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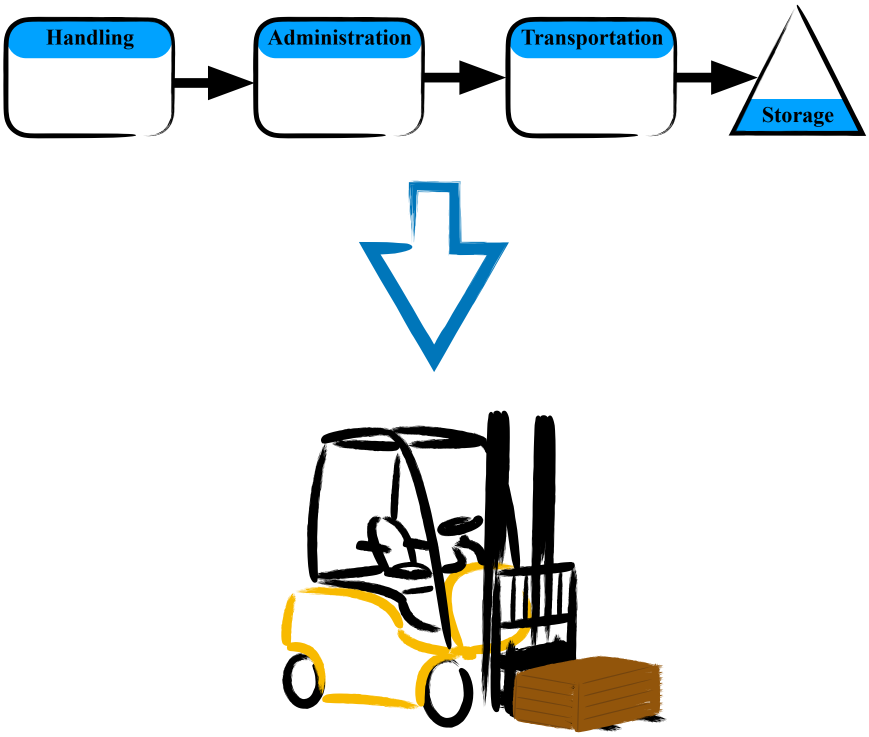

Evaluating automation potential in a material handling environment

A case study of using Materials Flow Mapping as a basis for evaluating Levels of Automation in material handling

Master's thesis in Production Engineering

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Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
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Master's Thesis 2019
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Cover: Illustration of MFM-activities as decision basis for material handling automation.

Typeset in LaTeX
Gothenburg, Sweden 2019

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Abstract

Automation in industry is increasing continuously with the introduction of digitisation and Industry 4.0. Methods for measuring and quantifying levels of automation in manufacturing operations exists and are well developed. One such method is the Levels of Automation (LoA), which can use Value Stream Mapping (VSM) as a basis for understanding and mapping the current state of the production. However, measuring and quantifying levels of automation in a material handling environment is not as widespread. Since material handling primarily consists of non-value-adding activities, the use of VSM is not ideal and other mapping methods developed specifically for material handling, such as Materials Flow Mapping (MFM), is of interest. This thesis investigates how the current and future levels of automation can be evaluated in a material handling environment using MFM and LoA. The research work is conducted as a case study of the internal material handling at Emerson Rosemount Tank Radar AB (RTR) in Mölnlycke. Through MFM-mapping and analysis, the focus area for the automation evaluation is obtained. To evaluate the levels of automation the LoA taxonomy developed for manufacturing is adopted to better suit the purpose of evaluating material handling tasks.
The thesis concludes that using MFM as a basis for evaluating automation is suitable, since it enables the measurement of non-value-adding activities, identifies a focus area and provides a detailed account of activities. The thesis also concludes that an adjusted LoA can be used to evaluate levels of automation in material handling, and proposes an LoA taxonomy adapted for material handling. The results of the case study also provides plausible future levels of automation for Emerson RTR.

Keywords: Levels of Automation, Materials Flow Mapping, Square of Possible Improvements, material handling, automation.

Acknowledgements

This project was carried out as a part of the Master of Science program in Production Engineering at Chalmers University of Technology, Gothenburg, Sweden. The project was carried out at Emerson Rosemount Tank Radar AB during spring 2019.

We would like to send our gratitude to our supervisor Adriana Ito for her commitment during the thesis, her expertise within the subject, as well as sharing her experience of scientific work procedures and thesis structure. We would also like to thank our examiner Johan Stahre for his help during this thesis, Lars Medbo that provided us with Materials Flow Mapping literature and Dan Li for discussion regarding Levels of Automation.

We would also like to thank Emerson Rosemount Tank Radar AB that allowed us to carry out the work at their production site and the kind reception we got during the whole project. Special thanks to our supervisor Jonatan Forsgren that helped us with whatever necessary for us to carry out the work. The whole OPI department, and especially the manager Jimmy Jonsson, for their helpfulness, Håkan Törnqvist and the Operations department for feedback and discussions.

John Persson & Simon Smedberg, Gothenburg, June 2019

Contents

List of Figures

List of Tables

List of Abbreviations

GFR	Gravity flow rack storage
HATS	Handling, Administration, Transportation, Storage
HBS	High-bay storage
JIT	Just-in-time
LoA	Levels of Automation
MFM	Materials Flow Mapping
MTO	Make To Order
MTS	Make To Stock
NNVA	Necessary but non-value-adding
NVA	Non-value-adding
PDA	Personal digital assistant (handheld computer)
PO	Purchase order
RM	Replenishment method
RTR	Rosemount Tank Radar AB
SSL	Safety stock level
TfC	Triggers for Change
VA	Value-adding
VSM	Value Stream Mapping
WIP	Work-In-Process
WMS	Warehouse Management System

1

Introduction

This chapter introduces the thesis and presents the background information, its purpose and focus. A brief description of the case is also provided along with the research questions and delimitations.

1.1 Background

Automation in industry has developed rapidly the past decades and with the entrance of digitisation and Industry 4.0 the next generation of production technology has started to grow, smart factories [1]. Factories with high automation levels are growing and there are examples of factories that are almost autonomous [2]. Since the early 1970s automation solutions have been increasing in manufacturing processes and created more flexible production strategies [3]. This has been necessary for especially western countries to meet the competition from low wage countries [4]. However, companies are in general good at cost calculations and to make return of investment estimations, but to judge beforehand what automation level is plausible in terms of efficiency is more complex. The Lean tool Value Stream Mapping (VSM) has in earlier research's been used as a basis for measuring the automation levels in production flows with focus at the efficiency, not on the human interaction with the technology [5]. So between 2004 and 2007 researchers at several universities in Sweden developed a methodology called DYNAMO to be able to find the right Level of Automation (LoA) in manufacturing environments, with focus on the human interaction with technology [6]. LoA is one part of this methodology that defines different levels of automation in a taxonomy to be used when measuring automation levels. It considers both physical and cognitive automation levels to find a suitable level for everyone in the flow [7]. In the pre-study of LoA, VSM could advantageously still be used as an alternative to map and measure the current situation and there is research on how to implement it with LoA [8][5]. However, VSM is focusing on eliminating non-value-adding (NVA) activities and the DYNAMO methodology is mainly developed for manufacturing operations. There is no equal framework for estimation of automation levels within material handling, that mostly consists of NVA activities, even though it is an area with high potential for benefiting from automation [4]. There is a method developed at Chalmers inspired by VSM that focusing on measuring and map these NVA activities, called Materials Flow Mapping (MFM). This method is using the same symbols and work procedure as VSM to map the current and future situation of material handling operations to find possible improvements [9]. As MFM is developed specifically for material handling, it is of interest to see how it can be used in combination with LoA to analyse the automation potentials in material handling operations.

1.1.1 Purpose

The purpose of the thesis is to investigate how the automation potential in material handling could be analysed and evaluated. This study is carried out as a case study to best test the tools MFM and LoA on a current situation with relevant problems. First, a pre-study is performed to understand the different processes of the case study company and their characteristics. Second, the current situation is investigated to identify the area of focus for the automation evaluation. Third, the current automation level is measured, and an estimation of the future plausible automation level will be derived.

1.1.2 Research questions

Three research questions are formulated to be answered during the project. The first two questions are of scientific nature and address the application of methods in this specific context. The third research question addresses the implications of the study for the case company.

RQ1: Can Materials Flow Mapping (MFM) be used as a basis for evaluating automation potential in material handling?

RQ2: How can Levels of Automation (LoA) developed for manufacturing be applied or further adapted to assess the current and future levels of automation in material handling?

RQ3: Which levels of automation are plausible for Emerson to implement?

1.1.3 Case description

Emerson is a multinational company with around 80.000 employees spread over 200 manufacturing locations all over the world with products in a wide range of markets. In Mölnlycke, Sweden, Emerson Rosemount Tank Radar AB (RTR) produce world leading high technology radar solutions for level measurement for marine, refinery and process applications. The branch employs around 400 workers in their new built facility with 9900 square meters of manufacturing space.

Emerson has recently started a global automation initiative and has encouraged branches to find automation solutions to improve efficiency. By this initiative, Emerson RTR has chosen to investigate several areas of potential improvements where their material handling is one such area. Since the production at Emerson RTR is station-based and they produce according to Make-To-Order (MTO) the production flow is highly uneven. This highly affects the material supply chain that needs to be both flexible and accurate to be able to feed the production with material. It is a very important part to ensure that the production always has the required material, without being inefficient. Emerson RTR follows a global company procurement strategy that defines their Safety-Stock-Level for all components based on their ABC classification, this strategy creates high inventory levels at Emerson RTR to ensure that they always have material available. However, Emerson RTR believes that their material handling has improvement potential and that an investigation of possible improvement areas is needed. The main arguments for this are:

- **Inventory accuracy:** Inventory accuracy in both the warehouse and the production can be improved, mainly because of the high level of manual work and low level of system support. Which leads to mistakes and subsequently a mismatch between the actual inventory level and registered level in the Warehouse Management System (WMS).
- **Long lead time in material handling:** The operating time for material handling is considered long, based on the time it takes from when a material order is created until it is closed.
- **High inventory levels in production:** Emerson RTR produce according to MTO but the material is not delivered according to this strategy, there is a small storage at each production cell that provides material for more than is needed.

The approach is to investigate whether MFM and LoA can be put together to achieve an automation analysis for the internal material supply chain. To prove this Emerson RTR is used as a case study to apply the reworked method into practice.

1.1.4 Delimitations

The case study will focus on the automation potential in the material handling, the high inventory levels that are affected by the procurement strategy and will not be considered since this is outside the scope of the global automation initiative. Within the case study, the focus will be on the automation potential in raw material handling. It will therefore not be considered to analyse the material handling or flow in the external supply chain or in and after the production. The scope of this study will then start where the goods arrive at the arrival zone inside the warehouse and the material handling operators receive the material from the supplier. It will end at the point where the production operators access the material at the workstations in production and the material becomes Work-In-Progress, as shown in Figure 1.1.

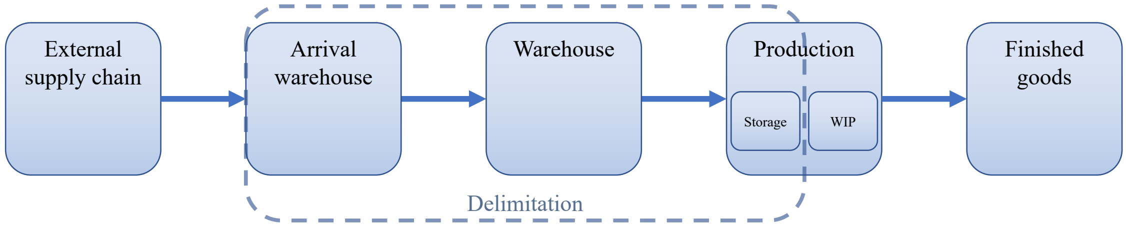

Figure 1.1: Illustration of the material flow delimitations of the scope.

The analysis will cover only a few carefully chosen components to represent the material flow and its problems. This is due to the complexity of doing several analyses with high quality within the deadline of the project. The amount of data that should be needed for these analyses will also take a too long time to collect and sort out. Since the study is carried out as a single case study it will be too specific to draw any general conclusions from.

2
Methodology

This chapter presents the methodology and research approach of the thesis. It also gives an insight into the structure of the study, data collection methods and how the validity and reliability are upheld.

2.1 Research approach

There are many ways to conduct thesis research, depending on numerous factors of the scope and aim of the work [10]. This thesis work was approached as a case study of the company Emerson Rosemount Tank Radar AB (RTR). Besides being a case study, the thesis also utilised an abductive reasoning approach. These concepts are further described in this section.

2.1.1 Case study approach

The case study as a research approach implies the detailed study of an object, often a company, within a certain setting [11]. To conduct a "rigorous" thesis work the approach of the research is of great importance. According to Yin, three conditions for choosing which approach to use can be stated [10, p.5]:

1. "The type of research questions
2. The extent of control an investigator has over actual behavioural events
3. The degree of focus on contemporary events as opposed to historical events"

Based on these conditions a choice can be made whether or not to conduct the study as a case. Since this study had no control over behavioural events and the focus was primarily on contemporary events, the strategy approach was therefore chosen to be a case study [10].

The idea of the approach and particularly the design of the study is to link the study from the initial step to the final. In other words, linking the collected empirical data to the research questions and to the final conclusions, to avoid that the collected data and the conclusions mismatch the research questions [10].

2.1.2 Abductive approach

A research approach that appears in case study research is the abductive approach, which is a form of an iterative process between the empirical and theoretical study part of a project simultaneously [12]. It can be described as a combination of the two more conventional research approaches, deductive and inductive [13]. A deductive approach starts from the perspective of theory and forming a hypothesis which is confirmed or denied by observations [11]. An inductive approach on the other hand starts from observations, forming a theory as an outcome of the research.

As the abductive approach enables going back and forth between theory and observations, it is possible with abductive reasoning to start out with a set theoretical framework, but at a later stage return to theory to alter the framework if observations do not match the prior theories [13]. This is something Dubois and Gadde [12] calls "systematic combining" or "theory matching", where theory, observations and analysis evolve simultaneously.

2.2 Data collection methods

When conducting a case study the data collection is central to the research, and therefore the structure and methods of the collection need to be considered carefully [10]. Case studies have often been seen as strictly qualitative research, as it favours the use of observations and open-ended interviews [11]. However, as Bryman and Bell [11] argues, case studies have the benefit of implementing both qualitative research methods as well as quantitative. Commonly, the collection of data can derive from several different sources of evidence and be acquired by different techniques of collection [10]. As Yin [10] argues there are six different sources that are useful when it comes to case studies; documentation, interviews, direct observation, participant-observation, physical artifacts, and archival records.

In case study theory, the use of multiple data sources is seen not just as a major strength, but as a necessity to uphold the quality of a study. It enables the study to cover more aspects, resulting in converging facts from different sources into more convincing conclusions [10]. There is also an instance where multiple sources of data cover different aspects of the study, leading to non-converging conclusions, which are analysed separately.

In this thesis, four types of sources were primarily used for data collection at different stages of the case study; interviews, direct observations, participant observations and archival records.

2.2.1 Interviews

While conducting a case study one of the integral sources of information is interviews. The strength of using interviews for data collection is that it is both insightful and targeted [10]. It can provide insight into the relations between other sets of data as well as focus strictly on one chosen topic of the study. There are as well some negative aspects to conducting interviews that should be noted and minimised. The main weakness is bias, both in form of the interviewee response but also in the formulation of questions. There is also a possibility of interviewees answering what they think the researchers want to hear, without truly reflecting upon the question first.

Interviews can be divided into three different types, with regard to how strict the topics and their questions are followed; open-ended interview, focused interview and survey [10]. In this thesis, the former two types of interviews were used.

2.2.1.1 Open-ended interview

Interviews of open-ended nature are looked upon as more of a conversation than an interview where questions can be asked of the respondent's opinions rather than just factual data [10]. Questions can be formulated beforehand but most commonly the interview is more a conversation around a certain topic. This type of interview also gives the interviewer the freedom to formulate questions during the interview based on the answers of the interviewee. However, this requires extra care to formulate the questions without bias and without putting the interviewee in a defensive position. This type of interview is to prefer in an exploratory phase of a study.

2.2.1.2 Focused interview

The focused interview differs from the open-ended interview in the aspect that the questions formulated beforehand, the line of inquiry, are followed in a stricter manner [10]. One way to use the focused interview is to obtain facts that have already been collected from other interviewees, but where multiple sources would be of advantage. However, an approach like this requires the formulation of questions to be considered carefully to avoid leading questions tainting the data.

2.2.2 Direct observation

To collect empirical data of contemporary events, behaviours, conditions and requirements of the case study, observations are a fitting source of evidence [10]. Direct observations can be described as being a passive observer studying the relevant events without taking an active role within the study. An observation can be performed formally, where the events and parameters are defined beforehand by using a protocol, and it can be performed casually, where observations are made while collecting evidence from other sources. The strength of doing direct observations is the fact that it portrays the actual procedure of events and behaviours and not just the ideal, supposed procedure. The drawback is however that it is both time-consuming and may affect the study objects to perform differently from usual.

2.2.3 Participant observation

Unlike direct observations, participant observations are not made as a passive observer but instead as an observer interacting with objects of the case study [10]. This is similar to the casually performed direct observations, where observations are made while interacting with participants of the case study through, e.g. interviewing. The strength of doing participant observations lies in obtaining an inside perspective that would not be possible if only passive data collection is made. The weaknesses of this type of observations are similar to direct observations, that it is time-consuming and that the interaction of participating can affect the performance of the study objects.

2.2.4 Archival records

Another form of data to collect is archival records, such as computer files and records. It can range from layout maps to service records, item lists and previously collected survey data [10]. Retrieving data from management systems, such as Warehouse Management System, is one way in which quantitative data can be collected for analysis purposes further along in a case study. The strength of this type of data source is that it is not created for the specific case study and can therefore, in most cases, be considered precise and unbiased. However, one weakness with looking at quantitative data in this way is that numbers do not automatically mean that they are precise, and this needs to be taken into consideration.

2.3 Reliability and validity

When conducting research projects the reliability and validity of the approach are important ways of evaluating and judging the quality of the research design [10]. These two concepts are a confirmation of the extent of accuracy and trustworthiness of the research work, as well as its repeatability [11]. However, Yin [10] argues that the categorisation of reliability and validity is much more complex than just dividing it into these two categories and therefore suggests four measures; reliability, construct validity, internal validity and external validity.

The reliability aspect of research work is to what extent the methodology and design of the approach could be repeated by future researchers [11]. This aspect questions if the results of measurements are consistent and repeatable, in other words, if the same steps and procedures are taken by another researcher it would yield similar results. Reliability has the aim of minimising the biases and errors of a research study [10]. To ensure reliability of a study, documentation of the research procedures are of great importance. By documenting and dividing the work into small steps it will enable the study to be performed again by either the same researchers or independent ones.

Construct validity aims at evaluating the concept of the research [11]. This type of validity reassures that the chosen measures of a concept actually reflects and answers what it is set out to do. To ensure construct validity, Yin [10] proposes to use multiple sources of evidence as well as having the report and its findings reviewed by key informants of the study. The usage of multiple sources of evidence is one of the strengths of case study research. Combining different types of data collection methods, e.g. interviews, direct observation, archival records, enables convergence of evidence into more convincing and accurate results and conclusions [10].

Internal validity focuses on the causality of the variables that have been used to draw conclusions [11]. This aspect of validity is not regarded in this research as it is only of concern to explanatory studies, where the causality of two events are explored [10].

The aspect of external validity is aimed at assuring the generalisability of the research work [11]. If it is possible to apply the findings of the research to other fields outside of its context. To test and to ensure this beyond all doubt, several replication studies need to be performed on other cases where theoretically the same results should occur [10].

2.4 Thesis methodology

This case study was divided into three phases; pre-study phase, mapping phase and automation phase. The pre-study consisted of exploratory literature studies and interviews to obtain the knowledge base for deciding the research approach as well as the preferred methods for each phase. The two latter phases were the main parts of the study with the purpose of answering the research questions. The mapping phase consisted of data collection of the present situation, as well as providing a decision basis for the automation phase. This phase consisted of evaluation of the present and future levels of automation. After the initial underlying literature study in the first phase, further study of literature was conducted for each phase along the way in an iterative manner as per the abductive approach. The abductive approach was utilised throughout the thesis. This was evident at the beginning of the automation phase where it was decided that the current taxonomy for Levels of Automation was not optimal when evaluating material handling processes, and therefore the theoretical framework needed to be altered.

In Figure 2.1 the three phases of the thesis methodology are illustrated with their main objectives and data sources.

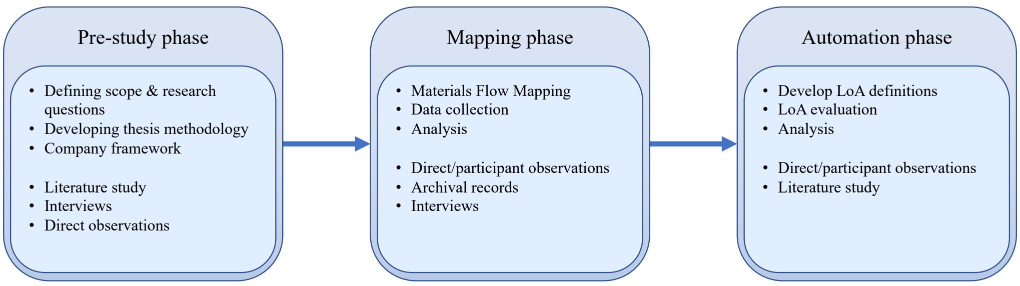

Figure 2.1: An illustration of the three phases of the thesis methodology.

2.4.1 Pre-study phase

The purpose of the pre-study was to obtain an understanding of the overall requirements to conduct the study, as well as a general understanding of the material handling, production and company as a whole. This started with determining and understanding the background to why the study was of interest to be carried out, continuing with defining the scope, posing relevant research questions and delimitations. This was done by conducting open-ended interviews with the stakeholders at the company as well as discussions with the supervisor at Chalmers. The defining of the scope and research questions led to the development of the thesis methodology. The project was divided into three phases to create a structure that is easy to follow and thereby ensuring the reliability of the case study. From the interviews and literature studies appropriate methods for the different phases were chosen.

To obtain a basic understanding, a framework of the company and its processes, direct observations and interviews were made to get a perception of the production groups and the different replenishment methods used in the plant. In this phase the study objects of the project were also chosen in close consultation with the company by interviewing stakeholders from different departments, such as production, logistics and warehouse management. The study objects were 13 components carefully chosen to represent the different scenarios and flows of the material in the warehouse, depending on replenishment method, frequency of use, production group and component type.

