1 Continuous supply

In Continuous supply, also referred to as line stocking, materials are distributed to assembly stations in regular packages, i.e. the packaging from the supplier is often used and the materials are not repacked unless it is necessary due to excessive volumes (Johansson, 1991). Each part number is usually stored in separate containers (Hansson and Medbo, 2012). The amount of materials exposed at the station is extensive, thus replenishment is discontinuous (Johansson, 1991; Caputo and Pelagagge, 2011). The benefit of continuous supply is the low replenishment effort and the drawbacks are space requirements due to the high amount of parts (Johansson, 1991) and the high materials holding costs (Caputo and Pelagagge, 2011). Furthermore, continuous supply is not suitable for variable product mixes since it creates high requirements on control and coordination (Caputo and Pelagagge, 2011).

3.2.1.2 Batch supply
Batch supply is a limited amount of materials, for a certain number of assembly objects that are being supplied to an assembly station (Johansson, 1991). Compared to continuous supply, fewer parts are displayed at the station, and more coordination is required for replenishment (Johansson, 1991). Batch supply requires more administration compared to continuous supply, but require less space at the assembly station (Johansson, 1991).

3.2.1.3 Kitting
Materials are delivered in kits where each kit contains parts required for one assembly object (Johansson, 1991). The definition by Bozer and McGinnis (1992) is "A kit is a specific collection of components and/or subassemblies that together (i.e., in the same container) support one or more assembly operations for a given product or 'shop order'" (pp. 3). The process of kitting is comprised by collection of the components at storage locations and component preparation if necessary, before they are placed in containers (Hua and Johnson, 2010). The preparation process of components could encompass removal of package material, counting, cutting, bending etc. (Hua and Johnson, 2010). Bozer and McGinnis (1992) claim there are stationary kits and travelling kits; the former remains at the same station during usage, and the latter travels along the product through multiple stations. The product and the kit can either share container or being stored in separate containers where the kit follows the product (Bozer and McGinnis, 1992).

Advantages of kitting include reduction of WIP (Work-In-Process) and space requirements at assembly stations and the fewer components stored at stations results in less effort during product changeovers (Bozer and McGinnis, 1992; Caputo and Pelagagge, 2011). Kitting further increase flexibility and control due to that only the kits are handled and routed in assembly and also facilitates materials delivery since fewer individual containers are replenished (Bozer and McGinnis, 1992). The time for operators to collect materials can also be reduced by kitting compared to if racks are used, since there is a relationship of required time for collecting materials and walking distance, thus the number of visits to the component racks are of importance (Hanson and Medbo, 2012). Additional benefits include the facilitation of robotic handling at stations (Bozer and McGinnis, 1992). The limitations of kitting include time and effort for preparation (Hanson and Brolin, 2013; Bozer and McGinnis, 1992) and an increase in required storage space (Bozer and McGinnis, 1992). Kitting can reduce man-hour consumption in assembly, but due to the additional handling of kits the overall man-consumption can increase (Hanson and Brolin, 2013). More limitations include that if components are defective in a kit the kit must be reassembled and that part shortages could lead to that missing components are picked from other kits (Bozer and McGinnis, 1992). Due to this, the materials handling is conducted twice, first the process of picking from another kit, and then the process of replenishing the kits from which parts were picked from (Bozer and McGinnis, 1992). Caputo and Pelagagge (2011) claim that kitting is beneficial to use in environments where the amount of components per assembly is high, e.g. in mass customization.

3.2.1.4 Sequencing
As seen in Figure 3.4, sequencing is not included in the model by Johansson (1991). However, sequencing is a common materials feeding principle in manufacturing companies and is thus included in this framework. The act of sequencing is to feed materials to the assembly stations according to a certain sequence (Ding and Sun, 2004). By sequencing, parts are presented to the operators in the order of usage (Sali et al., 2015). Sequencing can be referred to as a stationary kit, containing the required parts for one

single component of a certain type (Sali et al., 2015). Since sequencing can be viewed as a stationary kit, the benefits and drawbacks of kitting aligns with sequencing.

Sequencing is commonly used together with mix-model assembly which is frequently applied in the automobile industry due to component variations (Ding and Sun, 2004). Sequencing differs from continuous supply, batch supply and kitting, since it is usually not applied as the main feeding principle in assembly plants, but rather as a complement to other feeding principles (Hanson, 2012). Sequential supply is commonly applied to parts that have a high amount of variants (Hanson, 2012). Sequencing is typically the preferred materials feeding principle for heavy components in many variants (Wänström and Medbo, 2009).

3.2.1.5 Coupling materials feeding principles

Materials feeding principles are not exclusive, thus it is possible to couple the different principles. According to Johansson (1991), continuous supply, batch supply, and kitting are possible to apply simultaneously depending on the characteristics of the materials that are supplied. Saab automobile is one example that coupled four materials feeding principles in final assembly (Ellegärd et al., 1992). Variant materials were fed by kitting, routine materials by batching, small materials by continuous supply, and some materials by sequencing (Ellegärd et al., 1992).

3.2.2 Materials handling

Maynard and Zandin (2001) define material handling methods as how materials are moved between an origin and a destination. Methods of materials handling are comprised by three elements; what transport unit or container that is used for the move, the system used to move the part, and the equipment being used in order to conduct the move (Maynard and Zandin, 2001). Transporting units are referred to as "unit loads" and are described in packaging, i.e. section 3.2.5.2. This section focus on the materials handling system and the characteristics of materials handling equipment seen from a system perspective. The transport section on the other hand (section 3.2.4) is aimed at in-plant transport, i.e. transport suitable inside manufacturing plants, which is the scope of the thesis.

The materials handling system refers to how the moves are connected geographically and physically and is divided into two categories; direct and indirect systems (Maynard and Zandin, 2001). In direct systems, one unit (e.g. a pallet) of materials is moved directly from origin to destination, usually by the minimum distance possible. Movements in indirect systems are characterized by consolidation of units along predefined routes with multiple stops, e.g. trains of tow carts. Selecting direct or indirect systems depends on the distance from origin to destination and the flow intensity of materials (Maynard and Zandin, 2001). The direct system is suitable with a short or moderate distance and high flow intensity. The indirect system is suitable for movements with moderate or long distances and moderate or low flow intensity since movement costs are spread across all materials (Maynard and Zandin, 2001).

The equipment that is used to perform movement is mainly decided by the characteristics of the materials, e.g. volume, weight, length, size, shape and consistency (Lumsden, 2007). The movement distance and the intensity of materials will determine what equipment that should be used as illustrated in Figure 3.5 and Figure 3.6 respectively.

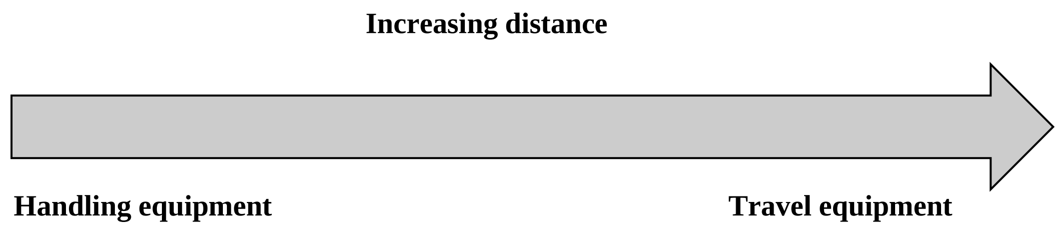


Figure 3.5. Relationship between distance and the purpose of the equipment.

For short distances the equipment should be adapted for handling of the materials, i.e. facilitating rapid load and unloading (Maynard and Zandin, 2001). Equipment adapted to handling is expensive to use for longer distances due to limited load capacity and low travelling speed (Maynard and Zandin, 2001). The equipment suitable for longer distances is more expensive for loading and unloading due to the bigger load but cost efficient for long distances (Maynard and Zandin, 2001).

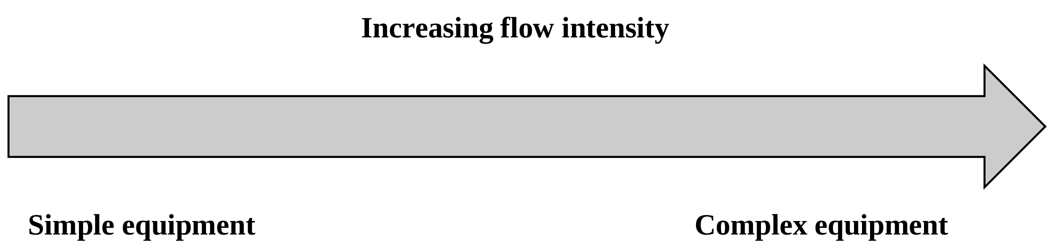


Figure 3.6. Relationship between flow intensity and equipment complexity.

For low flow intensity, simple equipment is suitable due to its high direct operating costs, and low purchase and ownership costs (Maynard and Zandin, 2001). However, the direct cost required to operate the equipment will make it expensive to use for high flow intensity (Maynard and Zandin, 2001). The complex equipment suitable for high flow intensity has opposing characteristics to simple equipment, i.e. high purchase and ownership costs, but low direct operating costs where the low direct operating costs are due to mechanization or automation (Maynard and Zandin, 2001). By combining the different characteristic of equipment, four general classes of materials handling equipment emerges as seen in Figure 3.7.

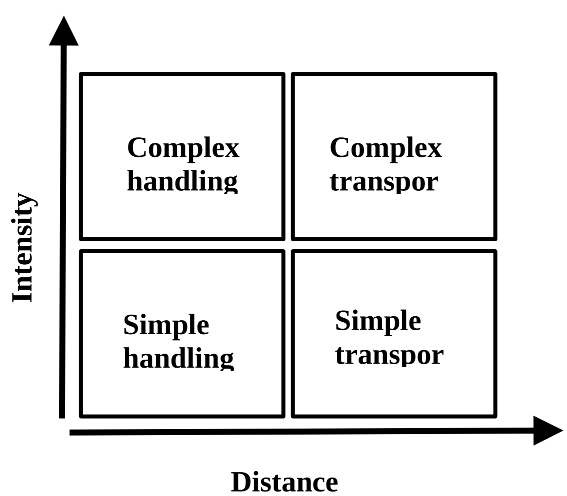


Figure 3.7.The four general classes of equipment, based on Maynard and Zandin (2001).

The scope of the thesis is materials handling in manufacturing plants, i.e. low distance and high flow intensity, thus a direct system. The materials handling equipment suitable for low distances and high flow intensities is, as seen in Figure 3.7, complex handling equipment. Section 3.2.4 covers transport specifically aimed at low distances and high flow intensity, which in this thesis is in-plant transport.

3.2.3 Storage

Storage is important in the materials supply system since it is the physical containment of units in warehouses, components near assembly lines, and finished products after assembly lines (Frazelle, 2001). Storage consists of storage equipment, e.g. a shelf or a rack, with the function to store units between transports and processes (Maynard and Zandin, 2001). The storage equipment must be compatible with the physical form of the unit that is to be stored (Maynard and Zandin, 2001). Storage equipment can be cheap in the form of a floor but also expensive as in an automated storage system (Maynard and Zandin, 2001). The most cost-effective storage equipment depends on the quantity of held materials and materials flow intensity (Maynard and Zandin, 2001). There are, according to Maynard and Zandin (2001), different types of inventory: raw materials, work-in-process and finished goods (see Figure 3.8). Raw materials are received from suppliers and require processing and are thus moved to storage. Work-in-process consists of all goods being processed in any of the activities between raw materials storage and finished goods storage. The finished goods storage is comprised of all completed goods awaiting shipment to customer and helps the company to meet fluctuations in customer demand.

Figure 3.8. Inventory in the manufacturing process.

3.2.3.1 Storage locations

Functions of storage include the abilities to meet demand during fluctuations, to allow variations in processes and to ensure smooth operations in the supply chain (Maynard and Zandin, 2001). The better planning of demand and prevention of uncertainties the less storage is needed (Maynard and Zandin, 2001) Maynard and Zandin (2001) present three different storage location alternatives; *central storage, in-line storage and no storage.* All the three storage location alternatives could be used in materials supply systems in manufacturing plants, thus this is of focus in this section.

Central storage and supermarket

Centralized storages and supermarkets consist of one or several areas where stored items are consolidated and subsequently transported to a point-of-use storage. This approach provides high inventory control, reduce space requirements at the production floor, and efficient use of handling labor. Central storage may also work as a point between assembly line and supplier as an area where the customer takes ownership of the unit and as an area where units are repacked into other containers, in kitting boxes or prepared somehow for the assembly line.

In-line and point-of-use storage

In-line and point-of-use storage is placed along the assembly line and is a decentralized storage and is optimal for keeping the distance minimized to assembly stations. The inventory levels in this type of storages is visually controlled, thus no information systems are used, i.e. “floor stock”. When materials are in floor stock they are no longer in the storage system, hence this type of storage is preferably located close to the working stations on the assembly lines, e.g. buffers in high-volume production. The inventory levels in point-of-use storage are based on balance in production lot size, run frequency, size of container and its capacity, and the time required for transporting materials. Replenishment is made from the central storage.

Continuous flow without storage

Continuous flow without storage has no units held up between operations, with no handling to and from storage and no tied up capital in storages, thus the cheapest solution. Requirements include that previous operations must have the same production rate. Continuous flows are vulnerable to variabilities in operations, transfer time, downtime and processing hours or shifts.

3.2.3.2 FIFO

The FIFO-principle (First-In-First-Out) is a picking principle used in storage (Lumsden, 2007). The principle states, as the name suggests, that the first materials to arrive in storage is also the materials to be picked first (Lumsden, 2007). FIFO is suitable for straight flows through storage, i.e. arrival and shipping are not conducted at the same location (Lumsden, 2007).

3.2.4 Transport

Transport as a concept can be viewed as multiple resources in movement (Lumsden, 2007). The resources refer to the goods and the load carrier. Transport adds value to products in two ways, the first is by moving products from the assembly line to the place where they are needed which creates place utility (Johansson and Johansson, 2006; Lumsden, 2007). The second way transport adds value is by creating time utility, i.e. products are moved at the correct time and with the correct speed from storage to the point where the products are needed (Johansson and Johansson, 2006; Lumsden, 2007). The focus in this section is on in-plant transport.

3.2.4.1 In-plant transportation

In-plant transport addresses what the name implies, i.e. transport inside the plant. Baudin (2004) claims that regarding in-plant transport, the greatest improvements are achieved if trips are eliminated rather than the distance. Reducing a transport distance between two assembly lines by 50 % makes little improvement compared to if the two assembly lines are integrated and hence eliminating the transport completely (Baudin, 2004). The first step in analyzing in-plant transport is thus to measure the frequency of transports and the volume being transported between two points, e.g. frequent and high volume transport could push for layout changes to eliminate the trips (Baudin, 2004). On the contrary, low volume and low frequency transport between two points may not be suitable as an improvement target (Baudin, 2004). If high frequency and high volume transports are identified, the second step in the analysis is to follow the shipments and observe what happens to it, e.g. by measuring how frequent the shipment is being touched during transport (Baudin, 2004).

The transport alternatives used for in-plant transport should also be evaluated to find improvement potential, e.g. forklifts should be used to move large bins since it is not economic to use forklifts for smaller bins (Baudin, 2004).

In Table 3.1, benefits and drawbacks of the different in-plant transport alternatives from Baudin (2004) and Maynard and Zandin (2001) are consolidated for a perspicuous view.

Table 3.1. Benefits and drawbacks of in-plant transport alternatives. Baudin (2004) = B, Maynard and Zandin (2001) = MZ.

Transport alternative	**Benefit**	**Drawback**
Forklift	B: Versatile and Powerful. MZ: Able to travel great distances, can access stacks of pallets and at high heights. It can carry up to several tons.	B: High purchase price, requirements on the driver, restrictions in terms of package sizes (i.e. not too small).
Pallet jacks	B: Do not require special training to operate, lower price compared to forklifts. MZ: Beneficially used on receiving docks to load and unload trucks.	B: Cannot access stacks of pallets, i.e. upper- and top racks of pallet stacks.
Push carts	B: Cheap, safe, can be operated by anyone in narrower aisles compared to forklifts.	B: Limited transport capability, not suitable for pallet loads.
Tuggers and trains of tow carts	B: Possibility to transport high volumes of items in box quantities to multiple locations with short intervals. MZ: Can tow a number of carts long distances.	B: Not suitable for pallet loads, long trains could be difficult to operate in narrow aisles.
Networks of conveyors	B: Continuous flow in small quantities, able to handle high volumes. MZ: Available in multiple variants and can convey a variety of materials with different characteristics.	B: Expensive, mainly used to transport parts within assembly lines - not between them unless volumes are high and steady. MZ: All variables need to be known far into the future before choosing variant.
Automated Guided Vehicles	B: No direct requirements of humans to operate the vehicle. MZ: Automatically picks and delivers materials from assigned locations. These vehicles come in multiple varieties.	B: Focus is aimed at the movement itself which is not the main concern. Main concern is preparing, loading, unloading and presenting materials. MZ: Requires an advanced guidance system and a control system that communicate with the AGV.

Furthermore, defining transport aisles is an important aspect to consider for in-plant transport systems. If the shop-floor lacks marked transport aisles, it could lead to that materials, equipment or other items end up blocking the transport aisles (Baudin, 2004). By having unmarked aisles it is not clearly stated where vehicles are operated, thus increasing the risks of accidents (Baudin, 2004).

3.2.5 Packaging

Everything that concerns packages and unit loads are included in this category. When units are received at manufacturing plants they arrive in packages that are optimized for the needs of the supplier. Single and multiple units may thus be repacked in new containers that are optimized for the manufacturing plant instead (Frazelle, 2002). Packaging is considered as an important area in supply chains since it surrounds, embraces and protects the unit inside all the way from commodity through the assembly processes in production to the final customer arriving in an attractive package (Chan et al., 2006; Robertson, 1990).

3.2.5.1 Packaging function

To make decisions regarding packaging it is necessary to know the functions and understand how it should perform. The suggested functions differs depending on the author. Robertson (1990) suggests the following six functions which are considered as suitable for the thesis; *Containment*, *Protection*, *Apportionment*, *Unitization, Convenience* and *Communication.* The six functions are described in Table 3.2.

Table 3.2. Functions of packaging based on Robertson (1990).

Function	**Description of the function**
Containment	Basic function. A wrap that contains the product and makes it possible to move.
Protection	Primary function. To protect the product from the outside environment, and to protect the environment from the product.
Apportionment	Desirable consumer sized packages. Apportioning in the right dimensions is important in mass-production due to the high volumes.
Unitization	Unitizing function. Consolidation of several packages into more few and appropriate packages to handle, e.g. several packages in one unitized pallet. Sometimes also a protective package is wrapped around the original package.
Convenience	Packaging allows the product to be experienced in a convenient way, e.g. toothpaste and soap pump.
Communication	The package talks to the customer. There are multiple different packages and designs that communicates the product inside or at a distribution center where the package carries a label communicating the content.

3.2.5.2 Unit loads

A single mass to be handled, i.e. transported or moved between two locations, is considered as one unit load (Tompkins et al., 2010). A unit load can consist of multiple boxes, containers or pallets enclosed by straps, tape or shrink wrapping etc. Benefits from several containers enclosed in one unit is that handling and transport are conducted more efficiently (Tompkins et al., 2010). However, there is trade-off between big and small unit loads since larger unit loads can carry more and need fewer transports but require more available space and increase the amount of work-in-process (Maynard and Zandin, 2001).

