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Analysis and Optimization of a Warehouse

MASTER'S THESIS

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Institute of Logistics Engineering

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Graz, February 2016

AFFIDAVIT

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In cooperation with:

voestalpine Böhler Welding Austria GmbH

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Also special thanks to my girlfriend and thanks to my friends.

Daniel Rathmayer Graz, February 2016

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List of Abbreviations

AGV	automated guided vehicle
ASRS	automated storage and retrieval system
BVL	Bundesvereinigung Logistik
eEPC	extended event driven process chain
EOS	economies of scale
EPC	event driven process chain
ESP	external service provider
EWM	extended warehouse management
FMEA	Failure Module and Effects Analysis
GI	goods-in
GO	goods-out
HU	handling unit
QS	quality assurance
RPN	risk priority number
SRS	storage and retrieval system
SSCC	Serial Shipping Container Code
VBA	value benefit analysis
VDI	Verein Deutscher Ingenieure
WIP	work in progress
WMS	warehouse management software

1 Introduction

Today, at the beginning of the 21st century, logistics is one of the crucial key competitive factors in global competition. Who would have thought that 30 years ago? For long times logistics was reduced to transportation, storages and forwarders. Logistics just happened in single steps of value creation. A lot has changed since then and now a global approach to the complete value-added process is lived (cf. [BAU08]).

Old fashioned companies have cost oriented perspectives. Their key figures are developed to monitor and reduce operational costs. Increasing operational processes´ efficiency to create lean supply chains is the aim of these old fashioned companies. However, modern companies see their supply chain as a tool to realize their strategies. They try to generate new value-added services and invest to improve competences and customer relationships (cf. [ADE02]).

Individual customer specific needs require individual solutions. Therefore, single customer orientation is necessary. By permanently adding new services with high flexibility according to customers´ needs, the logistics strategy is affected (cf. [PKR08]). “Bundesvereinigung Logistik” (BVL) published a survey, in which the majority of companies asked focus on flexibility and individualization within their strategies (cf. [SPG+05]).

The increasing demand of individual logistic solutions challenges the logistical thinking of efficiency, because more individuality leads to higher logistics costs (cf. [PFO04]). Especially the necessity of picking and sorting processes is enforced by high levels of individuality (cf. [AIK+08]).

1.1 Motivation

The motivation to write this Master´s Thesis arose from the author´s interests in data analysis and the creative process of developing optimized logistics systems within given boundaries. The fact that slight changes of things that were meant to be invariable, can effect mayor improvements, also encouraged the author to write this Master´s Thesis.

1.2 Research Question

The research question is how to improve historically grown and outdated logistic processes, warehouses or logistic systems by using simple approaches. Also the development of solutions with low investment costs is a challenging factor.

1.3 Project Partner

This Master´s Thesis is done in cooperation with voestalpine Böhler Welding Austria GmbH. voestalpine Böhler Welding Austria is part of the worldwide operating steel-based technology group voestalpine Group. Around 47,500 employees generated a revenue of EUR 11.2 billion in more than 50 countries on five continents in the business year 2014/15. The Group is one of the leading partners to the automotive and consumer goods industries in Europe and to the oil and gas industries worldwide. They are also world market leader in turnout technology, special rails, tool steel, and special sections (cf. [VOE16a]).

voestalpine Böhler Welding Austria offers product portfolio of welding consumables from own production. Approximately 2.000 products are constantly aligned to the up-to-date specifications of the most demanding industries and is adjusted, if necessary, to the market requirements under observance of the highest quality standards. Such a big variety of products generates many different types of packages. Products such as coils of cored wire or stick electrodes are mostly packed in cardboard boxes (cf. Figure 1-1). Such cardboard boxes can have various dimensions and therefore varying weights. Some wires are packed in cans too. Figure 1-2 shows some of these products in detail.

With an international network of 34 sales companies and 11 production units around the globe voestalpine Böhler Welding Austria is close to customers and can offer support for daily operational welding challenges. Research and development activities are driven by specific industry- or customer-requirements. By cooperating with leading companies of various industries, universities and research institutes, as well as their parent company voestalpine, voestalpine Böhler Welding ensure to push the edge of innovation.

Figure 1-1: Products ([VOE16b])

Figure 1-2: Products ([VOE16b])

2 Problem Analysis

In these first sections terms and definitions are discussed, which are important in upcoming investigations. Furthermore a detailed description of the complex of problems in intralogistics is given.

2.1 Terms and Definitions

This Master´s thesis is written in the special field of logistics. Logistics as a special field arose from military. Nowadays, logistics stands for designing and executing material- and information flow. The aim of logistics is to provide right goods in right amounts, at the right place, at the right time, with the right quality at the right price. These requirements are called the six R of logistics. (cf. [KOE04])
Material flow can be divided into internal and external material flow. In this Master´s Thesis only internal material flow is relevant. In internal material flows steps like goods-in, warehouse, production, assembly and forwarding are passed through. (cf. [WB99])
A material flow design is focusing on system thinking. Material flow systems consists of production, warehousing, transportation, picking and packing. Material flow systems´ aim is to realize short throughput times, small stock and adherence to delivery dates. (cf. [ND04])
Factories as well as material flow systems have to be flexible. Historically grown systems are usually very static. But flexibility is crucial to stay competitive and to meet a fast moving globalized industry. Also increasing needs for customer individualization requires flexible systems. (cf. SW04])

2.2 Complex of Problems

One of voestalpine Böhler Welding Austria´s production sites is located in Kapfenberg, Austria. Stick electrodes, solid wire and cored wire are produced there. Additionally, a forwarding department is located in Kapfenberg, which is receiving, storing, picking, packing and shipping various products all over the world. Since voestalpine Böhler Welding is part of the voestalpine group, a significant part of the product portfolio is produced by associate companies. The transportation of goods to the customer is proceeded by an external service provider (ESP).

The forwarding department has a high-rack storage with two manual driven cranes. The racks as well as the cranes are used and do not meet modern requirements of production or distribution. This leads to suboptimal processes and additional handling effort. A big variety of different products, product sizes, packages and a single item pallet strategy in combination with strongly varying bin occupation complicate storage processes significantly. Additionally, high degrees of occupation over long times and processes, which are not compatible with other warehouses in the supply chain are issues in the forwarding department.

2.3 Project Aims

The aim of this Master´s Thesis´ is to optimize the forwarding department´s processes on an operative and on a process level. In order to gather information about the current situation, all processes are going to be analyzed based on existing restrictions. The development of optimization approaches to improve processes is a significant part of this thesis, as well as the development of optimization approaches using alternative warehouse technology. According to voestalpine Böhler Welding Austria a reduction of the storage´s occupation of 25% and a reduction of 25% costs is expected from optimization outcomes. To reach this thesis´ aims the following work packages are defined:

1. Literature study
   The first step is a literature study about warehouse analysis, key figures and warehouse technology.
2. Survey of the current state
   Analysis of the warehouse´s layout, process- and material flow analysis and determination of key figures are the aim of the second work package.
3. Weak point analysis and optimization
   With the definition of weak points and their analyzation, optimization approaches and solutions are developed in the third work package. Furthermore, optimization potentials are determined in this package.
4. Presentation and documentation
   This project´s results are presented in meetings and a hardcover book version of this thesis. Additionally, all data are prepared to be used in future projects.

The outcome of this Master´s Thesis is a basis for the decision-making process, in which an appropriate concept for a new warehousing concept will be selected.