2.4.2 Mapping phase

The objective of the second phase in the project was to establish the current state of the material handling flow. The Value Stream Mapping-based Materials Flow Mapping (MFM) was chosen as the method that was best suited to determine and analyse material handling activities, as one of the strengths of MFM is evaluating necessary but non-value-adding activities (see Section 3.2.2). The mapping provided a visual understanding of the material flows, its activities, sequence and requirements.

The analysis of the mapping was done in two steps, HATS-analysis, see Section 4.2.2, and analysis of area for automation evaluation, see Section 4.2.3. Both of these analyses were based on the data obtained from the MFM. The HATS analysis was made to determine and illustrate the number and type of activities that is required for material to travel from the arrival to the production. It also shows the amount of time per activity and activity category, as well as the total lead time for the flow of each component. The HATS-analysis gives an overview of both the physical and the informational requirements related to the handling of material in the whole in-house supply chain. The analysis and identification of an area for automation evaluation were done to determine in which area of the flow the automation phase should be conducted. The material flow maps were divided into sections to determine where in the flow the most operator working time was needed, and thereafter focus the evaluation of the automation levels on this section.

2.4.2.1 Data collection

The mapping was performed by direct and participant observations of the material flow and the data was collected by observational time studies as well as archival records from the ERP-system of the company. All presented data for the mapping phase of this thesis is multiplied with a undisclosed factor, for secrecy reasons.

The processes for the material flow of all components were observed to identify the activities to be measured and set this into the sequences they were performed to get the whole flow. The sequences of activities for all components were drawn up in what could be called a draft and later discussed and validate with the different stakeholders before actual time studies took part. Since there was a rotation system between the operators and the different tasks, the tasks were performed a bit differently between the operators in some cases, but these differences had no impact on the time, only on the sequence.

From these observations and interviews with different stakeholders in both production and warehouse, a data protocol was created to collect all the data to facilitate the drawing of the map, see Appendix A. The data protocol and its parameters were inspired by the observations in the pre-study and literature [20]. It was of great importance to have measurable parameters both for the physical flow as well as for the information flow to ensure that both the movements and the triggers of the flow were mapped. These observations were then performed as formal observations.

The data collection was performed as time studies along with data collection from the ERP-system. Since the data from the ERP-system were logged every time material was moved, data of how long the material is in storage could be collected. At the storage points where the material was stored for days, retrieving the archival data from the ERP-system saved a lot of time-consuming work observing these storage times. It also contributed to a solid historical background of the inventory times that is impossible to collect by time studies.

The time studies were focused on the actual handling of the material and were carried out by observing an operator that performed the task with as little influence as possible form the observers. Along with the parameters, comments from the operators were also collected to understand problems and drawbacks with the procedures even better. These comments were not included in the drawing of the maps but were used in the analysis. Since the studies were done on actual material orders, several other components were handled during the same replenishment round as the chosen components. These components were not measured, but the time it took to handle these components affected the transportation time for the chosen components.

2.4.3 Automation phase

In the automation phase, the level of automation was evaluated for the section of the material flow chosen in the previous phase of the project. Since the Levels of Automation (LoA) taxonomy described by Frohm [14] was developed for manufacturing there was a need to adapt it to fit the purpose of evaluating material handling activities. The adaptation provided a taxonomy similar to the manufacturing LoA but with some small changes to the definitions and examples of the levels. The adopted LoA taxonomy derived from discussions with researchers at Chalmers where plausibility of applying LoA on material handling was discussed. Before the automation evaluation began the company specified the triggers for changing the automation levels. The Triggers for Change (TfC) were linked to improving inventory errors and decreasing the material handling time.

The LoA evaluation consisted of determining the current automation levels for the chosen section. The tasks in this section were measured and graded according to the LoA taxonomy adapted for material handling. Thereafter, plausible minimum and maximum levels of automation were derived for the tasks, in discussions with stakeholders at the company. The current level together with the minimum and maximum levels then formed the Square of Possible Improvements which showed the plausible levels of automation that the company can implement, as well as which tasks should be focused on.

2.4.4 Reliability and validity of this research work

The reliability of this research work was ensured by the documentation of each step and methods used to obtain the results and arrive at the conclusions. This ensured that errors and biases were minimised, and similar findings can be replicated by other researchers.

The construct validity of this research work was ensured by using multiple sources of evidence and having the concepts and findings continuously reviewed by key informants such as supervisors at the company and school. In the pre-study reviewing by key informants was done during the process of choosing methods and study objects, as well as when creating the company framework. The results of the mapping and analysis were also validated by key stakeholders at the company to ensure construct validity. In the automation phase, the concept of adapting LoA for material handling was validated through discussions with a researcher at Chalmers. The same applies to the evaluation of current, minimum and maximum levels of automation, where stakeholder at the company validated and contributed to the compilation of these.

The external validity, generalisability, of this research work is limited to the application on Emerson RTR regarding the concluded plausible future level of automation. However, the generalisability of using Materials Flow Mapping as a basis for investigating levels of automation, and using LoA in a material handling system is slightly higher, although further replication studies are necessary to ensure higher external validity.

3

Theoretical framework

This chapter provides an overview of the relevant theoretical framework used in this thesis work, which is divided into Production and logistics systems, Mapping and Automation. The theory was derived both from initial literature study and iterative literature study during the thesis work.

3.1 Production and logistics systems

A production system can be described as a system with "the process of creating goods and/or services through a combination of material, work, and capital" [4, p.43]. The production system can be regarded as an open system, a system which interacts, affect and is affected by other systems in its environment. The notion of a production system being an open system means that as long as it is not interacting and combined with other systems such as logistics it has little value [4]. The same applies to the logistics system which is regarded as an open system which has limited value on its own [15].

The structures of the production system control the material flow of the production and closely interact with the material supply logistics system by triggering the replenishment of material with information signals [4]. These signals can be triggered in different ways depending on the type of system that is applied in production.

3.1.1 Push and Pull systems

The planning operation of a production system can be divided into a push or pull system, with the most fundamental being the push system [4]. By basing the production and its planning on forecasting, production orders and material are pushed out to each operation in the production flow. The parts in a push system therefore move as soon as they are able to, without consideration of the status of downstream operations [16]. The pull system however, does not move parts until the downstream operation signals that the parts are needed. Contrary to the push system, the planning is not based on forecasting, but on the actual need of the system. The signals that pull the material are triggered by the consumption and movement of the material. The pull system was inspired by and can be likened to the shelves of a supermarket, where they are restocked when products are sold [17]. The replenishment is in other words determined by the consumption. These systems are illustrated in Figure 3.1, by Bellgran and Säfsten [4].

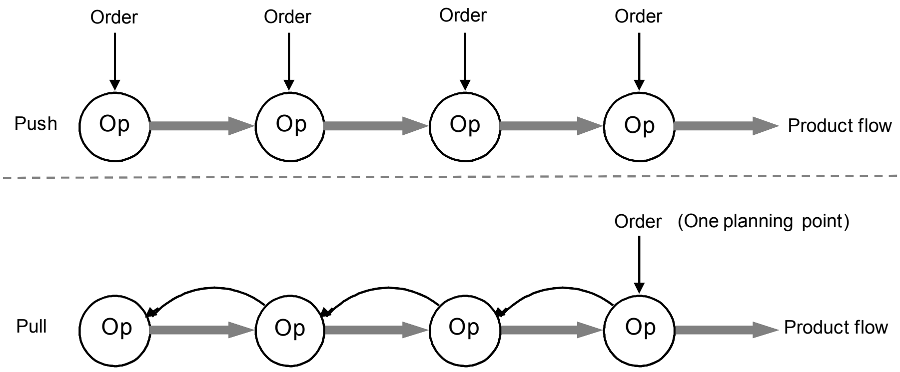

Figure 3.1: Illustration of push and pull systems. Picture taken from Bellgran and Säfsten [4, p.201].

By using a pull system over a push system, the Work-In-Process (WIP) in the production can be decreased lowering the capital binding, as well as the number of material handling steps [16]. The pull system is one of the necessities of the Just-In-Time (JIT) principle developed by Toyota [17]. Without the pull system the main idea of JIT, delivering the right material at the right time and in the right quantity would not work.

3.1.2 Pull signals

Pull signals is the way in which downstream operations are able to communicate with upstreams operations, tying together the different workstation as well as warehouse operations [16]. There are several ways of doing this, where a reorder point system is the basis of issuing pull signals. Here, a minimum level of inventory is set as the trigger for order of material. When the minimum level is reached a replenishment order is sent to refill the inventory level to a predetermined maximum level of inventory. The minimum level is set so that the demand during the lead time of the replenishment is covered by the safety stock.

3.1.2.1 Kanban

A kanban is a pull signal that only contains and carries information between production locations, contrary to the bin system where the pull signal is a mixture of information carrier and physical carrier [16]. The idea of kanban is to lower the inventory and WIP throughout the value chain by delivering the material Just-In-Time. The kanban cards are used as signals for the movement of material when the inventory at a given location reaches a critical level. A kanban is then sent to trigger replenishment of the material. In this way the demand of the production drives the replenishment of material and the inventory is kept at a low level, only the needed material is stored at the location.

3.1.2.2 Two-bin system

The two-bin system consists, as the name suggests, of two bins as manual pull signals that can travel between the production and their replenishment area [16]. The bins are most often presented on flow racks in the production, where an empty bin is seen as a material order. The bins contain information about material, shelf location and designation to the specific material, e.g. in the form of a bar code. The quantity of one bin must be able to cover the demand during the replenishment lead time, so that the production is continuously flowing.

3.1.3 Milk runs

The milk run is a type of transportation that can be applied both in the external supply chain and inside the walls of the production plant. This replenishment method is suitable for material with a repeatable and stable flow between fixed locations [16]. The milk run is carried out by tugger carts or similar vehicles that are able to pick up and drop off materials along a fixed route. The idea of the milk run is that one operator can handle the delivery of numerous components in one transport, which would take several turns using a forklift. During the run along the fixed route the operator drops off packages or bins filled with components while simultaneously collecting empty bins or kanban cards for packages. The material for the collected bins and kanban cards are then refilled on the next milk run.

3.2 Mapping

Mapping is a tool to visualise different flows, both operations and materials, in an easily understandable way. The most common one is Value Stream Mapping (VSM) developed by Toyota and strongly linked to the Lean principles [18]. From VSM, Materials Flow Mapping (MFM) has been developed to cover up the lack of focus on quantifying the material handling part of a value stream.

3.2.1 Value Stream Mapping

To identify improvement areas and to evaluate possible improvement actions, the state and processes of the current process must be identified. As Bicheno & Holweg [18] describes, mapping the process is the "Meta Tool" of Lean and one of the major analysis instruments. VSM consists of identifying all activities, value-adding and non-value-adding, along the value chain from raw material to customer, and enables reducing the waste that non-value-adding activities cause [19]. VSM enables understanding and visibility to the flow in a simple manner, as Rother & Shook [19] describes it; it is a pencil and paper tool to visualise the value stream, its processes and how the information flows.

VSM places importance on the information flow within a production facility, not only the material flow. The physical flow of material is often the most prominent of the two, but the information flow aspect is of equal importance when accurately mapping the value stream. Therefore, VSM covers both the physical flow of material and the flow of information which governs the activities. The two flows can be regarded as two sides of the same coin, which both needs to be mapped to identify improvement potentials and achieve a value-adding flow. It covers both the physical flow of material and the flow of information which governs the activities [19].

The idea of VSM being a pencil and paper tool is to keep it simple and encourage information collection by observation, not using standardised times, but instead gather current-state information by direct observations of the processes. In the first step of drawing the current-state map one product or product family is chosen to be followed door-to-door. All the activities, both material and information, along the path of the product are documented using a predetermined set of symbols to represent the different kinds of activities [19]. The purpose of VSM is not just to visualise the current state of the production, but also to construct a future state map of the intended improved flow, which is the second step. The final part of the method is to construct an action plan of how to get from the current state to the future-state [18].

The main benefits of VSM are that it highlights not only the waste, but also the origin and root cause of it, and provides a link between material and information flows. This makes VSM not merely a quantitative tool but instead a qualitative communication tool that can drive the change process in a production company. Further benefits with VSM are that it describes how the current flow works, how the future state should be designed, what needs to be done to achieve that and how it will affect the holistic flow [19].

3.2.2 Materials Flow Mapping

As effective as VSM is when it comes to identifying, analysing and improving production processes in the manufacturing environment, it has some weakness assessing the importance of material supply in a value stream [9]. Defining manual operations as value-adding (VA), non-value-adding (NVA) or necessary but non-value-adding (NNVA) does not fit material supply, as value-adding is regarded as operations that directly increases final value to the customer. Judging by this definition, close to all material supply activities are classified as either NVA or NNVA. Therefore, MFM was developed based on VSM, to assess the material flow using different performance measures than the traditional VSM [9].

Just like VSM, MFM provides a visual description of the material flow, but unlike VSM it documents and measures material supply activities in four different categories Handling (H), Administration (A), Transportation (T) and Storage (S). Using HATS to describe the material supply activities will subsequently make the flow of

NNVA activities visible and analysable [9]. In Table 3.1 a description of the HATS activities can be seen.

Table 3.1: Description of HATS activities [20].

Handling (H)	An activity with the purpose of handling a product or component, e.g. loading or unloading.
Administration (A)	Activities such as to tally arrival quantity or scanning of labels.
Transportation (T)	Activities with the purpose of moving a product or component from one place to another.
Storage (S)	Storage points of products or components along the material flow.

When conducting the MFM method the first important step is to define the study object and the scope of the mapping, to clarify which nodes of the supply chain that is regarded and who is the end user. The next important consideration is collecting the data, which is done by direct observation of the supply chain and interviews of operators and managers to gain more knowledge of the operations. As Finnsgård, Medbo and Johansson [9] state, when collecting the data and constructing the map it is preferable to follow one individual component at the time for a better result. When the data is collected, the sequence of the activities can be mapped. Together with all the relevant data collected the final materials flow map can then be constructed, including process descriptions, requirements and additional information. Re-iterating the MFM with the involved actors is an important part of the process of mapping to validate the work along the project. The following analysis of the MFM involves assessing the data of the HATS activities Handling, Administration, Transportation, Storage. The HATS data is analysed with regard to the number of activities, total timing for the categories and averages. From this analysis a future state map and an action plan can be generated [9].

By analysing this type of data, MFM focuses on parts of the value stream that VSM often miss, the non-value adding activities. The strength of MFM is that it provides an overview and understanding of the materials flow with the possibility to assess important activities and performance of the supply chain [9].

3.3 Automation

Automation is historically defined as a technology which performs a task undependable of human assistance [21]. This definition creates an "on or off" relation to automation to choose between machines or humans [7]. Today we know that automation is a tool to help humans perform different tasks rather than to replace them and automation is more and more common in companies manufacturing operations [4]. The range of possibilities has expanded rapidly since IT and data entry the industry which creates almost endless variants to choose among and automation is no longer only connected to physical tasks as lifting and transportation but also to tasks such as control and information flow [22]. Because of this extension automation could today be divided into two categories, physical and cognitive automation. Physical automation is often referred to as mechanical with a focus on replacing human muscle power with a different kind of equipment. Cognitive automation is more focused on how to help humans perform their task. It could be both how the information of how to perform a task is delivered and how to control that the task is performed right [22]. However, there is no definition of what the right automation level is. Bellgran and Säfsten states in their book:

"The purpose of right automation is to allocate tasks between man and machine in the most suitable way in each situation" [4, p.310].

Since every company has different systems with different drawbacks and problem, the right automation level is different in all situations for all companies. There have been different pieces of research within the area trying to develop a tool or taxonomy to find the right automation level for a certain task. Most of this research has been focusing on either on the physical or the cognitive automation levels [14]. However, there has also been research that tries to merge these two scales into one taxonomy for a more holistic view.

3.3.1 Levels of automation

The Levels of Automation (LoA) taxonomy was developed by Frohm et al. between 2004-2007 as a part of the DYNAMO project [6]. The taxonomy was inspired by several other historical taxonomies concerning either physical or cognitive tasks but with the difference that it combined these two allocations into one taxonomy. The definition of levels of automation had before often been divided into either a physical scale, often referred to as mechanical tasks or a cognitive scale with a focus on information and control [14]. Frohm et al. combined these two allocations into one taxonomy to create a more holistic tool. However, the taxonomy is created so that the two scales are independent of each other. It contains seven different levels from totally manual to totally automatic at both scales, with various levels in between which in total creates 49 different possibilities.

Table 3.2: Levels of automation matrix [23].

LoA	Mechanical and Equipment	Information and Control
1	**Totally manual** - Totally manual work, no tools are used, only the users own muscle power. E.g. The users own muscle power	**Totally manual** - The user creates his/her own understanding for the situation, and develops his/her course of action based on his/her earlier experience and knowledge. E.g. The users earlier experience and knowledge
2	**Static hand tool** - Manual work with support of static tool. E.g. Screwdriver	**Decision giving** - The user gets information on what to do, or proposal on how the task can be achieved. E.g. Work order
3	**Flexible hand tool** - Manual work with support of flexible tool. E.g. Adjustable spanner	**Teaching** - The user gets instruction on how the task can be achieved. E.g. Checklists, manuals
4	**Automated hand tool** - Manual work with support of automated tool. E.g. Hydraulic bolt driver	**Questioning** - The technology question the execution, if the execution deviate from what the technology consider being suitable. E.g. Verification before action
5	**Static machine/workstation** - Automatic work by machine that is designed for a specific task. E.g. Lathe	**Supervision** - The technology calls for the users' attention, and direct it to the present task. E.g. Alarms
6	**Flexible machine/workstation** - Automatic work by machine that can be reconfigured for different tasks. E.g. CNC-machine	**Intervene** - The technology takes over and corrects the action, if the executions deviate from what the technology consider being suitable. E.g. Thermostat
7	**Totally automatic** - Totally automatic work, the machine solve all deviations or problems that occur by it self. e E.g. Autonomous systems	**Totally automatic** - All information and control is handled by the technology. The user is never involved. E.g. Autonomous systems

The taxonomy in Table 3.2 can also be presented in a matrix with the two scales as axes. To visualise how the levels are classified, the matrix shows the division of human- and machine-driven tasks for the different LoA [7]. The colours represent the areas of the division, where the darkest blue shows that there is an overlap between the technology performing the task and human performance and control.

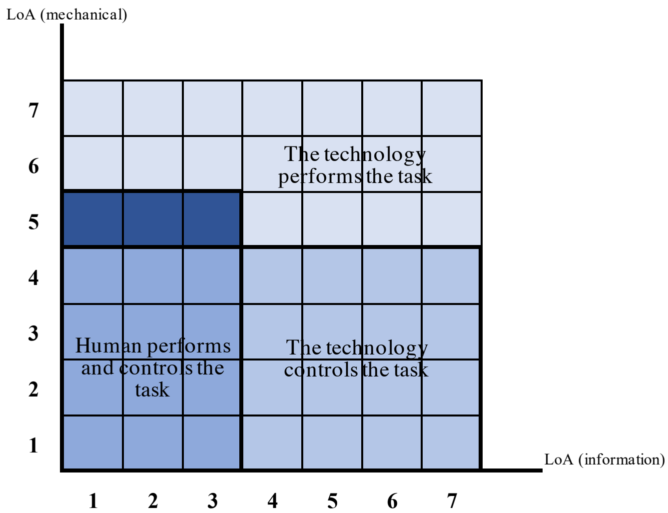

Figure 3.2: The different levels of the LoA taxonomy visualised in a matrix [7].

From the taxonomy in Figure 3.2, minimum and maximum levels of possible automation for all different tasks are set to delimit the analysis to only the relevant areas. It is of great importance that all the stakeholders are involved in this process to give credibility to the analysis, preferably in a workshop. The minimum level should be the minimum level of automation needed to perform the task at a suitable pace without any risk for the operators involved in the task. The max-level should represent a solution which advantages exceed the investment cost. These minimum and maximum levels are inserted in the matrix and create what is called the Square of Possible Improvements (SoPI). It is within this area, solution space, the company has its potential to improve. The current automation level is then measured and inserted in the matrix to see if and in what direction a change is possible. Based on this a solution can either be discussed for the single task or several SoPI can be inserted into the same matrix to find out a feasible improvement for the whole operation [22]. Performing an analysis of the whole operation is preferable since it gives less complexity in the implementation. An analysis at task level will create several different suggestions for improvements that together could be hard to achieve.

4

Results

This chapter presents the empirical findings and results of the case study. It is divided into Pre-study results, Mapping results and Automation analysis results.

4.1 Pre-study

To get an understanding of the production and how the material is replenished a short background description is necessary. By direct observations and interviews, a fundamental framework of the system as a whole was obtained. From this pre-study the study objects for the mapping is derived.

4.1.1 Triggers for changes

Emerson Rosemount Tank Radar AB's (RTR) main Trigger for Change (TfC) is to increase their efficiency which is created by the global automation initiative. At Emerson RTR this automation initiative creates an opportunity to investigate different areas with potential to benefit from automation to make them more efficient, the internal material supply chain was one such area. Today Emerson RTR thinks that their material handling could be more efficient and the inventory accuracy could be improved. So the TfC set for Emerson RTR are:

- Improving inventory accuracy
- Decreasing the material handling time

Emerson RTR considers that this will have a positive effect on the inventory levels out in production, with decreased inventory levels and enable them to deliver material more just-in-time (JIT).

4.1.2 Production and replenishment

As a manufacturer of high technology radar solutions for level measurement, Emerson RTR's production is of low volume and many variants. In general, the production is based on Make-To-Order (MTO) as the products are made and shipped against customer orders. Some exceptions can be seen as certain sub-parts are Make-To-Stock (MTS) against supermarkets. However, these parts are then assembled and shipped MTO. The site in Mölnlycke is primarily focusing on adding value in terms of assembly, and has very little raw material manufacturing. The production is divided into eight production groups, P1 to P8, assembling against customer orders for marine, refinery and process industry. The groups are station based in a cell layout type of production design, which enables flexibility while making a high variety of products.

The warehouse is situated in the same building as the production, in an adjacent premises with one entry and exit point between them. The warehouse has three primary storage locations, High-Bay Storage (HBS), picking storage and entresol storage. In the HBS the biggest components are placed, with the least frequently used furthest up. The HBS consists of eight shelves with a total height of approximately 10 meters. In the picking storage the components which are most frequently used and of small size are kept to facilitate the picking for the material handlers. In the picking storage the height is five shelves in total approximately 2.5 meters. The aisles in the picking storage are wide enough to fit the tugger carts which delivers most of the material. Above the picking storage there is a second-floor storage, an entresol (mezzanine), and it is accessible by stairs. This is also a picking storage, but contains components with a low frequency of use and of small size, as it requires extra time for walking, picking and transporting material without mechanical aid.