3.2.5.3 Pallets

Pallets comes in various designs and sizes and there are multiple types and materials available for pallets. Tompkins et al. (2003) list different pallet types and corresponding characteristics which is summarized in Table 3.3.

Table 3.3. Summary of pallet types and characteristics from Tompkins et al. (2003).

Material	**Characteristics**	**Typical applications**
Wood	Medium durability with high repairability. Material is biodegradable and recyclable.	Diverse area of use: grocery, automotive, durable goods, hardware
Pressed Wood fiber	Medium durability but low repairability	Bulk bags, order picking, printing, building materials
Corrugated fiberboard	Low durability and low repairability. Biodegradable and recyclable material.	Used for one-way shipping in grocery, lightweight paper products and industrial parts
Plastic	High durability with medium repairability. Recyclable material.	Captive or closed loop systems, automotive
Metal	High durability and medium repairability.	Captive or closed loop systems, heavy equipment, aerospace

Lumsden (2007) provide several benefits of using pallets with collars. The usage of collars enables stacking of pallets since the collar supports the pallet above. Pallet with collars also facilitate the creation of transport units, e.g. with bulk loads that are harder to load efficiently. However, such loads usually requires additional packing material such as plastic foil. Furthermore, the collars of the pallet protects the goods from damage or theft during transport.

3.2.5.4 Containers

In terms of containers there are disposable and reusable containers where the former is commonly made of carton and the latter of plastic (Baudin, 2004). Reusable containers, which provide several benefits compared to the traditional carton, comes in multiple variants. Three typical reusable containers are stackable containers, nestable containers and collapsible containers (Baudin, 2004). Nesting, which allows empty containers to be inserted in other empty containers, combined with stacking reduces materials handling (Tompkins et al., 2010). A benefit of using reusable containers of plastic is that packing quality is higher since they offer better protection against handling damages compared to corrugated disposable cardboard boxes (Baudin, 2004). In most cases, the total cost of using reusable containers is lower compared to disposable containers, but it depends on the purchase price of the two and the transport frequency (Baudin, 2004). Furthermore, reusable containers do not generate waste to the same extent as disposable containers, thus an environmental benefit follows with reusable containers (Baudin, 2004).

3.2.6 Manufacturing planning and control

The concept of manufacturing planning and control is encompassing. Jonsson and Mattsson (2009, p. 6) define manufacturing planning and control as "one part of the subject area of logistics, often defined as planning, development, coordination, organization, management and control of materials flows from raw materials suppliers to end users". In manufacturing companies there are multiple planning levels and a common planning practice is "Manufacturing Resource Planning" involving all planning levels except the highest planning level, i.e. company strategy and goal (Jonsson and Mattsson, 2009). Manufacturing Resource Planning is illustrated in Figure 3.9.

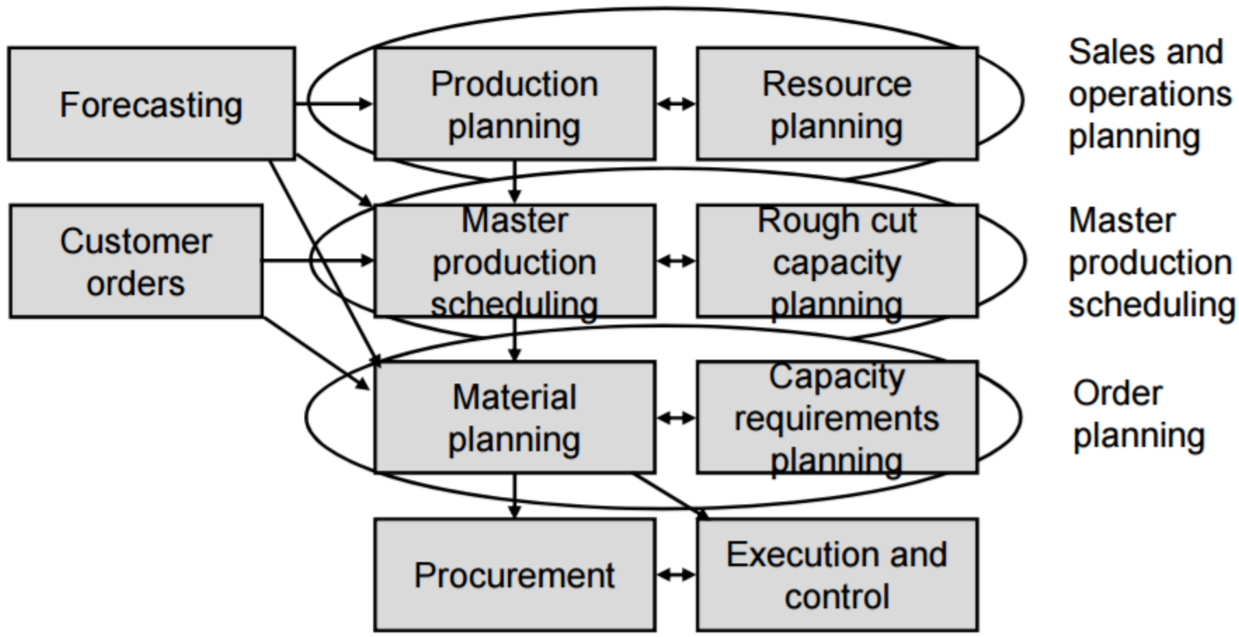


Figure 3.9. Manufacturing Resource Planning, from Jonsson and Mattsson (2009).

Manufacturing Resource Planning has two perspectives; *the materials perspective* which is the left column, i.e. Production planning down to Procurement, and the *capacity perspective* which is the right column, i.e. Resource Planning down to Execution and Control. On short planning horizons, the materials perspective has more significance than capacity planning and vice versa (Jonsson and Mattsson, 2009).

Finnsgård (2013) claims that activities performed in materials supply systems in terms of executing and controlling materials flows are mainly comprised of administrative tasks, e.g. bar-code scanning, handling kanban cards and ordering materials. The materials ordering can either be by pushing a button or by using computer terminals (Finnsgård, 2013). The focus in this section is thus on materials planning.

The central part of materials planning is to ensure, in a cost effective manner, that demand is matching supply as larger discrepancies either leads to excessive stocks or shortage in materials (Jonsson and Mattsson, 2009). The act of balancing supply and demand is comprised of two dimensions: quantity and time. The quantity dimension refers to supplying the correct quantities according to demand, and the time dimensions refers to supplying materials at the correct point in time when demand occurs (Jonsson and Mattsson, 2009). Aligning supply with demand in terms of right quantities is usually the smaller problem compared to the synchronization of supply and demand at the right point in time (Jonsson and Mattsson, 2009). Synchronization too early in time will increase the tied up capital and too late leads to shortages (Jonsson and Mattsson, 2009).

3.2.6.1 Materials planning methods

To facilitate synchronization of supply and demand when planning for manufacturing and purchasing orders, there are several materials planning methods available. The common characteristic of the methods is that they address the time dimension, i.e. at what point in time orders starts or are sent to suppliers and at what time inbound delivery takes place (Jonsson and Mattsson, 2009). The environments in which materials planning methods are used can be divided into push and pull (Lumsden, 2007). A commonly used materials planning method for push environments is *Materials Requirements Planning (MRP)* (Lumsden, 2007) and for pull environments two common variants of re-order points are the *two-bin system* and *kanban* (Lumsden 2007; Jonsson and Mattsson, 2009).

Materials requirements planning

Materials requirement planning (MRP) is a planning method used for production and inventory management (Ptak and Smith, 2011). MRP aims to answer three questions; (1) What to make and buy, (2) the amount to buy and make, and (3) at what point in time to buy and make it (Ptak and Smith, 2011). In order to answer these questions MRP systems use the data of current stock levels to calculate the required amount of materials and at what point in time the materials are needed (Ptak and Smith, 2011). MRP is suitable to use for parts with dependent demand and especially for parts with occasional but large demand (Axsäter, 1991). According to Axsäter (1991), there are prerequisites in order to conduct MRP which are;

- Production software, incorporating production plans for end-products with a time horizon longer than total lead-time from purchase to final product
- Access to demand for all parts, including spare parts
- Documentation providing the structure of sub-parts included in other parts
- Data of current stock levels, active orders and backlogs should be available
- Lead-time for each SKU must be available

Re-order points

Re-order point is the most commonly used planning method and is built upon that a new order should be placed when the stock level has declined to the order/re-order point (Lumsden, 2007; Jonsson and Mattsson, 2009). The stock level should from this point and until order delivery, cover for the demand during the lead-time plus the safety stock (Lumsden, 2007; Jonsson and Mattsson, 2009). Benefits of the re-order point system includes that it is easily understood and the possibility to use historic data to decide the re-order point, i.e. forecasted future demand is not a necessity (Jonsson and Mattsson, 2009). Re-order point systems are suitable to use for items that have short lead-times and rather steady demand, e.g. screws (Jonsson and Mattsson, 2009). However, re-order point is usually the only alternative if the demand is unpredictable, e.g. for spare parts, since no other method is better suited (Jonsson and Mattsson, 2009). As mentioned earlier, two common variants of the re-order point system, used in pull environments, are kanban and two-bin system which are explained below.

Kanbans are used as communication methods in pull systems to facilitate agreements i.e. to only send materials when the customer is ready for it (Liker and Meier, 2006). Kanban thus control inventory and comes in different forms, e.g. cards, empty spaces, carts, or any other way for the customer to send a signal that new materials can be sent (Liker and Meier, 2006). The form of kanban depends on the circumstances, e.g. if supplier and customer lack direct visual contact, cards or electronics signals would be preferable while an empty space is not (Liker and Meier, 2006). The container quantity in a kanban should not be too big since a reduction in quantity will increase flexibility in the replenishment process, but also reduce size of the work area and waste (Liker and Meier, 2006).

The two-bin system, or bin-system, is a physical form of the re-order point where usually two-bins of different sizes are used (Jonsson and Mattsson, 2009). Materials withdrawals are conducted from the larger bin until depletion and when this occurs an order for new materials is placed (Jonsson and Mattsson, 2009). Subsequently, withdrawals are made from the smaller bin which contains the amount of materials corresponding to demand during lead-time plus safety stock, until arrival of the new materials (Jonsson and Mattsson, 2009). The two-bin system is suitable to use for class C-products from the ABC-classification (Stevenson, 2005).

3.2.6.2 ABC-classification

Inventory classification is conducted since it would be unrealistic to allocate equal inventory management resources to all items, e.g. equal inventory management resources to nuts and bolts as to entire engines. The ABC classification is used to allocate inventory items in terms of monetary investments, profit potential, sales or usage volume, or stock out penalties (Stevenson, 2005). A common way to classify inventory items by using ABC-classification is to multiply the annual volume of the item with its cost (Flores and Whybark, 1988; Jonsson and Mattsson, 2009). Stevenson (2005) refers to this value as “annual dollar value”. Annual dollar value is subsequently used to group items into A, B and C where A is the most important items, B is moderately important and C is the least important (Stevenson, 2005). In a typical ABC-classification, A-items constitute approximately 10-20 % per cent of the total number of items, but around 60-70 % of the annual dollar value (Stevenson, 2005). C-items on the other hand usually account for 50-60 % of the total items but only 10-15 % of the annual dollar value (Stevenson, 2005).

The ABC-classification can be useful when designing materials supply systems. According to Stevenson (2005), A, B and C items should be assigned different control efforts. For A-items there should be frequent reviews of stock levels to ensure control of withdrawals in order to reach high customer service levels. C-items on the other hand should be assigned control methods that do not require much resources, e.g. two-bin system and bulk orders, while B-items are assigned control methods between the two.

3.3 MATERIALS PRESENTATION AT ASSEMBLY STATIONS

How materials are presented at assembly stations is a central area to consider since the scope of the thesis is limited to the materials supply systems inside the manufacturing plant. Materials presentation is the final step of materials handling before materials are assembled onto the product and how materials are presented at assembly stations influence productivity and quality (Baudin, 2002). Presentation of materials to assembly stations should be within arm’s reach, unpacked with the smallest dimensions facing out and placed in way that facilitates installation (Baudin, 2002). Another important aspect to consider is to ensure that materials are presented in a way that reduces the risk of confusing the operator. Defective products are the result if materials are confused at the assembly station (Baudin, 2002). Finnsgård et al. (2011a) further argue that how materials are presented impacts the performance in terms of space, non-value adding work and ergonomics. In assembly, the goal is to minimize the non-value adding time in order to make value adding time as big as possible of the total time.

Value adding time is the time from conducted activities which add value to the product (Finnsgård, 2013). Value adding activities in assembly operations are either assembly or pre-assembly (Finnsgård, 2013). One central part of non-value adding activities is materials handling which can be further divided into; walking to fetch materials, picking preparation, picking, package handling, and line feeding activities conducted by the operator (Finnsgård, 2013). The reason why non-value adding time should be eliminated for operators is due to that assembly time is more expensive compared to materials handling time since assembly work is serial and materials handling work is parallel (Baudin, 2002). One added second of unscheduled work for one operator makes all the remaining operators have to wait that extra second for every product assembled, i.e. if hundreds of products are assembled and each shift requires hundreds of operators, the added labor time is extensive (Baudin, 2002). However, adding one second to a materials handler does not affect the remaining materials handlers due to the parallel work in contrast to the serial work on the assembly line.

The results from the study by Finnsgård et al. (2011a) show that picking time for parts are reduced to half the initial picking time by using smaller containers instead of pallets. Smaller containers enable materials to be presented closer to the assembly object which reduce the walking distance, hence reducing picking time as well (Finnsgård et al., 2011a; Finnsgård, 2013). The movement where operators turn 180 degrees in order to fetch materials located behind them is referred to as “washing machine” movements by Baudin (2002) and is illustrated in Figure 3.10.

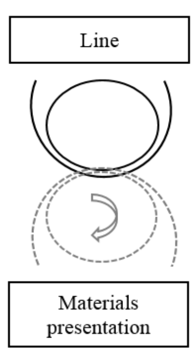


Figure 3.10. “Washing machine” movement.

If possible, washing machine movements should be avoided since it requires time from the operator which could be used for assembly instead. A solution to avoid washing machine movements is provided by Baudin (2002) where a materials supermarket is used to deliver materials in narrow flow racks piece-by-piece to the operator. The operator does not need to turn around since the materials arrive at the exact same location in the flow racks. Wider flow racks are used simultaneously which deliver kits of additional materials prepared by a materials handler (Baudin, 2002). The operator knows exactly where to pick materials due to the narrower flow racks and can thus avoid the washing machine movement (Baudin, 2002).

Regarding deliveries of materials to assembly stations, deliveries should be conducted in quantities that align with consumption rates and at fixed intervals (Baudin, 2002).

3.4 PERFORMANCE OF MATERIALS SUPPLY SYSTEMS

In order to make appropriate decisions of how options in the areas of the materials supply systems should be selected, it is important to understand how the materials supply system should perform (Hanson, 2009). How to measure performance differs in the reviewed literature. Slack and Lewis (2008) judge performance of operations (operations is defined as “the activity of managing the resources and processes that produce and deliver goods and services”, pp. 1) based on five performance objectives: quality, speed, dependability, flexibility and cost. In terms of materials supply systems, the speed dimension is mainly of interest regarding materials supply to external customers according to Hanson (2009). Speed is relevant for in-plant materials supply systems when it comes to supporting other dimensions, e.g. cost efficiency and delivery reliability according to Hanson (2009). Since the scope of the thesis is in-plant materials supply, the performance measurements selected by Hanson (2009) suitable for in-plant materials supply systems are used. The four performance measurements presented by Hanson (2009) are: *reliable materials supply, efficient handling in the materials supply operations, support to assembly operations, and variant and volume flexibility*.

3.4.1 Reliable materials supply

Key objectives for materials supply systems include the ability to provide the correct materials, in the right quantities and at the right time to assembly (Hanson, 2009). Absence of correct materials frequently leads to interruptions in assembly and thus delays in production which is costly (Hanson, 2009). An additional key objective is to ensure that the materials delivered are delivered in a satisfying condition to assembly (Hanson, 2009). To achieve this, packaging, handling equipment and handling principles should be designed to prevent materials from damages and since the characteristics of materials differs, the requirements may be different (Hanson, 2009).

3.4.2 Efficient handling in the materials supply operations

Monetary measurements and physical data are two different approaches of measuring efficiency (Öjmertz, 1998). The advantage of physical data is the higher stability and the possibility of making a closer connection between physical data and materials flows (Öjmertz, 1998). Physical data as measurement enables a direct connection to execution of activities along a materials flow that reflect the resource consumption (Öjmertz, 1998). Such physical data could be time consumption or the amount of operations in terms of materials handling (Öjmertz, 1998). Materials handling operations are in this case referred to as lifting or putting down a unit materials and potentially with transport in-between (Öjmertz, 1998). The amount of storage points in the materials flow should be minimized (Hanson, 2009). Since inventory requires materials handling, a reduction in the amount of storage points reduce materials handling (Maynard and Zandin, 2001). An additional aspect to consider in terms of efficient handling in the materials supply operations is space. Space should be used efficiently in terms of materials handling since it is linked to costs (Maynard and Zandin, 2001).

3.4.3 Support to assembly operations

The line should be supplied with a set amount of materials in a set time interval that is based on demand (Baudin, 2002). The support to assembly operations is important, e.g. how materials are presented during delivery impacts on productivity and quality of assembly operations (Baudin, 2002). Materials should be presented in certain ways to reduce unnecessary work and maximize value-adding time for the operator, e.g. unpacked with the smallest dimension towards the assembler and within arm's reach to facilitate assembly operations (Baudin, 2002). Kitting and point-of-use storage can beneficially be used in parallel, the kitting should be performed before the assembly and in boxes adapted to what it should contain (Baudin, 2002).

3.4.4 Variant and volume flexibility

The materials supply system must be able to support the flexibility required from the production system, i.e. if the production system has many different variants the supply system need to have the ability to supply all these variants to where they are needed (Hanson, 2009). Four types of flexibility is provided by Hanson (2009). The first type of flexibility a materials supply system should be able to support is in terms of volume, which represents the materials supply system's ability to handle variations in production volumes. Product mix is the second type of flexibility which represents the materials supply system's ability to handle the amounts of different products. The third flexibility type is in terms of modifications, which represents the materials supply system's ability to handle any modification in the product. The fourth flexibility type is in terms of new product introductions, which represents the materials supply system's ability to handle introduction of new products (Hanson, 2009).

3.5 MATERIALS FLOW MAPPING

Finnsgård et al. (2011b) have developed a tool referred to as Materials Flow Mapping (MFM) based on value stream mapping. MFM is used to describe materials flows through supply chains by schematic illustrations and enables assessment of materials flows performance variables (Finnsgård et al., 2011b). The authors provide a methodology containing seven steps of how materials flow maps are compiled where the steps are presented below.

Decide on the study object, scope, and requirements

Deciding on the scope is important in since it decides the appropriate length of the flow to be studied and the requirements from the end user which is highly influencing the materials flow design.

Data collection

The first important decision in this step is to choose if the flow should be followed in an upstream or downstream direction. The recommendation is to follow the flow downstream first and subsequently upstream from the point-of-use. The authors recommend that one individual component should be followed and that the data collection must not interfere in the process. Tools to use in data collection include standardized sheets for the activities and that the flow is video recorded to facilitate time measurements. By interviewing operators and managers along the flow, requirements influencing the flow design are captured.

Compilation of data collection

The first step in compilation of data collection is to illustrate the flow schematically, followed by analysis of the data.

Analysis of video material

The purpose of the video recordings is to be used for construction of the MFM flow and its activities. Time measurements should be determined to highest possible extent.