3 Course of Investigation

As it is described in chapter 2.3, this Master´s Thesis´ aim is to optimize the forwarding department´s processes on an operative and on a process level. This chapter gives the theoretical background for upcoming analyses of warehouses and material flows. Material flow systems are described as well as steps how to simplify and analyze them. Methods for analyzing the actual state of a material flow system show how to record and assess current states. Furthermore, the process of order picking is discussed briefly. A short discussion about material flow planning completes the collection of methods needed for this project.

3.1 Material Flow Systems

Material flow systems store, transport, merge and separate products. Broad knowledge about existing technologies in this area is the prerequisite to design efficient material flow systems. A large variety of technologies provides many different configurations (cf. [HSN+07a]). Therefore, such systems are rather complex and they have to be simplified for analyzations. Simplifications called models like flow charts, graphs or tables are used to simplify real and complex systems. Figure 3-1 shows the typical steps in modelling material flows. For complex systems usually qualitative schemes are used in first place before they are transformed into quantitative visualizations (cf. [AF09], p. 47-48).

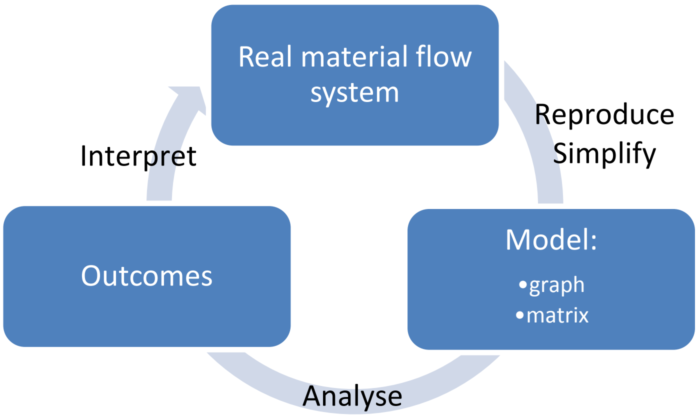

Figure 3-1: Steps in Modelling (cf. [AF09])

3.2 Analysis of the Actual State

The analysis of the actual state of a material flow system contains identifying, recording and assessing. (cf. [AF09])

Identifying and Recording the Actual State

First step in recording, is to clarify relevant parameters. These parameters are part of processes, IT-systems, material data, means of transport and warehouses. Also product data as well as external transportation data is a parameter to be clarified. Parameters can be gathered in a primary and a secondary assessment.

Primary assessed data are gathered especially for a certain analysis, which is necessary if existing data does not meet the required quality. Methods like surveys, workshops or multi-moment recording are used. Secondary assessed data is originally gathered for other investigations and is used in multiple applications. Layout drawings, bills of material or production programs are secondary data. Recorded data has to be checked if it is plausible, complete, redundant and consistent. After verification, data can be rearranged and connected to gather additional information (cf. [AF09], p. 234-241). Additionally, data can be distinguished between static and dynamic data. Static data is constant for a long period of time, like the number of different products, product properties, storage capacity and strategies. They are independent from customer orders. However, dynamic data is order and time related such as the number of orders each day or goods-in movements per day. With this kind of data, movements are recorded (cf. [HSN+07b], p. 336-338).

Assessing the Actual State

The process chain related assessment focuses on customer´s benefit. Process chain management is more than aiming for new technical solutions, innovations and efficiency, it is about customer´s needs. Therefore, the quality of logistics services such as achieved delivery dates, product´s condition, information and flexibility due to changes is important. A process chain analysis gives insight into material and information flow and comes up with illustrations to record and understand processes easily (cf. [AIK+08], p. 384-388). One popular way to illustrate process chains are event-driven process chains (EPC). Such process chains start with an event. Events are followed by functions which create new events. Connections between events and functions are logical operators (and, or and xor) (cf. [KSN92]). The extended event-driven process chain (eEPC) contains additional information about data and resources (cf. [SCH99]). The Figure 3-2 shows a legend of used icons and their meaning while used in an eEPC. Besides events and functions, also a process path is used. Process paths are links to other processes. The information icon shows used information like picking lists or orders. Participating persons, departments, organizations are displayed in oval icons.

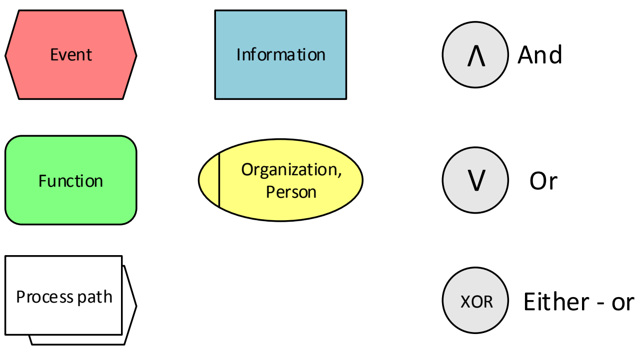

Figure 3-2: eEPC Legend

Besides the process chain, also the material flow has to be investigated in an analysis of the actual state. The material flow analysis is separated into seven steps, which are data acquisition, material flow matrix, transportation matrix, distance matrix, transport intensity matrix, determining costs, material flow optimization(cf. [AIK+08], p.394). A material flow matrix gives information about material moving from one area to another, whereas a transportation matrix shows the resulting numbers of transportations. The distance matrix correlates transportations between areas with actually driven ways and a multiplication of transportation and distance matrix results in a transport intensity matrix. This intensity´s unit is for example Pallets x meter (Palm). To show material flow in a graphical way, Sankey diagrams can be used. These diagrams give insights into quantity and complexity of material flows. Sankey diagrams can be schematic (independent from actual layout) or structural (placed into a layout) (cf. [AF09], p. 251). Another way of illustrating material flow information is to sort and summarize data. One way to do this is the ABC-Analysis. Here data´s criteria like sales or costs are shown in correlation to groups of products. After sorting data groups, usually 20% of all products (groups) generate 80% of the chosen criteria (cf. [MAR11], p. 35).

Another way of assessing material flow and warehouse data is to determine key figures. They can be separated into absolute figures (stock, sum of moved weight) and relative figures (volume utilization, pick performance per picker) (cf. [AIK+08], p. 397). In literature a lot of key figures for warehouses can be found, for example the Storage Capacity (Equation 3-1). It describes the maximum number of unit loads able to be stored inside a storage due to rack construction. The Product Range reflects the number of different products stored. The Warehouse Occupancy is a correlation of the dynamic value of the actual number of stored unit loads and the static storage capacity. The Range of Storage (Equation 3-2) shows the time span in which stock on hand can ensure an average goods-out material flow. The Inventory Turnover (Equation 3-3) shows how often the whole stock is replaced during a certain period of time (cf. [HSN+07c], p. 110-111). The GI-GO Ratio (Equation 3-4) reflects correlations between in- and outgoing goods over certain time spans (cf. [TIN07], p. 101).

$$O = \frac{Number\ of\ Occupied\ Bins}{Warehouse\ Caparity} \times 100$$

Equation 3-1: Warehouse Occupation

$$R = \frac{Average\ Inventory}{Average\ GO\ per\ Time}$$

Equation 3-2: Range of Storage

$$T = \frac{GO\ per\ Time}{Average\ Inventory}$$

Equation 3-3: Inventory Turnover

$$GIGO = \frac{GI}{GO}$$

Equation 3-4: GI-GO Ratio

The failure module and effects analysis (FMEA) is a supporting method to assess failures, consequences and causes. It is an up to date risk analysis method and provides documentation and a knowledge basis. Decisions can be defended from potential criticism. The method rates failures with three different criteria and points from one to ten. These are severity (1-no effect, 10-hazardous), occurrence (1-seldom, 10-almost inevitable) and detection (1-certain, 10-almost impossible). Out of a multiplication of these three values, a risk priority number (RPN) between 1,000 and 1 derives. With this RPN failures can be compared (cf. [WER12]).