To replenish the material the company has a material handling group which handles incoming goods, finished goods as well as the replenishment to the production. Incoming goods are received at the arrival centre in the adjacent warehouse where it is unpacked, inspected and registered. Thereafter, it is transported to the HBS, picking storage or entresol storage. Finished goods are transported from the production area to a designated area in a second adjacent finished goods warehouse. To provide the material to the production groups, the material handling group uses four different replenishment methods. They are governed using different trigger signals and delivery methods.

Replenishment method 1

Replenishment method 1 (RM1) consists of two milk runs along two different fixed routes in the production, delivering the most frequently used components. The RM1 runs are carried out continuously during the day and supply the production with material using physical kanban bins and cards as replenishment pull signals. The material is delivered to production in the bins or its original supplier packaging by operator-driven tugger carts, one for each RM1 route. During the milk runs the kanbans are collected while the material is replenished to the production groups. Even though the idea of the RM1 runs is to deliver the material with milk runs, some components are physically too big or too many to be transported by the tugger carts and must therefore be delivered individually by forklift. The material on the RM1 replenishment method is delivered to fixed and allocated spaces, either in material specific racks, bins or floor spaces.

Replenishment method 2

Replenishment method 2 (RM2) is triggered by a pull signal, much like the RM1 method. However, instead of the physical kanbans of the RM1 method, the RM2 method uses electronic trigger signals to the Warehouse Management System (WMS) to order material, like a reorder point system. Each component on the RM2 has a minimum and maximum inventory level in the storage points in production. When the minimum level is reached, a material order appears on the Personal Digital Assistant (PDA) of the material handler and the material is picked and delivered along with the material of the RM1 run. The delivery volume should always correspond to reaching the maximum level of the production storage point. The material on the RM2 is delivered to fixed and allocated spaces, either in material specific racks, bins or floor spaces.

Replenishment method 3

Delivery of material on replenishment method 3 (RM3) is triggered by customer orders. The production planning coordinator receives the orders and registers them as manufacturing orders for the different production groups. A material order is then placed to the WMS which ends up in the PDA of the material handling operators. The transportation of material is carried out with either forklift or tugger cart with a special kart on tow, depending on the size and quantity of the components and its destination. The material is delivered to drop zones in the production groups. These drop zones are not allocated for any specific material, compare to RM1 and RM2 material.

Replenishment method 4

Replenishment method 4 (RM4) is based on material need from customer orders, just like the RM3 method. The production planning coordinator receives orders from customers and registers them as manufacturing orders. As soon as the manufacturing orders are registered, a material order for the components on RM4 is sent to the material handling group via the WMS. The difference between RM4 and RM3 is the way the material is presented. The RM4 material is delivered by forklift on a pallet of mixed material, but of the same manufacturing order, while RM3 delivers mixed material from different manufacturing orders on the same pallet or kart. The RM4 material is, just like the RM3 material, delivered to drop zones in the production groups. These drop zones are not allocated for any specific material, compare to RM1 and RM2 material.

4.1.3 Studied components

Choosing the right components to study is of high importance to achieve visualisation of the material flow which represents an as large portion of the flow as possible. By interviewing stakeholders from the warehouse management team as well as the production logistics team and production groups, it is possible to choose components that best represent the overall material flow. The idea of representing the material flow is choosing components that cover the different replenishment methods, components that are used frequently and less frequently, as well as components that are delivered to different production groups. This ensures that a holistic view of the material flow is be obtained. From the interviews a first set of components is reached and through an iterative process of interviewing and direct observations the chosen components are reviewed and revised, to exclude components which do not represent the overall flow and include the ones that better represent it. Through this process the components shown in Table 4.1 are chosen as the most representative study objects.

Table 4.1: Components chosen as study objects.

	Replenishment method	**Component type**	**Warehouse location**
Comp 1.	RM1	Electronic (PCB)	Picking storage
Comp 2.	RM1	Plastic	Picking storage
Comp 3.	RM1	Mechanical	High-Bay storage
Comp 4.	RM1	Electro-mechanical	Picking storage
Comp 5.	RM1	Mechanical	High-Bay storage
Comp 6.	RM1	Electronic (PCB)	Picking storage
Comp 7.	RM2	Electro-mechanical	Entresol
Comp 8.	RM2	Mechanical	Picking storage
Comp 9.	RM2	Electro-mechanical	Picking storage
Comp 10.	RM2	Plastic	Picking storage
Comp 11.	RM3	Plastic	High-Bay storage
Comp 12.	RM3	Mechanical	High-Bay storage
Comp 13.	RM4	Electro-mechanical	Entresol

The iterative process of interviewing stakeholders and observing the flow enables the work to be validated early in the process strengthens the credibility of the method.

As previously mentioned, the chosen components are of different replenishment methods, delivered to different production groups, stored in different warehouse locations and have a different consumption. The components are also of a different type, ranging from simple mechanical and plastic components to electro-mechanical and electronic. These characteristics require different handling. The electronics cannot be opened or repacked anywhere outside an Electrostatic discharge Protected Area, which are situated in the production cells processing these components.

4.2 Mapping

The scope of the mapping is set as when the material arrives at the building, excluding the external supply chain, until it reaches the production. It is necessary to limit the study to meet the time frame and since the focus is on the internal process, the external deliveries are not of interest for the stakeholders of the project. The end of the scope is set to be when the material changes from inventory to Work-In-Progress (WIP) in production. It is considered important to include the time that the material is stored in production since this is described as a problem from the stakeholders and of importance for the TfC's.

4.2.1 Current state

From the data collection, described in Section 2.4.2.1, the Materials Flow Mapping (MFM) map for each component is created in Visio[1]. A legend of the MFM symbols can be found in Appendix B, and the MFM maps of the components are presented in Appendix C.

Replenishment method 1

All the material is passing through the arriving zone and is handled in the same way. The delivery note is taken and the Purchase Order number (PO-number) is inserted into the WMS to get all the information about the component and the order. The delivery note also reveals the quantity of the delivery which is checked against the order in the WMS and roughly checked against the psychical components to see so it is matching. At the same time as the PO-number is inserted in the system, the status of the component is set as *arrived* and the total inventory level is updated with the delivered quantity and the intermediate storage point at arrival is updated with the delivered quantity. The components are sorted out and placed in pallets at the arrival storage point, which is marked after the warehouse location, so the first handling is done here. If the components are of the quantity and size that fits on a single pallet it is delivered to another intermediate storage location suitable for pallets. The operator responsible for the warehousing are checking visually when a pallet at the arrival storage point starting to be full or when there is much material at the pallet storage for the arriving goods, there is no prioritisation of what material to be picked first at this point but the operator just takes one of choice. When the material is picked the operator creates an order in the WMS that the material is in movement and have left the arrival storage point towards its warehouse location. The arriving component has now no psychical inventory location but is stored virtually in the system on the operator's PDA. This is always done with the help of a forklift and the material, regardless of quantity, is transported in or at a pallet for ergonomics reasons. When the material later is unloaded at its warehouse location the WMS is also updated with correct inventory locations. The material is then stored at its location until an operator coming for delivery out to production.

The only exception here is component 6 that has two different storage points in the warehouse. The first one is in the High Bay Storage (HBS) where the material is stored on pallets. The second one is in the picking storage and consists of Gravity

[1] Visio - `https://products.office.com/en-us/visio/flowchart-software`

Flow Racks (GFR), to facilitate the picking, where the material is stored in their original cardboard boxes. The first warehouse location stores the Safety-Stock-Level (SSL) for the components while in the GFR the material that is supposed to be delivered out to production is stored. The delivery from the HBS to the GFR is based on a minimum level that is triggered in the WMS when it is reached and an operator then moves material from the HBS to fill up the GFR. In the HBS the FIFO is marked by which month the material arrived while in the GFR the material is marked by which date it was put in the GFR.

In production, there is a 2-bin system so that when one bin is empty it is placed at a certain location to be picked up by the operator at that replenishment round. the bins are stored in flow racks to make the material more accessible in production. The bins are often picked up at the same time as already taken material is delivered out, the exception is when there is a lot of outgoing material, then all the material is unloaded before another round with only picking up bins is performed. When the bins are arriving in the warehouse all the bar-codes are scanned to get a picking-list in the WMS where information about location and quantity is reviewed, at the same time an order is created in the WMS. The material is then picked up at its location and the operator scans the bar-code at the shelf to confirm the taken quantity. The inventory levels are updated and the material is set as *in movement*, the inventory location is again a virtual location at the operators PDA. The transportation out to production is performed with help from a tugger cart and there are always several other components picked up and delivered at the same round. When the material is unloaded to its production location the order is finished and the inventory location is updated. The material is then stored in the flow-racks until it is used and becomes WIP in the system and is drawn from the inventory level.

Replenishment method 2

The components are delivered and handled at arrival in the same way as for the components delivered by RM1. The handling at arrival is highly dependent of the suppliers. It depends on how much material is packed in each delivery. For components within RM2 it tends to be more small articles delivered in big batches, but also single item packages contained in a bigger package, so there is some more handling in terms of picking and placing packages in the right pallet at the arrival storage point. The material is then moved from the arrival storage point to its warehouse locations in the same way as RM1 components with one exception.

Component 7 has its warehouse location at an entresol location. This entails that the psychical movement takes longer time and demands more activities. What happens is that the pallet with material going up at entresol is placed on a fixture containing of three bundled pallets. These pallets are then lifted up to entresol with a forklift. The operators go up at entresol, takes a pallet loader and pick up the fixture of the three bundled pallets with the pallet with materials in it to the components respectively warehouse location. Since there is no room for a forklift up at entresol the fixture is necessary to create good ergonomically conditions for the operators when unloading the material. When the material is unloaded its picked up and put at ordinary shelves and the inventory levels are updated in the WMS.

Instead of finding the empty bins visually as in RM1 an order is created in WMS when a component reaches its minimum level out in production. Two times a day the operator checks for orders in the PDA and collect all the components that need refills. Similar to RM1, the material is set in movement and the inventory location is temporary set to virtually be the operators PDA. The transportation is not set to a fixed route but the operators have to figure out the best route to deliver the components as fast as possible. If there are few components to pick up on RM1, RM2 can be delivered more than two times a day and the round is often combined together with RM1 to be more efficient. When reaching the production the material is often just dumped in the bin at its location, regardless of how much or little material there is in it.

Replenishment method 3 & 4

Component 13 can be viewed as a similar type of component as the ones on RM2. It is stored at entresol so it goes through the same process as described for RM2. The two other components are a bit more complex to handle.

Component 11 is expensive and is delivered in packages of 4 with various overall batch sizes. The supplier has some standard packages and if the order does not meet these quantities the packages are filled up with paper and plastic to protect the other packages from movements inside the big one. This creates a lot of extra work at arrival where the operators have to open up the big package and sort out the small boxes. These small boxes are also provided with plastic straps that the operators have to remove before it is put at arrival storage. If the batch size is big the boxes are instead placed on a new pallet and put at the intermediate storage.

Component 12 is a heavy article and can weight up to 20 kg, which comes in single packages in a pallet together with other components of the same sort but different sizes. These pallets are put at the intermediate storage together with packing labels loose in the pallet. When these components are about to be put at their warehouse location, the handling can differ. If one of these variants are of much greater quantity there is no sorting and all components are put at the same warehouse location. But if there are no variant of greater quantity there is a sorting out process, where every single component is picked out and put at a separate location.

The flow maps show that the number of activities in general is the same, 18-19 with component 6 as an exception because of the extra storage point in the warehouse and the extra movements it entails. The time differs widely because of the different features of each and every component, mainly because of the different delivery packages.

4.2.2 HATS-analysis

To analyse the current state of the material flow for all the studied components, a HATS-analysis is performed. As described in Table 3.1 the HATS-analysis categorises the activities in handling, administration, transportation and storage. In this study the handling activities mostly consist of unpacking, loading and unloading packages, picking and placing components and sorting packages. For the administrative activities the primary task is the scanning of bar codes on shelves and kanban IDs, as well as to check the incoming quantity of material at the arrival station. The transportation activities are regarded as an operation where the purpose of the activity is to move the material from one place to another. These transportation activities consist of forklift, tugger cart for milk runs, and in some cases manual transportation of components. The storage activities are the points along the material flow where a designated area has the sole purpose of storing material.

The analysis is divided by the different replenishment methods RM1, RM2 and RM3 & RM4 to showcase the characteristics of each method. The number of activities of each HATS-category is presented for the material flow of every component, as well as the total time of each HATS-category. The total number of activities and the lead time for each component flow is presented as well. These are the variables which the HATS-analysis is based upon.

Replenishment method 1

The HATS-data for the six material flows of the RM1 components are presented in Table 4.2. The components are the ones delivered to the production via milk runs, and all of them are stored in the picking storage, except component 3 and 5 which is stored in the HBS.

Table 4.2: HATS analysis data of the RM1 components.

	Component 1		Component 2		Component 3	
	Nb. of activities	Total time	Nb. of activities	Total time	Nb. of activities	Total time
Handling	5	109 s	5	129 s	7	224 s
Administration	8	100 s	8	106 s	7	73 s
Transportation	3	684 s	2	1489 s	3	88 s
Storage	3	34.8 days	3	96.4 days	3	28.2 days
Activities/ Lead time	19	34.8 days	18	96.4 days	20	28.2 days
	Component 4		**Component 5**		**Component 6**	
	Nb. of activities	Total time	Nb. of activities	Total time	Nb. of activities	Total time
Handling	5	334 s	5	305 s	12	722 s
Administration	8	173 s	8	119 s	19	742 s
Transportation	3	455 s	3	1279 s	6	1047 s
Storage	3	28.7 days	3	33.4 days	4	22.3 days
Activities/ Lead time	19	28.7 days	19	33.4 days	41	22.3 days

At first sight it is evident that the storage times for each component is significantly longer than all the other activities (H, A and T) combined. In fact, the storage time for each component accounts for more than 99 % of the lead time. This is evident comparing the storage time and lead time for each component, which shows that the actual material handling work (handling, administration and transportation) for the operators are just a fraction of the lead time. Aside from component 6, the storage time for each component is divided at three storage points, arrival storage, HBS or picking storage, and the storage location in the production cell.

There are several reasons for the long storage times of the components, with procurement strategy and inventory accuracy being the main factors. The procurement strategy is based on keeping high safety stock levels to avoid shortages in production. This leads to long storage times for all the studied components. Errors in inventory accuracy often occur when material is lost in the warehouse, e.g. when small components are dropped behind a shelf and cannot be found, or when the quantity of component varies between packages and the wrong amount is picked. It can also occur due to the human factor when picking large quantities of small components piece by piece by hand, or bad calibration of equipment when using scales to count quantities. There are also instances when scrapping material in production is not reported and material is situated on the wrong shelves in the warehouse. These are all reasons for uncertainty regarding the inventory volumes and subsequently it leads to increased procurement to avoid unexpected shortages.

Aside from the long storage times it is also evident that there is a considerate amount of time spent on transportation activities for each component. This involves transportation to the arrival storage point, to the HBS or picking storage and then out to the production cells. As these components are all delivered with milk runs that replenishes several types of components simultaneously, the transportation time of a component includes picking up and dropping off other components, which are unrelated to the flow of the studied component. This is the case for components on both RM1 and RM2. For example, when component 1 is picked in the warehouse and the transportation out to the production begins, the tugger cart stops to pick up other components on the way out. This leads to the transportation time of component 1 increasing without any activities being performed related to this particular component.

Regarding the transportation time, component 3 differs a bit from the others, as it has a short amount of transportation time relative to its other activities. This is due to the fact that it is not delivered on a milk run despite being regarded as a component on RM1. This material is picked and delivered individually by forklift, as the components are big and need a separate pallet.

Another interesting observation from the HATS-analysis is the total number of activities for component 6. It is twice as many as for any other of the RM1 components. This is due to multiple storage points in the warehouse, one primary point in the picking storage and one secondary point in the HBS. The material is placed in the HBS at first and later moved to the picking storage, with the purpose of making it easier to pick for the milk run operators. This re-storage of the material results in just one more storage point compared to the other components, but in twice as many handling, administration and transportation activities. While moving the material to a new storage point a lot of time is spent on handling and administration activities, as can be seen in Table 4.2.

Replenishment method 2

In Table 4.3 the HATS-data is presented for the components replenished with RM2, which is the reorder point system delivered by milk runs. For these four components the warehouse storage location is the picking storage, except for component 7 which is located on the entresol on the second floor.

Table 4.3: HATS analysis data of the RM2 components.

	Component 7		Component 8		Component 9		Component 10	
	Nb. of activities	Total time	Nb. of activities	Total time	Nb. of activities	Total time	Nb. of activities	Total time
Handling	8	218 s	5	244 s	5	162 s	5	233 s
Administration	10	263 s	6	72 s	6	108 s	6	119 s
Transportation	7	456 s	3	101 s	3	385 s	4	512 s
Storage	3	86.4 d	3	82.0 d	3	59.3 d	3	32.5 d
Activities/ Lead time	28	86.4 d	17	82.0 d	17	59.3 d	18	32.5 d

Similar to the components on RM1, it is evident that the RM2 components also have long storage times that account for more than 99% of the lead time, leading to the material handling work for operators being just a fraction of the total time. Just as for the RM1 components, the long storage times are affected by the procurement strategy and problems in inventory accuracy. The uncertainty of the inventory levels affects the procurement strategy to procure material, leading to excessive inventory levels and long storage times.

The transportation times for these components are shorter than for RM1 components, even though they are delivered on milk runs together with RM1 components. This comes down to RM2 components being replenished less frequently and when the demand of RM1 material is lower. Even though the time for transportation is lower it is still the most time consuming activity for the RM2 material, as it is delivered with milk runs. There is one exception to this, component 8, which is picked in the area of the warehouse close to the production and dropped off in the nearest production cell.

Another observation that can be made is that component 7, which is stored on entresol, requires more administration than other components. This comes down to the need to package and label components which are stored up at entresol to be able to manually carry them down to be distributed on the milk run.

Replenishment method 3 & 4

In Table 4.4 the HATS-data of components on RM3 and RM4 is presented. These are the components that are customer order specific and delivery is triggered by manufacturing orders. Component 11 and 12 are stored in the HBS and component 13 is stored at entresol.

Table 4.4: HATS analysis data of the RM3 and RM4 components.

	Component 11		Component 12		Component 13	
	Nb. of activities	Total time	Nb. of activities	Total time	Nb. of activities	Total time
Handling	5	454 s	10	503 s	7	131 s
Administration	7	118 s	7	123 s	7	88 s
Transportation	2	295 s	4	130 s	5	303 s
Storage	3	17.8 d	3	34.2 d	3	81.3 d
Activities/ Lead time	17	17.8 d	24	34.2 d	22	81.3 d

In Table 4.4 the HATS-data of components on RM3 and RM4 is presented. These are the components that are customer order specific and delivery is triggered by manufacturing orders. Component 11 and 12 are stored in the HBS and component 13 is stored on entresol. Just as for the components on the other replenishment methods, RM3 and RM4 components have long storage times which account for the most parts of the lead times. Similar to RM1 and RM2 this is due to the high inventory levels that are kept both in the warehouse and in the production.

For component 11 and 12 a large part of the operator work is handling activities. Both these components are big and hard to handle, as well as packaged in a complex way with an excess of cardboard and plastic wrap, demanding a lot of handling.

4.2.3 Identifying area for automation evaluation

To delimit and identify where in the material flow a potential automation solution is best suited, the flow is divided to determine which part of it requires the most operator working time. It is clear that the material supply flow can be divided into three different sections, with the storage points as decoupling points, illustrated in Figure 4.1. The sections then only include the handling, administration and transportation activities, which is the work of the operators.

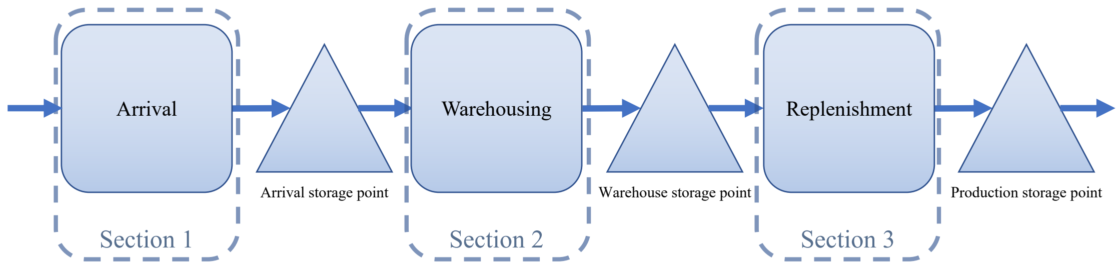

Figure 4.1: An illustration of the material flow divided into three sections.

Arrival - section 1: The first part of the flow where the material is registered as incoming material and later on stored at an incoming goods shelf ready to be put in the warehouse.

Warehousing - section 2: The second part of the flow where the material is moved from the incoming goods area to its warehouse location, either in the HBS, picking storage or entresol.

Replenishment - section 3: The last part of the flow where the material is picked in the warehouse and transported to the production.

By having mapped the complete flows of the different components the distribution of the operator working time can be calculated. The distribution of the working time on the different replenishment methods is presented in Figure 4.2.

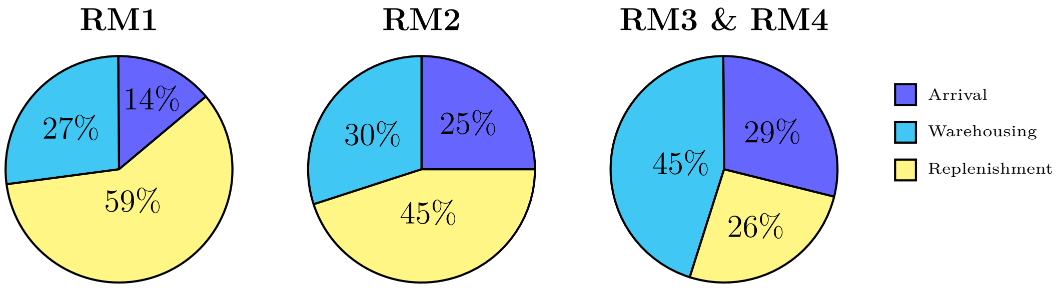

Figure 4.2: Distribution of operator working time between arrival, warehousing and replenishment for the components on the different replenishment methods.

For the six components on RM1, 59% of the operator working time is spent replenishing the material from the warehouse to the production. This is due to the fact that the material arrives and is put at its warehouse storage point in big quantities and packages that requires minimum repackaging. However, when it is picked on the replenishment run the delivery quantities are much smaller and in most cases require time-consuming repackaging into bins. There is also a lot of transportation between different shelves during the replenishment part.

For the four components on RM2 it is slightly less time spent on replenishment in relation to the other sections. It is still the biggest portion of the operator working time, but arrival and warehousing take slightly more time here. This is due to the packaging and sizing of the components studied on RM2, which consists of smaller packages delivered in greater quantity, demanding more time while handling at both arrival and while storing in the warehouse. Another factor that increases the warehousing time is the fact that some of the material is placed on entresol, which requires more administration for the operators.