Compile the MFM

All relevant data gathered should be compiled for the MFM, including identified requirements and descriptions of processes.

HATS analysis

Conduct an analysis of the MFM where the included activities are denoted handling, administration, transport, and storage. The amount of activities and their time measurements should be summarized, including averages.

Reiterate

The compiled MFM should be validated by the company and other actors involved. Re-iterate if steps are missing in the MFM or if additional data is needed for the activities.

4. DESIGN MODEL

This chapter contains a synthesis of the six areas of materials supply systems and materials presentation at assembly stations from the theoretical framework in chapter 3. From now, this chapter is referred to as "design model". The design model is used for facilitating the selection of different design options which aim to increase performance in materials supply systems. The design model is subsequently applied in order to answer research question 4 in Chapter 7. Only areas that affect design of a materials supply system is included in this design model, thus measurements such as performance measurements for materials supply system and MFM are not included.

4.1 AREAS OF THE MATERIALS SUPPLY SYSTEM

The six areas of materials supply systems described in the theoretical framework are summarized individually to create a synthesis to be applied in the selection of available options in materials supply systems design.

4.1.1 Materials feeding principles

The selected materials feeding principles in a materials supply system have significant effect on several central aspects. The materials feeding principles and four corresponding characteristics that affect performance of materials supply systems are displayed in Table 4.1. Control requirements refer to the requirements in terms of controlling the materials feeding principle and space requirements refers to the space required at the line to store materials. Handling requirements refer to all handling required in order to conduct the feeding of materials. Capabilities to handle high amount of product variants refer to the possibilities each materials feeding principle has in terms of handling a high amount of product variants.

Table 4.1. Materials feeding and corresponding characteristics.

Material feeding principle	**Control requirements**	**Space requirements at assembly stations**	**Handling requirements**	**Capabilities to handle high amount of product variants**
Continuous supply	Low	High	Low	Low
Batch supply	Medium	Medium	Medium	Medium
Kitting	High	Low	High	High
Sequencing	High	Low	High	High

As seen in Table 4.1 the effects of material feeding principles varies. In order to select suitable material feeding principles, desired outcome of the aspects in Table 4.1 should be considered. However, selecting one materials feeding principle does not exclude the others. As stated in the framework, all of the materials feeding principles are possible to use simultaneously but on different materials. Both the constraints on the line to be used and the materials to be supplied must be considered. The same materials could be supplied by all of the four principles to four different lines. One single line may also be supplied by materials by all four principles.

4.1.2 Materials handling

Focus in the materials handling section is the materials handling system and the handling equipment. Transport units are originally included but is covered under "Packaging" and hence removed. Materials handling systems are divided into direct and indirect systems where direct systems are characterized by moving one unit of material directly from origin to destination. Indirect systems on the other hand are characterized by consolidation of units along multiple stops. The intensity of materials flows and the distance can be used to determine which of the two systems that should be used in a particular environment. Table 4.2 shows a selection table for selecting materials handling system.

Table 4.2. Selection matrix for direct or indirect materials handling system.

	Low flow intensity	**Moderate flow intensity**	**High flow intensity**
Low distance	Direct system	Direct system	Direct system
Moderate distance	Indirect system	Indirect/direct system	Direct system
High distance	Indirect system	Indirect system	Indirect system

Materials handling equipment is divided into four types of equipment as seen in Table 4.3 which can be used to select correct equipment.

Table 4.3. Selection matrix for materials handling equipment.

	Low flow intensity	**High flow intensity**
Low distance	Simple handling	Complex handling
High distance	Simple transport	Complex transport

As seen in Table 4.2 and Table 4.3, distance and materials flow intensity are key parameters to consider when selecting what system and what handling equipment to use.

4.1.3 Storage

Selecting what type of storage to use depends on several aspects, e.g. distance to the line and level of inventory control. Table 4.4 shows storage types and corresponding characteristics. No storage is included in Table 4.4 to show its characteristics for comparison with the other two types of storage.

Table 4.4. Various storage types and corresponding characteristics.

	Storage type	**Required distance to line**	**Level of inventory control**	**Benefits**
Central storage	Centralized	Long	High	High space utilization, efficient handling in labor
Point-of-use storage	Decentralized	Short	Low	Minimized distance to assembly station, monitoring system is not required
No storage	Continuous flow, no storage	None	N/A	No storage between operations and no handling is required

The amount of storage points in the materials flow should be minimized. Regarding the use of FIFO in storage, it is suitable to use for straight flows through storage, i.e. arrival and shipping are not conducted at the same location.

4.1.4 Transport

Greatest improvements in terms of transport are achieved if trips are eliminated rather than reducing its distance. Analyzing the volumes being transported and transport frequency will facilitate selection of the correct transport routes and equipment used for transportation. Focus should be aimed at high frequency and high volume transports, since these types of transports have improvement potentials. If such transports cannot be eliminated by layout changes, the covered distance should be reduced.

Since selection of materials handling equipment is covered in materials handling, transport alternatives will be of focus here. A selection table is created in Table 4.5 which is based upon frequency and volume of transports to select the right transport alternative.

Table 4.5. Selection table for transport alternative.

	Small transport units	**Large transport units**
Low frequency	Push cart	Pallet jack
High frequency	Tuggers and trans of tow carts	Forklift

Creating aisles, or routes, only for in-plant transport is an additional important aspect to avoid that materials block the way and to avoid accidents.

4.1.5 Packaging

The two types of packaging mainly used are pallets and containers. Pallets are available in multiple materials with different benefits and drawbacks. The desired durability, repairability and recyclability are central aspects to consider when selecting pallets. The materials to be loaded on the pallet should also be considered, e.g. lightweight materials are not usually target for metal pallets. Pallets with collars can be used for materials that need extra protection against handling damages. Wood, plastic and metal pallets are commonly used and the recommended usage for each of the three pallets are presented in Table 4.6.

Table 4.6. Pallet types and corresponding recommended usage.

Pallet material	Recommended usage
Wood	If various materials are to be loaded on it and if cost is of essence. Wood has a wide general use, medium durability and the high repairability makes it economic
Plastic	Suitable to use if durability and total weight is of essence. The plastic pallet has a low weight, high durability and medium repairability
Metal	Suitable to use if the materials to be loaded are heavy. It has high durability and medium repairability

When selecting containers, the decision of whether to use disposable or reusable containers has to be made. Reusable containers are suitable to use when packing quality is prioritized since they provide better protection against handling damages. Fragile parts should thus be used with reusable containers. Table 4.7 shows the two containers and their characteristics.

Table 4.7. Reusable containers, disposable boxes and their characteristics.

	Total cost	Packaging protection
Reusable container	Low	High
Disposable boxes	High	Low

Additionally, disposable boxes require more handling resources compared to reusable containers, thus implementation of reusable containers will likely reduce materials handling resources.

4.1.6 Manufacturing planning and control

There are various material planning methods to use for materials planning. When to use what methods depends on the materials. Re-order points comes in multiple variants and two of them, which are described in the theoretical framework, are two-bin systems and Kanbans. The two-bin system is suitable to select for materials with lower annual dollar value, i.e. usually C-articles in a traditional ABC-classification. Kanban can be used for a high variety of articles where pull-principles are used. Material requirements planning is suitable to use for parts with dependent demand and for parts with occasional but large demand.

ABC-classification of inventory should be conducted since all materials should not be allocated equal attention. The control efforts for the categories differs where A-products have frequent reviews, MRP is suitable for this purpose, and C-products can be controlled by using planning methods with less control, e.g. two-bin systems.

4.2 MATERIALS PRESENTATION AT ASSEMBLY STATIONS

All non-value adding work the operator performs should be minimized since the assembly time of each operator is expensive compared to the time of materials handlers. A central part of the non-value adding time for operators is materials handling. The key aspects to consider in terms of materials presentation at assembly stations are presented in Table 4.8.

Table 4.8. Key aspects to consider for materials presentation at assembly stations.

Aspect to consider	**Description of aspect**
Distance between operator and materials presentation	Materials should be presented within an arm's reach from the operator.
Opened packages	Materials should be presented in such a way that the operator does not need to open the package.
Comprehensible presentation	The risk of confusing materials should be minimized as much as possible. Defective products are the result of confusing materials presentation.
Materials presentation that facilitates installation	The materials should be presented in way that facilitates mounting on the assembly object. The smallest dimension of the materials should be facing out.
Size of containers for materials presentation	The containers used for materials presentation should be minimized to reduce picking time.
"Washing machine" movements by operators	Should be avoided if possible due to the time required. Can be avoided by narrow flow racks connected to a supermarket in combination with kitting.

5. CURRENT STATE

The current state of the materials supply system at Adient is explained in this chapter. The sections in this chapter are equal to the areas in the materials supply system model suggested by Johansson and Johansson (2006).

5.1 MATERIALS FEEDING PRINCIPLES

Multiple materials feeding principles are used simultaneously at Adient. There is currently no standardization in terms of what materials feeding principle to use with what materials. Continuous supply is the preferred way of feeding materials but is not always applicable. The process of selecting materials feeding principle is thus mainly restricted to space availability at the line in order to use continuous supply. If space limitations arises, batch supply, kitting and sequencing are used as feeding principles instead of continuous supply. The physical size of the materials and the amount of materials in each package are thus the foundation for selecting materials feeding principles according to the production manager and the operations manager. The materials feeding principles are described in this section.

5.1.1 Continuous supply

Smaller materials in terms of size such as screws, nuts and bolts are presented in racks at the lines and are usually fed by continuous supply. The characteristics of continuously supplied materials in general are low space requirements of materials. However, continuous supply is also used for frames which are not small in terms of size and thus require extensive space at the lines. Currently there is no system nor calculation model to determine inventory levels at the lines and replenishment is conducted arbitrarily in frequency and amount. Continuous supply is, according to the production manager, the most preferred principle but is not possible to apply in areas with low space availability. If space availability is low, batch supply, kitting and sequencing are used instead. Furthermore, the parts to the kitting area are fed by continuous supply.

5.1.2 Batch supply

Batch supply is currently used for some parts. Parts that have high space requirements and are not suitable for continuous supply nor sequencing nor kitting, are fed to the lines in batches. The foam for the center seat of the second row is supplied to the third line in batches due to high space requirements and the low amount variants. Since there are only two options for the center seat of the second row (extendable child seat or armrest) batch supply is used. Backside covers are also supplied in predetermined batches delivered in wagons to the second and third line.

5.1.3 Kitting

Kitting is used for the first row of seats, i.e. the first line, due to space limitations and long walking distances for operators in order to fetch materials. The implementation of kitting at the first line freed up space and reduced the distance required for fetching materials.

The first line assembles the passenger and driver seat that contains different components and variants due to customized configurations, especially at the last part of the line where a kitting area is used. The number of variants due to unique customizations is the reason kitting is used here. The kitting areas, denoted “Kit 1” and “Kit 2” in Figure 5.1, consist of five racks.

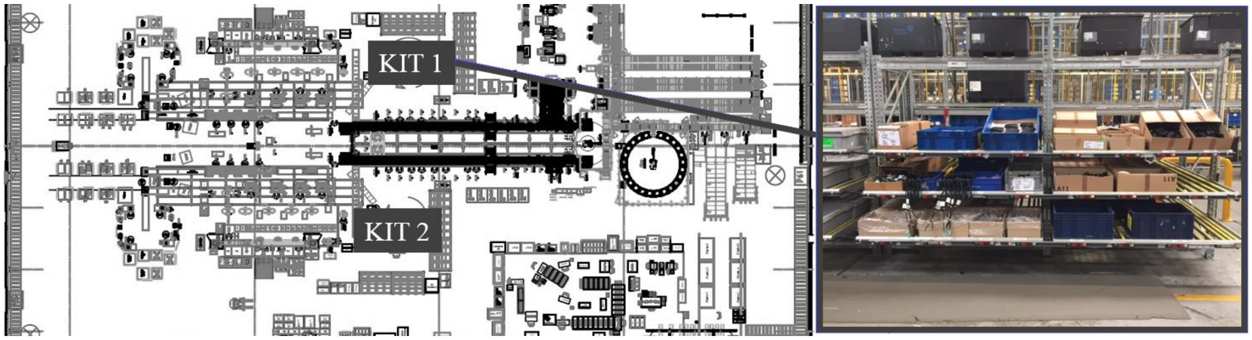


Figure 5.1. Location of the kitting areas “KIT 1” and “KIT 2 “ (left) and one rack of a section in “KIT 1” (right).

Empty boxes, i.e. the kits, are placed on a wagon (see Figure 5.2) and an operator starts picking smaller components for the kits from the racks. Each kit is according to a unique seat configuration. A single kitting box is used by several stations and the kitting box travels with the seat along the line (see Figure 5.3). The kitting boxes are therefore “travelling kits” according to Bozer and McGinnis (1992) since they travel along on the line. At the first station, an empty kitting wagon is fetched and replenished. When replenishment of the kitting wagon is completed, the wagon is subsequently transported a few meters to the next station. Only when any of the four kitting wagons are emptied, replenishment of a new wagon starts. The next station to receive the kitting wagon conducts preassembly of the parts in the kitting boxes and subsequently replace the parts in the kitting boxes. The kitting boxes are then transported to the line by the use of a flow rack, leading up to the line.

Figure 5.2. One of four wagons on which kitting boxes are placed for delivery to assembly.

At the third station, the kitting boxes are fetched and manually placed on the line, see Figure 5.3.

Figure 5.3. Kitting box on the assembly line next to a front seat.

When the kitting box has fulfilled its purpose throughout the line, the empty kitting box is placed on an empty wagon at the final station and the procedure is repeated.

5.1.4 Sequencing

There are multiple parts being sequenced to the lines, e.g. seat foam, seat trim, and backrest frames. The decision about which parts to sequence is based on space requirements and assembly balancing. However, there is currently no standardized way of determining what materials that are to be sequenced. If materials have high space requirements, sequencing is one suitable alternative to continuous supply as a materials feeding principle. By using this principle the materials can be allocated to another location with more space. Sequencing is also selected when it is problematic to align the workload at assembly stations with the takt-time. To reduce workload at the assembly stations, materials are relocated upstream to a sequencing station working in parallel with the assembly line. The act of relocation enables the assembly stations to align in accordance with the takt-time. Sequencing can also be selected as materials feeding principle due to ergonomic reasons. In one case, the measurements of a packaging were exceeded and thus making it non-ergonomic for the operators at the station. However, by sequencing the materials the measurements of the package were within allowed limits.

Every line is to some extent supplied by sequencing. The ten sequencing stations are explained in the following section. The sequencing stations located in the outer storage area is depicted in Figure 5.4 and the sequencing stations located in the inner storage area is depicted in Figure 5.5. Inner and outer storage are illustrated in Figure 5.9 in section 5.3. Each sequencing station is presented in Table 5.1 with station number, sequenced material and a description of the station process.

The locations of the sequencing stations are mainly based on deliveries of materials, e.g. sequencing station 1 were placed a long way from the lines but close to the inbound transports of the materials. The general process of sequencing at Adient is that one picker at each sequencing station fetches the materials to be sequenced. The location of materials in the sequencing stations are based on high and low runners (high and low consumption rates) where high runners are located close to where the picker starts to pick.

Materials with high consumption have a buffer of two accessible pallets, giving the forklift driver time to replenish one pallet simultaneously as the picker picks from the next pallet. This is however not the case for all material variants, some only have one accessible pallet meaning that when one of these pallets are emptied the picker cannot proceed picking that material until the pallet is replaced by a forklift driver.

The materials picked at the sequencing stations are placed in compartments in wagons, as seen in Figure 5.5. Subsequently, each wagon is retrieved by a forklift driver which delivers the wagon to the correct assembly line.

The sequencing stations in the outer storage area is displayed in Figure 5.4 and are denoted as “SEQ 1-7” and the sequencing stations located in the inner storage are denoted as “SEQ 8-10” in Figure 5.5. The sequencing stations are from now on referred to only as “SEQ 1-10”. The sequencing stations are located below the racks, i.e. the racks on the first levels are removed to make room for sequencing stations. Materials consumed at the sequencing stations are usually stored in the racks located above.

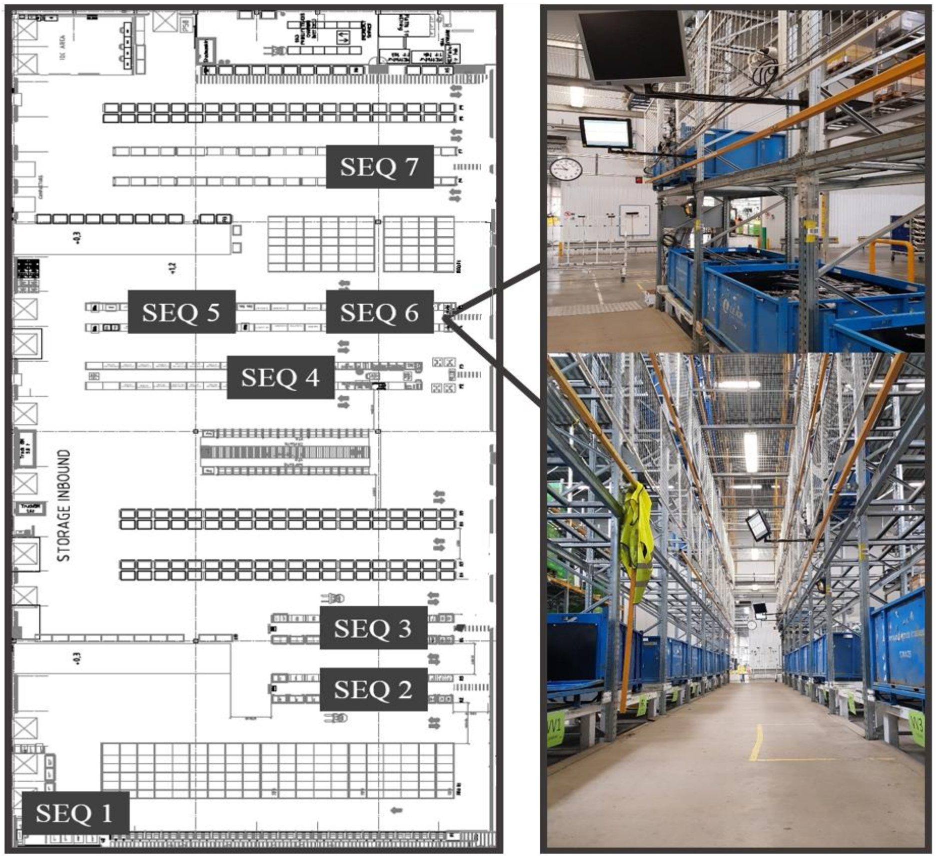


Figure 5.4. Layout of the outer storage, containing locations for SEQ 1-7 (left) and SEQ 6 (right).