Finding problems is one thing, but determining causes is another. The five whys technique is a tool to determine the root causes of problems. Beginning at the end, the result of the problem, this technique asks why five times and leads to its cause. Three key elements to effective use of the five whys technique are accurate statements of problems, honestly answered questions and the aim to get to the root of problems and resolve them. The technique was developed by Sakichi Toyoda for the Toyota Industries Corporation (cf. [SER09]).

3.3 Order Picking

Order picking as part of the material flow contains a large variety of processes. Based on VDI, (cf. [VDI94]) these processes can be distinguished into following basic functions:

- Transportation of goods to disposal
- Goods disposal
- Picker´s movement
- Picking
- Transportation to goods-out
- Goods-out
- Return transport

Among others, picking systems can be organized in single step or double step picking. During single step picking the customer´s order is always directly connected with the picking process. A customer´s order is directly converted into a picking list, with quantities and storage positions of goods. In a double step picking organization, taking and merging goods are separated processes. In this case all common products of different orders can be taken and moved in one step, to be sorted afterwards (cf. [MAR11], p. 35-38). Basic strategies in order picking are man-to-goods and goods-to-man strategies. Man-to-goods order picking is characterized by a moving picking person towards storage locations. Usually, this picking person is picking one single order to bring it to a goods-out station and start with the next pending order. Goods-to-man strategies do have stationary pickers and goods are moved to certain picking stations (cf. [MAR11], p. 41).

3.4 Material Flow Planning

Material flow planning correlates with mid-term and long-term aims of companies. Material flow planning can be separated into four steps: (cf. [AF09], p. 269)

- Rough planning
- Ideal planning
- Real planning
- Detailed planning

The general aim of the rough planning is to develop material flow concepts, alternatives and to prepare a basis for management decisions. Ideal planning describes the best technological and organizational solution without thinking of any restrictions. Real planning matches the ideal planning into reality including all restrictions. Detailed planning defines every single detail of a material flow system after one single solution is chosen. (cf. [AF09])

To assess planned systems it is indispensable to use quantitative methods. Defined numerical values are easy to assess. However, if there are system properties, which are connected with each other and their values connected indirectly, an assessment method with weighted criteria has to be used. For example a method like the value benefit analysis (VBA). In this method criteria are defined and weighted. By adding points from one (bad) to ten (good) a utility value can be calculated. This value is dimensionless and compares different options. Value benefit analysis are decision supports (cf. [AF09], p. 275-276). Further risks of value benefit analysis are the possibility of subjective rating, influence of personal experiences, difficulties in defining criteria and kicking out optimal solutions (cf. [HSN+07a], p. 352).

4 Implementation

Concerning the project aims in chapter 2.3, the cooperating company´s forwarding department actual state is analyzed regarding layout, processes, costs, material flow, warehouse data and order data. Based on these analyzations a weak point analysis is conducted in order to point out rated issues, which are going to be improved. These improvements are realized in development of optimization approaches (cf. chapter 4.3) and specific solutions (cf. chapter 4.4).

4.1 Analysis of the Actual State

The analyses of the actual state shows a detailed reproduction of the actual situation in the cooperation partner´s forwarding department. Starting with a detailed layout analysis, investigations give a good overview about the forwarding department. Afterwards, processes that had been analyzed and their costs lead to detailed visualized process illustrations. Also material flow-, warehouse-, as well as order data is investigated. An expert analysis of used hardware completes the analysis of the actual state.

4.1.1 Transportation, Load Units and Packaging

By means of transport and conveyance all movements of goods, pallets, cases and other load units are performed with two forklift trucks and two pallet stackers. Transportation of good outside the warehouse is only performed by trucks. This is due to the fact that all streets around the warehouse succumb Austrian road traffic regulations and the forklift trucks are not suffice equipped to satisfy the traffic regulations. The external transport (everything outside the warehouse, which is shown in Figure 4-2) is realized by an external transport service (ESP). External transport can be distinguished between truck deliveries from international partners, mostly from plants in Germany and Italy, and intra site deliveries. These are good deliveries from the other plant in Kapfenberg.

A variety of different load units are used in the warehouse. The most common one are Europallets. These load units are used in the high-rack storage as well as in all other areas. Also at the production line Europallets are used. A second type of load units, used in the production line are cargo boxes. Additionally wooden cases in different dimensions are used. For small shipments paperboard containers are build up and filled.

Products such as coils of cored wire or stick electrodes are mostly packed in cardboard boxes (cf. Figure 1-1). These have clearly defined packing patterns depending on their dimensions. Such cardboard boxes can have various dimensions and therefore varying weights. An average stick electrode box weights between 15kg and 20kg and according to the product´s length (250mm, 350mm, 450mm) the boxes´ measurements are 400mm x 280mm x 110mm in average. Coils usually have following measurements 325mm x 325mm x 120mm. Some wires are packed in cans which are standing in pairs on pallets and are fixed with jaws that mounted on the pallet. These are relatively high units, which are stored in the high-rack storage´s layer E2.

4.1.2 Layout Analysis

Embedded in an old historic grown industrial site (cf. Figure 4-1) the building, in which the forwarding department is placed, is shown as building "A". The location of the forwarding department´s close up, which is described in the following abstracts, is shown in the dashed blue box named "B". The external transportation service provider ESP is located in parts of building "C".

The forwarding department´s different functional areas can be divided into 20 sections. To describe functionalities and properties of these different sections, they are highlighted with different colors. All these sections which are used by the forwarding department on a daily basis, are shown in Figure 4-2 and named in Table 4-1.

High-Rack Storage (1)

The high-rack storage is a manual storage and retrieval system (SRS). It is served by two manual storage and retrieval cranes. The storage and the cranes were built in 1985. From 2000 to 2012 many updates, such as the technological upgrade of the cranes have been made. Since then the cranes´ conductor rails are located on the ground instead of on the top, which simplifies maintenance work significantly. The high-rack storage´s capacity of 4,500 storing positions (Europallets) is divided into five aisles in Y-direction (horizontal) with 50 storage positions in the X-direction (horizontal) and nine storage levels in Z-direction (vertical). In the Z-direction the storage is organized into three main layers according to their bin height and accessibility. Layer one defines levels two to eight (bottom up). This level´s bin height is 830mm and the accessibility for picking is not restricted. The topping level nine is defined as layer two because bins in this level got a larger height while having the same accessibility as in layer one. For example barrels filled with coils can be stored only there. The lowest level in the high-rack storage has a reduced accessibility because of the storage crane´s down positon and is defined as layer three. Mainly layer one and two are used for daily business. Each one of the 4,500 storing positions has a safe working load of 1,500kg. In addition to this three level vertical subdivision the Storage is also divided into two large areas for fast and slow moving goods. The assignment of goods, if they are slow or fast movers is not done by the forwarding department. Therefore, changing these assignments is not within this thesis' remit. Another rather small area in the high-rack storage the first aisle´s extension. Aisle one has got 18 (two bins over nine levels) additionally bins which are used for mixed pallets. All the other storage bins are filled with just one single product type with the same batch number.