When it comes to the components on RM3 and RM4 most time (45%) is spent on moving the material from the arrival to the warehouse. This is due to the studied components on these replenishment methods are complex to handle in two of the cases and placed on entresol in the last case. Since these components are replenished with fewer other components, the replenishment runs also take less time, leading to a lower percentage of time spent on replenishment.

Besides only looking at the distribution of operator working time on the different section of the flows, it is of interest to look at which replenishment method is used the most to deliver material to the production. As is shown in Figure 4.3, the percentage of material orders delivered by RM1 was 66% last fiscal year, compared to 6% on RM2 and 28% on RM3 and RM4. Almost twice as many material orders are carried out using RM1 compared to RM2, RM3 and RM4 together.

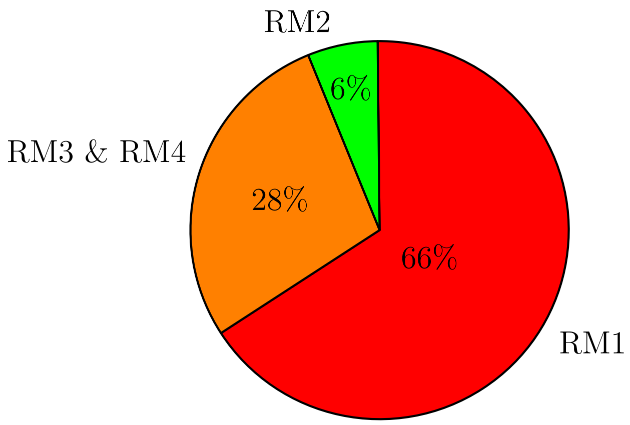

Figure 4.3: Number of material orders for the replenishment methods in FY18.

Taking both Figure 4.2 and Figure 4.3 into consideration it is clear that the material handling operators are spending most time delivering material on RM1 and that the most time-consuming section is the replenishment, the delivery of material from the warehouse to the production. It is therefore of interest to analyse where in the replenishment section the operator working time is largest. If it is while picking material in the warehouse or if it is while delivering the material to the production. From the time data collection of the Materials Flow Mapping it is possible to see the distribution of operator working time, as is showed in Figure 4.4.

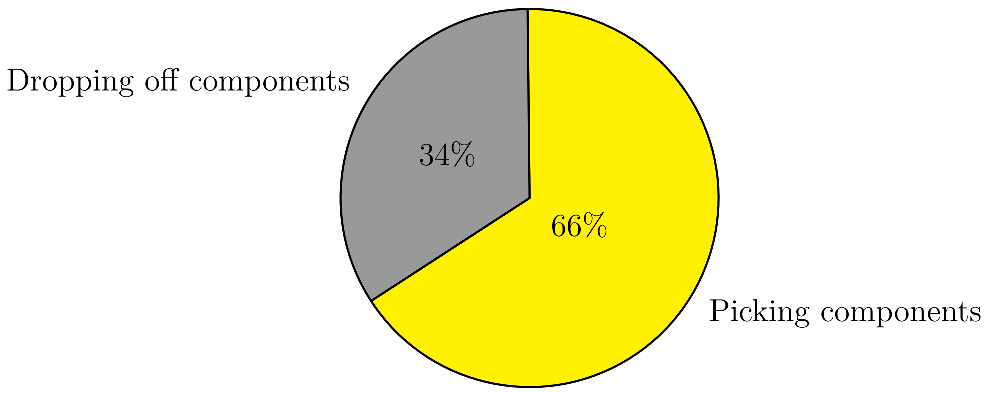

Figure 4.4: Distribution of operator time spent in warehouse picking the material versus time spent in the production delivering material.

From the figure it is clear that the operators spend most of the replenishment part picking material compared to delivering it. This is easily explained by the fact that for almost all material the repackaging, opening of packages, and piece by piece counting and picking is done in the warehouse. The delivery to the production is done in the bins or packaging that the material will be stored in at the production, leading to the operators just dropping the material off without further handling.

Through this analysis of the most interesting area for automation evaluation it is clear that the focus of the evaluation should be the operation of picking material in the warehouse and the tasks that affect this area.

4.3 Automation analysis

Based on the mapping and the analysis the automation analysis tool is developed. Since the HATS-analysis limited the automation evaluation to the picking of material, Levels of Automation (LoA) is considered as a suitable tool. Since this tool was developed for manufacturing operations some adjustments need to be done to fit material handling better. In consensus with a current researcher within the field it is considered that such adjustments are possible to implement.

4.3.1 LoA taxonomy for material handling

The original LoA taxonomy, Table 3.2, has defined the different level with a title, a small description in text and support it with an example. By rephrasing the taxonomy it becomes more applicable to the purpose of evaluating the level of automation in material handling. Examples within material handling and transportation are also produced to exemplify each level. It is of importance that the definition of each level is as close to the original taxonomy as possible to make the study more credible and to make sure the usage of the taxonomy is similar to the original one. This means creating an addition to the tool rather than creating a new one. For the physical part the focus is on both materials handling such as in physical treatment of the material and as in transportation. The physical treatment of the material is focused on how the material is presented to the operator rather than the actual picking movement. This is because this activity is considered having too much influence of other factors that is hard to change, such as the packaging from the supplier and the wide variations in component characteristics. As in the initialising phase of creating the original LoA taxonomy the focus in defining the levels is always human oriented [24]. The adopted taxonomy for LoA in material handling is presented in Figure 4.5.

Table 4.5: LoA taxonomy adjusted for material handling, based on Frohm et al. [14].

LoA	Mechanical and Equipment (Physical)	Information and Control (Cognitive)
1	**Totally manual** - Totally manual work, no tools are used, only the users own muscle power. E.g. The users own muscle power.	**Totally manual** - The user creates his/her own understanding for the situation, and develops his/her course of action based on his/her earlier experience and knowledge. E.g. The users earlier experience and knowledge.
2	**Static tool** - Manual work with support of static tool. E.g. Carriage, gravity flow rack or cutter.	**Decision giving** - The user gets information on what to do, or proposal on how the task can be achieved. E.g. Work order.
3	**Flexible tool** - Manual work with support of flexible tool. E.g. Manual pallet lifter or scale.	**Teaching** - The user gets instruction on how the task can be achieved. E.g. Checklists or manuals.
4	**Automated tool** - Manual work with support of automated tool. E.g. Forklift or overhead crane (hydraulic hoist).	**Questioning** - The technology question the execution, if the execution deviate from what the technology consider being suitable. E.g. Verification before action.
5	**Static machine/workstation** - Automatic work by machine that is designed for a specific task. E.g. Conveyor system or paternoster lift.	**Supervision** - The technology calls for the users' attention, and direct it to the present task. E.g. Alarms or lights.
6	**Flexible machine/workstation** - Automatic work by machine that can be reconfigured for different tasks. E.g. Automated Guided Vehicle or Automatic Storage & Retrieval System.	**Intervene** - The technology takes over and corrects the action, if the executions deviate from what the technology consider being suitable. E.g. Thermostat.
7	**Totally automatic** - Totally automatic work, the machine solve all deviations or problems that occur by it self. e E.g. Autonomous systems.	**Totally automatic** - All information and control is handled by the technology. The user is never involved. E.g. Autonomous systems.

Based on the earlier work on LoA for manufacturing [14][22] and discussion with a current researcher, the levels of automation for material handling can be described in further detail to clarify the differences between the levels.

Mechanical and equipment (Physical) levels

$LoA_{physical}$ 1 : The task is performed totally manual with no help from any type of equipment. There is only the operators own muscle power that moves or pick the material.

$LoA_{physical}$ 2 : The task is performed manually but with a static tool. The tool is not adjustable in any sense but only performs the task in one way. E.g. for transportation it could be a basket or carriage that would only carry the material from one point to another. For handling it could be a gravity flow rack that helps an operator pick the material by presenting it in the same way all the time.

$LoA_{physical}$ 3 : The task is performed manually but with a flexible tool that can be adjusted to several different tasks. E.g. for transportation it can be a manual pallet lifter that can both transport and lift material of different kinds and ways. For handling it can be a digital scale that weighs and count material based on their weight.

$LoA_{physical}$ 4 : The task is performed manually but with an automated tool that relieves the human from physical burden. E.g. for transportation it could be a forklift that transport and lifts material without help from human muscle power but human control. For handling it could be an overhead crane that helps the operator pick and lift material weightless.

$LoA_{physical}$ 5 : The task is performed automatic with human monitoring but is not flexible enough to perform other than a specific task. E.g. for transportation is a conveyor system that can transport material from one point to another but is hard to adjust to other locations. For handling it could be a paternoster lift that helps the operator access and pick the material easily but still needs monitoring.

$LoA_{physical}$ 6 : The task is performed automatic, still with human monitoring but it is more flexible and can be adjusted to several different tasks. E.g. for transportation it could be AGVs that can transport material to several different places and be redirected easily. For handling it can be an Automatic Storage & Retrieval System that can handle and transport material of different kinds and present it at one place, as well as keeping track of all the material itself.

$LoA_{physical}$ 7 : The task is performed totally autonomous without human involvement. E.g. a system that combines both transportation and handling and performs everything by itself and can change tasks or execution itself.

Information and control (Cognitive) levels

$LoA_{cognitive}$ 1 : The operator performs the task out of own experience. There is no help from any system or instruction and the operators act totally on their own.

$LoA_{cognitive}$ 2 : The operator get instructions of what to do to perform the task, e.g. a work order containing what material to pick and what aids to use.

$LoA_{cognitive}$ 3 : The operator gets instruction of how the task can be performed, e.g. manuals that explain in what order different task is needed to be done to achieve the result, the information is mainly given in text formate.

$LoA_{cognitive}$ 4 : The operator get questioning before or after a task is performed to make sure that the task is performed correctly, e.g. verification's that needs to be accepted before the next task can be performed.

$LoA_{cognitive}$ 5 : The operator gets supervision from the system when a task should be performed, e.g. pick-by-light that show you what to pick or where to deliver the material.

$LoA_{cognitive}$ 6 : The technology perform the task instead of the operator, e.g. a thermostat that regulates the temperature automatically to the correct value without any control from the operator.

$LoA_{cognitive}$ 7 : The technology perform and design the task by itself, e.g. the system does not need any human interaction but solve problems by its own.

From this adjusted LoA-taxonomy the automation analysis of the current state could be started.

4.3.2 LoA measurement

To measure the LoA values the work has to be divided into tasks to reach the right level of detail. The activities of the MFM maps are too detailed to measure LoA for each activity but serve as a basis for the identification of tasks. The MFM-activities are grouped together to form tasks, they can therefore be seen as sub-tasks as shown in an example in Figure 4.5.

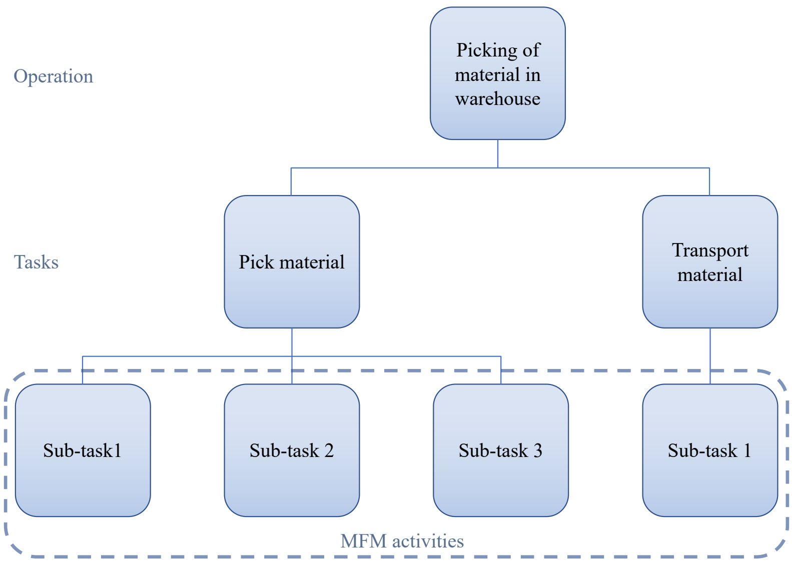

Figure 4.5: An example on how the MFM-activities form the tasks that are evaluated in the LoA analysis.

Appendix D shows how the activities from the MFMs are grouped together to form the tasks that are evaluated in the LoA analysis. This shows that each component has two tasks that are included in the operation of picking material in the warehouse, picking and transportation, as exemplified in Figure 4.5.

The measurement of the automation level is done for the picking task of each component as well as for the transportation task of each component. The results are presented separately for the picking and transportation tasks, as the aim is to find a common Square of Possible Improvements (SoPI) for the picking tasks, and a common SoPI for the transportation tasks.

4.3.2.1 Picking tasks

The results of the LoA measurements for the picking tasks of the components are divided into two figures, depending on whether the components are picked from the HBS or entresol and picking storage. In Figure 4.6 the LoA measurement of the picking tasks are shown for the components in the picking storage and entresol.

LoA (phy)	Comp. 1	Comp. 2	Comp. 4	Comp. 6	Comp. 7	Comp. 8	Comp. 9	Comp. 10	Comp. 13
7									
6									
5									
4									
3									
2	M		M	M					
1		M			M	M	M	M	M

LoA (cog)	Comp. 1	Comp. 2	Comp. 4	Comp. 6	Comp. 7	Comp. 8	Comp. 9	Comp. 10	Comp. 13
7									
6									
5									
4									
3	M	M	M	M		M	M		
2					M			M	M
1									

Figure 4.6: The measured physical and cognitive LoA for the picking of components located in the picking storage and entresol.

As can be seen, the automation level is consistently low in regards to both physical and cognitive automation. This is hardly surprising since the components are small and picked manually with little to none mechanical aid. Some of the components are presented in flow racks which provides some help to the operators, however most components are picked directly from shelves with the lowest level of automation possible.

The cognitive automation aspect of the picking of these components is slightly higher than the physical. The picking task for most components are provided with instructions on how the task should be performed, with information such as quantity to pick, storage location and in which order it should be picked. There are some exceptions, where the picking of some components requires the operator to have some prior knowledge of the picking process which lowers the cognitive level measurement.

In Figure 4.7 the LoA measurement of the HBS picking tasks are shown.

LoA (phy)	Comp. 3	Comp. 5	Comp. 11	Comp. 12
7				
6				
5				
4	M			
3				M
2				
1		M	M	

LoA (cog)	Comp. 3	Comp. 5	Comp. 11	Comp. 12
7				
6				
5				
4				
3		M		M
2	M		M	
1				

Figure 4.7: The measured physical and cognitive LoA for the picking of components located in the HBS.

For the tasks of picking these components the measured physical LoA is higher than the previous components. This is due to some of these components being big and heavy, which requires forklifts to handle them. Component 3 and 12 are typical components that fit into this description. However, not all components stored at the HBS have a high level of automation. Component 5 and 11 are material that can be picked without any mechanical aid since there size and weight are of no concern.

The cognitive automation level for the picking of these components is similar to the ones in the picking storage and entresol. Some activities require some previous knowledge or assumptions of how it should be done, which yields a level 2 of cognitive automation.

4.3.2.2 Transportation tasks

The transportation tasks that are evaluated are those that occur within the warehouse in connection to the picking of material. Just as for the picking tasks, the transportation tasks are presented in two different figures depending on the location in the warehouse. Figure 4.8 shows the LoA measurement of the transportation tasks of components in the picking storage and entresol.

LoA (phy)	Comp. 1	Comp. 2	Comp. 4	Comp. 6	Comp. 7	Comp. 8	Comp. 9	Comp. 10	Comp. 13
7									
6									
5									
4	M	M	M	M		M	M	M	
3									
2					M				M
1									

LoA (cog)	Comp. 1	Comp. 2	Comp. 4	Comp. 6	Comp. 7	Comp. 8	Comp. 9	Comp. 10	Comp. 13
7									
6									
5									
4									
3									
2	M	M	M	M		M	M	M	M
1					M				

Figure 4.8: The measured physical and cognitive LoA for the transportation of components located in the picking storage and entresol.

The physical level of automation is generally higher for the transportation of material in the warehouse. Many of the components are transported with either tugger cart or forklift directly after they have been picked. There are some exceptions to this when it comes to component 7 and 13. These are stored on the second floor of the warehouse, the entresol, which requires them to be manually transported down to the ground floor. This yields a score of 2 on the LoA scale.

The cognitive LoA of these transportation tasks are low. There are some instructions of what needs to be done to perform the task but in general no information on how it should be performed or in which order.

Figure 4.9 presents the measured LoA for the transportation tasks of components located in the HBS of the warehouse.

LoA (phy)	Comp. 3	Comp. 5	Comp. 11	Comp. 12
7				
6				
5				
4	M	M	M	M
3				
2				
1				

LoA (cog)	Comp. 3	Comp. 5	Comp. 11	Comp. 12
7				
6				
5				
4				
3				
2	M	M	M	M
1				

Figure 4.9: The measured physical and cognitive LoA for the transportation of components located in the HBS.

When it comes to the transportation tasks of the components in the HBS, they all have the same physical LoA, as well as cognitive LoA. The physical aspect of the LoA is down to every task being performed with forklift or tugger cart and no manual transportation is needed.

The cognitive automation is similar to that of the previous components. They all have a low level since there is limited information on what is required to carry out the tasks, but there is still some information regarding what to do.

4.3.3 Minimum and maximum LoA

When the measured value is concluded the potential minimum and maximum levels are set in consensus with the stakeholders of the processes to be able to identify the potential minimum and maximum automation level. By including the stakeholders the levels are validated and more accurate from the beginning, and a too extensive process can be avoided. The minimum levels are based on what the absolute minimum need to perform the task is. In this case it would be to pick and transport material from one point to another which can be made very simple without any tools or aids, so these levels are in most of the cases easy to set. The maximum levels however are based on how realistic the implementation of a certain level would be.

To judge this, assumptions need to be taken regarding how a future state would look like on each level and how likely that and other necessary changes would be. Since the stakeholders know their processes best it gives more credibility to these assumptions when they are included in the process.

4.3.3.1 Picking tasks

The results of the minimum and maximum LoA for the picking tasks are presented in two figures, depending on the storage location, just like the previous LoA measurement.

LoA (phy)	Comp. 1	Comp. 2	Comp. 4	Comp. 6	Comp. 7	Comp. 8	Comp. 9	Comp. 10	Comp. 13
7									
6	Max	Max	Max	Max	Max	Max	Max	Max	Max
5									
4									
3									
2	**M**		**M**	**M**					
1	Min	**M** Min	Min	Min	**M** Min	**M** Min	**M** Min	**M** Min	**M** Min

LoA (cog)	Comp. 1	Comp. 2	Comp. 4	Comp. 6	Comp. 7	Comp. 8	Comp. 9	Comp. 10	Comp. 13
7									
6									
5	Max	Max	Max	Max	Max	Max	Max	Max	Max
4									
3	**M**	**M**	**M**	**M**		**M**	**M**		
2	Min	Min	Min	Min	**M** Min	Min	Min	**M** Min	**M** Min
1									

Figure 4.10: The minimum and maximum physical and cognitive LoA for the picking of components located in the picking storage and entresol.

For the components stored in the picking storage and entresol, the levels become totally equal with a range of 1-6 for the physical scale and 2-5 for the cognitive scale, see Figure 4.10. Since all these components are stored in similar ways the levels could be set the same. Even if the characteristics of the components are somewhat different this does not affect the levels since the handling of these components is similar either way. This created a big range for the physical scale with high maximum levels due to the possibilities in the warehouse and set low since the components are of that type that they can be handled totally manual. The cognitive scale is set a bit more narrow since the operators need some information to deliver it right the minimum levels are set to 2. The maximum levels are set to 5 since a higher level calls for a higher physical level and then such actions as correction will be redundant.

LoA (phy)	Comp. 3	Comp. 5	Comp. 11	Comp. 12
7				
6	Max	Max	Max	Max
5				
4	**M**			
3	Min			**M**
2				Min
1		**M** Min	**M** Min	

LoA (cog)	Comp. 3	Comp. 5	Comp. 11	Comp. 12
7				
6				
5	Max	Max	Max	Max
4				
3		**M**		**M**
2	**M** Min	Min	**M** Min	Min
1				

Figure 4.11: The minimum and maximum physical and cognitive LoA for the picking of components located in the HBS.

For the components in the HBS, the levels of the physical automation is a bit more fluctuating while the cognitive scale is equal between 2-5, see Figure 4.11. The main reason for this is that the characteristics of these components are of those variations that affect both the packaging and the handling. It is also seen that component 3 and 12, the two that stand out, have the highest current value. This is because these components are tough to handle due to their weight and size. So because of ergonomic reasons, the stakeholders argue that the minimum levels cannot be lower.

4.3.3.2 Transportation tasks

The minimum and maximum LoA results for transportation are also presented in two figures depending on the storage location. Figure 4.12 shows the evaluation of the transportation tasks for components in the picking storage and entresol.

LoA (phy)	Comp. 1	Comp. 2	Comp. 4	Comp. 6	Comp. 7	Comp. 8	Comp. 9	Comp. 10	Comp. 13
7									
6	Max	Max	Max	Max	Max	Max	Max	Max	Max
5									
4	**M**	**M**	**M**	**M**		**M**	**M**	**M**	
3									
2	Min	Min	Min	Min	**M**	Min	Min	Min	**M** Min
1					Min				

LoA (cog)	Comp. 1	Comp. 2	Comp. 4	Comp. 6	Comp. 7	Comp. 8	Comp. 9	Comp. 10	Comp. 13
7									
6	Max	Max	Max	Max	Max	Max	Max	Max	Max
5									
4									
3									
2	**M**	**M**	**M**	**M**		**M**	**M**	**M**	**M**
1	Min	Min	Min	Min	**M** Min	Min	Min	Min	Min

Figure 4.12: The minimum and maximum physical and cognitive LoA for the transportation of components located in the picking storage and entresol.

The figure shows that the minimum and maximum physical LoA for the transportation of each component is very similar. The maximum level is the same for each component due to the fact that the characteristics and sizes enable a similar automation solution for each component. From the discussions with the stakeholders it is clear that all these components can be transported using a level 6 LoA, corresponding to a flexible machine. The minimum level is the same for every component, except one, for the same reasons. The minimum level of component 7 is lower due to the fact that the size and quantity of the transported components could be carried out with even less mechanical aid, level 1.

The cognitive LoA of the transportation tasks can be improved on considerably from its measured value. From the discussions with the stakeholders it is evident that it is plausible that the tasks can be performed with cognitive aids that can intervene and correct actions if the execution is wrong.

Figure 4.13 shows the LoA of the transportation tasks for components in the HBS.