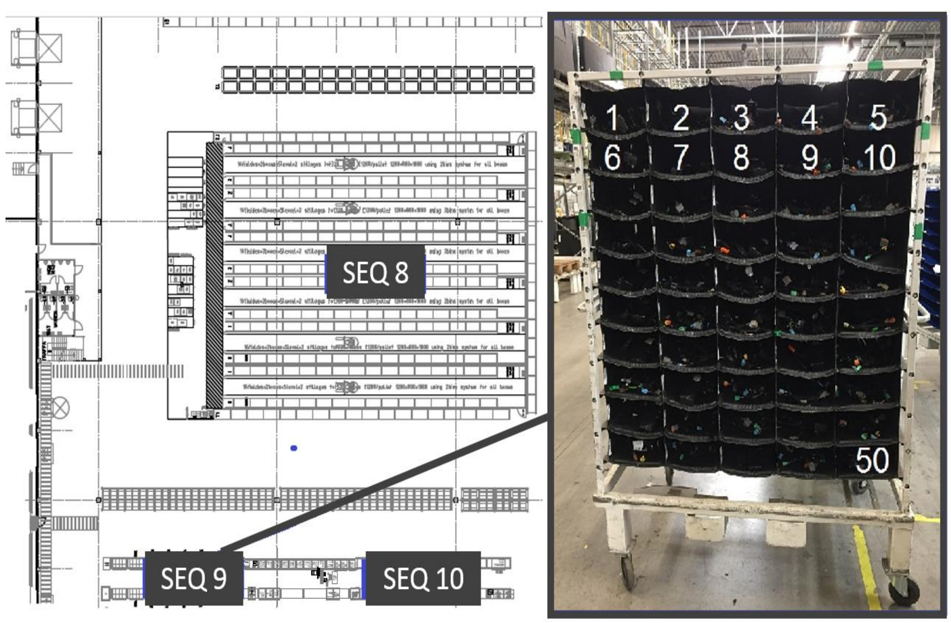


Figure 5.5. A layout of the inner storage area containing SEQ 8-10 (left) and a sequencing wagon with 50 slots at SEQ 9 (right).

The ten sequencing stations sequence different components and are conducted by different processes. The materials being sequenced and a description of the sequencing processes are found in Table 5.1.

Table 5.1. Description of the sequencing stations located in outer storage.

Sequencing station	**Sequenced components**	**Sequencing description**
1	Foam and seat heating for: cushion to second line, backrest and cushion to fourth line.	The foam is sequenced in numbered wagons with racks according to order lists from customer.
2	Foam and seat heating for: the cushion and backrest to third line.	Sequencing is conducted in a similar way as in station 1.
3	Foam for: backrest to second line. Seat heating to second line.	Sequencing is conducted in a similar way as in station 1.
4	Foam: For cushion to first line. Seat heating to first line.	Sequencing is conducted in a similar way as in station 1.
5	Seat trim, foam and seat heating for: Backrest to first line.	The foam is sequenced together with seat trims in numbered wagons with racks according to order lists from customer.
6	Frames for backrest to first line	The frames are sequenced in six-armed numbered wagons according to order lists from customer.
7	Bolster and armrest to second line	Sequencing is conducted in a similar way as in station 1.
8	Seat trim for all rows of seats, i.e. all lines	Sequenced according to customer order lists. Various wagons are used for sequencing depending on the seat trim.
9	Airbags for first row of seats, i.e. the first line	Sequenced in wagons with 50 compartments (see Figure 5.5)
10	Hard back for the back of the backrest to the first line	Sequenced in wagons according to order lists from customer.

5.1.5 Pre-assembly

Pre-assembly is conducted at two locations in the plant, denoted “PRE 1” and “PRE 2” in Figure 5.6. The first pre-assembly station PRE 1 receives a sequencing wagon with headrests from SEQ 8, these are pre-assembled and placed in sequencing wagons as finished headrests ready for final assembly on the first line. This station is located in proximity to the first line. The second pre-assembly station PRE 2 assembles armrests and headrests for second row of seats, and is located in proximity to the third line.

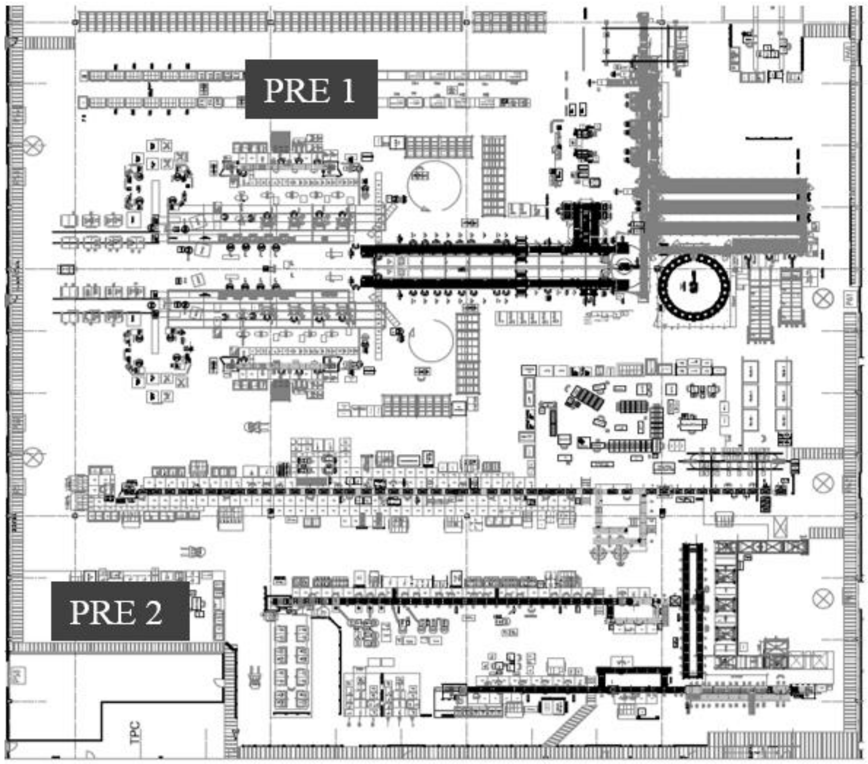


Figure 5.6. A layout of the inner storage showing the locations of PRE 1 and PRE 2.

5.2 MATERIALS HANDLING

This section explains the materials handling system at Adient. Transport units and materials handling equipment are not included since the two are covered in packaging and transport respectively. The focus in this section is on materials flows as parts of the materials handling system.

5.2.1 Materials flows

The materials supply system at Adient has certain characteristics in terms of its materials flows. The basic principle is that materials handling is divided into four types of flows;

- Materials flows from arrival of goods to storage
- Materials flows from storage to kitting or to sequencing
- Materials flows from sequencing to pre-assembly
- Materials flows from kitting, storage, sequencing and preassembly, up to the line

The materials flows are illustrated in Figure 5.7 and each flow is described in the sections below.

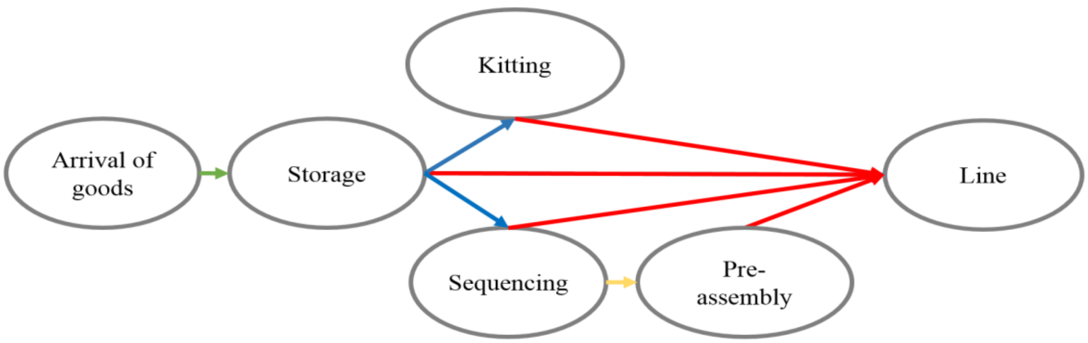


Figure 5.7. Green is materials flows from arrival of goods to storage. Blue is from storage to kitting or to sequencing. Yellow is from sequencing to pre-assembly. Red is from kitting, storage, sequencing and pre-assembly up to the line.

Materials flow from arrival of goods to storage

Incoming goods arrives at two locations; inner- and outer storage (see Figure 5.9) depending on the materials. Materials handling tasks at the inner storage includes unloading trucks and transport of the goods to storage or to SEQ 8. At the outer storage the same type of materials handling are conducted, i.e. unloading the truck by using a counterbalance forklift and transport materials into storage and sequencing stations.

Materials flow from storage to kitting or to sequencing

At the kitting stations there are racks with materials and only when materials are consumed replenishment is conducted. The kitting stations are replenished directly from storage.

Materials flow from sequencing to pre-assembly

The pre-assembly stations are supplied by sequencing stations. The task of the pre-assembly is to pre-assembly parts from the sequencing wagons and put the pre-assembled parts back in the same sequence.

Materials flow from kitting, storage, sequencing and pre-assembly, up to the line

Regarding the materials handling up to the lines, materials handling tasks are allocated to certain lines and products. The first line is supplied with materials from SEQ 4-6, SEQ 8-10, KIT 1-2, PRE 1 and from storage. The second line is supplied from storage, except the sequencing wagons and pre-assembly which are supplied from SEQ 1, SEQ 3, SEQ 7, SEQ 8 and PRE 2. For the third line, materials are supplied from storage except from materials that are supplied from SEQ 2, SEQ 8 and PRE 2. The fourth line is supplied from storage apart from sequencing stations SEQ 1 and SEQ 8. Figure 5.8 shows an example from each of the four different materials flows on a layout map of the manufacturing plant.

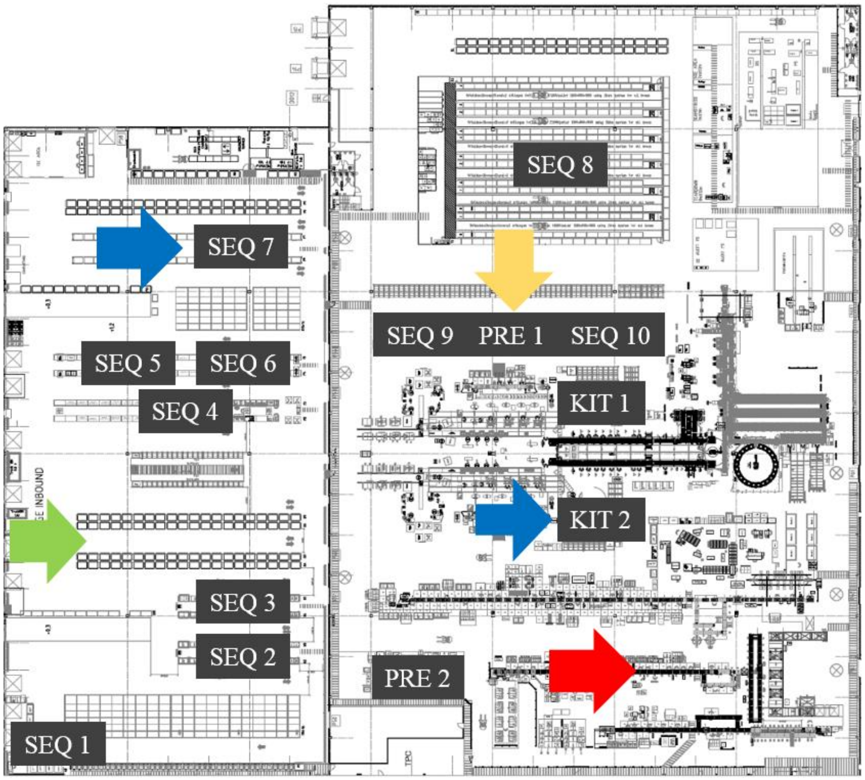


Figure 5.8. Example of each of the four materials flows. Green is from arrival of goods to storage. Blue is from storage to kitting or to sequencing. Yellow is from sequencing to pre-assembly. Red is from kitting, storage, sequencing and pre-assembly to the line.

5.3 STORAGE

The storage areas are divided into three areas; *point-of-use storage* at assembly lines, and *outer storage* and *inner storage* to which incoming materials arrive (See Figure 5.9).

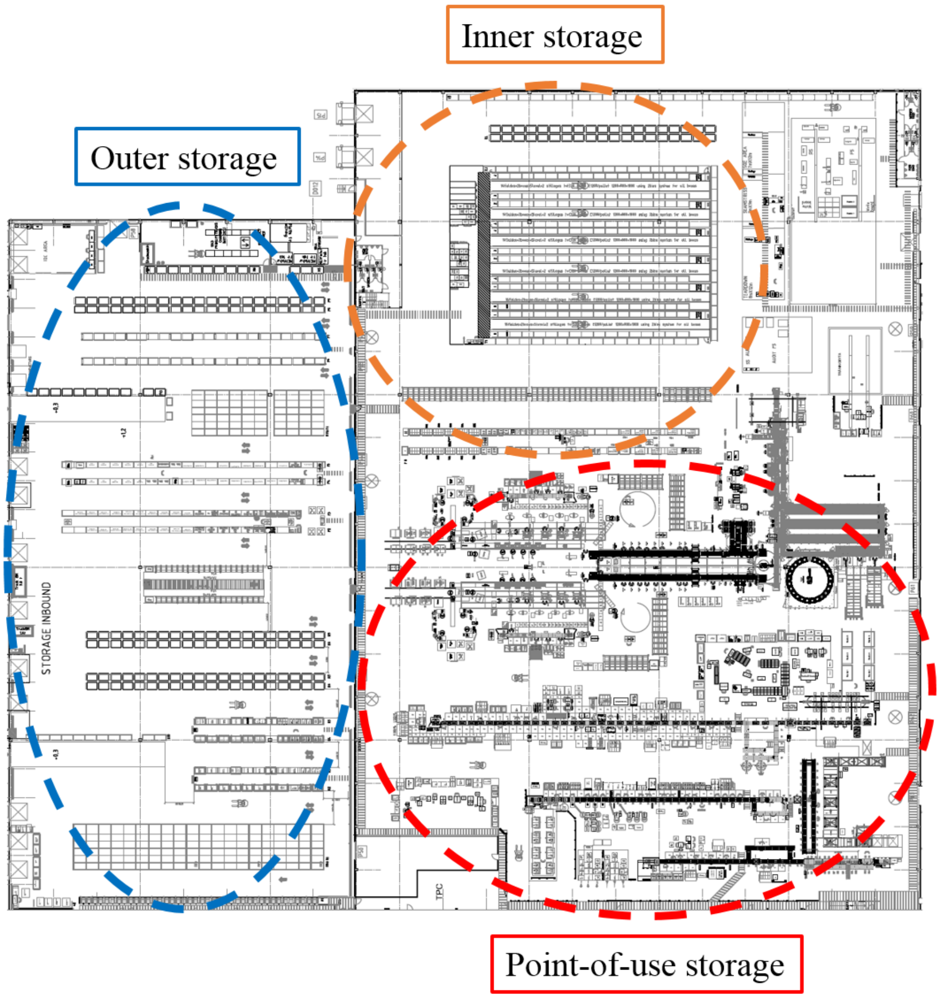


Figure 5.9. A layout of the Adient Torslanda plant with included division of areas. The blue marking shows the outer storage area, the orange marking shows the inner storage and the red marking represents the point-of-use storage along the lines.

5.3.1 Point-of-use storage

The point-of-use storage is located along the lines, in the form of racks, pallets and wagons. Different racks at the line are used depending on the size of the materials. For screws and nuts that come in small cardboard boxes, smaller and sloped racks are used. For plastic containers, larger sloped racks are used. The racks are customized to fit the materials stored at the assembly stations. Pallets are used for bigger materials such as frames. Usually there are two pallets for each article, when one is empty the other one is picked from and the empty one is replenished, i.e. a two-bin re-order point system. A wagon with materials is prepared at a station before it reaches the point-of-use storage and is used for batched and sequenced materials. Each wagon supplies one assembly station with materials, hence when it arrives at the point-of-use storage it is not moved. New materials are retrieved from the outer and inner storage.

Assembly is conducted on elevated platforms next to the lines (Figure 5.10). The elevation of the platform prohibits variable distances for the point-of-use storage, i.e. wagons can only be placed at a fixed distance from the assembly line. The width of the platform varies from line to line and from station to station.

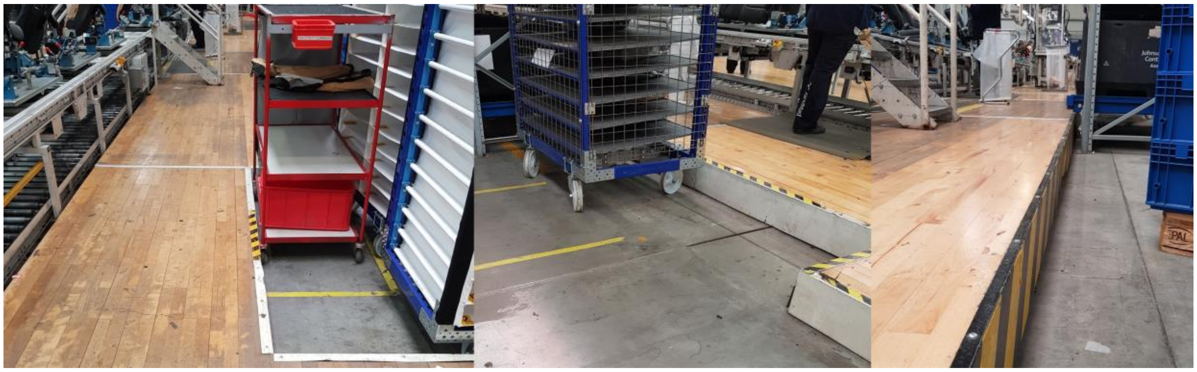


Figure 5.10. One of the wooden platforms at the second line.

5.3.2 Outer storage

The outer storage is the recipient of all incoming goods except the seat trims which arrive at the receiving area at the inner storage. The racks in the outer storage are organized according to article numbers to facilitate location tracking, i.e. a fixed location storage system is used. Arriving goods at the outer storage is picked up by a forklift and then placed in the storage racks. Materials are assigned locations in the outer storage depending on what line(s) it serves, i.e. racks are grouped together if serving the same lines. On each rack, materials are sorted per article number in ascending order. The location denoted "Pallets disassembly" in Figure 5.11 is what the name implies, i.e. where pallets are disassembled into smaller pieces. Pallets eligible for this process are pallets with additional pieces such as collars. The storage area above the pallet disassembly in Figure 5.11 plus the inner storage area in Figure 5.13 store materials for the first line. The storage area below the pallet disassembly in Figure 5.11 stores materials for second, third and fourth line.

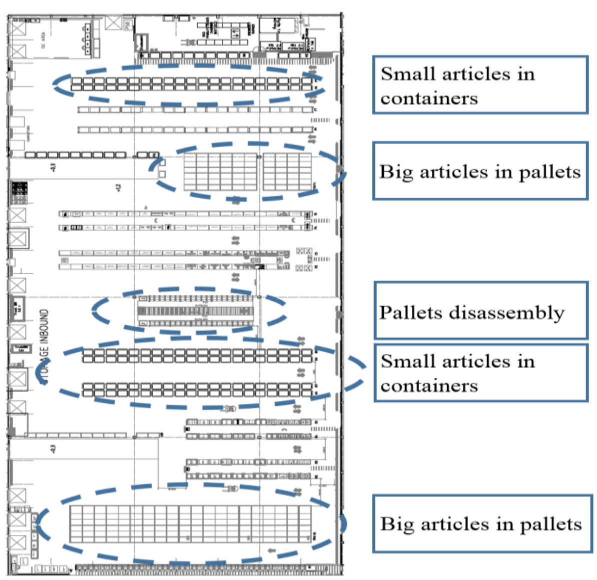


Figure 5.11.A layout of the outer storage with included sections for product groups.

FIFO-racks (First-In-First-Out) for pallets are used in the outer storage area to ensure that FIFO-principles are applied (see Figure 5.12). Pallets are loaded onto pallet flow racks which enable pallets to slide down, thus facilitating FIFO-principles. The pallet is picked up from the opposite side, i.e. replenishment and picking is conducted on different sides of the racks. These racks are according to the logistics manager well performing and facilitates FIFO-principles.