The rack on the storage's front face is called transfer rack and is used for processing goods-in and out and for storing quality assurance (QA) products (cf. Figure 4-3). This rack´s capacity is 144 bins (16 bins over 9 levels). The first three levels in this rack are used for goods-in (GI) and out (GO) and are accessible with a forklift truck from the prestorage area (2 in Figure 4-2) outside the storage. From level four to the top the transfer rack is used for quality assurance (QA) goods because they have to be stored inaccessible from outside the storage. Due to this reason QA goods are also stored in the middle of the high-rack storage. As the storage system and its storage and retrieval cranes are old, they are not any longer state of the art. Aisle change times are not state of art anymore and given the fact they are manually driven, employees have to enter and leave the storage area through a door. Due to safety reasons, the power supply is cut when the door is opened. Besides finished goods and QA goods, there are also storage bins filled with empty pallets.

Figure 4-1: Factory Premises

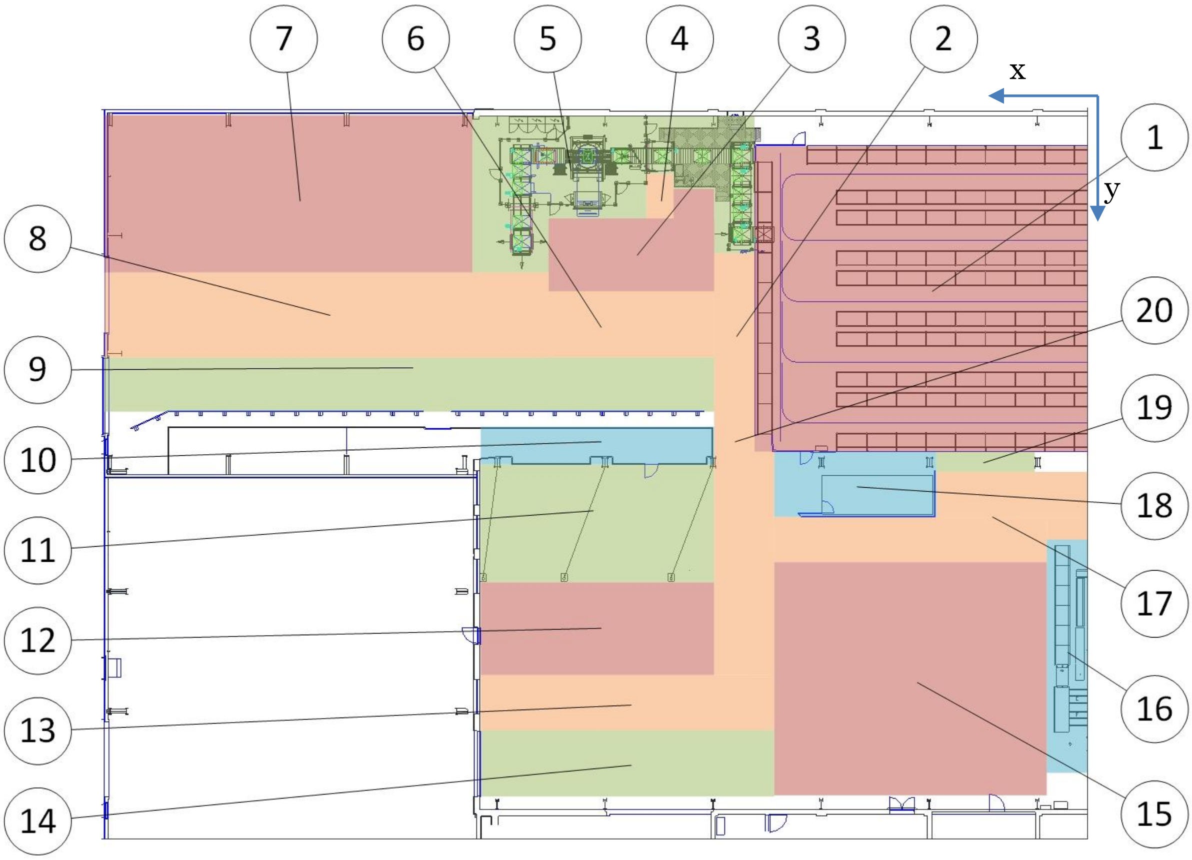

Figure 4-2: Layout – Areas

Table 4-1: Areas

No.	Description	No.	Description
1	High-Rack Storage	11	Case Packing Station
2	Prestorage Area	12	Case Storage
3	Truck Load and Unload Buffer	13	Truck Load and Unload Area
4	Fork Changeover	14	Truck Lane
5	Shrink Wrapping Machine	15	Production Storage Area
6	Truck Load and Unload Area	16	End of Production Line
7	Ground Storage Area	17	Transferring Area
8	Roadway	18	Forwarding Office
9	Truck Lane	19	Mixed Rack
10	Employees´ IT and Break Room	20	Bottleneck

Procedures inside the high-rack storage are done in blocks. Which means either a lot of goods-out processes are done before a lot of goods-in processes are executed, or vice versa. Not only goods-in and goods-out are executed inside the high-rack storage. Also all picking processes are done inside.

Prestorage Area (2)

Forklift trucks are loading and unloading the transfer rack at the high-rack storage´s front face in the prestorage area. To get from one side of the warehouse to the other vehicles have to pass this small but frequently used area (cf. Figure 4-3).

Truck Load and Unload Buffer (3)

This area is used as a buffer while trucks are unloaded and loaded. Pallets are temporarily stored on the ground until they are further proceeded (cf. Figure 4-4).

Fork Changeover (4)

At this station forklift trucks can mount and remove longer forks which are needed during loading and unloading trucks.

Shrink Wrapping Machine (5)

This machine is used to foil completely picked orders on pallets. It is fully automated and was built in 2015. It is connected to the high-rack storage. Therefore, it can be loaded directly with a crane from inside the storage. The machine can also be loaded by a forklift truck. The unloading dock on the other side can be reached by forklift trucks from three directions. The machine can also print and tag labels and is able to carry up to 17 pallets at the same time.

Truck Load and Unload Area (6) & (13)

In this area trucks are being loaded and unloaded. In both cases employees are using forklift trucks. While loading and unloading trucks in area 13, employees have to pass the marked bottleneck (20).

Ground Storage Area (7)

The ground storage area is used for load units, which are marked with a goods-out note. According to information on this notes, load units are sorted and put together in marked sections. Some of them can be piled. Also load units with customer pick up notes are stored in this area.

Figure 4-3: High-Rack Storage´s front face

Figure 4-4: Truck Load and Unload Buffer

Roadway (8)

This area is a roadway to store and retrieve load units in the ground storage area (7). At the end of this roadway is a truck gateway.

Truck Lane (9) & (14)

Trucks are using this lane so forklift trucks can unload and load them. They enter the warehouse through an automatic truck gateway.

Employees´ IT and Break Room (10)

Employees can print tags, check orders or correct mistakes at this workplace. There is also a break room for the employees.

Case Packing Station (11)

At this area wooden cases are packed with goods and by adding a dispatch note they are made ready-for-shipping. To support employees packing, two vacuum gripper are implemented at this workstation. Unfinished picked pallets as well as empty pallets are also stored in this part of the warehouse temporarily. Additionally a small workplace is installed in this area in which single product cardboard boxes can be opened and refilled.

Case Storage (12)

Finished picked and packed wooden cases are stored on the floor in this section. They can be piled in three to four levels.

Production Storage Area (15)

Load units, which come out of production and already have a customer order are stored in the production storage area. In this section goods are stored on the floor and are, if necessary piled on each other in two levels. Marking lines on the floor divide this storage area in different sections. (cf. Figure 4-5)

End of Production Line (16)

In this section one of two production line ends. The second one is about 20m to the right of the shown layout in Figure 4-2. From there employees of the forwarding department transfer the load units either to the high-rack storage´s goods-in (2 & 1) or to the production storage area (15). Both lines have a buffer to ensure a smooth production process.