LoA (phy)	Comp. 3	Comp. 5	Comp. 11	Comp. 12
7				
6	Max	Max	Max	Max
5				
4	**M**	**M**	**M**	**M**
3	Min			
2		Min	Min	Min
1				

LoA (cog)	Comp. 3	Comp. 5	Comp. 11	Comp. 12
7				
6	Max	Max	Max	Max
5				
4				
3				
2	**M**	**M**	**M**	**M**
1	Min	Min	Min	Min

Figure 4.13: The minimum and maximum physical and cognitive LoA for the transportation of components located in the HBS.

Also for the transportation of components in the HBS the minimum and maximum LoA are similar. There is one exception in the physical LoA of component 3, which due to its size and delivery volume has to be performed with minimum automation level of 3. Other than that, the same minimum and maximum levels apply for the HBS components as for those in the picking storage and entresol.

4.3.4 Square of Possible Improvements

To visualise potential future automation levels, the minimum and maximum LoA are inserted into a matrix to find the Square of Possible Improvements (SoPI). The focus is to find a solution space in the SoPI where a solution could be adapted for all tasks of the same kind. This is done by inserting all picking tasks into the same matrix to find a SoPI that is common for all the tasks. The same is done for all transportation tasks to limit the solution space and find a common automation level.

4.3.4.1 Picking tasks

Figure 4.14 shows the SoPIs for the components in the picking storage and entresol. The numbers in the matrix represent where the measured level of automation for each component is today.

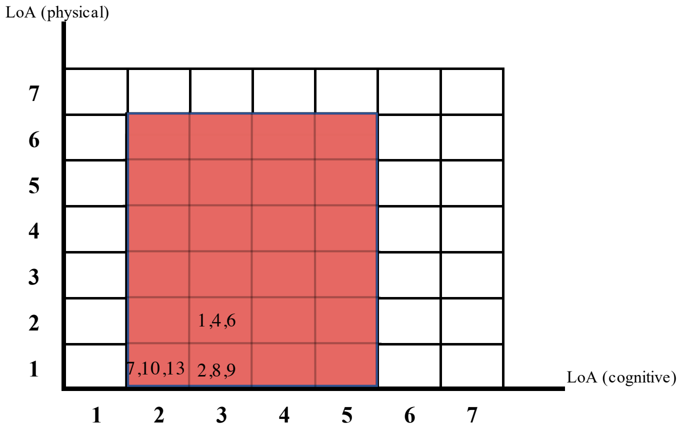

Figure 4.14: The Square of Possible Improvements (SoPI) for the picking of components stored in the picking storage and entresol. The red area is the intersection of all SoPIs.

The red area illustrates the intersection of all the tasks, which in this case overlaps, providing an automation solution area of 24 different combinations. The interesting part is that the measured values all are down in the left corner with both low physical and cognitive level. This indicates that the current levels of automation are near the minimum and there is room for improvements.

Figure 4.15 shows the SoPIs for the picking tasks of components in the HBS. The numbers in the matrix represent where the measured level of automation for each component is today.

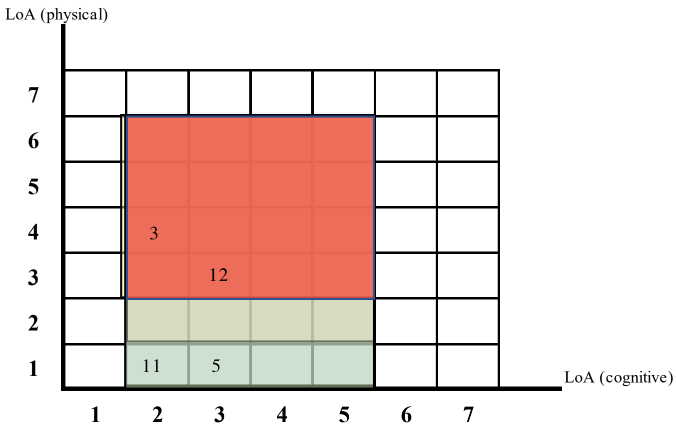

Figure 4.15: The Square of Possible Improvements (SoPI) for the picking of components stored in the High-Bay storage. The red area is the intersection of all SoPIs.

For the components in the HBS the SoPIs differs between each other, each component represented by its own colour in the matrix while the intersection is the red part. The intersection in this case becomes smaller creating an area of 16 possible combinations. This means that component 5 and 11 is outside the intersection and should be prioritised for improvement. To move these into the intersected area is needed to balance the automation level before increasing others, otherwise the unbalanced system could create disturbances in the future.

Figure 4.16 shows a combined SoPIs for all warehouse locations, picking storage, entresol and HBS. By combining Figure 4.14 and 4.15 it is possible to obtain a SoPI that is common and applicable for all picking tasks regardless of the storage location. The numbers in the matrix represent where the measured level of automation for each component is today.

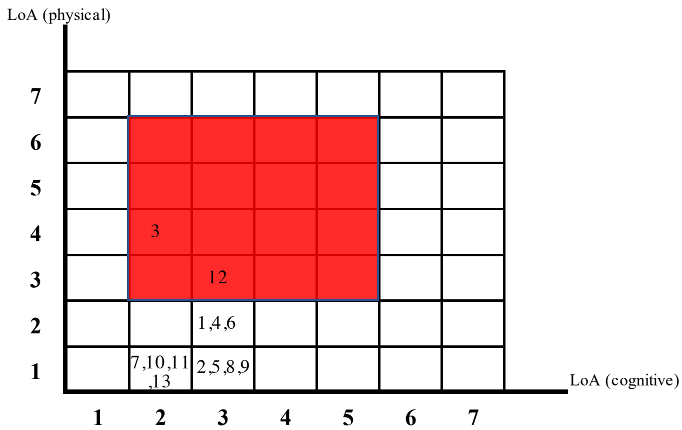

Figure 4.16: The Square of Possible Improvements for the picking of all components, combining the intersections of Figure 4.14 and 4.15.

The red area represents the SoPI for all picking tasks. The combined SoPI provides a solution space of 16 different automation combinations (LoA$_{physical}$ = 3-6, LoA$_{cognitive}$ = 2-5). All picking tasks except two are outside the combined SoPI which means that these should be prioritised when increasing the automation level. To include these tasks in the SoPI, it is primarily the physical automation level that needs increasing. However, if the physical automation levels were to be increased, the cognitive aspect of the tasks are also in the lower part of the SoPI and has great potential for automation improvement. The tasks that are outside the SoPI are primarily tasks that involve picking components that are stored in the picking storage or entresol. Two of the components that are stored in the HBS are also outside the SoPI, which is due to that they are small components picked without any mechanical aid. This shows that low levels of automation for picking correlate with the size of the components primarily, as well as their storage location.

This combined SoPI shows the plausible levels of automation that Emerson RTR can implement and also which tasks should be prioritised when increasing the automation level. The area of the SoPI which includes 16 different automation level combinations, is still rather large, which is due to the fact that the evaluated tasks are very much alike, both regarding the measured LoA and the plausible minimum and maximum levels. Therefore, there are many possible automation solutions that would increase the automation level of the company.

4.3.4.2 Transportation tasks

Figure 4.17 shows the SoPIs for the transportation tasks of components in the picking storage and entresol. The numbers in the matrix represent where the measured level of automation for each component is today.

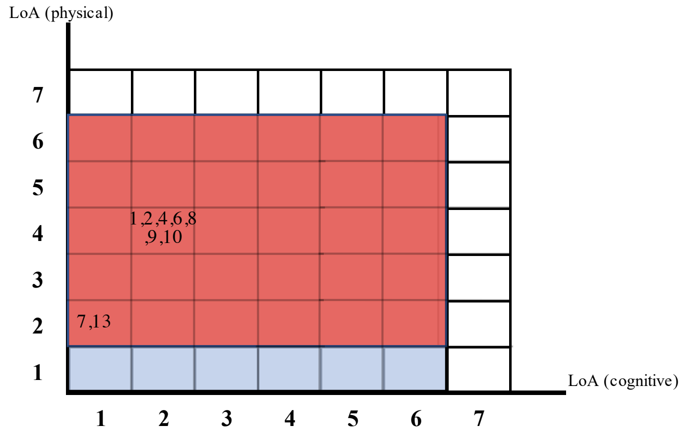

Figure 4.17: The Square of Possible Improvements (SoPI) for the transportation of components stored in the picking storage and entresol. The red area is the intersection of all SoPIs.

For the transportation tasks in the picking storage the components maximum and minimum levels differ between each other. Each component is represented by its own colour in the matrix while the intersection is the red part. The intersection narrows the SoPI to 30 different combinations, with all measured levels being within the area. The transportation tasks for component 7 and 13 are at the bare minimum level down in the left corner of the intersection while the other measured values are a bit higher, especially at the physical scale. This indicates that the automation level is a bit unbalanced and component 7 and 13 should be prioritised. The reason for the tasks of these components being lower than the other is that they are stored on the second floor in the entresol storage. This requires manual transportation, which lowers the physical LoA.

Figure 4.18 shows the SoPIs for the transportation tasks of components in the HBS. The numbers in the matrix represent where the measured level of automation for each component is today.

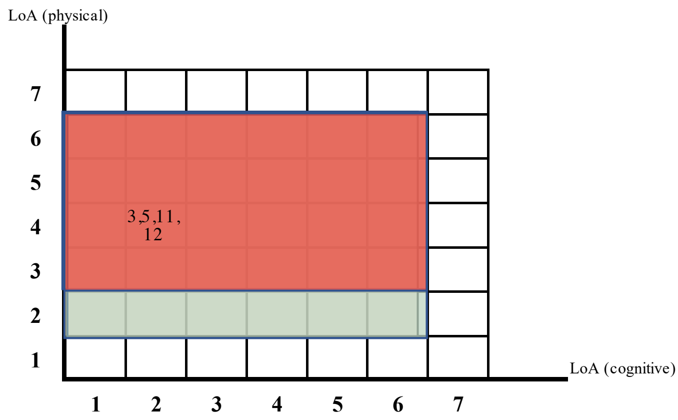

Figure 4.18: The Square of Possible Improvements (SoPI) for the transportation of components stored in the High-Bay storage. The red area is the intersection of all SoPIs.

For the transportation tasks in the HBS the components maximum and minimum levels also differ between each other. Each component is represented by its own colour in the matrix while the intersection is the red part. The intersection narrows the SoPI to 24 different combinations, with all measured levels within. The measured levels for the components are gathered tight in the matrix which indicates a balanced automation level where the physical level is in the middle and the cognitive is low.

Figure 4.19 shows a combined SoPIs for all warehouse locations, picking storage, entresol and HBS. By combining Figure 4.17 and 4.18 it is possible to obtain a SoPI that is common and applicable for all picking tasks regardless of the storage location. The numbers in the matrix represent where the measured level of automation for each component is today.

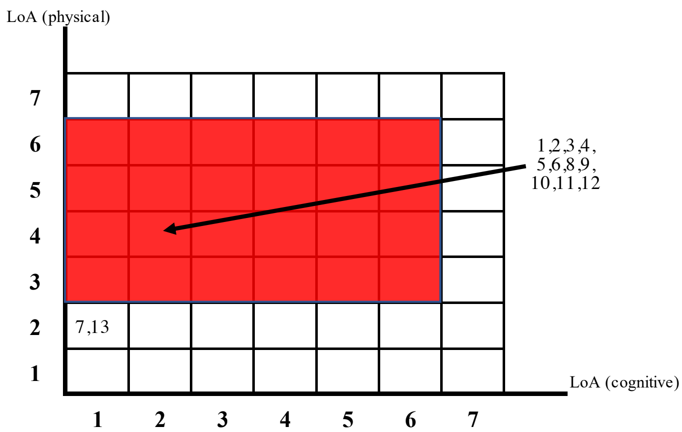

Figure 4.19: The Square of Possible Improvements for the transportation of all components, combining the intersections of Figure 4.17 and 4.18.

The red area represents the combined SoPI for all transportation tasks. The combined SoPI provides a solution space of 24 different automation combinations (LoA$_{physical}$ = 3-6, LoA$_{cognitive}$ = 1-6). All transportation task except two are within the combined

SoPI, so these should be prioritised when increasing the automation level. The main reason why these two components have that low measured level of automation is that both of them are stored at entresol which demands manual transportation. So to increase the physical level the manual transportation could be removed and the components could be included in the combined SoPI. Also the cognitive level should be prioritised for all components since it is low right now and to balanced it up with the physical level it will be necessary.

5 Discussion

This chapter presents the discussion of the case study results implications on the posed research questions and how the chosen methods were applicable for the aim of the thesis. The reliability and validity of the research is also discussed, as well as future research.

5.1 Case implications

The purpose of the thesis is to test if Materials Flow Mapping can be used as a basis for evaluating automation in material handling and if Levels of Automation developed for manufacturing can be applied or further adapted to assess automation levels in material handling. The following section discusses the implications of the case study on the purpose of the thesis.

5.1.1 Mapping

The mapping phase of the study intends to serve as a basis for evaluating the current automation levels as well as investigating the potential future automation levels. The usage of Materials Flow Mapping (MFM) enables visualisation and analysis of flows that consist of activities that are mainly non-value-adding. This is one of the strengths of MFM that differentiate it from the more recognised VSM tool. This is essential when MFM is to be used as a basis for further analysis of where in the flow automation evaluation should be focused. By doing this, an area for automation evaluation can be chosen and a time-consuming process of evaluating and analysing the whole flow with regards to automation can be avoided.

From the mapping it is possible to see the exact sequence and number of activities that are required for the material to progress from the arrival in the warehouse to the production. It is also effective for identifying the information flow that triggers the operations in the material flow. This level of activity detail that MFM provides is a great basis for the definition of the tasks that are needed to evaluate the automation level. The detailed activities can be considered as sub-tasks to the tasks that are evaluated using the LoA taxonomy. Therefore, the MFM tool provides more than simply just identifying an area for improvement or excess of a certain type of activity, it provides a detailed account of the work procedure and tasks in the material flow.

As stated, the MFM provides a clear picture of the type of task that accounts for the most amount of lead time in the material flows. In the case of Emerson Rosemount Tank Radar AB (RTR) it is evident that the storage activities account for almost the whole lead time. If the MFM were to be used similarly to the lean tool VSM, the storage time would be considered as the priority focus area for improvement actions. However, when using MFM as a basis for automation evaluation, the writers of this thesis consider that conducting an automation evaluation on the storage activities is not plausible since there is no work done to the components when they sit in storage. Instead of focusing on one type of activity, like the storage activities, it is possible to use MFM and the data obtained from the HATS-analysis to identify an area for automation evaluation. The results of Section 4.2.3 shows that MFM can be used to identify an area of the material flow that contains the most material handling time, and subsequently where the automation evaluation should be focused. Dividing the areas with the storage points as decoupling points is a good approach for this analysis. It can be regarded as the material moving through the flow in three steps, with the storage points being breakpoints at which the material buffers.

The results and analysis of the mapping depend a great deal on the choice of study objects for the MFM. The components that are studied in this case are chosen through observations, interviews and suggestions from stakeholders in the company. Since the writers of this thesis do not have sufficient knowledge of the material handling, much trust is put in the company stakeholders to choose representative components. This introduces the possibility of a certain bias to the mapping phase of the thesis. Since Emerson RTR does not know exactly where in the material flow the automation analysis should be performed, the components are chosen to represent as many scenarios as possible of the material flow, as described in Section 4.1.3. In a case where the company knows which part of the material handling the automation analysis should be conducted, the study objects can be chosen to only represent that specific part of the flow.

There are some complications of using the MFM method to evaluate the material flow. For the best result it is suggested to follow one individual component [9]. However, components are seldom handled and transported separately. Instead, components are often delivered by milk runs, where several components are picked at different locations in the warehouse and delivered to different locations in the production. Therefore, when mapping one specific component, there are instances of time being spent on handling other components. This leads to the time of certain activities being distorted. For instance this occurs when a component which is mapped is picked and placed on the tugger cart for transportation to the production. During this transportation several other components are picked at different locations in the warehouse. Therefore, the flow map of the studied component will seem to have an activity with long transportation time from the warehouse to the production. This leads to "hidden" activities that do not concern the handling of the studied component. To avoid the "hidden" tasks the researchers could decide to follow a group of components. However, in this case that approach would not work for several reasons. Firstly, it is hard to define the start and end of the flow if components are picked and delivered to different locations. Secondly, since the exact same combination of components is seldom delivered more than once on a milk run, it is hard to define a group of components that would yield a representative flow map. Thirdly, if a group of components could be defined, this group is not handled and transported as a group throughout the flow. The group would differ between each storage point, regarding to combination of components and quantity.

There is some deviation in this thesis' use of MFM from the methodology described by Finnsgård et. al. [9]. The full MFM methodology is an iterative tool that as well as mapping the current state, also includes constructing a future state of the material flow. This thesis only applies the mapping and analysis of the current state of the flows. However, designing a future state would be particularly useful when choosing, implementing and analysing an improved material flow, or in this case a new level of automation. This is not done in this thesis as that is outside the scope. After the LoA analysis MFM could be used to visualise the future material flow. Combining these two tools in an iterative process can then be used to evaluate the material flow, identify an improvement area, measure the current levels of automation, defining possible future levels of automation, and support and evaluate the implementation of a future automation solution.

The approach this thesis takes on using MFM for finding the area to focus the automation evaluation on, does not guarantee that this is the area in which an automation increase will yield the best holistic system-wide improvement. It simply points out the area which has the most operator working time.

5.1.2 Automation analysis

The automation analysis phase intends to analyse the current levels of automation and based on the result plausible future levels. The original LoA taxonomy for assembly operations uses 7 levels for both physical and cognitive tasks. One of the purposes of the thesis is to evaluate if the original LoA taxonomy can be used or how it can be adapted to fit material handling. The original LoA taxonomy, developed for manufacturing operations [14], uses rather broad definitions of each level of automation. These definitions are judged to be suitable for evaluating LoA in material handling as well. Keeping the number of levels at 7 for both physical and cognitive LoA, as well as keeping their definitions, is reasonable for several reasons. First and foremost, the taxonomy for LoA in manufacturing operations is developed and validated in several case studies [23]. Furthermore, the usage of the LoA adapted to material handling will be very similar to the use of the original LoA, making the material handling LoA taxonomy in addition to the "LoA toolbox". Lastly, it keeps the level of detail at an adequate level. To have more levels will be too detailed and creates an unnecessary complexity when measuring the LoA of tasks.To have fewer and more distinct levels removes this uncertainty since it will be less ambiguous when setting the LoA of tasks. When it comes to the definition of level 7, it is should be viewed as a totally autonomous system with no human interaction. This is a level that is very hard to define and exemplify both in LoA for manufacturing and for material handling.

Even if the number of levels and the definitions are suitable to evaluate LoA in material handling, the titles and examples of each level does not fit or make sense with regard to material handling. For example, "Automated hand tool" as a title and "Hydraulic bolt driver" as an example do not apply very well if one is evaluating material handling activities. Therefore, parts of the LoA taxonomy must be adapted to exemplify the material handling purpose better. Some of the titles are changed by removing the restriction that a tool has to be handheld, e.g. "Automated hand tool" is changed to "Automated tool". This is done due to the fact that automated tools in material handling are rather big, e.g. forklift or overhead crane, and should not be restricted to being hand tools. The adjusted taxonomy gives two examples of material handling tools/equipment for each physical level, one for handling and one for transportation, and one example for each cognitive level. It can be viewed as the HATS-activities handling and transportation exemplifying the physical aspect of LoA and administration the cognitive. This makes the connection between MFM and LoA in the analysis much clearer and creates a natural transit between the two tools of analysis. It can be argued that the reason why the MFM and the material handling LoA works so well together is due to the fact that it is developed in conjunction with this one case in mind. It is not certain that it would be the same natural transit between MFM and LoA if it were applied in another case. With this in mind, the material handling LoA taxonomy is adapted to be as general as possible, but further replication case studies are needed to prove the generalisability.

The approach of use for LoA in this study is a bit different from the approach when using it for manufacturing operations. First of all, the use of LoA in manufacturing focuses on evaluating and analysing a certain workstation and its tasks, to find a Square of Possible Improvements (SoPI) for the whole workstation. In this case it is hard to confine the material handling activities into workstations. It is even hard to confine the material handling into work areas, as the tasks are performed at different locations in the warehouse depending on the ever-changing material orders. Instead of dividing the evaluation and analysis by workstations, this thesis divides it by the type of task. From the MFM analysis it is evident that the operation of picking components in the warehouse should be focused on and evaluated. This operation consists of two types of tasks for the handling of each component, illustrated in Figure 4.5 and Appendix D. The evaluation is subsequently divided into analysing picking tasks and transportation tasks. This enables finding a SoPI for all picking tasks and one for all transportation tasks. This makes it possible for Emerson RTR to find and implement holistic automation solutions that will fit the picking and transportation of all components. In Emerson RTR's case this is evident. There are a total of around 4500 different components in the warehouse, with only 13 of them being studied in this case study. To find a separate future level of automation for the handling of each one of these components would be both time-consuming and unnecessary since there cannot be such an implementation where every component get its own solution. This is why finding SoPI's that cover the handling of as many components as possible is preferred.

Emerson RTR has the potential to benefit from a higher level of automation than they have today. The scope of the project was not to propose a specific automation solution, but to show Emerson RTR where to focus the continued work, and within which span of LoA it is reasonable to aim. Based on the result of the case study it can be seen that the current level of automation is low. There are three types of storages in the warehouse that have been part of this analysis, the HBS that have a higher level of automation since there is a need of a forklift to pick material from it, the picking storage and entresol where the level is lower since almost everything is performed manually. From the SoPI, in Figure 4.16, it is evident that an increase of the level of automation in the picking storage should be prioritised, primarily in physical LoA but also in cognitive. Both since the automation level is low, but also since a better way of presenting the material for the operators would enable an increase of inventory accuracy. The operators will also benefit from a higher cognitive level of automation when picking the material. Helping them pick the right material and quantity, or even deliver the material to one place where the operators can pick, goods-to-person, it will be beneficial. When it comes to the LoA of the transportation tasks, the SoPI in Figure 4.19 shows that with regards to transportation the components on entresol should be prioritised. In the current situation these components are transported differently to the other. To find a solution that would work for all these components that are outside of the SoPI must be prioritised.