Figure 5.12. FIFO pallet flow rack.

5.3.3 Inner storage

Inner storage consists of four storage racks located in proximity to the front seat line and contains parts for first line, which articles mainly are for kitting, and SEQ 8 where seat trims for all lines are sequenced. This storage is organized in the same manner as outer storage, i.e. according to article number in ascending order with picking according to the FIFO-principles. A fixed storage location system is used as in outer storage. The type of racks being used is seen in Figure 5.13. The two racks located closest to the first line have sequencing stations for the first line located in the bottom of the racks and the articles needed for these stations are stored above them in racks.

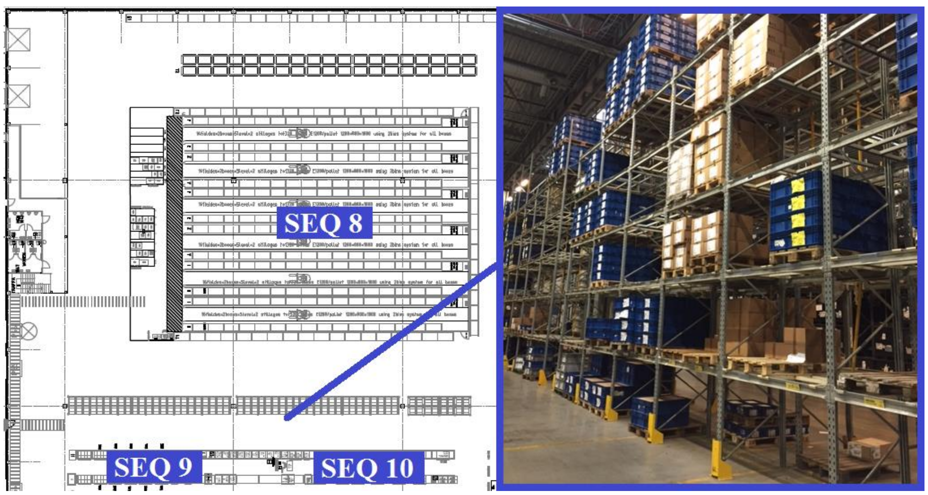


Figure 5.13. Inner storage area (left) and type of racks used (right).

Trim for the seats are stored at SEQ 8 (See Figure 5.14) and is comprised of six aisles where picking is conducted. Every aisle is organized according to product group and sequencing wagon, thus each sequencing wagon has a given number which is linked to corresponding aisle, i.e. each aisle contains all articles that are needed for each wagon. Each aisle typically entails articles for two to three different sequencing wagons. The aisles are divided into sections where article numbers are assigned a location in the racks. A computer in the forklift gives the picker a sequenced order list with including locations of each articles number. Figure 5.14 illustrates one of the aisles.

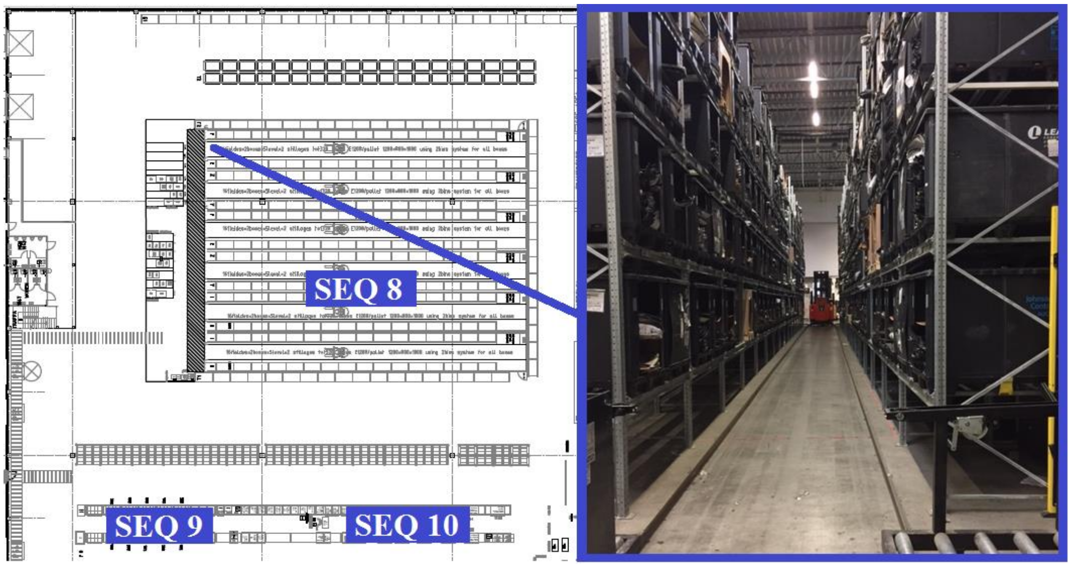


Figure 5.14. Inner storage (left) and one of the six aisles and a picking forklift at SEQ 8 (right).

5.3.4 Storage management

Two storage management principles that are currently used are FIFO (First-In-First-Out) and a special technique to balance picking aisles at SEQ 8.

5.3.4.1 FIFO

A FIFO-system (First-In-First-Out) is used in all storage areas for articles picking in order to know what to pick to prevent articles from becoming obsolete. Colors constitute the basis for the FIFO-system. Incoming articles are marked with red, orange, blue or green upon arrival, which color depends on what color that is currently used at that particular month. For example, in month 1 incoming articles are marked with green, in month 2 articles are marked with red and so on. If article 1234 is delivered in month 4 it will be marked with orange. This implies that for the pickers, orange is the last color to pick. The order of picking should be green, red, blue and last orange as illustrated in Figure 5.15. The following month the color scheme starts over again and the green color is used. Articles with high demand will not be marked with colors since the risk is very low they become obsolete due to the high turnover.

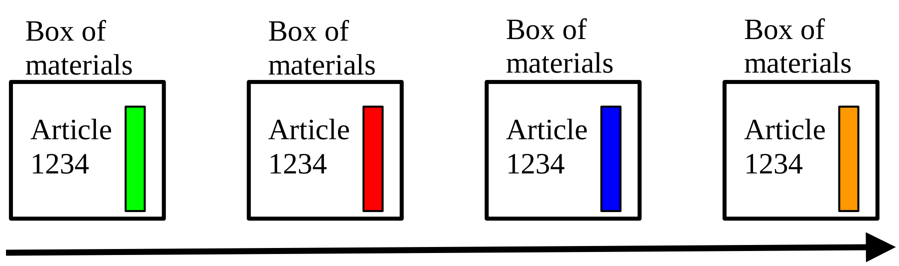


Figure 5.15.Color marking of article numbers.

5.3.4.2 Store Management at SEQ 8

Unique storage management principles are used at SEQ 8. What is being stored in each aisle depends on the time required for picking the articles into sequencing wagons. Articles for sequencing wagons that require extensive picking time and articles for sequencing wagons that require limited picking time are mixed in each aisle. The picking time for all articles is thus "balanced" between the aisles to ensure that the aisles are capable of supplying the articles in time. Not balancing the picking time becomes an evident problem if the picking time exceeds the takt time at the line to where the articles are destined for.

5.4 TRANSPORT

This section focus on what transport alternatives that are used in order to transport materials inside the plant and how transport in terms of materials replenishment is conducted.

5.4.1 In-plant transport

There are currently six alternatives that are used for transport inside the plant where each is described below.

Counterbalanced forklift

The counterbalanced forklifts (see Figure 5.16) are mainly used to unload arriving materials from trucks at outer storage, which subsequently are transported to the storage racks. Since some arriving trucks are unloaded from the side where a gap appears between the truck and the unloading platform, a counter balanced truck is necessary due to its reach. For instance, the electric pallet forklift is not compatible with such a gap. The forklift is also used for other purposes such as transporting sequencing wagons.

Reach forklift

The reach forklift (see Figure 5.16) is the most common type of forklift at Adient. Reach forklifts are used to move materials from racks in outer and inner storage and to transport materials from storage to the lines.

Figure 5.16. Counterbalanced forklift (left) and reach forklift (right).

Pick forklift

Pick forklifts (see Figure 5.17) are used at inner storage for picking seat trim. Wheels mounted horizontally on each side of the pick forklift provide the possibility of going back and forth in the aisles while maintaining safe distance to the racks. Furthermore, it is possible to move the cockpit of the forklift vertically, thus enabling the forklift driver to pick materials at several levels of storage. This enables picking of single parts from pallets in the racks, rather than picking the entire pallet and subsequently replace it in the rack.

Electric pallet forklift

Electric pallet forklifts (See Figure 5.17) are used for unloading arriving trucks at the inner storage. The electric pallet forklift is a flexible and handy forklift which requires limited space during usage.

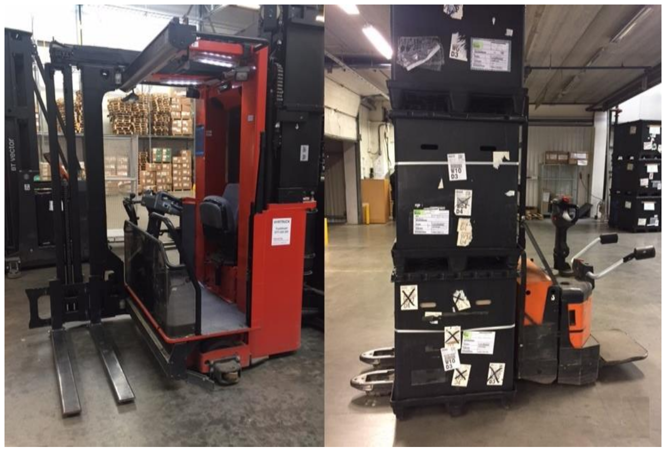


Figure 5.17. Pick forklift (left) and electric pallet forklift (right).

Platform powered pallet forklift and electric tow tractor

Platform powered pallet forklifts and electric tow tractors (see Figure 5.18) are used at the inner storage. The platform powered pallet forklift is small in size, hence suitable for transporting smaller pallets or wagons from one point to another, e.g. sequencing wagons from SEQ 8 to the lines. Due to its limited reach in terms of height, it is not possible to use for loading and unloading pallets in the storage racks. The electric tow tractor has a towing hook that is used to connect wagons.

Figure 5.18. Platform powered pallet forklift (left) and electric tow tractor (right).

5.4.2 Materials replenishment and transport

Transport in terms of materials replenishment is usually conducted by supplying one station at a time, i.e. no milk runs are conducted. Forklift drivers receives replenishment requests in walkie-talkies by operators when materials are needed. Since the types of forklifts that are being used are not suitable for loading different types of materials simultaneously, materials are transported individually to each destination.

5.5 PACKAGING

This section describes the packaging that is used at Adient. The different types of packages used are divided into three categories; *Pallets*, *Disposable and reusable containers*, and *special dimensions packages*.

5.5.1 Pallets

In general, three categories of pallets are used; wooden pallets, plastic pallets and metal pallets. The design of pallets varies depending on what it contains and its purpose.

Wooden pallets

Wooden pallets are often used in the standardized dimensions of a EUR-pallet which can be used with standardized pallet collars to increase load capacity. The collars help to contain the units inside as well as creating a single mass to handle, i.e. the creation of a unit load. Depending on the size of units or components that the wooden pallet should contain, the number of collars varies. When increasing the number of collars the height of the unit load is increased which is advantageous for utilizing the space in the unit load. In this case, foam for second line is contained and, as seen in Figure 5.19, an amount of three collars (low-collar wooden pallet) is used to contain the foam optimally.

If larger content is to be stored, the amount of collars can be increased. As seen in Figure 5.19, a four collar wooden pallet (high-collar wooden pallet) is used for larger metal components to contain frames for the third line.

Figure 5.19. Low-collar wooden pallet (left) and high-collar wooden pallet (right).

Plastic pallets

Two of the plastic pallets used at Adient is displayed in Figure 5.20. The pallet to the left in Figure 5.20 is a stackable plastic pallet which is used to contain seat trim. Stackable plastic pallets are received from suppliers and are easily picked and stored on top of each other in storage racks. To the right in Figure 5.20 is a plastic pallet with a flap on the side to facilitate picking.

Figure 5.20. One stackable plastic pallet with lid and walls (left) and one with a flap on side for easy picking (right).

Metal pallets

Figure 5.21 illustrates a metal pallet that Adient uses for transporting and storing Airbags. The pallet is packed with Styrofoam boxes that contains airbags, where the Styrofoam is used for protection since the airbags are sensitive to impacts. The metal pallet is composed of metal walls to further increase protection of the airbags. As can be seen in Figure 5.21, one wall can be removed to facilitate picking.

Figure 5.21. Metal pallet containing Styrofoam boxes with airbags.

5.5.2 Disposable and reusable containers

There are two types of containers used at Adient, disposable containers made of cardboard and reusable containers made of plastic.

Disposable containers

Disposable containers vary in design and size and is used for containing smaller units. The smaller containers are strapped together on a wooden pallet to comprise one unit load and enable transport. As seen in Figure 5.22, the pallet containing seven containers has a label for the entire unit load and when the pallet is transported to the line it is unstrapped and picked as single containers. Containers are also placed and used on sloped racks at assembly stations to avoid additional handling in terms of repacking in other containers.

Figure 5.22. Unwrapped wooden pallet unit load of cardboard containers with detachable lids.

Reusable containers

Containers are used for various components. Plastic standardized containers are used for small metal components, small plastic components, cables etc. The standardized containers provide the ability to be stacked on top of each other. The stackability is beneficial from a handling point of view since it facilitates creation of larger unit loads. Figure 5.23 illustrates nestable containers to the left, and stackable plastic containers to the right.

Figure 5.23. Empty nestable containers (left) and stackable plastic containers with plastic parts (right).

5.5.3 Special dimension packages

For some units and components the standardized unit loads and pallets are not suitable. Due to this, special dimension packaging with customized design is used to fit the specific unit or component. In the warehouse where foam for the seats are stored, a pallet of special dimensions is used with an attached container on top of it to create a unit load. This container has four walls and a lid to enable stacking of pallets on top of each other but also for protection of the unit, in this case the foam. The walls are removable to enable picking from the side which is beneficial since these unit loads are frequently used at the sequencing stations in the warehouse where the foam is sequenced and put on sequencing wagons. Figure 5.24 shows one of these larger wooden pallets with an attached container. Figure 5.24 also shows a special metal container with which is used for heavy metal units such as metal frames.

Figure 5.24. Metal container for larger metal units (left) and larger wooden pallet with an attached container for foam (right).

5.6 MANUFACTURING PLANNING AND CONTROL

The collected data of manufacturing planning and control at Adient is presented in this section. The data collected is only from material planning methods.

5.6.1 Re-order point systems

Re-order point systems are used at assembly stations in the materials supply system in the manufacturing facility, but not for materials planning from external suppliers.

5.6.2 Materials Requirements Planning

According to the material requirements planner, the company uses a material requirements planning system for materials supply from external suppliers. The system automatically receives orders from the customer during night time and orders during the day is manually registered. The orders received every day cover an order horizon of 6 months and every fourth week they receive orders for the upcoming 12 months. Every material requirements planner has certain responsibilities according to supplier and product. The order interval and amount purchased depends on product, supplier and distance to the supplier. Some orders are sent every day, usually to bigger suppliers, some once a week and some just on certain dates, usually for smaller suppliers. All materials in the factory is ordered via EDI, hence by material requirements planning.

5.6.3 ABC-classification

The company uses an ABC-classification for the material that is based on amount of sold pieces and price per piece. They currently have a 70/20/10 distribution for a total of 1787 pieces, thus 1231 A-class, 327 B-class and 229 C-class. The reason ABC-classification is used is mainly due to differentiation in stocktaking frequency. A-products have higher stocktaking frequency, i.e. once a month, B products every other month and C products every third month. One reason is to keep safety stocks low for A-products.

6. How is the current materials supply system at Adient performing?

The four performance measurements by Hanson (2009) are used to measure performance of the materials supply system at Adient. The six areas of the materials supply system have varying effect on the four performance measurements. Due to this, all six areas are not evaluated in each performance measurement. The performance is measured by using data from interviews and observations at the shop floor.

6.1 Performance measurement 1 (PF 1) - Reliable materials supply

The logistics manager argue that the most important performance measurement of the materials supply system is reliability. The operations manager claims that since the plant works with JIT the requirements on the production system, thus the materials supply system, in terms of reliability are high. As Hanson (2009) describes, the main objective of a materials supply system is to provide correct materials, at the right time, and of correct amount to assembly. Materials feeding principles thus have large impact on this performance measurement.

Of the materials feeding principles, kitting is considered as well performing in terms of reliability in materials supply with no low performing areas except for the boxes used for the kits. Some of the kitting boxes were worn out and holes in the boxes had emerged due to this. The performance of sequencing has a major impact on overall performance of materials feeding principles since the principle is used to feed materials to all lines. The production manager claims that one problem with sequencing in general in terms of reliable supply is that occasionally incorrect materials are supplied and supplied at the wrong time, e.g. that materials are delivered in the wrong sequence or that materials deliveries are delayed. However, the amount of materials delivered is usually correct. The overall performance of sequencing is considered as satisfying in terms of reliable materials supply. Batch supply and continuous supply are considered as reliable in terms of providing correct materials, at the right time and of correct amount.

Hanson (2009) further claims that an additional key objective for the materials supply system is to provide materials in satisfying condition where packaging, handling equipment and handling principles should be designed to avoid damages. Packaging in terms of preventing damages is not considered as problematic and is thus well performing in terms of reliability in materials supply. The handling equipment used for transport in the materials supply system is perceived as reliable according to the logistics manager. The forklifts used for transport is in line with industry standards and have high uptime. The handling principles used are also considered as well performing and no indications were found that the handling principles are low performing in terms of reliable materials supply.

6.2 Performance measurement 2 (PF 2) - Efficient handling in the materials supply operations

Efficiency in handling in the materials supply operations is investigated by using physical data as a measurement on activities along materials flows in production. When using physical data as measurement on each activity, the level of detail is increased and the possibility to identify unnecessary resource consumption increases, hence efficiency improvement potential. Like Öjmertz (1998) states, physical data can be used as a direct connection to execution of activities along a materials flow and thereby also the resource consumption. Decision is made that the physical data is collected by MFM methodology as described by Finnsgård et al. (2011b). Focus of the MFM are the number of materials handling activities, what types of handling activities that are performed, time required in the activities, distance each activity requires and stock levels in storage points. Due to this, MFM is considered as suitable to use in order to collect physical data.

6.2.1 Continuously supplied frames to first and third line

The decision is made to use MFM for continuously supplied frames for cushion to first and third line since own observations indicate that inefficiencies occurs in these two materials flows. From now on "frames for cushion" to these two lines are only referred to as "frames". During observations it is evident that the frames require extensive space at the lines due to its size and the amount of variants (see Figure 6.1).

The MFM for frames to first line is seen in Appendix B and the MFM for frames to third line is found in Appendix C. From the MFM in Appendix B, the line storage at the first line is extensive with 171 frames divided between 16 part numbers. The 16 part numbers are packed in pallets containing 8 frames, thus making the space requirements for storing such amounts of frames high as seen in Figure 6.1. The line storage at the third line (Appendix C) is comprised of 8 part numbers making a total of 62 frames. The package size of pallets to this line is 5 or 6 frames per pallet compared to 8 pieces per pallet for the first line. The amounts of pallets in the line storage thus corresponds to approximately 22 pallets of frames on the first line and approximately 12 pallets of frames on the third line. As seen in Figure 6.1, the amount of pallets is space demanding where the frames require 252 square meters at the first line and 89 square meters at the third line.