Transferring Area (17)

This area is used to unload the production line (16) and to load and unload the mixed load unit rack (19).

Forwarding Office (18)

In this office the foreman manages all customer orders and distributing picking lists to the rest of the employees. The office is connected to the accounting department via a letter shoot system with which already picked order lists are sent.

Figure 4-5: Production Storage

Mixed Rack (19)

A single rack with 30 storage bins (six horizontal times five vertical) is filled with different products, which exist just in small numbers in the warehouse in order to save space in the high-rack storage. In this rack different products are stored in one bin.

Bottleneck (20)

The bottleneck is part of the roadway and therefore the connection between the two halves of the warehouse. With a width of 2,556mm only one forklift truck at a time is able to pass this point.

4.1.3 Forwarding Department´s Processes

As mentioned in chapter 2.3, one of the project aims is a process analyzation. Therefore, all processes in the warehouse, which are subject of this thesis´ investigations are described in this chapter. These processes are initiated by deliveries, production output, quality assurance, and customer orders, which is why they are divided into three types:

- Goods-In Processes
- Warehouse Processes
- Goods-Out Processes

As described in chapter 3, a reliable way to illustrate processes and information connected with them is the extended event driven process chain (eEPC). Each of the processes analyzed within this thesis have been displayed an illustration, that is shown in the appendix (cf. chapter 8.2.1). A more compact and less detailed process reproduction is shown after each process description. Used icons are described in Figure 3-2.

Starting with de goods-in processes products are either delivered by trucks or they are provided at the end of a production line. In any case these products are counted, and transferred to the place they belong. This place is either the high-rack storage or the production storage. When products are transferred into the high-rack storage they pass the transfer rack and are stored into an empty bin. With a hard copy picking list employees are picking orders inside the high-rack storage and transfer finished units to the shrink wrapping machine. After that the goods-out process starts. Load units are loaded into trucks, which move these load units to the ESP. After products have left the building the goods-out process is done.

All named areas in the following processes are named like they are described in Figure 4-2: Layout – Areas.

4.1.3.1 Goods-In Processes

As goods-in processes, activities are described in which any kinds of goods, products or load units are stored either in the high-rack storage, ground storage or production storage area. Therefore goods coming in trucks from vendors, associate companies or from other sites in Kapfenberg are handled in goods-in processes. To simplify the variety of goods-in processes they are classified into two types:

- Truck Delivery
- Production Output

Truck Delivery

Either truck deliveries from international partners or intra site truck deliveries are transported directly into the warehouse. After a truck has arrived the trailer is parked at the truck lane (9 or 14) (cf. Figure 4-2) where it is prepared to get unloaded by forklift trucks with long forks. While unloading, all units are checked if they are tagged as goods-out (GO tag). If not they are placed on the ground in the truck load and unload buffer (3). If necessary the protective foil is removed before the number of cardboard boxes on each load unit is counted. They are then compared with the custom advice note and if necessary some of the delivered goods are, depending on their batch numbers, resorted on other load units. After sorting, counting and reviewing the load units, they can be checked into the system. This means one of the product bar codes is read with a hand-held scanner, which is connected via Wi-Fi with the warehouse software. Also the batch number and the amount of boxes at the load unit have to be typed into the hand-held scanner. A tag is fixed at the top of the load unit, to show that a load unit is checked in. A forklift truck with short forks picks the tagged load unit up and transports it to the prestorage area (2) where it is transferred into the high-rack storage´s (1) transfer rack. Due to safety reasons, no long forks are allowed to be used for this process step. Depending on the load unit´s height, the forklift truck driver has to decide either to hand the load unit over to the transfer rack´s second level (PRE2), or, if the critical height is exceeded, to hand it over to the third level (PRE3).

Back to the point where the forklift truck driver is unloading the trailer in the truck load and unload area (6). Here the forklift truck driver has to check whether there is a GO tag at the load unit or not. If there is such a tag, the load unit is proceeded to the ground storage area (7) where it is stored short-term. At the GO tag a good's batch number and also a note with the amount of load units with the same batch number are placed. According to this information load units are sorted into batch blocks into the ground storage area (7) and checked into the system´s software with the ground storage area as storage location. After linking the load unit with the stored location the goods-in process of internationally delivered goods and intra site delivered goods is completed. With one trailer a random mixture of load units with or without GO tags can be delivered. In case of an intra site delivery additionally transfers into the trailer have to be performed at the same time. This part of the process is described in the dispatch process (cf. chapter 4.1.3.3), which is part of the goods-out processes. Coordination and integration of these two simultaneously ongoing processes is within the executing employee's responsibility. In Figure 4-6 the goods-in process truck delivery is shown in a compact process chain. An expanded event driven process chain (eEPC) is shown in the appendix (cf. Figure 8-2 and Figure 8-3).

Production Output

The production line´s output is provided at two conveyors in area 16 (cf. Figure 4-2). With a placed production order, a production employee informs the forwarding department´s foreman about estimated point in time of finishing production and the planned amount of output. During the ongoing production, the foreman is communicating this production information to the other employees. After this, all employees know that there will be a production output and therefore they will keep an eye at the production line´s traffic lights, which show the production conveyor´s occupancy. The employees are responsible for emptying these two conveyors. At the production line´s end the production plan shows if the pending load unit is made-to-order or if it is made-to-stock. In the first case, the load unit is transferred to the production storage area (15). Another employee counts the cardboard boxes sorted at the load unit, which came out of the production line. After counting, the products are checked in. Further steps are the same as in a truck delivery goods-in process. In case of a made-to-stock production, pending load units are transferred to the truck load and unload buffer (3). There they are proceeded the same way as they are in the truck delivery goods-in process. After this a forklift truck moves this load unit into the transfer rack´s second level where a SRS crane can pick it and proceed with the SRS goods-in process (cf. chapter 4.1.3.2). The process is visualized in an eEPC-figure in the appendix (cf. Figure 8-1). A compact but less detailed process visualization is shown in Figure 4-7.

4.1.3.2 Warehouse Processes

The following warehouse processes are defined as processes, which do not have initial and ending situations making products physically entering or leaving the warehouse building. Processes inside the high-rack storage, picking-, packing- and quality assurance processes are described. To enable a clear overview all actions in this section are classified into the following processes:

- SRS Goods-In
- Picking List Preparation
- SRS Goods-Out
- Small Order Picking
- Case Packing
- Quality Assurance

SRS Goods-In

Either a truck delivery process or a production output process can be initiator of a SRS goods-in (SRS GI) process. Both preceding processes end with the load unit placed in the transfer rack. This is where the SRS GI process starts. The SRS crane driver picks up the load unit at the transfer rack, reading the tag that had been fixed on top in one of the previous processes. The bar code is read with a hand-held scanner and an aisle, in which the load unit is going to be stored, is chosen. Due to aisle changeover durations, SRS crane drivers intend to choose the aisle, which they are standing in front of. If the chosen aisle is full another aisle is suggested by the hand-held scanner and the SRS crane driver has to accept the long changeover time to move to another aisle. Having driven into the new aisle, which happens forwards and backwards from the driver´s point of view the system suggests an empty storage bin where the load unit is to be stored. The information given by the hand-held scanner contains the side in the aisle (left or right), the height (level one to nine) and the exact position (bin one to 50). Positioned in front of the empty storage bin, the load unit is stored and connected with this location by scanning the storage bin´s bar code. After this step the goods-in process is completed, if the SRS crane is driven back empty to the transfer rack and ready to pick up the next load unit. Figure 4-8 shows an illustration of this process. In the appendix in Figure 8-4 this process is shown as an eEPC.