Despite the obvious potential for increasing the LoA, Emerson RTR has to consider other factors that may affect or be affected when implementing an automation solution. The inventory levels of the company are of a significant amount and the focus should be to investigate how this will be affected by implementing a new automation solution and to establish a plan of how to lower these levels before taking further actions. Even if this is outside the scope of this thesis it should be stated as a prerequisite for investing in automation for the sake of the company. The high inventory levels may hide underlying problems that have a significant impact on the factors Emerson RTR want to improve. By lowering the inventory levels at first it is possible to see these previously unidentified problems, this is often referred to as the Japanese lake and is something every company striving towards Lean manufacturing should be aware of [18]. To make investment or changes before potential problems are investigated will be a huge risk that can be devastating in the future. Even if the inventory levels are outside the scope of the thesis, Emerson should consider reducing these to identify hidden problems. Implementing new levels of automation will also affect the replenishment methods of the production, and these may therefore have to be redesigned. A higher level of automation could enable Emerson RTR to deliver material JIT to the production, which would lead to decreasing the inventory levels in production, as well as increasing the inventory accuracy. Then replenishment rounds have to be focused on delivering material with more precision, higher speed and smaller quantities, which would require that they are redesigned. Also there should be more focus on where to deliver the material in the production, the material may have to be delivered to work desks of the production groups and not to small storages outside the cell as today.

5.2 Methodology

The research methodology of the thesis was designed and conducted as a case study with an abductive approach. By using Emerson RTR as the case, it was possible to evaluate and draw implications and conclusions for the research questions based on the case study results. Abductive reasoning was an approach that was discussed early in the study, with regards to the automation analysis phase, since in the beginning it was not clear whether the existing manufacturing LoA was suitable to evaluate the level of automation in material handling. Therefore, the study was designed to have an abductive approach where the theory, observations and analysis was developed simultaneously during the automation analysis. This introduced what Kovacs [13] calls a creative element into the case study.

One of the drawbacks and frequent arguments against conducting case study research is the external validity, generalisability, of the research [10]. It is not possible to generalise to a great extent when a case study is conducted on a single case. However, since both MFM and LoA are methods tested and validated by other researchers, some external validity is upheld. These methods, especially LoA, are previously tested in different contexts, but to increase the external validity of combining MFM and LoA on material handling systems further replication studies have to be conducted. Since the LoA for material handling was adapted in connection to this specific case, there is a risk that it might not be as applicable to material handling systems that have a significantly different starting-point of automation.

Regarding the data collection of the thesis a few things should be considered. Time data for the mapping was only collected once per studied component. Instead, the focus was to collect time data of several different components flows to generalise and draw conclusions on different flow scenarios. This enabled a more holistic view of the material flow, compared to studying and repeatedly collecting data of the flow on one component. However, by doing this it is possible that the measured times include deviations from the observed operator work procedure that slightly distort the material handling lead times of the components. It should also be noted that when observing operators executing a task, the performance of the operators can be affected by the fact that they are observed. This kind of bias is hard to circumvent but has to be acknowledged. Moreover, the information obtained from interviews conducted during the thesis has to be considered with a critical mindset. The interviewees might have expressed certain biases when, for example, discussing the choice of studied components, as well as the possible minimum and maximum levels of automation during the automation analysis. To minimise these biases, interviews were conducted with several stakeholders from different departments to get multiple perspectives. However, all the interviewees were from within the company. It was apparent that the stakeholders had different points of view when it came to which components to study. They tended to have a bias towards studying components that affected their everyday work and that would highlight problems that frequently occurred for them.

5.3 Future research

As previously mentioned, future research should focus on replication studies of combining using MFM and LoA in material handling environments, to obtain higher external validity. It would be of interest to study cases where the starting-point of the level of automation is at a different level than that of Emerson RTR, to see if it is applicable to a broad spectrum of material handling systems.

Future research should also focus on how MFM and LoA can be used in connection with the implementation of a new material handling automation system. Here it would be of interest to study how conducting a future state MFM map can be used to evaluate the Triggers of Change that initiated the implementation.

6
Conclusion

This chapter presents the conclusions to the posed research questions.

The overall purpose of the thesis is to investigate whether Materials Flow Mapping (MFM) and Levels of Automation (LoA) could be used together to analyse the automation potential in a material handling system. Three research questions are answered during the thesis that concludes if and how this is possible.

RQ1: Can Materials Flow Mapping (MFM) be used as a basis for evaluating automation potential in material handling?

Based on the results of the case study it can be concluded that using MFM as a basis for evaluating current and potential future levels of automation is indeed suitable. By mapping the complete flows of several components, it is possible to measure and categorise non-value-adding activities, and identify the sequence of activities, operating times and information flow. These can be used to delimit the automation analysis to focus the study on a specific area of the flow. However, this does not guarantee that the optimal area is in focus in terms of system-wide improvement. MFM is also able to map the current state of a material handling system with great detail of activities. This level of detail is a great basis for the definition of the tasks that are evaluated with regard to the level of automation. All this creates the link between the two methods which concludes that MFM is suitable as a basis for automation evaluation.

RQ2: How can Levels of Automation (LoA) developed for manufacturing be applied or further adapted to assess the current and future levels of automation in material handling?

From the result of the case study it is shown that LoA is applicable for evaluating material handling operations, with some further adaption. With small adjustments to the LoA taxonomy develop for manufacturing operations, a similar LoA taxonomy, adapted for material handling, could be created. The adapted taxonomy involves changes to the titles of the levels, as well as examples fitting to material handling tasks. From this taxonomy it is possible to measure the current LoA of the material handling system, both for tasks such as picking and handling of material, and transportation of material. From the adapted LoA taxonomy, discussions with stakeholders can be held to define the minimum and maximum automation levels. These levels then define the potential future levels of automation in material handling by generating confined Squares of Possible Improvement (SoPI). To obtain a future state of automation that is reasonable for the handling of all the study objects, SoPI's should be created for each type of task, e.g. *picking of material* and *transportation of material*. From these SoPI's it is then evident which tasks should be focused on when implementing a level of automation.

RQ3: Which levels of automation are plausible for Emerson RTR to implement?

The SoPI's of the automation analysis provide the plausible levels of automation that Emerson RTR could implement. Based on the result of the case study Emerson RTR should focus on increasing their automation level of the picking tasks in the picking storage. All these components are outside of the SoPI because of the manual work in this part of the warehouse. Because of the small size of the components in this storage location and the manual work, there is a higher risk for inventory errors in this area compared to the HBS. By increasing the cognitive automation in this area the warehouse operators can perform their tasks with more precision. It is however impossible to say exactly what level of automation Emerson RTR should aim for without further investigation since it also depends on other aspects that are not considered in the case study. The result is rather an indicator of where Emerson RTR should focusing future analysis and within which span of LoA they should aim.

Fulfilment of purpose

The overall purpose that was set out in the beginning of the thesis was to investigate how automation potential in material handling could be analysed and evaluated. Since the approach of combining the methods, MFM and LoA, had not been used for automation evaluation in material handling before, the researchers of this thesis aimed to test this through a case study. The purpose was fulfilled by evaluating and developing these methods, and the thesis thereby provides a systematic approach to investigate automation potential in a material handling environment.

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A

Appendix

Component: XX					
Activity sequence	1	2	...	n-1	n
Activity explanation					
H/A/T/S					
Operators (qty)					
Cycle time (sec)					
Equipment					
Volume					
Average quantity (Storagepoints only)					
Packaging					
Component characteristics					
Information flow					
From					
To					
How					

Figure A.1: Protocol for MFM data collection.

B

Appendix

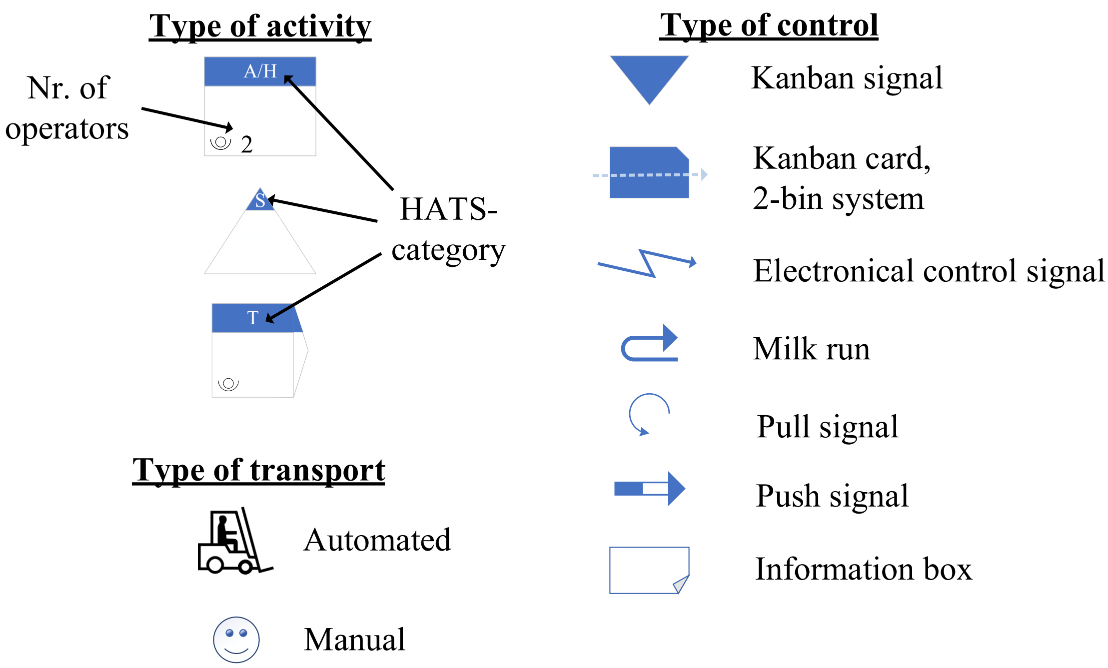

Figure B.1: Legend of the MFM-symbols.

C

Appendix

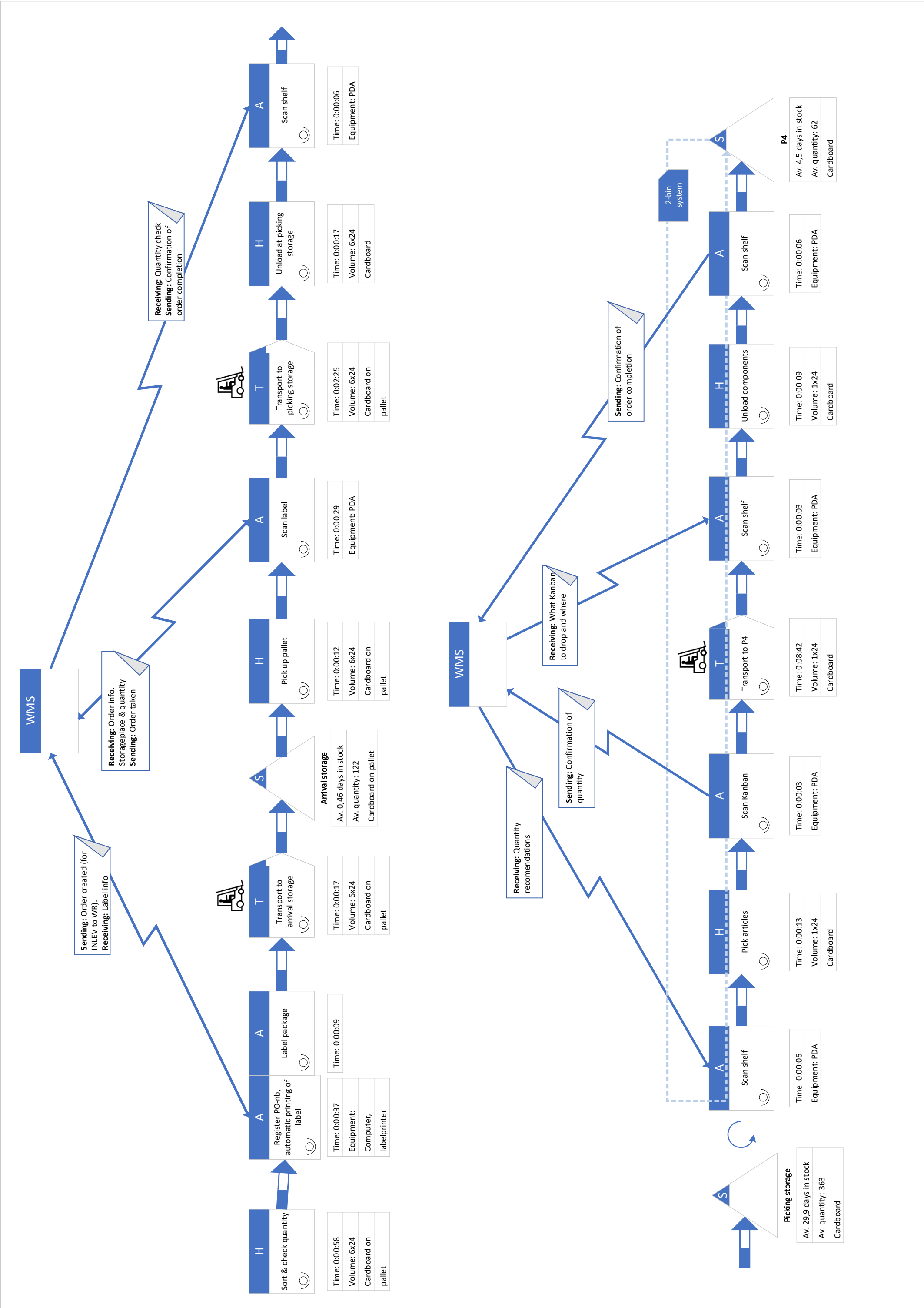

Figure C.1: Material flow map for component 1.

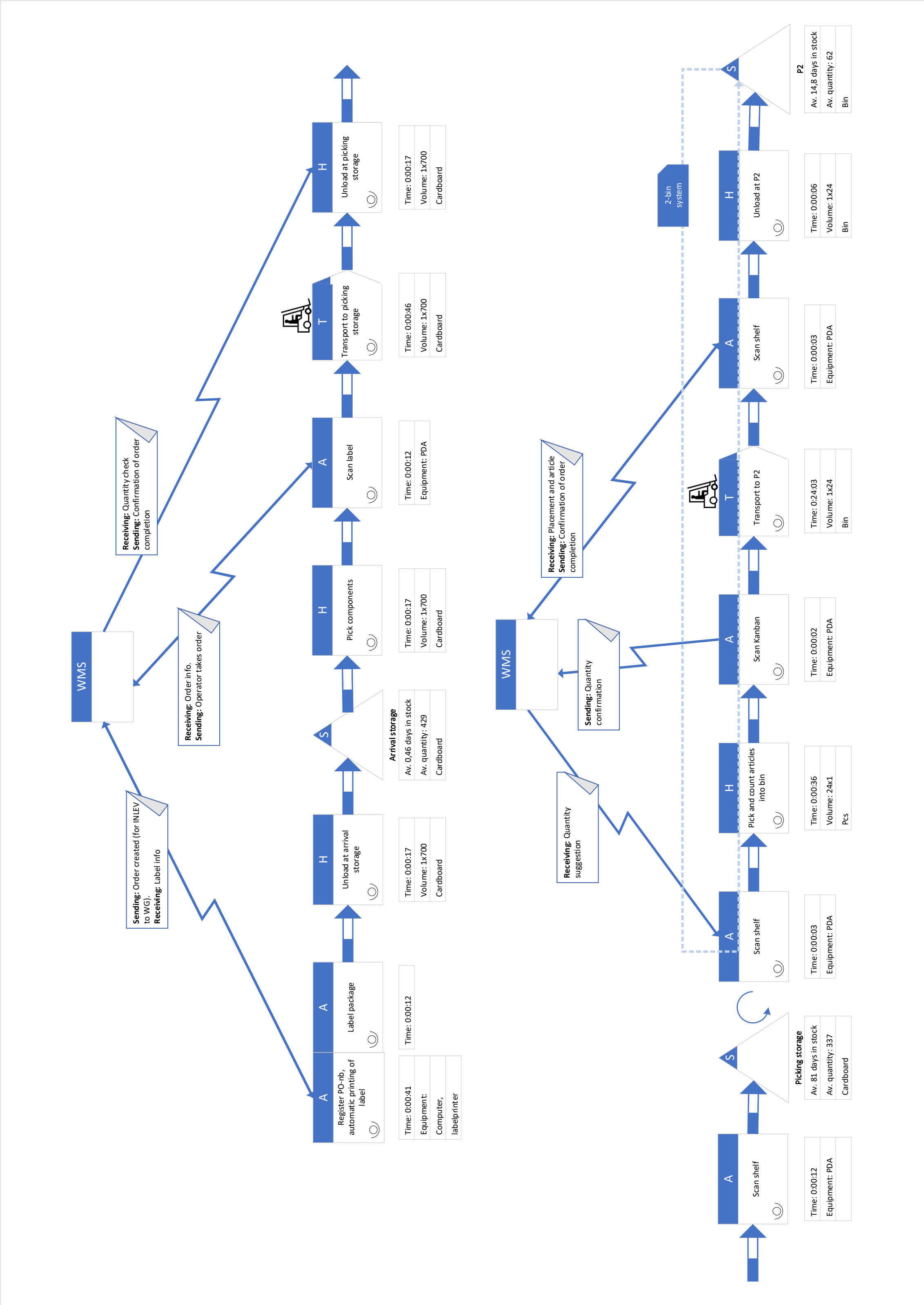

Figure C.2: Material flow map for component 2.

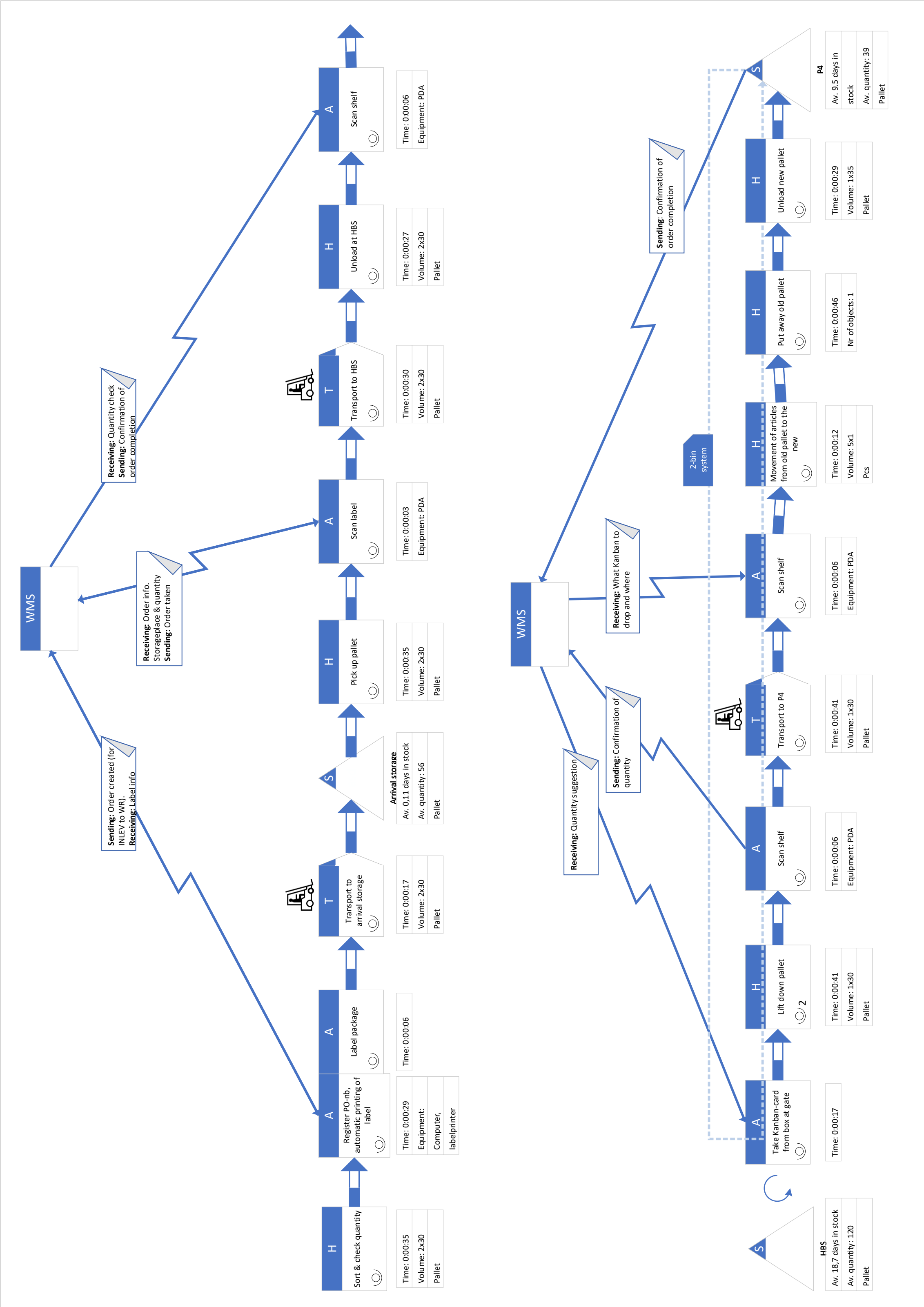

Figure C.3: Material flow map for component 3.

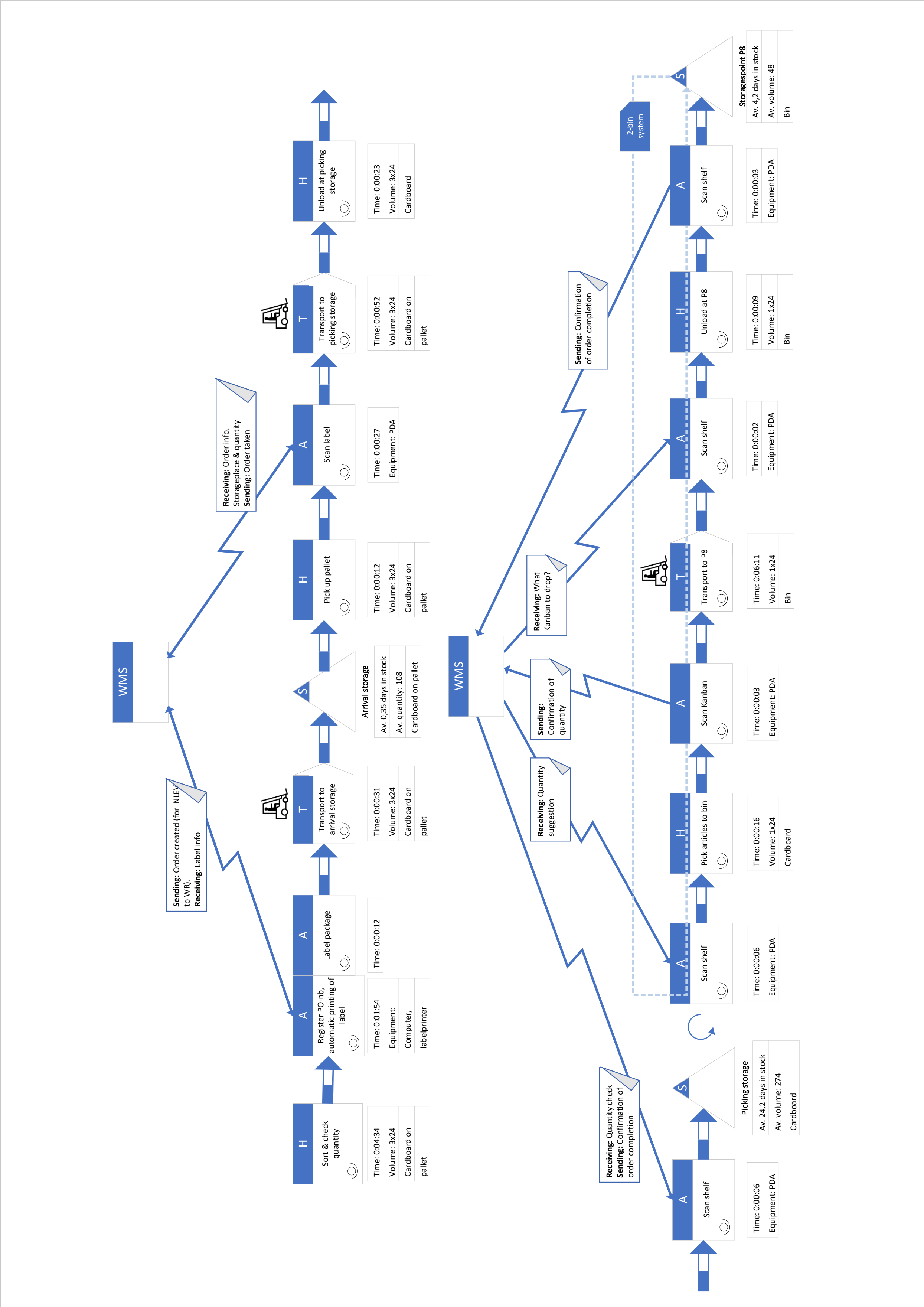

Figure C.4: Material flow map for component 4.