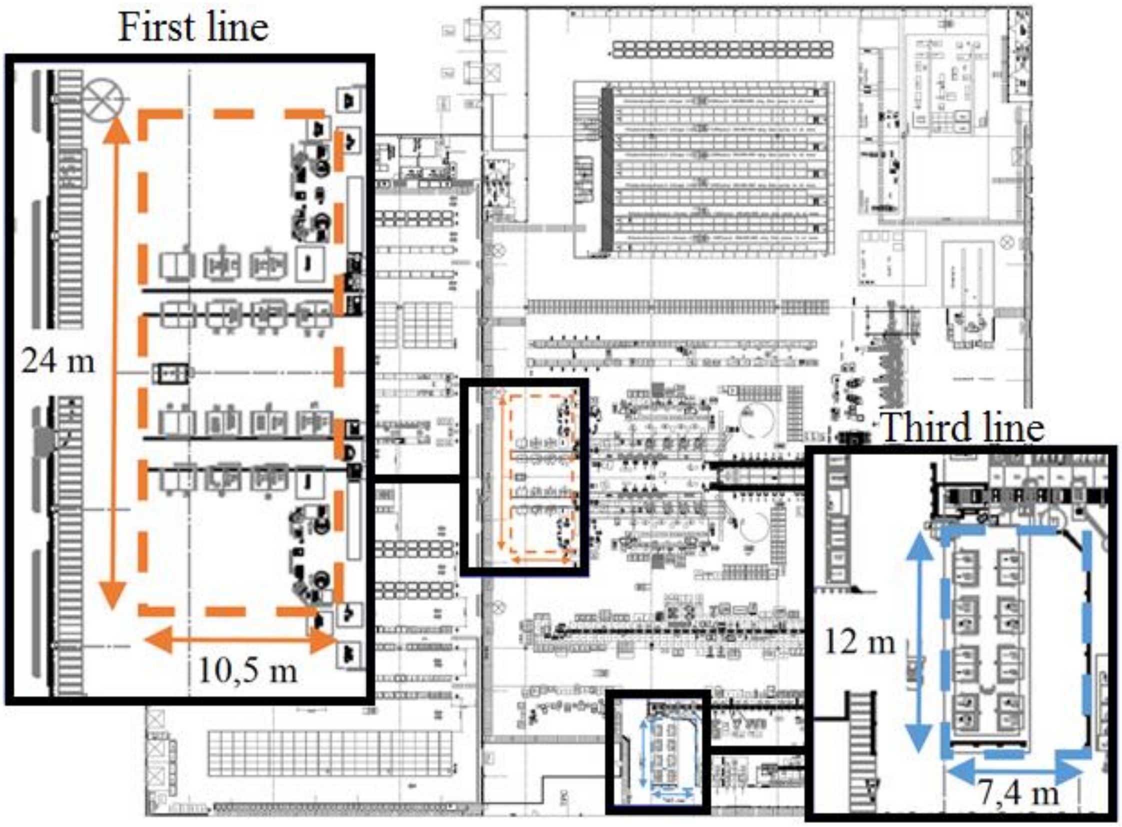


Figure 6.1. The space required by frames for first line (orange) and for third line (blue).

The conclusion from the two MFM is that the frames are not well performing in PF 2. Extensive space is required for the frames at the lines and also high inventory levels at the lines.

6.3 Performance measurement 3 (PF 3) - Support to assembly operations

The support to assembly is important according to Baudin (2002) where materials presentation impacts productivity and quality of assembly operations. In terms of support to assembly stations, performance measurement is evaluated, as suggested by Baudin (2002), by the required distance for the operator to fetch materials and how the materials are presented at the assembly stations. The production manager claims that the materials supply system currently does not provide the correct support to assembly. The operations manager argues that there is no standardized way of how materials are presented at the assembly stations, e.g. what racks or pallets to use.

6.3.1 Distance from materials presentation to assembly line

Elevated platforms are used next to the lines (see Figure 5.10) due to ergonomic reasons, i.e. the differences in the operator's height make the platform a necessity in order to meet the ergonomic regulations for assembling. The drawback of the platforms is that materials can only be presented “outside” the area of the platform due to the elevation of the platform. Figure 6.2 illustrates how the distance from assembly line to materials presentation is measured. As described by Baudin (2002) the distance between materials presentation and assembly station is what matters but since all assembly stations are located at the line in this case, the distance between the assembly line and materials presentation is measured. The selected locations for measuring and the measures for each location are found in Appendix F.

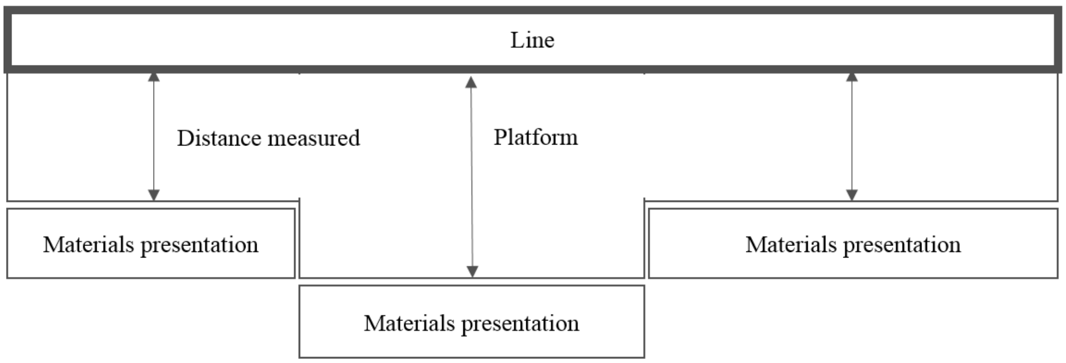


Figure 6.2. How the distance from materials presentation to assembly line is measured.

Materials presentation refers to racks, wagons or pallets. All the materials presentation are located behind the operator next to the lines. It is estimated that if the distance is 105 cm or shorter, the operator fetches materials simply by rotating 180 degrees in the same spot as seen in Figure 6.3. If the distance exceeds 105 cm, the operator is expected to start walking in order to reach and thus fetch the materials. If the operator starts walking the non-value adding time increases.

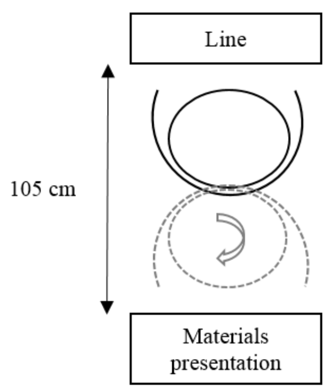


Figure 6.3. Rotation of the operator for materials fetching.

The exact distances between materials presentation and assembly at each line are presented in Appendix F. Three measured distances on first line and third line, 1:4, 1:5 and 3:1 in Appendix F, are especially long since the distances on average are 5.25 meters and 6 meters for fetching frames. The longest distances for fetching the frames are thus 10.5 meters and 12 meters respectively at these locations.

6.3.2 Materials presentation at assembly stations

The production manager claims that forklift drivers should open the packages presented at the assembly stations before operators are to use the materials. However, operators frequently have to open the packages themselves which usually are sealed taped cardboard boxes. The packaging engineer claims that the operators are not ought to open the packages themselves. Packages are identified at assembly stations that are considered to not support the assembly stations. Cardboard boxes that are used for some materials are not supporting assembly. According to the packaging engineer some packages are sealed by the supplier due to safety reasons and the forklift drivers often pile boxes at the assembly line. The piling of boxes prohibits preparation of the boxes for assembly. When stressed operators use knives to open the boxes the risk of injuries increases. Operators were provided with new knives designed to prohibit injuries during the opening process of boxes. At one assembly station on the fourth line a cardboard box is torn open by the operator (see Figure 6.4) in order to make materials inside visible for fetching. If the front is not torn open the operator has only partial visibility of the materials inside the box due to the height of the rack. Such processes of preparing the packaging for materials fetching increases non-value adding time for the operators.

Figure 6.4. Cardboard box at assembly station on the fourth line.

Cardboard boxes is the most commonly used packaging type according to the packaging engineer. Reusable containers of plastic (Figure 5.23) and cardboard boxes with detachable lids (Figure 5.22) are also used but to a lower extent compared to cardboard boxes. The main obstacles for using reusable containers is the distances to suppliers, i.e. the return flows of the containers is expensive to distant suppliers.

6.4 PERFORMANCE MEASUREMENT 4 (PF 4) - VARIANT AND VOLUME FLEXIBILITY

According to Hanson (2009), flexibility of the materials supply system is based on how the materials supply system adapts to the production system. Performance of flexibility of the materials supply system is measured from four types of flexibility.

Product mix

There are currently 4446 variants produced in the plant, thus putting the materials supply systems under high pressure to provide a wide variety of materials. The logistics manager argue that the materials supply system is high performing in terms of product mix flexibility since 4446 variants are possible to produce. 1276 different trim variants contribute to the high total number of variants. The production manager expresses that the materials supply system could be improved in terms of adaptability to the production system. As Hanson (2009) argues, the measurement of flexibility is relative and aimed at how well the materials supply system aligns with the production system demands. However, the overall product mix flexibility of the materials supply system is considered to be performing well.

New products and product modification flexibility

The two types of flexibility related to new products and modification of products presented by Hanson (2009) are handled similarly and due to this, these two types of flexibility are fused together here.

When a new product is introduced the materials supply is not immediately integrated into the materials supply according to the logistics manager. A team referred to as the launching team creates a kit for the new product for testing purposes to ensure successful materials supply before the materials of the products are integrated into the rest of the materials supply system. When Adient changes a product or a component in production, a "clean cut" is conducted. A clean cut is made to consume all the old materials before starting to consume any new materials and it is the responsibility of the materials supply to provide production with all old materials before supplying the new. Occasionally this process is unsuccessful but in general it performs well.

Volume flexibility

Since the company only supplies to one single customer, the requirements of volume flexibility derives directly from the customer. The customer uses what is referred to as the "chimney model" and suppliers must meet the volume flexibility requirements in this model. The model is comprised of ten classes of products. Products with high demand have a maximum volume flexibility of 20 per cent. The high demand products are thus allowed to be increased or decreased by 20 per cent in volume. Low volume products have a flexibility range of 300 per cent up and down in terms of volume. The logistics manager claims that the challenge is when the customer stays within the flexibility boundaries for low volume products, but place orders for them in a row. Seats with built in massage is one such example that has low demand but requires extensive assembly time. Customer orders with 20 massage seats in a row are thus very challenging for production, but not problematic for the materials supply system in terms of providing the amount of materials required.

6.5 SUMMARY OF PERFORMANCE MEASUREMENTS

The conclusion from the measured performance is that the materials supply system is performing well in PF 1 and PF 4. The materials are in general supplied in a reliable way and since the materials supply system is able to adapt to the production system in terms of offering materials for 4446 variants of seats, flexibility is considered as high performing. However, in PF 2 and PF 3 potential for improvements is identified. From the MFM for frames to first and third line, space and inventory could be more efficiently used. Support to assembly in terms of the distance from materials presentation to the assembly line and the materials presentation could be improved in performance.

7. HOW CAN THE MEASURED PERFORMANCE AT ADIENT BE INCREASED?

This chapter is divided into two parts. In the first part the performance measurements from Chapter 6 are evaluated in order to target areas for performance increase. The second part provides suggestions of how to increase performance in the target areas. The evaluation of performance measurements and the suggestions for performance increase is conducted by using the design model in Chapter 4.

7.1 TARGET AREAS FOR PERFORMANCE INCREASE

The performance measurements in Chapter 6 are evaluated in order to target areas for performance increase.

7.1.1 Continuously supplied frames to first and third line

Foam, trim and frames are the three materials requiring the highest amount of materials handling that are currently being sequenced. Foam requires extensive space due to its size and trim is available in 1276 different variants, thus making both the materials suitable for sequencing in accordance with Table 4.1 in the design model. In the current state all foam and all trim is sequenced, however for the frames it is only the backrest for first row of seats that is sequenced. The decision to sequence these frames was due to ergonomic requirements and the other frames are fed by continuous supply. Feeding frames by continuous supply requires extensive space at the assembly lines (see Figure 6.1) due to the size of the frames but also due to the amount of variants. According to Table 4.1 in the design model, the characteristics of the frames, i.e. space demanding and the high amount of variants, make frames suitable to use with sequencing instead of using continuous supply as materials feeding principle.

The materials fetching distance for picking frames is especially long compared to other materials as described in Chapter 6. As Baudin (2002) argues, long fetching distances increase the non-value adding time in assembly. The support to assembly in accordance with PF 3 is expected to increase if sequencing is used instead of continuous supply for the frames for first and third line since the non-value adding time will be reduced. Feeding frames through sequencing will also free up space in proximity to the assembly line compared to if continuous supply is used to feed materials in accordance with Table 4.1 in the design model. The conclusion is that continuously supplied frames to first and third line is a target area where performance increase should be aimed for due to the potential performance increase.

7.1.2 Distance from materials presentation to assembly line

As seen in Appendix F, the distances from assembly line to materials presentation all exceed 105 cm. The especially long distances at the first and third line (1:4 and 1:5 and 3:1 in Appendix F) are reduced by the first suggestion for increased performance later in section 7.2.1. However, the remaining distances should be reduced in order to increase performance in terms of support to assembly in accordance with Table 4.8 in the design model. In PF 3 it is estimated that when the distance from materials presentation to assembly line exceeds 105 cm, the operators starts to walk in order to fetch materials. Since all measured distances from materials presentation to assembly line exceed 105 cm, the distances are targeted in order to increase performance in PF 3.

7.1.3 Materials presentation at assembly stations

In PF 3 in Chapter 6 it is evident that performance in terms of support to assembly operations could be increased by making adjustments in materials presentation at the assembly stations. As seen in Table 4.8 in the design model there are multiple aspects of materials presentation at assembly stations that are not taken into consideration. Materials presentation at assembly stations is thus a target area for performance increase.

7.1.4 Summary of target areas

The target areas for increased performance are summarized in Table 7.1. The corresponding areas mainly affected in the materials supply system are also provided.

Table 7.1. Target areas for increased performance and corresponding areas mainly affected of the materials supply system.

Target area for increased performance	**Mainly affected area of the materials supply system**
Continuously supplied frames to first and third line	Materials feeding principles
Distance from materials presentation to assembly line	Storage
Materials presentation at assembly stations	Packaging/Storage

7.2 SUGGESTIONS FOR INCREASED PERFORMANCE IN TARGET AREAS

Suggestions for increased performance for continuously supplied frames to first and third line, distance from materials presentation to assembly line and materials presentation at assembly stations, are provided in this section.

7.2.1 Implement sequential supply of frames to first and third line

The suggestion for increased performance in continuously supplied frames to first and third line is to implement sequential supply of frames for these two lines. In the current state the storage of frames for the first and third line are located in the frames storage in FIFO-pallet flow racks. To implement sequential supply for frames to first and third line, new sequencing stations are required. The future sequencing stations for frames are preferably located where the FIFO-pallet flow racks are located ("big article in pallets" in Figure 5.11). The FIFO-pallet flow racks are switched to the same set up of racks that are used in the current state at SEQ 6 as seen in Figure 5.4. However, not all the FIFO-pallet flow racks ought to be removed but enough racks to free up required space for the sequencing stations. Since the storage space in the FIFO-pallet flow racks are not fully utilized it is reasonable to believe that some racks are possible to remove. By switching the FIFO-pallet flow racks, two new sequencing stations are created, denoted "SEQ A" and "SEQ B" in Figure 7.1. Since sequencing of frames is conducted at SEQ 6 in (see Figure 5.4) the same setup should be used for SEQ A and SEQ B as in SEQ 6.

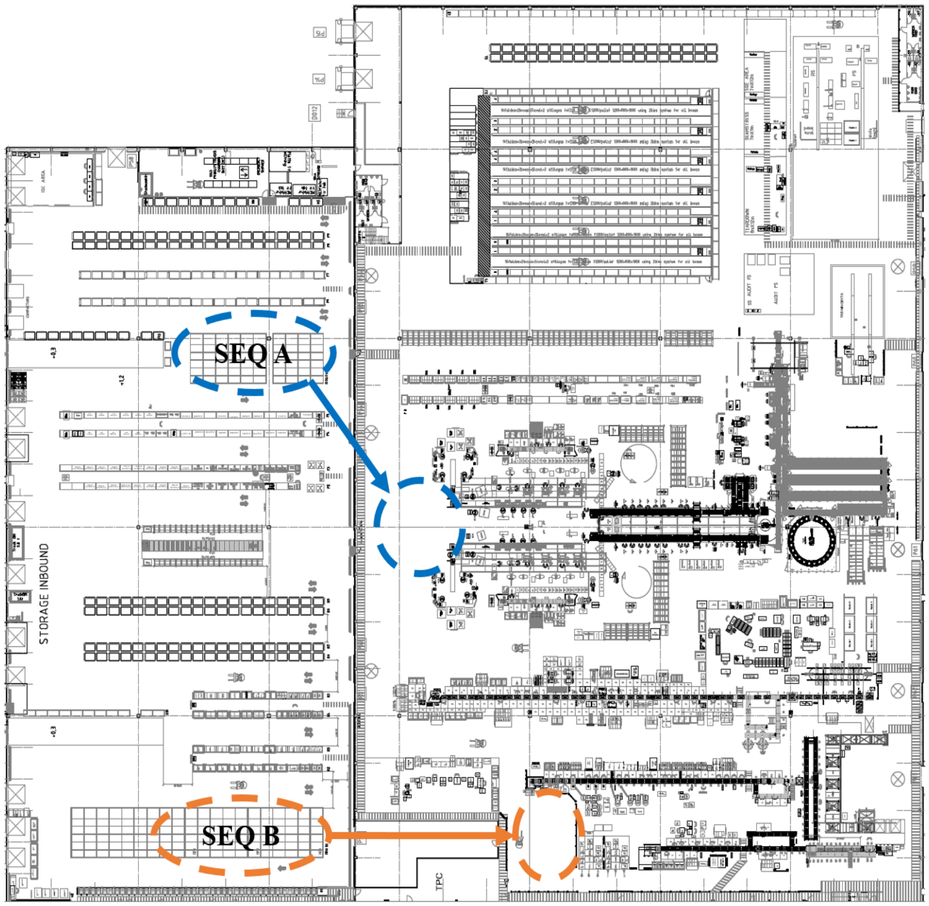


Figure 7.1. The locations of the new sequencing stations for frames to first line (blue) and to third line (orange).

Future state for the first line

Space savings from using sequencing instead of continuous supply at the first line is 252 square meters (see Figure 6.1). Furthermore, by sequencing all frames to the first line it is possible to reduce one operator, i.e. only one operator is stationed at two stations. This is considered as possible since the total assembly time for the two stations are measured to an average of 23.5 and 24.5 seconds, i.e. a total of 48 seconds (see Appendix G). The takt time is 63 seconds so the remaining 15 seconds are allocated for walking to the other assembly station and picking a frame from the sequencing wagon (see Figure 7.2). The remaining operator is relocated to the new sequencing stations, i.e. SEQ A in Figure 7.1. An additional benefit of the future state is that the storage point at the assembly station is removed due to the implementation of sequencing.

The forklift driver that previously was responsible for replenishment of frames to the first line is instead responsible for delivering sequencing wagons to the first line and to ensure that frames are replenished for the picker at SEQ A. It is estimated that the new working tasks reduce the total occupancy of the forklift driver, thus increasing efficiency.