Picking List Preparation

For picking goods a picking list is necessary. The picking list is generated out of customer orders. The foreman checks the warehouse management system for pending picking lists and prints them. Picking lists got information about ordered products, amounts, and storage locations on them. Important information and notes for special packing are highlighted after this step. After this preparation the picking list is handed into a shelf where other employees can access it. This shelf is checked frequently. The foreman supervises this process and ranks pending picking lists according to their urgency and order. Having been taken by employees, processes like SRS goods-out, small order picking or case packing are proceeded with the picking list (cf. Figure 4-9 and appendix Figure 8-5).

SRS Goods-Out

After the picking list is prepared, the SRS crane driver takes the printed picking list out of the shelf in the foreman´s office. Some additional information about orders, urgency or special treatments can be noted. Back at the SRS crane´s seat the crane driver checks the picking list. The crane driver compares picking lines and plans pallet packing patterns to use as less pallets as possible. This means he decides on sequence of lines to pick and on how the cardboard boxes are placed on the pallets. Since the remaining stock is mentioned on the picking list, the crane driver know whether he will need empty pallets. At the appropriate bin, the product and batch numbers are checked to make sure the right bin has been reached and the line is marked as done on the picking list. Next, the SRS crane driver picks the right amount of cardboard boxes manually on the pallet loaded on the crane. Sometimes employees are not able to slide them, because of cargo security mats, so boxes have to be lifted. If the employee´s planned pattern requires further goods picked on the pallet in use the next storage bin is being approached. If further picking or packing outside the SRS is necessary, the pallet is loaded into the transfer rack´s first level where forklift trucks can reach it. Additionally the picking list is added on top of the load unit in order to pass on information. Processes like case picking or small order picking follow. If no more picking is needed for a pallet the SRS crane driver loads it into the shrink wrapping machine (5). After being shrink wrapped the load unit is ready for shipping. The crane driver has to check the picking list again whether there are lines left to pick. If there are, the driver will do so. If the picking list is done the SRS crane driver sends the picking list with letter shoot from the foreman´s office to the accounting department. After this either a dispatch process or a customer pick up process is started. Figure 4-10 shows the SRS goods-out process. A more detailed version (eEPC) can be found in the appendix in Figure 8-6 and Figure 8-7.