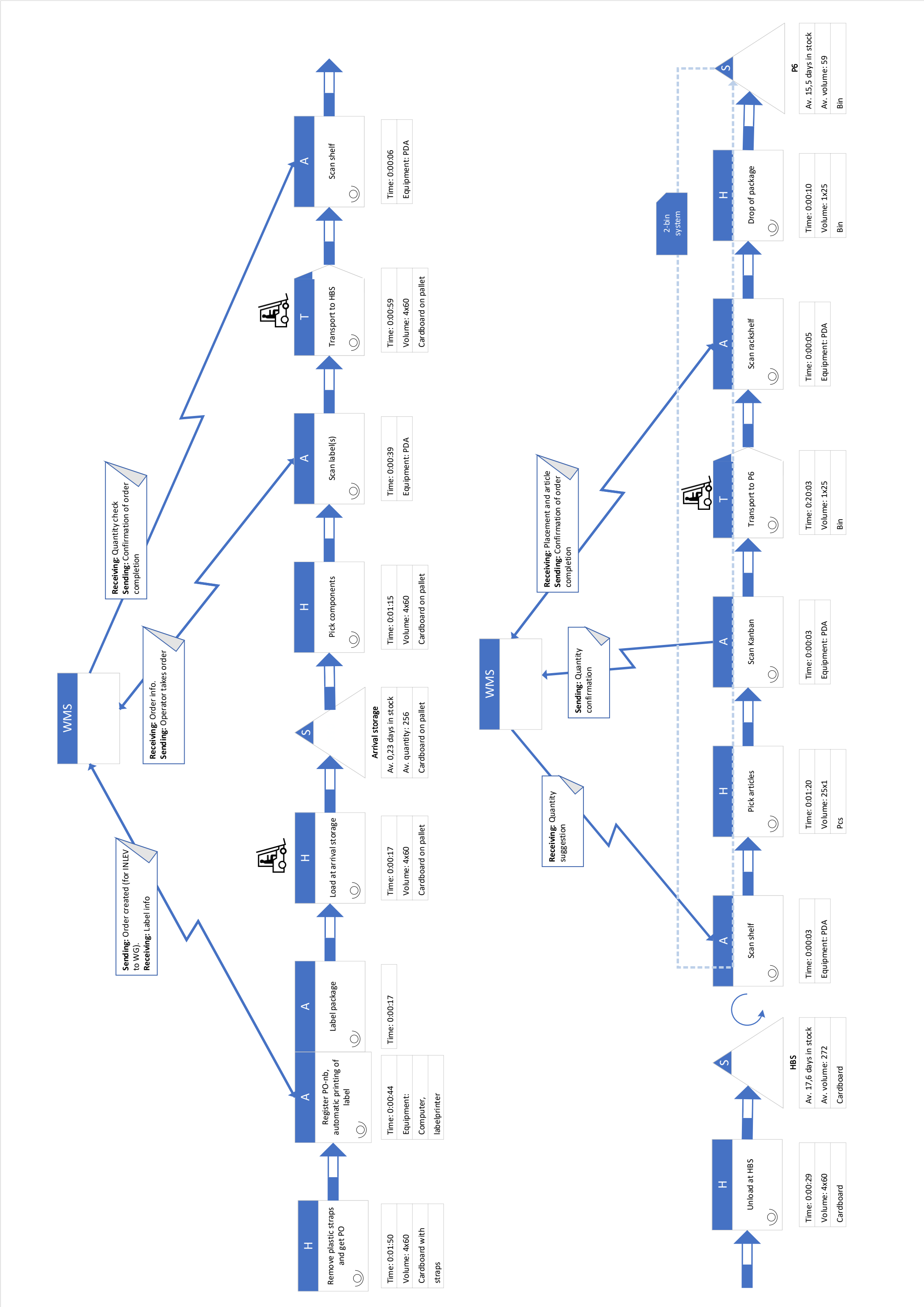

Figure C.5: Material flow map for component 5.

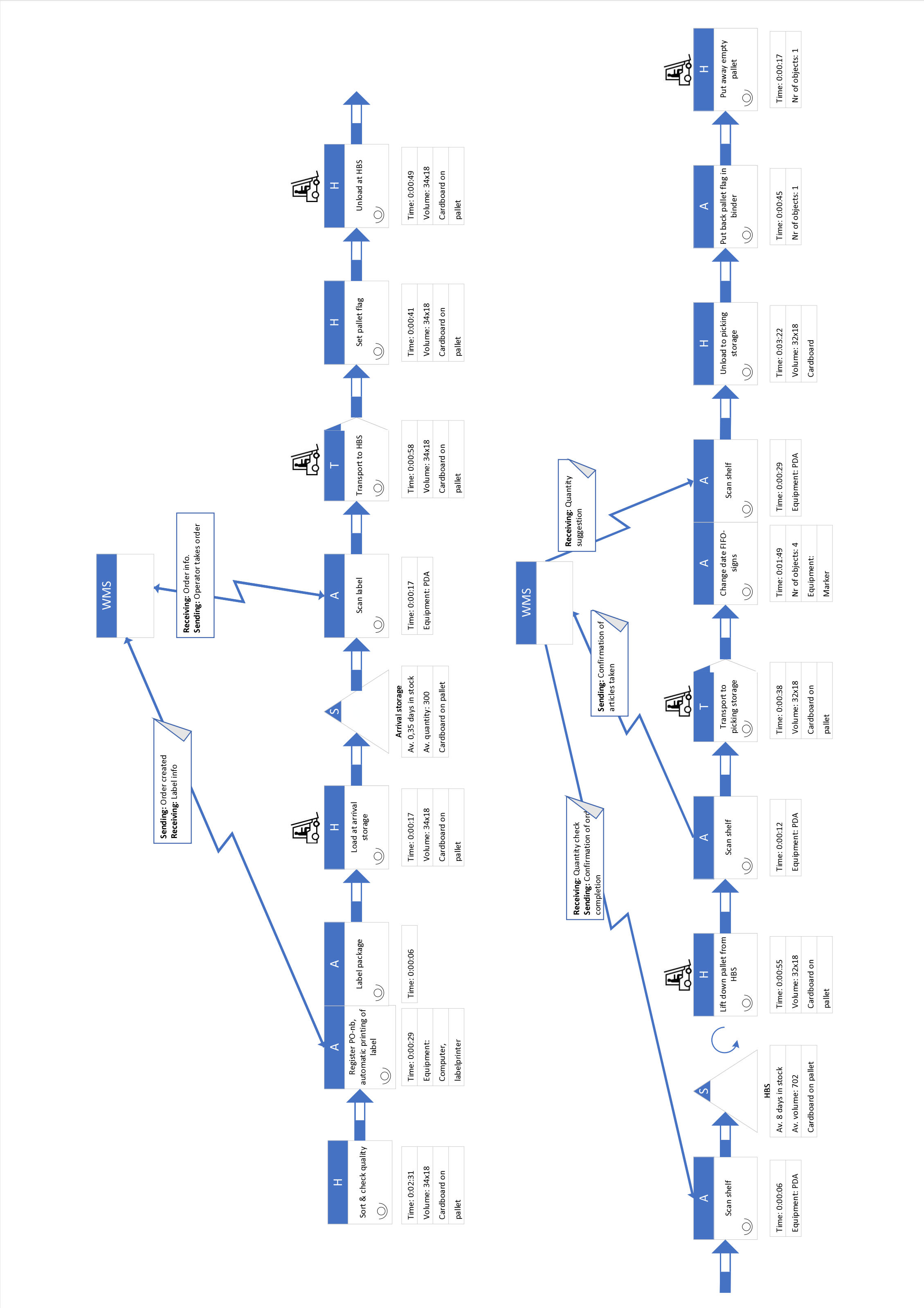

Figure C.6: Material flow map for component 6, part 1 of 2.

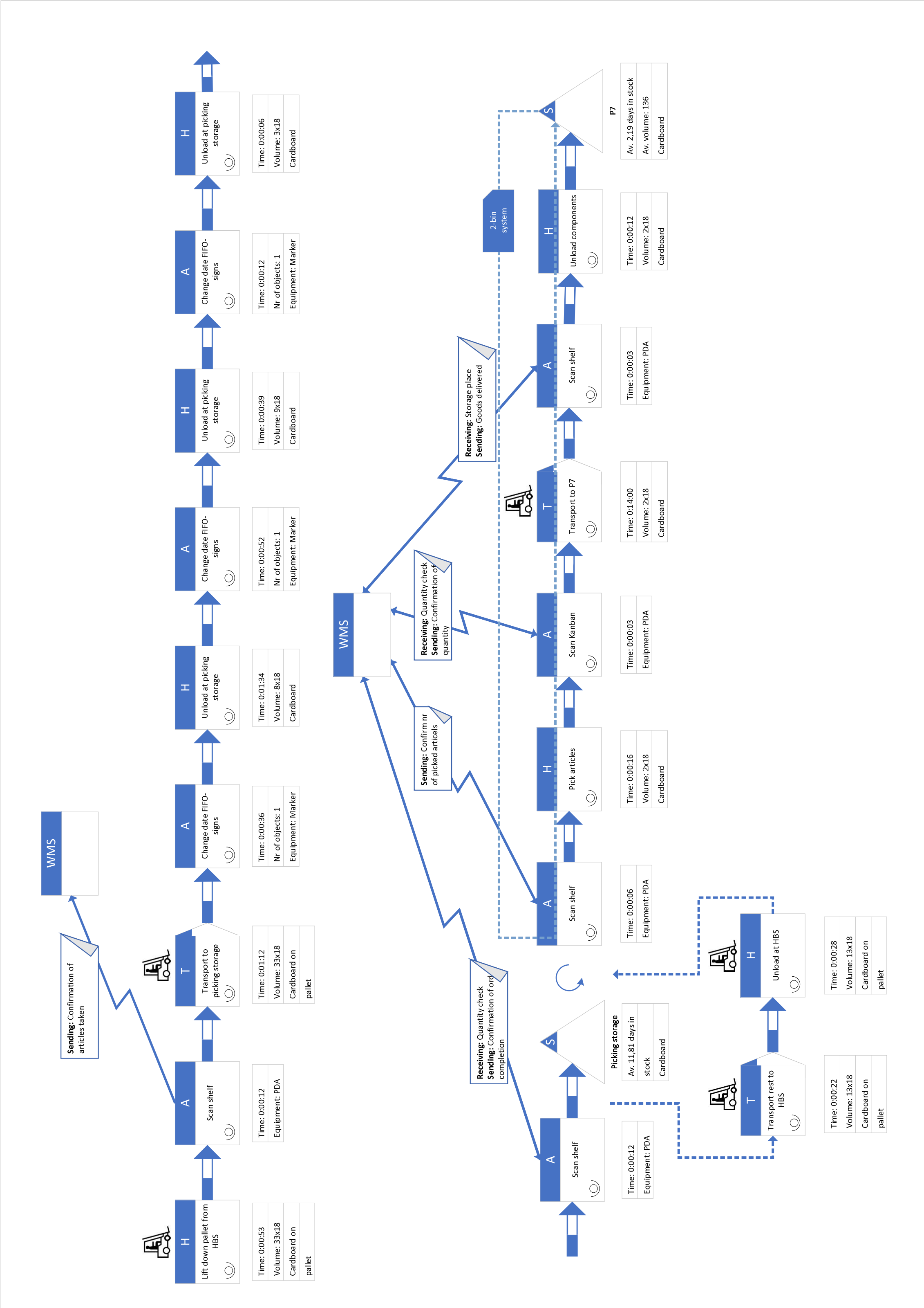

Figure C.7: Material flow map for component 6, part 2 of 2.

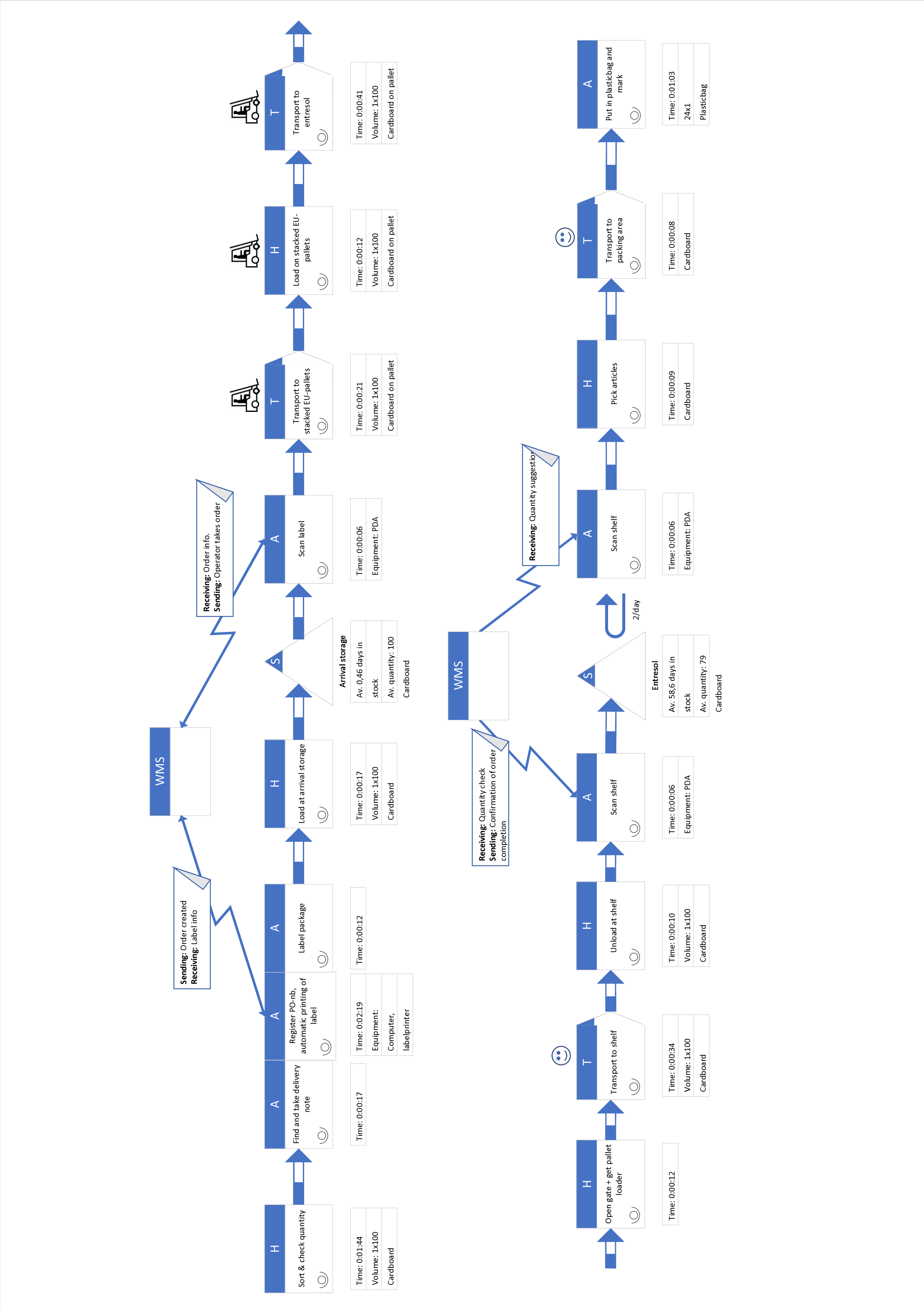

Figure C.8: Material flow map for component 7, part 1 of 2.

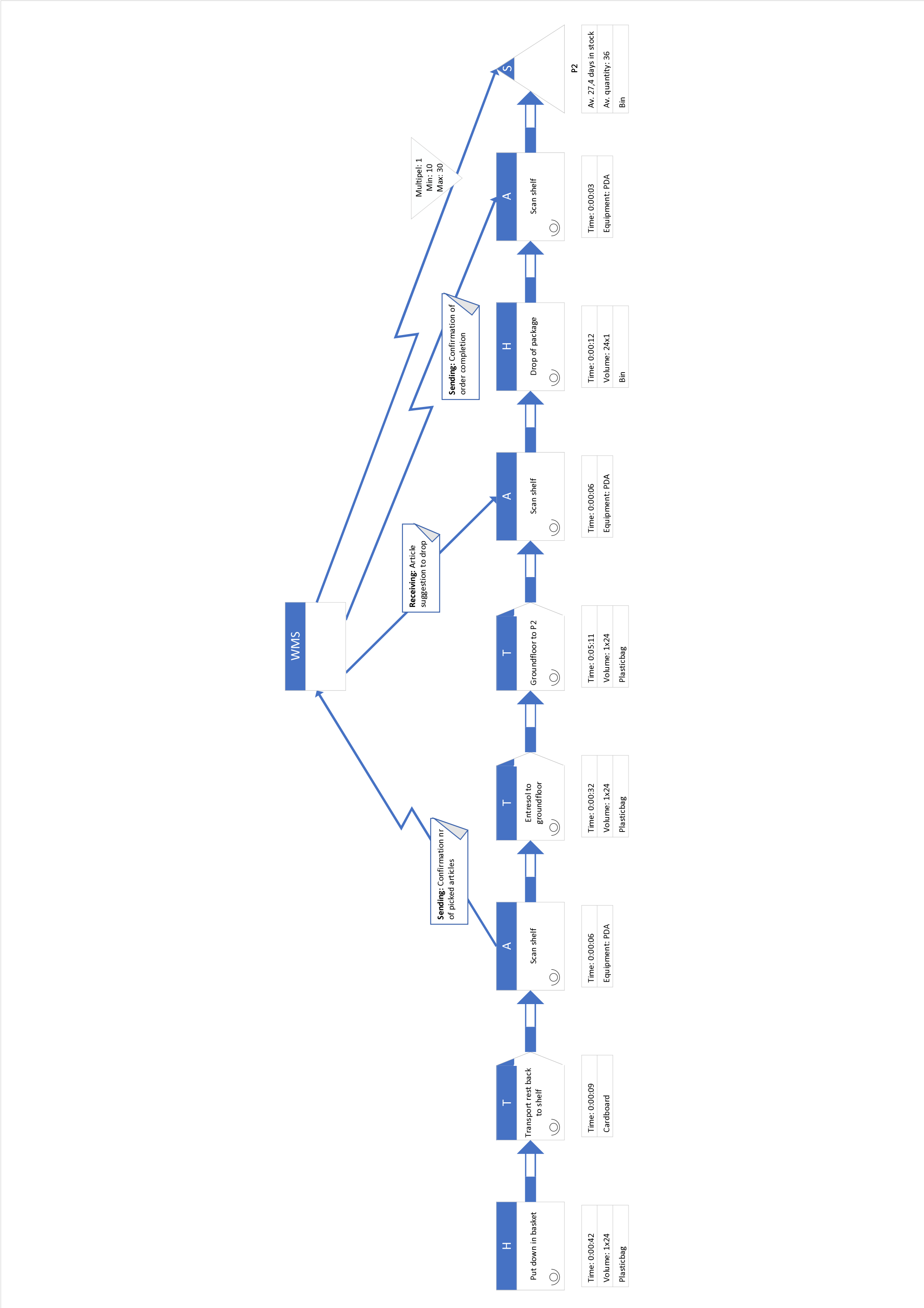

Figure C.9: Material flow map for component 7, part 2 of 2.