As seen in the MFM for future state for the first line in Appendix D, the number of activities will increase as a result from implementing sequential supply of frames compared to continuous supply of frames. However, this is considered as acceptable since the resource requirements are the same and with respect to the benefits mentioned above.

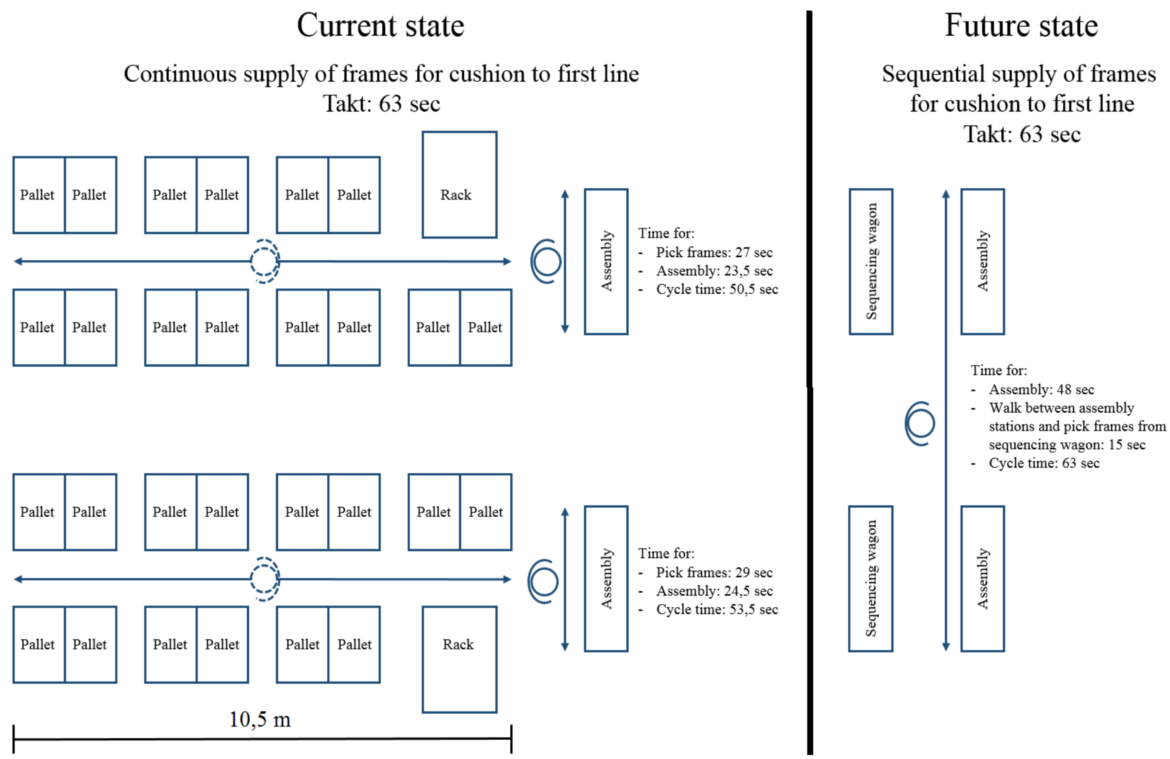


Figure 7.2. Current and future state for supply of frames to first line.

Future state for the third line

The picker at the third line with the task of only picking frames is relocated to SEQ B in Figure 7.1. Since the picker is currently able to pick frames within takt time, conducting sequencing of the frames within takt time is executable. The frames are thus sent on sequencing wagons from SEQ B to the third line (see Figure 7.3) which will free up space of 89 square meters (see Figure 6.1). An additional benefit of the future state is that the storage point at the assembly station is removed due to the implementation of sequencing.

The forklift driver that previously was responsible for replenishment of frames to the third line is instead responsible for delivering sequencing wagons to the third line and to ensure that frames are replenished for the picker at SEQ B. It is estimated that the new working tasks reduce the total occupancy of the forklift driver, thus increasing efficiency.

The drawback of implementing sequential supply of frames is equal to the drawback of implementing sequential supply of frames at the third line, i.e. the number of activities will increase (see Appendix E). However, this is considered as acceptable since the resource requirements are the same and with respect to the benefits mentioned above, as in the case with the first line.

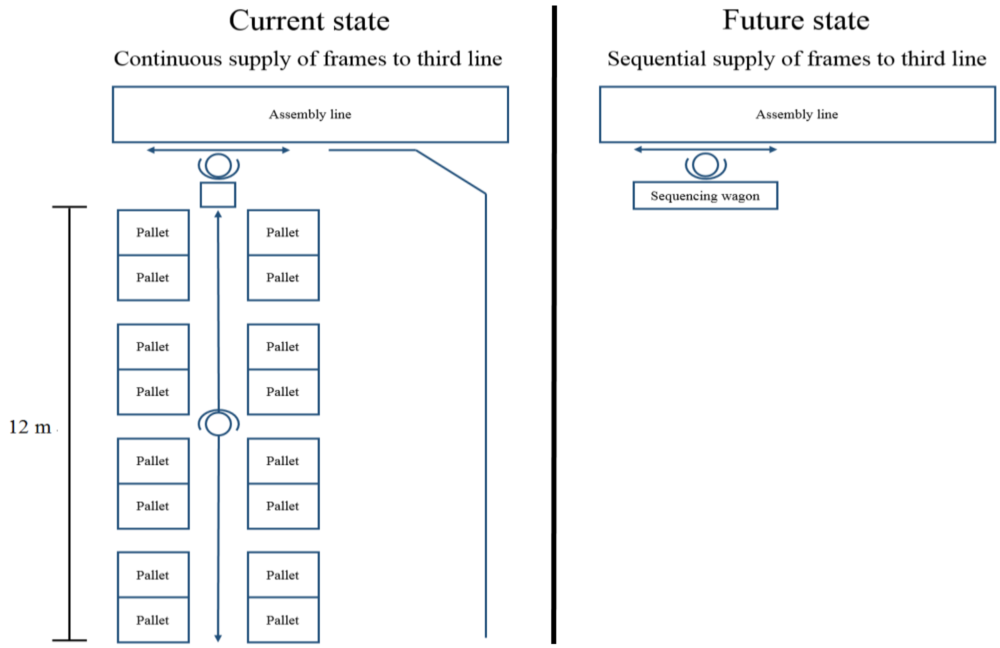


Figure 7.3. Current and future state for supply of frames to third line.

Summary of the performance increases of using sequencing for frames

The drawback of implementing sequential supply of frames to the first and third line is the increased number of activities. However, the potential benefits are considered as more valuable than the drawback. Performance is increased in PF 2 since space is freed up at the assembly stations, storage points at the assembly lines are removed, and that occupancy of forklift drivers is reduced due to the fewer transports.

The implementation of sequencing also increase performance in PF 3 due to that the distance for materials fetching is decreased in accordance with Table 4.8 in the design model. Greatest reductions are achieved at measure locations 1:4, 1:5 and 3:1 where the maximum distance will decrease from 10.5 meters to 1-2 meters and from 12 meters to 1-2 meters. By using sequencing wagons instead of the high-collar wooden pallets (Figure 5.19) the materials are presented in a better way. The higher materials presentation in the form of a wagon instead of a pallet on the floor is more ergonomic to the operators. By presenting the materials higher the degree of bending for the operators is reduced.

7.2.2 Reduce distance from materials presentation to assembly line

The suggestion for increased performance is to reduce the length of the platforms in order to facilitate closer materials presentation to the assembly line (Figure 7.4). Table 4.8 in the design model indicates that the materials should be within arm's reach for the operator and that "washing machine" movements should be avoided. However, eliminating "washing machine" movements completely is estimated to be expensive due to the extensive investments in equipment that is required. In other words, "washing machine" movements are not eliminated by reducing platform length but the non-value adding time is reduced since the a platform length of a maximum of 105 cm will eliminate walking. This suggestion thus means that operators are still performing "washing machine movements" but non-value added time in terms of walking is eliminated completely which will increase performance in PF 3.

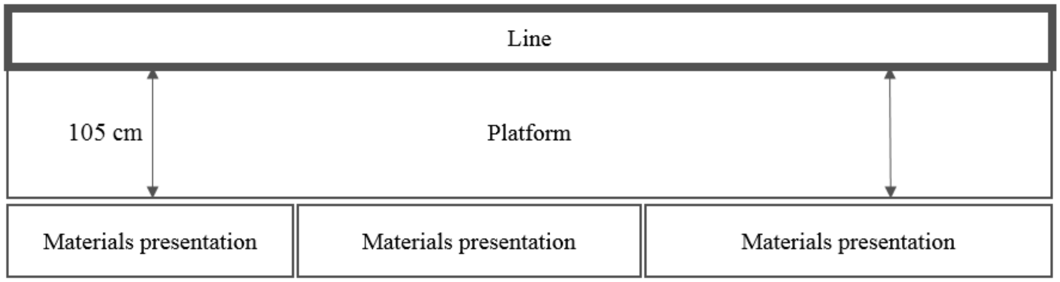


Figure 7.4. Suggested platform length.

7.2.3 Improve materials presentation at assembly stations

The suggestion for increased performance in PF 3 in terms of materials presentation is to ensure that operators do not prepare boxes themselves for assembly as described in Table 4.8 in the design model. The forklift drivers must ensure that the boxes are ready for assembly upon delivery to the line at all times. As stated in Chapter 4 in the design model, it is important to ensure that as much as possible of non-value adding time is allocated to the materials handlers due to that assembly time is more valuable than the time of materials handlers.

Racks should be used that are designed to prevent piling of boxes and thus prohibit forklift drivers from delivering boxes if the racks are full to avoid boxes from ending up on the floor. If boxes are placed on the floor "comprehensible presentation" in Table 4.8 is not achieved due to the risk of the operator placing the box in the wrong rack while moving the box from the floor. The consequence of confusing materials is defective products as described in Table 4.8 in the design model. The size of the containers used for materials presentation should be reviewed in terms of their size. Containers used for materials presentation at the assembly stations should be kept at minimum measures in accordance with Table 4.8 in the design model.

As stated in the design model in Table 4.7, reusable containers of plastic provide benefits compared to disposable containers for materials presentation at assembly stations. Reusable containers of plastic reduce the total cost and increase the packaging protection compared to disposable boxes. The recommendation is to aim for reusable containers as the first choice and have cardboard boxes as the second choice when deciding on packaging with suppliers. Since repacking materials from cardboard boxes to reusable containers require additional materials handling, the recommendation is to make suppliers send materials in reusable containers instead.

7.2.4 Summary of benefits from the suggestions for performance increase

Table 7.2 summarizes the improvement suggestions, the corresponding performance measurement being increased and how performance is increased from the improvement suggestions in section 7.2.

Table 7.2. Improvement suggestions, the corresponding performance measurement being increased and how performance is increased.

Improvement suggestion	**Performance measurement**	**How performance is increased**
Implement sequential supply of frames to first and third line	Performance measurement 2 - Efficient handling in the materials supply operations Performance measurement 3 - Support to assembly operations	The storage points of frames at the first and third line are eliminated. Space elimination of 252 square meters at first line and 89 square meters at third line. Walking distances for operators are reduced, thus lowered non-value adding time. Transport frequency for replenishment is reduced, thus reduced occupancy for forklift drivers.
Reduce distance from materials presentation to assembly line	Performance measurement 3 - Support to assembly operations	Reduction in non-value adding time for operators by reducing platform length to enable closer materials presentation at assembly stations.
Improve materials presentation	Performance measurement 3 - Support to assembly operations	Non-value adding time is reduced by ensuring that materials are prepared by materials handlers for assembly. This is achieved by ensuring that materials are only placed in the assigned racks and that boxes are not stacked. Furthermore, extended use of reusable containers. Ensuring that cardboard boxes (if cardboard must be used) are opened and prepared.

As Table 7.2 shows, all three improvement suggestions are aimed at increasing performance in PF 3 since the potential for performance increase is considered as highest in this area. Furthermore if sequential supply of frames is implemented, performance in PF2 will increase as well.

8. DISCUSSION

The purpose of the thesis was to investigate how performance of the materials supply system at Adient could be increased. From this purpose, four research questions were formulated. Research question 1 was answered by creating a synthesis of existing literature, i.e. the design model. The purpose of the design model was to use it to increase performance with the suggestions for performance increase in the materials supply system. However, not all areas of the materials supply system were involved in the improvement suggestions, thus making parts of the design model excessive. The decision of creating a design model prior to having targeted areas for performance increase was not optimal. Since it was not known what should be increased in terms of performance, the design model was too encompassing and lacked the dimension of package sizes, i.e. the amount of materials in each package. Since package sizes of materials highly influence all areas in the materials supply systems, this aspect should have been included. If the study were to be repeated the design model would be created once targeted areas for performance increase were known and it would include package sizes.

Research question 2 was answered by collecting data and describing the current state at the company. The results were useful since data was collected in each of the six areas of the materials supply and the data was essential in order to answer research question 3 and research question 4. The results from research question 3 were of such quality that the research question itself could be answered but the method of measuring performance could be improved. The lack of standardization of how performance should be measured makes the method challenging to replicate while still achieving the same results, i.e. the degree of reliability is questionable. The exact tools and approaches for measuring performance of materials supply systems should be decided on since the performance measurements by Hanson (2009) could be interpreted differently depending on the recipient.

The results from research question 4 were considered as valuable since the performance was increased as the research question aimed for. The results are believed to be valuable for manufacturing companies aiming to increase performance in their materials supply system since the results show how the measurements are used to create concrete suggestions that increase performance. However, a challenge in terms of increasing performance is the trade-off between the benefits of increased performance in one area and the potential drawbacks in another. This was evident in the MFM for the first and third line where the suggestions for increased performance did increase performance in multiple areas but also created more activities in the flow compared to before. It was not evident what areas in the MFM that should be prioritized over others. Although some areas, e.g. the increased number of activities in the MFM as mentioned above, experienced a decrease in performance, the suggestions for increased performance are considered to increase performance for the materials supply system as a whole.

9. Conclusions

This thesis has contributed to extend knowledge of how materials supply system should be designed, how they should be measured and how performance can be increased by providing concrete improvement suggestions. The conducted literature review showed that both guidelines for designing materials supply systems, and measurements for performance measurements of materials supply system exist. However, the link between performance measurements results, how materials supply system should be designed and concrete suggestions for increased performance has not been evident in existing literature. This thesis exemplifies how the results from performance measurements can be transformed into concrete suggestions for increased performance in materials supply systems.

Further research

Suggestions for further research are to increase the knowledge of the performance measurements and how to use them. As explained previously, the lacking standardization of how the measurements should be conducted in practice indicates a need for further research. Furthermore, the design model for materials supply systems in this thesis could be useful to extend in further research. Due to the limited time of this thesis, the design model could not be created in a higher level of detail. An encompassing and thorough design model of how materials supply systems should be designed would be useful for manufacturing companies.

REFERENCES

Axsäter, S. (1991). *Lagerstyrning*. Studentlitteratur, Lund.

Baudin, M. (2002). *Lean assembly: the nuts and bolts of making assembly operations flow*. Productivity Press.

Baudin, M. (2004). *Lean Logistics: The nuts and Bolts of Delivering Materials and Goods*. Productivity Press.

Blaxter, L., Hughes, C. and Tight, M. (2006). *How to Research*, *3rd ed*. Open University Press, Berkshire, UK.

Bozer, Y. A. and McGinnis, L. F. (1992). *Kitting versus line stocking: A conceptual framework and a descriptive model.* International Journal of Production Economics, Vol. 28, No.1, pp- 1-19.

Bryman, A. and Bell, E. (2011). *Business research methods, 3rd ed*. Oxford University Press Inc., New York, USA.

Bryman, A. and Bell, E. (2015). *Business research methods, 5th ed.* Oxford University Press Inc., New York, USA.

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

Chan, F. T. S., Chan, H. K. and Choy, K. L. (2005). *A systematic approach to manufacturing logistics*. The International Journal of Advanced Manufacturing Technology, 29(9), 1088-1101.

Danese, P., Romano, P., Bortolotti, T. (2012). *JIT production, JIT supply and performance: investigating the moderating effects*. Industrial Management and Data Systems, Vol. 112 Iss: 3, pp. 441-465.

Ding, F. Y. and Sun, H. (2004). *Sequence alteration and restoration related to sequenced parts delivery on an automobile mixed-model assembly line with multiple departments.* International Journal of Production Research, Vol. 42, No. 8, pp. 1525-1543.

Ellegärd, K., Jonsson, D., Engström T., Johansson, M. I., Medbo, L. and Johansson, B. (1992). *Reflective Production in the Final Assembly of Motor Vehicles – An Emerging Swedish Challenge.* International Journal of Operations and Production Management, Vol. 12 Iss 7/8 pp. 117 - 133.

Ellis, K. P., Meller, R. D., Wilck IV, J. H., Parikh, P. J. and Marchand, F. (2010). *Effective material flow at an assembly facility.* International Journal of Production Research, 48(23), 7195-7217.

Finnsgård, C., Wänström, C., Medbo, L. and Neuman, P. (2011a). *Impact of materials exposure on assembly workstation performance*. International Journal of production research.

Finnsgård, C., Medbo, L. and Johansson, M. I. (2011b). *Describing and assessing performance in material flows in supply chains: a case study in the Swedish automotive industry*. Chalmers University of Technology.

Finnsgård, C. (2013). *Materials exposure: The interface between materials supply and assembly*. Thesis for the degree of doctor of philosophy. Chalmers University of Technology.

Flores, B. E. and Whybark, C. (1988). *Know your ABC.* Management Decision, Vol. 26 Iss 3 pp. 20-24.

Frazelle, E. H. (2001). *World-Class Warehousing and Material Handling, 2nd ed*. McGraw-Hill Education. AA.

Frazelle, E. H. (2002). *Supply chain strategy: The logistics of supply chain management*. McGraw-Hill Companies, Inc.

Hancock, D. R. and Algozzine, B. (2015). *Doing Case Study Research: A Practical Guide for Beginning Researchers, 2nd ed*. Teachers College Press.

Hanson, R. (2009). *On the options available in the design of in-plant materials supply systems.* Licentiate Thesis, Department of Technology Management and Economics, Chalmers University of Technology.

Hanson, R. (2012). *In-plant materials supply: Supporting the choice between kitting and continuous supply.* Thesis for the degree of doctor of philosophy, Department of Technology and Management and Economics, Chalmers University of Technology.

Hanson, R. and Medbo, L. (2012). *Kitting and time efficiency in manual assembly*. International Journal of Production Research, 50:4, 1115-1125.

Hanson, R. and Brolin, A. (2013). *A comparison of kitting and continuous supply in in-plant materials supply*. International Journal of Production Research, 51:4, 979-992.

Hua, S. Y. and Johnson, D. J. (2010). *Research issues on factors influencing the choice of kitting versus line stocking*. International Journal of Production Research, 48:3, 779-800.

Johansson, M. I. (1991). *Production Research: Approaching the 21st Century*. In: M. Pridham and C. O'Brien (Eds.), Taylor and Francis, London, pp. 225-230.

Johansson, E. and Medbo, L. (2004). *On the use of product data in the design of the materials supply systems.* Journal of Manufacturing and Technology Management, Vol. 15 Iss 7 pp. 641-650.

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

Johansson E. (2007). *Towards a design process for materials supply systems*. International Journal of Operations and Production Management, Vol. 27 Iss 4 pp. 388 – 408.