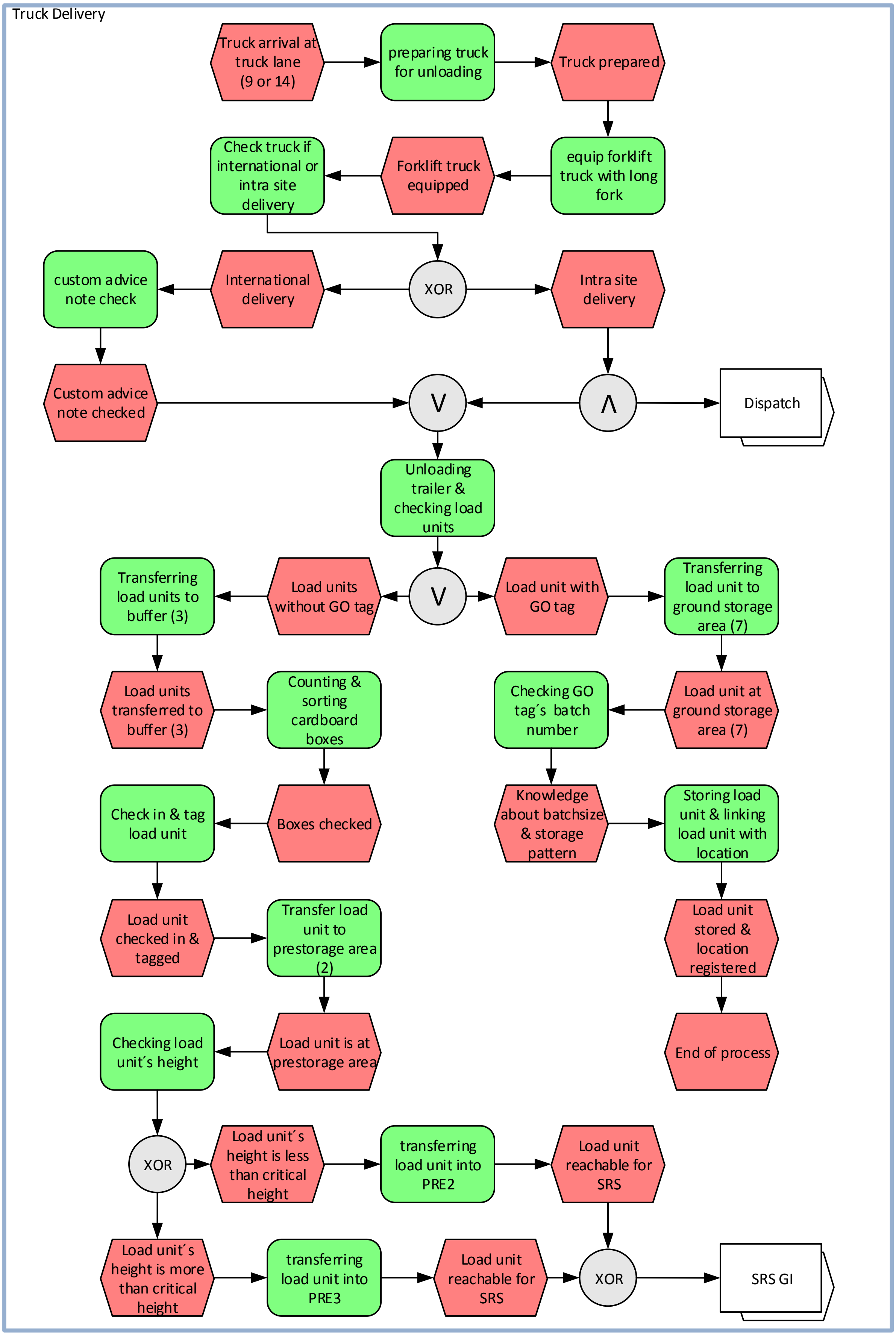

Figure 4-6: Truck Delivery - Compact Process Chain

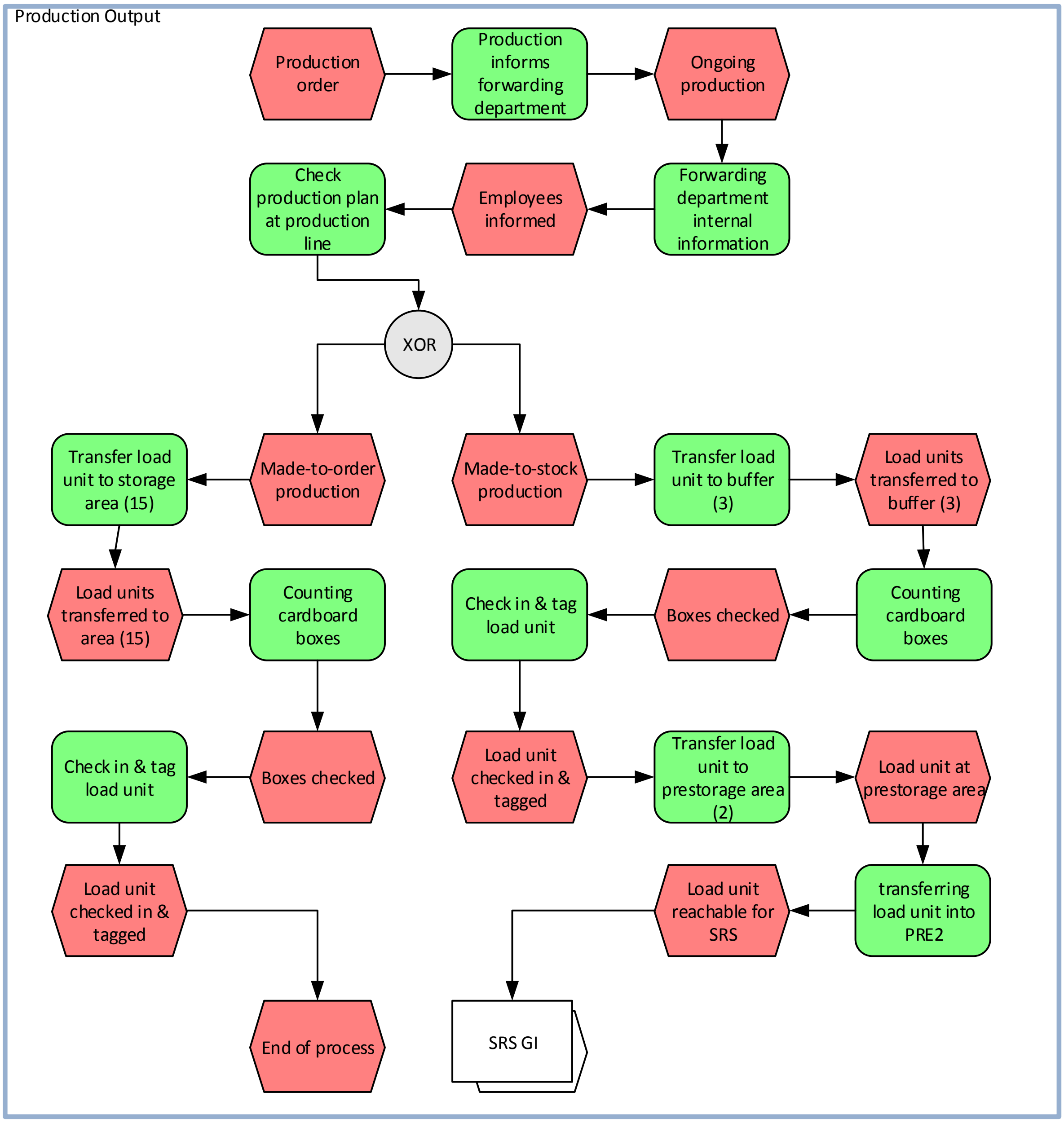

Figure 4-7: Production Output - Compact Process Chain

Figure 4-8: SRS Goods-In - Compact Process Chain

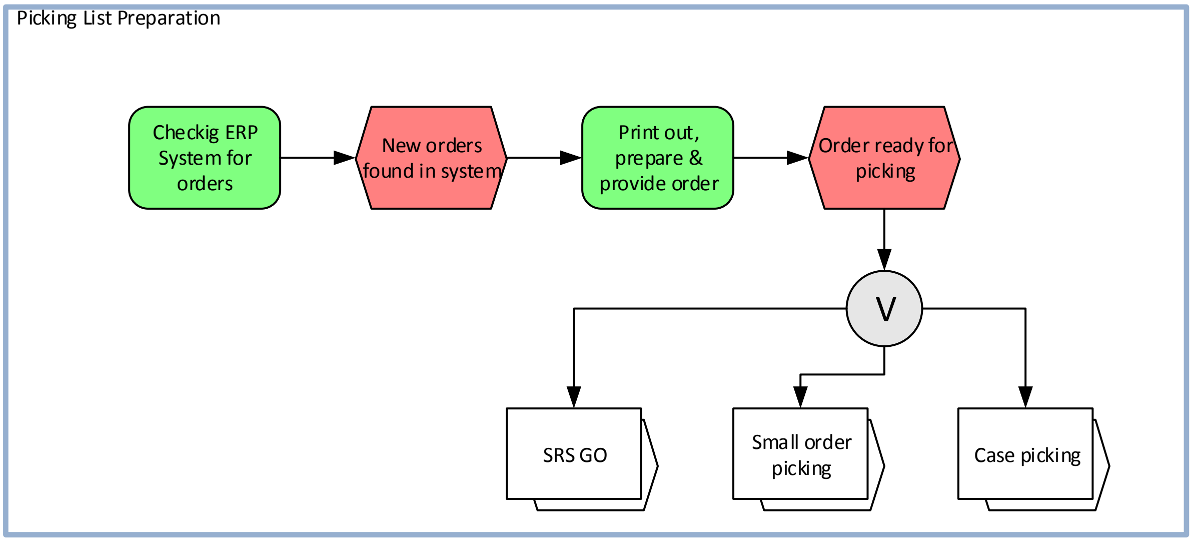

Figure 4-9: Picking List Preparation - Compact Process Chain

Small Order Picking

Some orders consist of just a view cardboard boxes of different products. Most customers ordering these small amounts are known very well to order a second time a day. This is when the small order picking process is used. After retrieval of goods from the high-rack storage the appropriate load units are moved with forklift trucks from the transfer rack´s first level to the case packing station (11). There these load units are temporarily stored while they are waiting for possible additional orders from the same customers. The picking list, which has been on top of the load unit since the end of the SRS goods-out process has been reached, shows the work in progress status. The foreman and the employees are monitoring new incoming goods. If there is a second order of the same customer, the SRS crane driver is informed about this and the SRS goods-out process goes on. After the new load unit is picked up at the transfer rack, these products are added to the previous load unit. Also the new picking list is added to the load unit. Then the load unit is moved to the shrink wrapping machine (5) and then it is ready for shipping and the dispatch process starts. In the meantime, an employee sends the appropriate picking list with the letter shoot from the foreman´s office. Figure 4-11 shows a compact version of this process which is also visualized in an extended event driven process chain diagram in the appendix in Figure 8-8.

Case Packing

After load units are provided at the transfer rack (1) out of the SRS goods-out process an employee is informed that the order is needed to be packed in wooden cases. This employee prepares a proper wooden case and the appropriate load unit can be transferred to the case packing station (11). There it is positioned with a pallet stacker or a forklift truck at an appropriate height for picking and packing. Picking and packing is performed either with a manual vacuum gripper and lifting system or by hand. This depends on size and weight of the cardboard boxes. When the employee has finished packing the order he adds filler material into the case and closes it. After adding a goods-out tag at the case it is ready for shipping. Employees get these tags from the employees´ IT room (10). This process´ single steps are shown in a compact version (cf. Figure 4-12) as well as in an eEPC diagram (cf. appendix Figure 8-9).

Quality Assurance

In the quality assurance process the forwarding department provides and stores goods. It is important that all quality assurance (QA) products are inaccessible at any time except during the QA itself. In the high-rack storage goods are inaccessible anyway but when QA relevant products are in any other storage areas, they have to be bordered with a red ribbon. No one is allowed to pick anything which is bordered with such a red ribbon except QA employees. Additionally QA relevant products are marked with a red “QS” on their cardboard box. A quality assurance document has to be signed and passed on by the foreman if a QA process is done.

All processes defined as warehouse processes are described and visualized. After goods-in processes and warehouse processes the remaining forwarding department processes are summarized in the goods-out processes. These processes are defined and described in chapter 4.1.3.3.