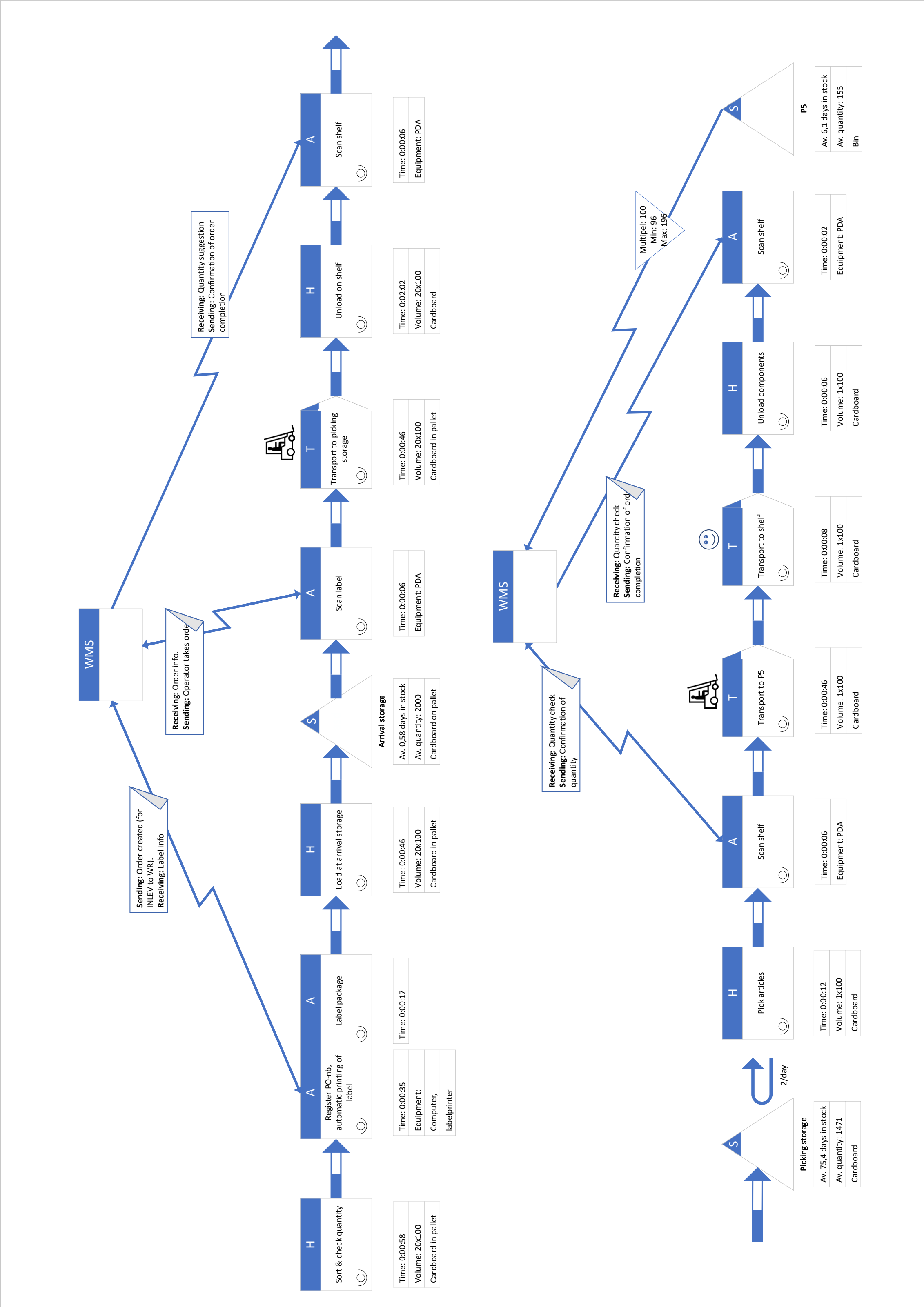

Figure C.10: Material flow map for component 8.

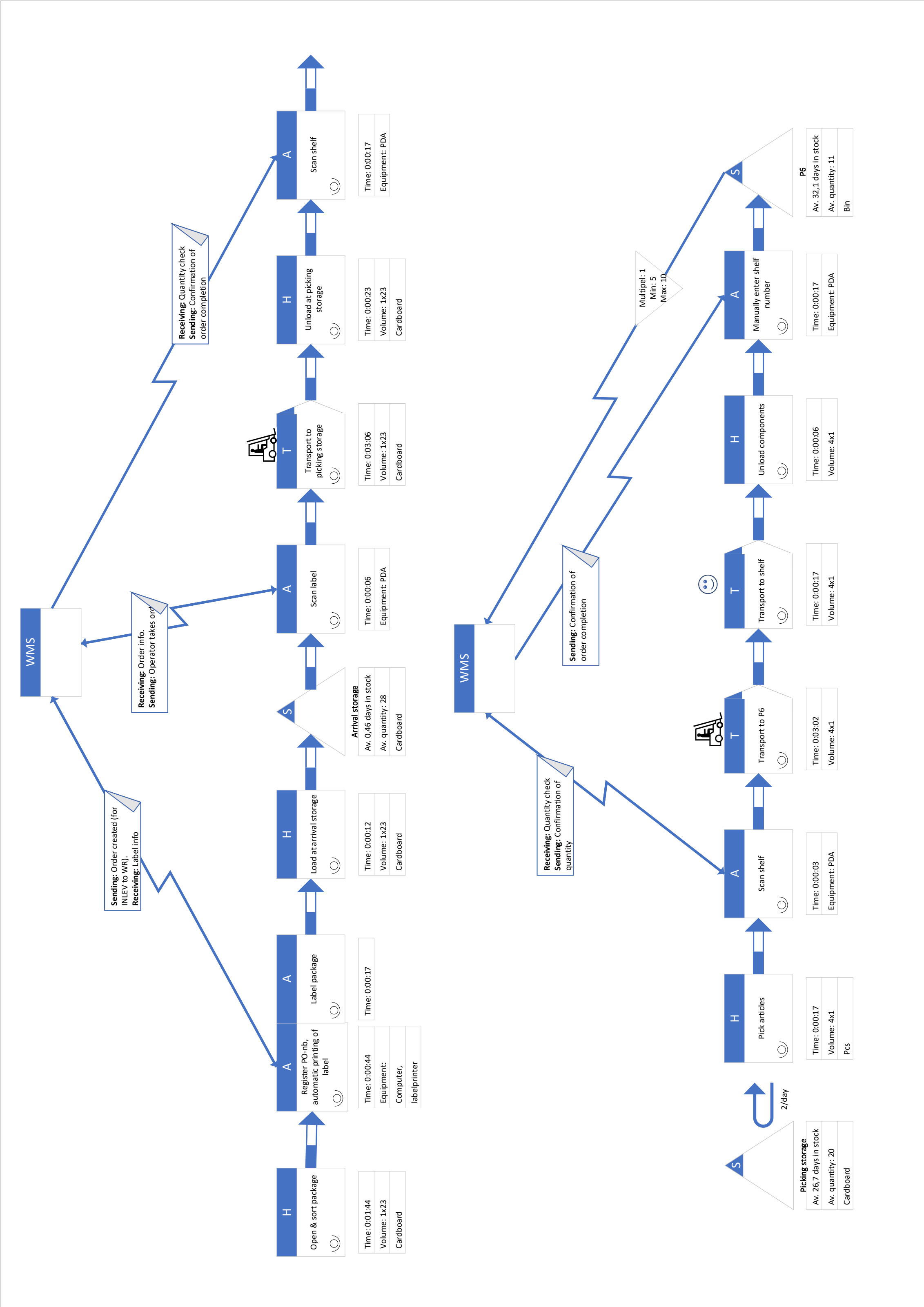

Figure C.11: Material flow map for component 9.

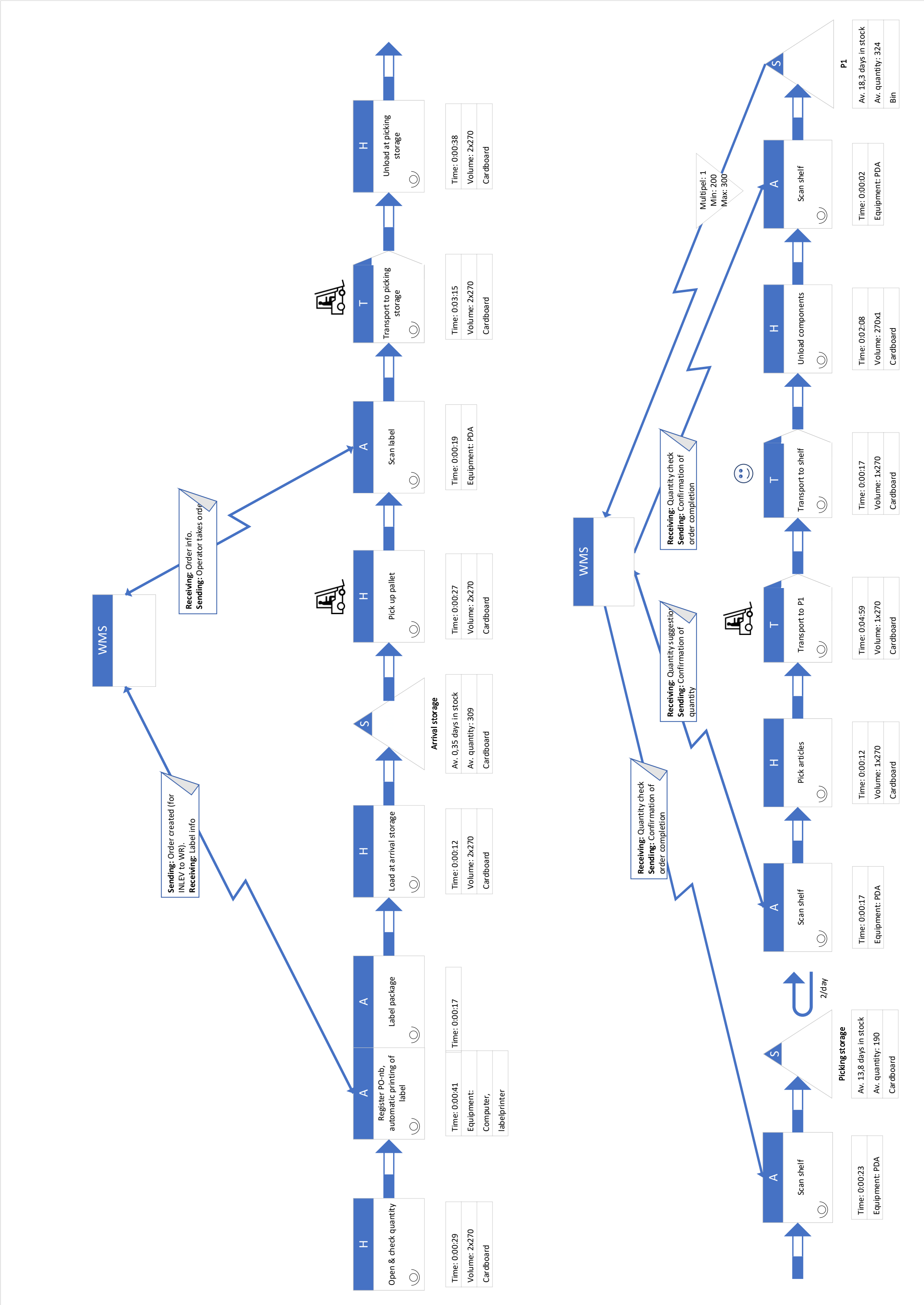

Figure C.12: Material flow map for component 10.

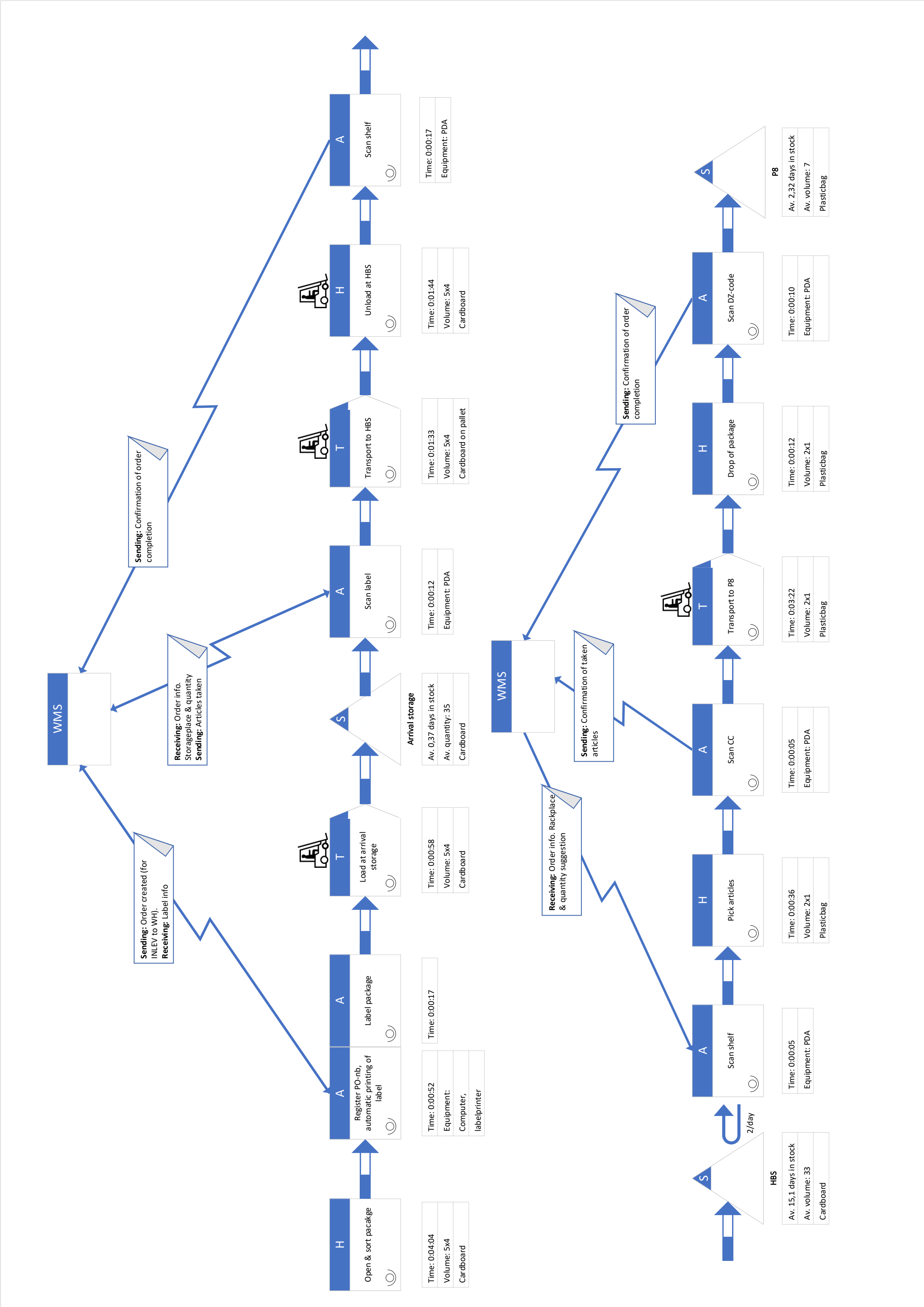

Figure C.13: Material flow map for component 11.

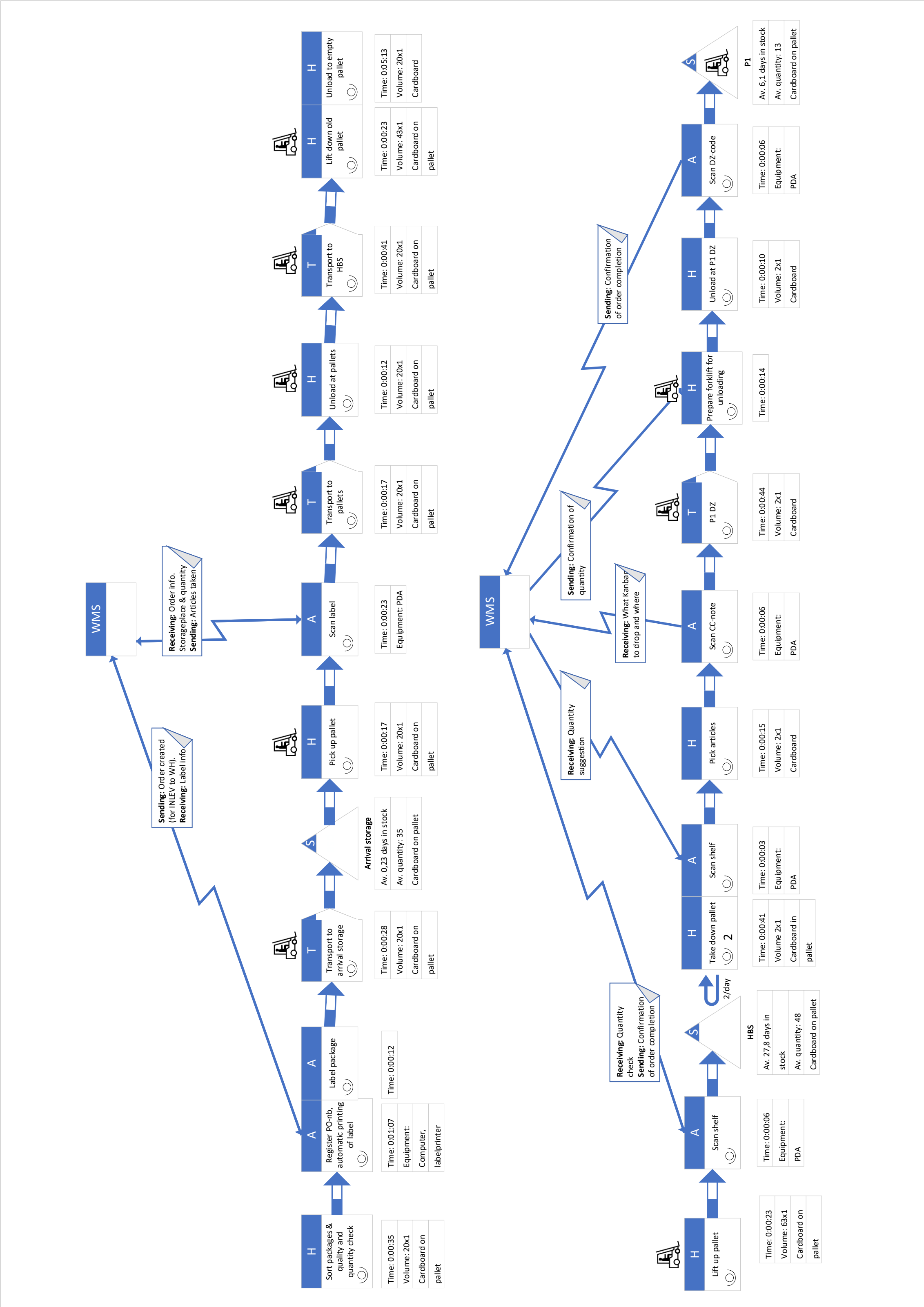

Figure C.14: Material flow map for component 12.

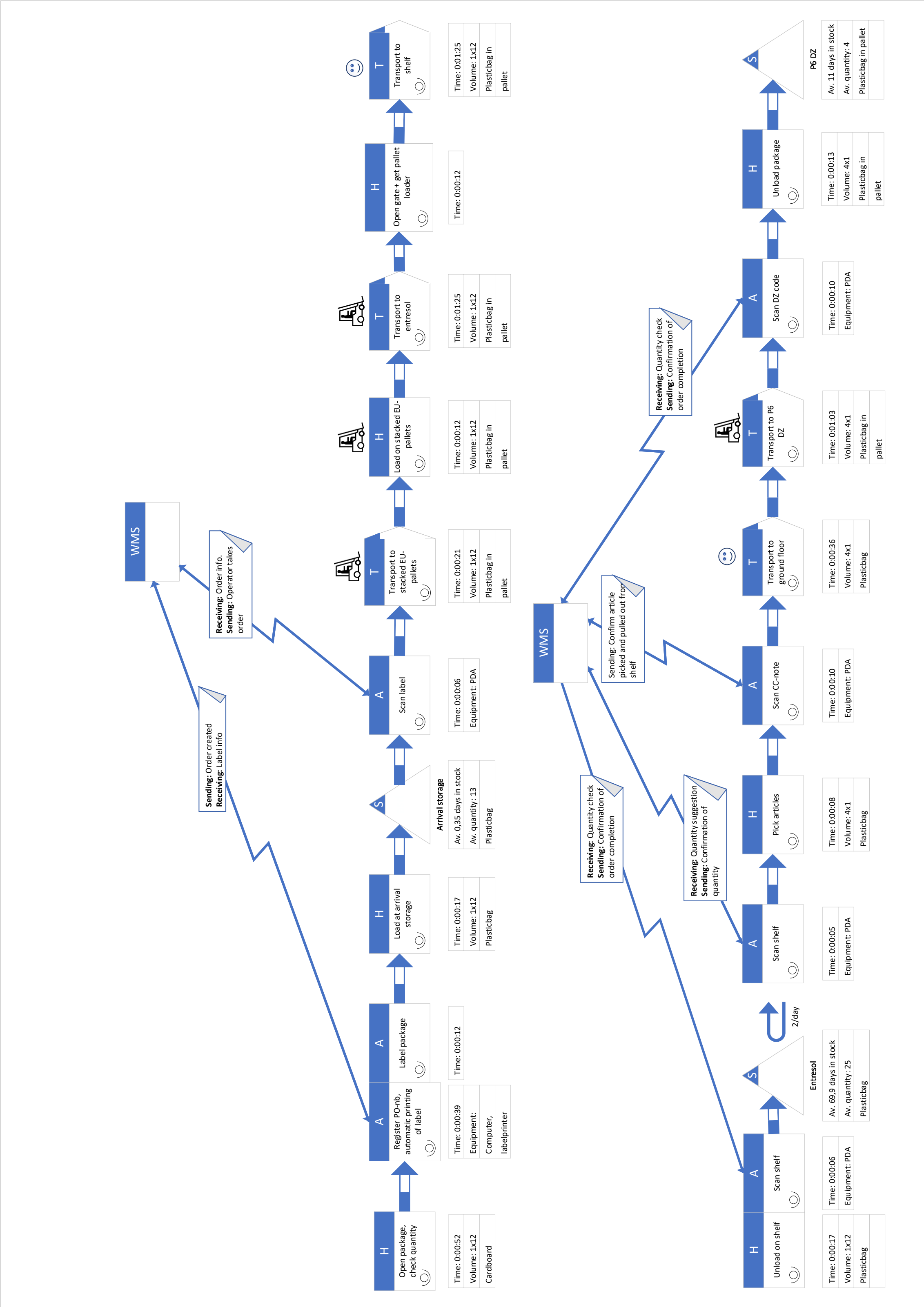

Figure C.15: Material flow map for component 13.

D

Appendix

Table D.1: The MFM-activities that make up the tasks that are evaluated in the LoA analysis.

Component	Task	MFM-activities (sub-tasks)
1	Pick material	Scan shelf
		Pick components
		Scan kanban
	Transport material	Transport (tugger cart)
2	Pick material	Scan shelf
		Pick components and count them
		Scan kanban
	Transport material	Transport (tugger cart)
3	Pick material	Get kanban-card from box and scan
		Lift down pallet
		Scan shelf
	Transport material	Transport (forklift)
4	Pick material	Scan shelf
		Pick components to bin
		Scan kanban
	Transport material	Transport (tugger cart)
5	Pick material	Scan shelf
		Pick components
		Scan kanban
	Transport material	Transport (tugger cart)
6	Pick material	Scan shelf
		Pick components
		scan kanban
	Transport material	Transport (tugger cart)
7	Pick material	Scan shelf
		Pick components
		Repack (put in plastic bag and mark)
		Scan shelf
	Transport material	Transport (manual)
8	Pick material	Pick components
		Scan shelf
	Transport material	Transport (tugger cart)
9	Pick material	Pick components
		Scan shelf
	Transport material	Transport (tugger cart)
10	Pick material	Pick components
		Scan shelf
	Transport material	Transport (tugger cart)
11	Pick material	Scan shelf
		Pick components
		Scan CC-note
	Transport material	Transport (tugger cart)
12	Pick material	Take down pallet
		Scan shelf
		Pick components
		Scan CC-note
	Transport material	Transport (tugger cart)
13	Pick material	Scan shelf
		Pick components
		Scan CC-note
	Transport material	Transport (manual)