Johansson, E. (2009). *Information management for materials supply systems design*. International Journal of Production Research, 47:8, 2217-2229.

Jonsson, P. and Mattsson, S-A. (2009). *Manufacturing Planning and Control*. McGraw-Hill Education.

Liker, J. K. and Meier, D. (2006). *Toyota Way Fieldbook*. McGraw-Hill Professional.

Lumsden, K. (2007). *Fundamentals of logistics*. Chalmers University of Technology.

Maynard, H. B. and Zandin, K. B. (2001). *Maynard's Industrial Engineering Handbook, 5th ed*. Industrial engineering support for materials management, Chapter (McGraw-Hill Professional, 2001 1992 1971 1963 1956), Access Engineering.

Ptak, C. and Smith, C. (2011). *Orlicky's Material Requirements Planning, 3rd ed.* McGraw-Hill Professional.

Robertson, G.L. (1990). *Good and Bad Packaging: Who Decides?*. International Journal of Physical Distribution and Logistics Management, Vol. 20, No. 8, pp. 37-40.

Sali, M., Sahin, E. and Patchong A. (2015). *An empirical assessment of the performances of three line feeding modes used in the automotive sector: line stocking vs. kitting vs. sequencing*. International Journal of Production Research, 53:5, 1439-1459.

Slack, N. and Lewis, M. (2008). *Operations strategy, 2nd ed.* Pearson Education.

Song, J-S. and Zipkin, P. (2003). Handbooks in Operations Research and Management Science, Vol 11. *Supply Chain Operations: Assemble-to-Order Systems, Chapter 11*. Elsevier Inc.

Stevenson, J. W. (2005). *Operations Management, 8th ed.* McGraw-Hill Irwin.

Tompkins, J. A., White, J. A., Bozer, Y. A., and Tanchoco, J. M. A. (2003). *Facilities Planning, 3rd ed*. John Wiley and Sons, New York.

Tompkins, J. A., White, J. A., Bozer, Y. A., and Tanchoco, J. M. A. (2010), *Facilities Planning, 4th ed*. John Wiley and Sons, New York.

Wänström, C. and Medbo, L. (2009). *The impact of materials feeding design on assembly process performance*. Chalmers Publication Library (CPL).

Öjmertz, B. (1998). *Materials Handling from a Value-Adding perspective*. Department of Transportation and Logistics, Chalmers University of Technology.

APPENDIX A – PRODUCT GROUPS

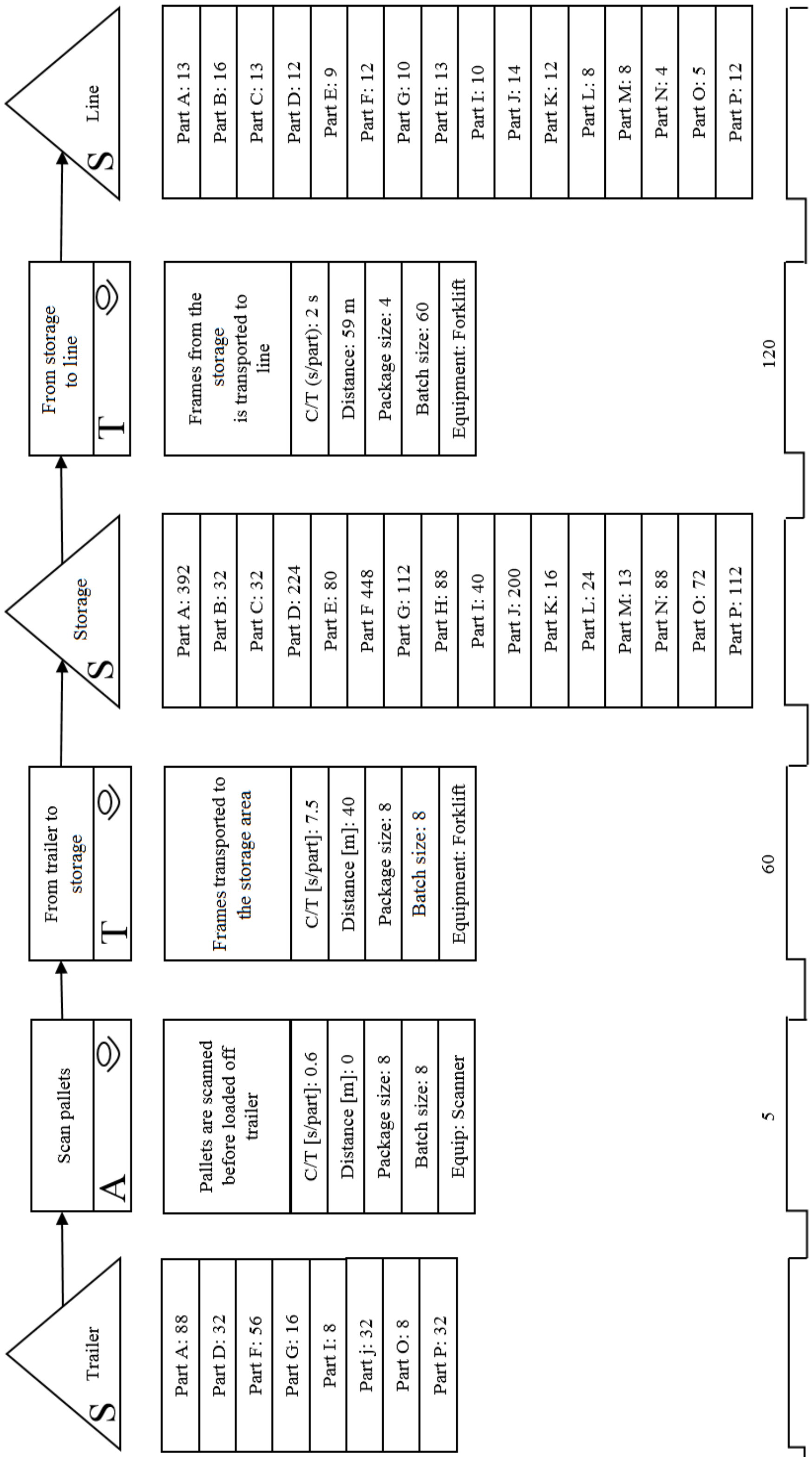
Foam	Two foam “pieces”, cushion and back, i.e. the “padding” of the seats
Frame	Steel frames on which the components are installed on
Headrest	Headrest for the seats
Armrest	The armrest that can be folded down in the second row of seats.
Bolster	Side bolster, type of cushion, on the side of the second row seats.
Cover	Cover for the backside of the second and third row of seats
Electric components	Cables and other components such as seat warmer
Seat trim	The clothing of the seat, either leather or cloth
Airbag	Only on the front row seats
Plastic components	Various plastic components, e.g. crash pad on the backside of first row of seats
Screws	Multiple screws being used

First row of seats.

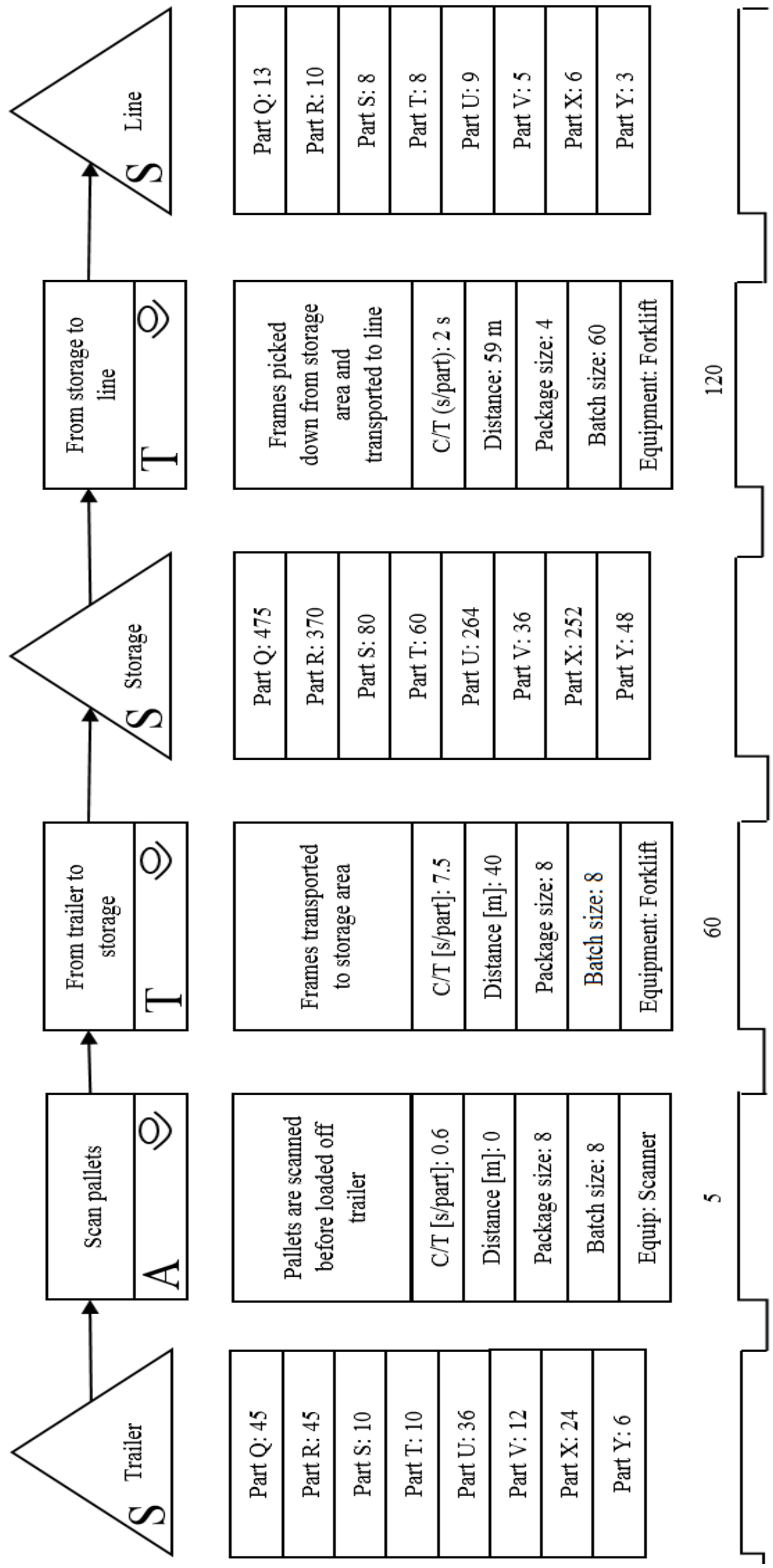
Second row of seats.

Third row of seats.

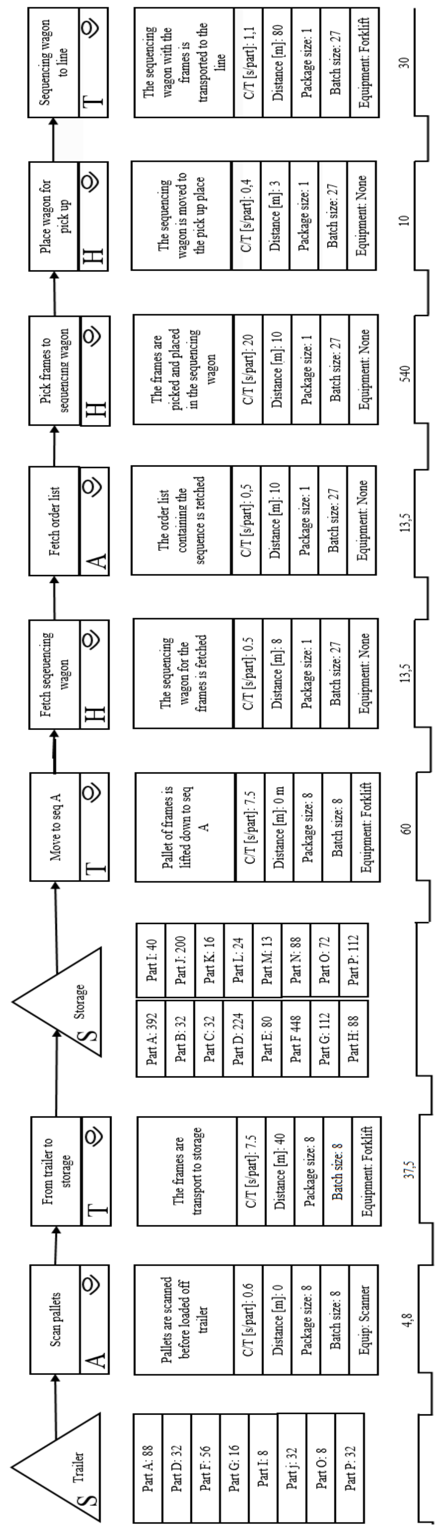
APPENDIX B – MFM FOR THE FIRST LINE IN CURRENT STATE



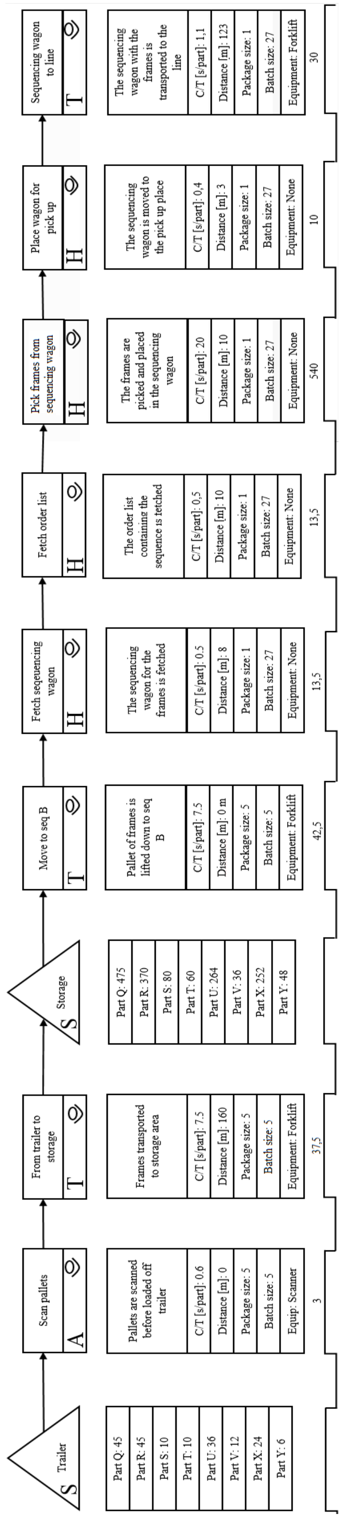
APPENDIX C – MFM FOR THE THIRD LINE IN CURRENT STATE



APPENDIX D – MFM FOR THE FIRST LINE IN FUTURE STATE



APPENDIX E – MFM FOR THE THIRD LINE IN FUTURE STATE



APPENDIX F – LINE MEASURES

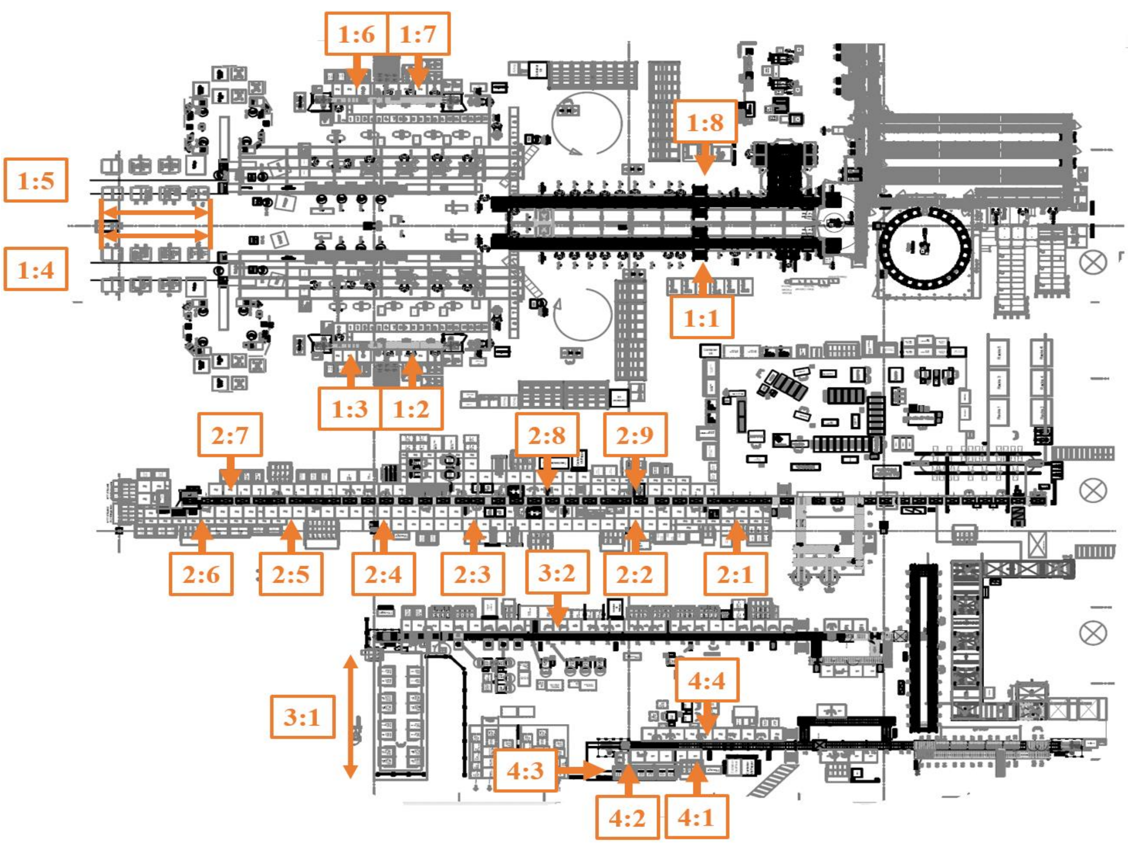
For some of the measured locations the distance varies, thus an average is used.

Line:Location	**Distance to materials presentation [cm]**
1:1	185
1:2	155
1:3	125
1:4	525 (0-1050 cm)
1:5	525 (0-1050 cm)
1:6	125
1:7	155
1:8	185
Average	248

Line:Location	**Distance to materials presentation [cm]**
2:1	190
2:2	110
2:3	250
2:4	125
2:5	185
2:6	300
2:7	120
2:8	235
2:9	170
Average	187

Line:Location	Distance to materials presentation [cm]
3:1	600 (0-1200 cm)
3:2	125
Average	363

Line:Location	Distance to materials presentation [cm]
4:1	125
4:2	160
4:3	200
4:4	125
Average	153



APPENDIX G – TIME MEASUREMENTS FOR FRAMES TO FIRST LINE

L = Left seat

R = Right seat

Unit: Seconds per task

Measure	**Pick frame (R)**	**Cycle time (R)**	**Pick frame (L)**	**Cycle time (L)**
1	21	40	28	57
2	32	48	30	60
3	37	56	21	43
4	28	55	45	72
5	20	41	20	40
6	19	31	22	45
7	16	32	30	73
8	20	42	24	45
9	15	40	35	57
10	29	55	37	60
11	15	34	33	60
12	12	33	32	59
13	53	79	33	58
14	36	65	28	54
15	23	55	21	44

16	23	51	25	45
17	36	65	35	51
18	32	55	26	50
19	42	75	29	50
20	37	65	23	43
AVG	27	51	29	53

Average	Right	Left
Picking	27	29
Assembly time	23,5	24,5