4.1.3.3 Goods-Out Processes

When load units are leaving the warehouse building at the end of any process, this process is defined as a goods-out process. Following processes are analyzed, described and visualized:

- Dispatch
- Customer Pick Up

Dispatch

Either load units prepared in processes like SRS goods-out, small order picking or case packing process are shipped in the described process. Additionally an empty trailer (emptied in the truck delivery process) is needed. At the same time as the trailer is being unloaded in the truck delivery process, the trailer is also being loaded in the dispatch process. When the trailer is fully loaded again employees wait for a new truck to arrive. Then the full trailer is moved to ESP and the new trailer is unloaded and loaded just like the previous one. After a trailer has left the building, it is out of the department´s responsibility. Figure 4-13 and appendix Figure 8-10 show this process.

Customer Pick Up

Load units prepared in the SRS goods-out, small order picking or case packing process are either shipped by ESP (dispatch process) or they are picked up by customers. In the second case, a customer arrives at the warehouse at the truck load and unload area (9). There paperwork has been prepared already. After looking for the proper load units or goods they are loaded at the customer´s vehicle. When the customer leaves the building with his goods this process is finished. This process is visualized in Figure 4-14 and in the appendix on Figure 8-11.

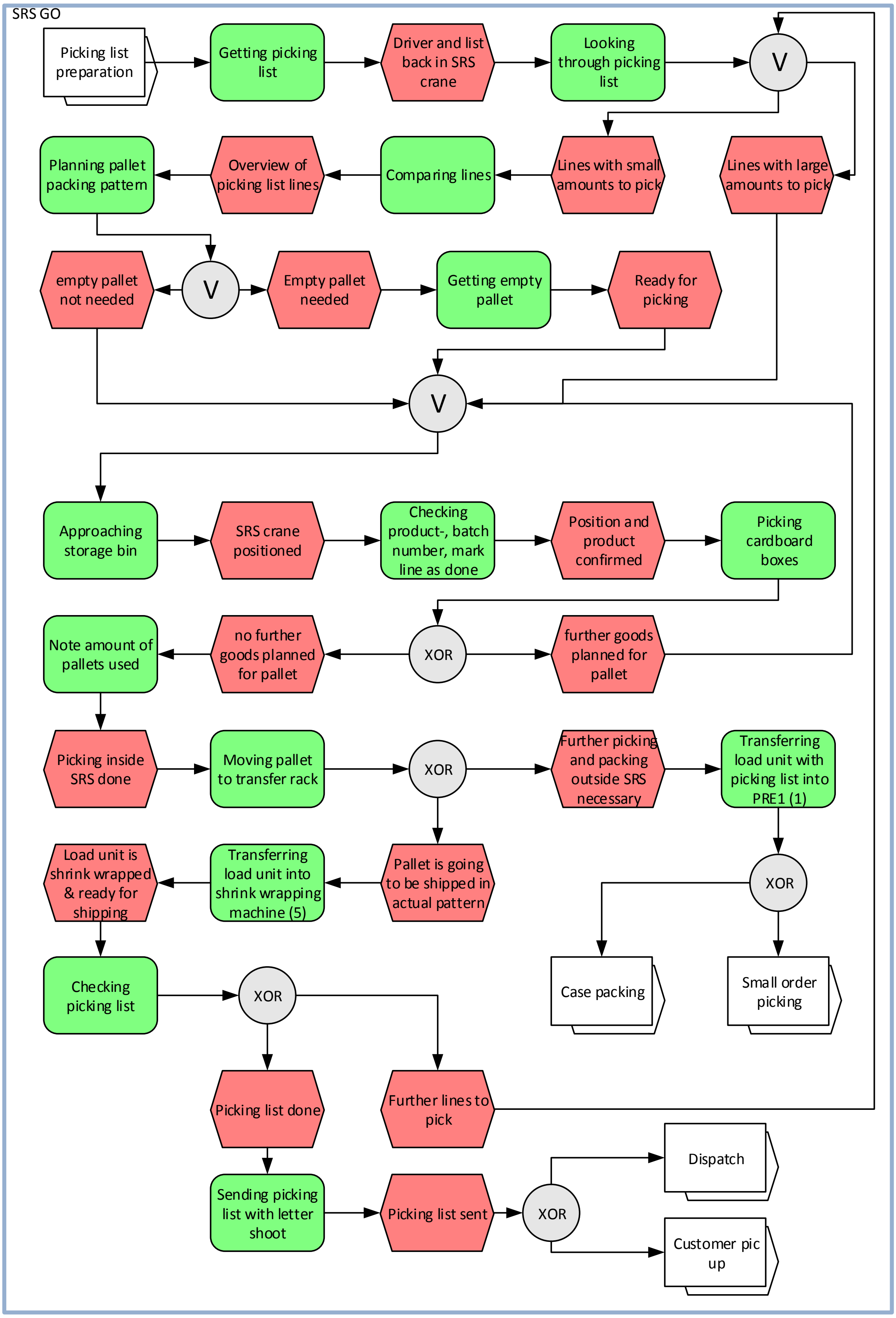

Figure 4-10: SRS Goods-Out - Compact Process Chain

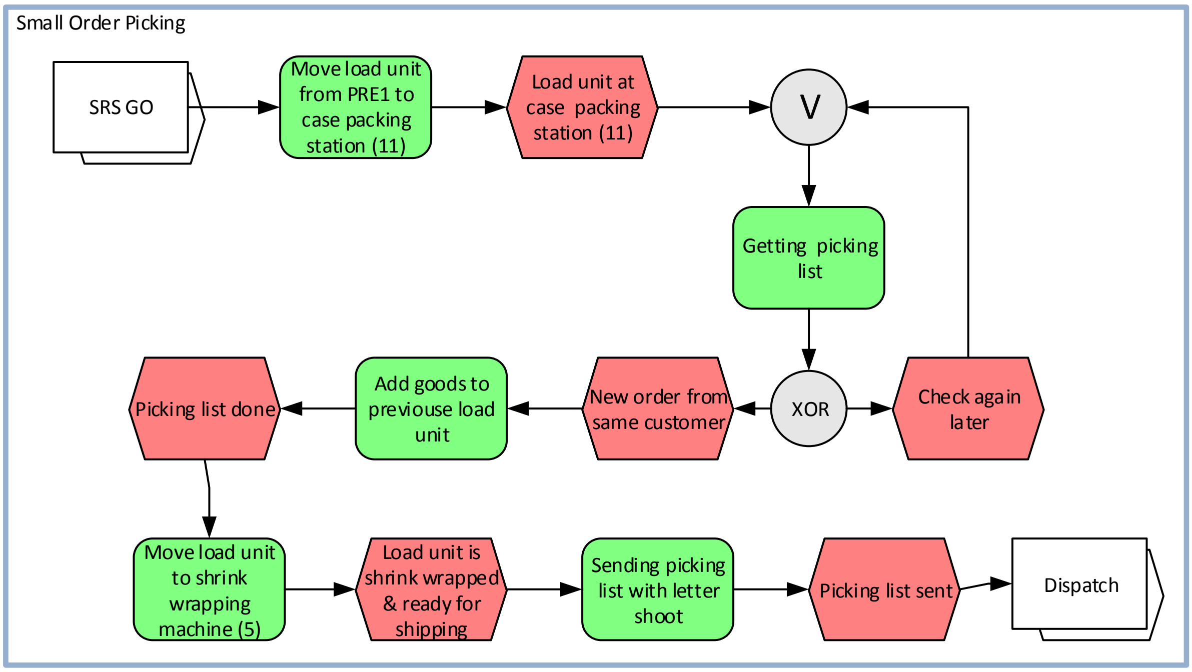

Figure 4-11: Small Order Picking - Compact Process Chain

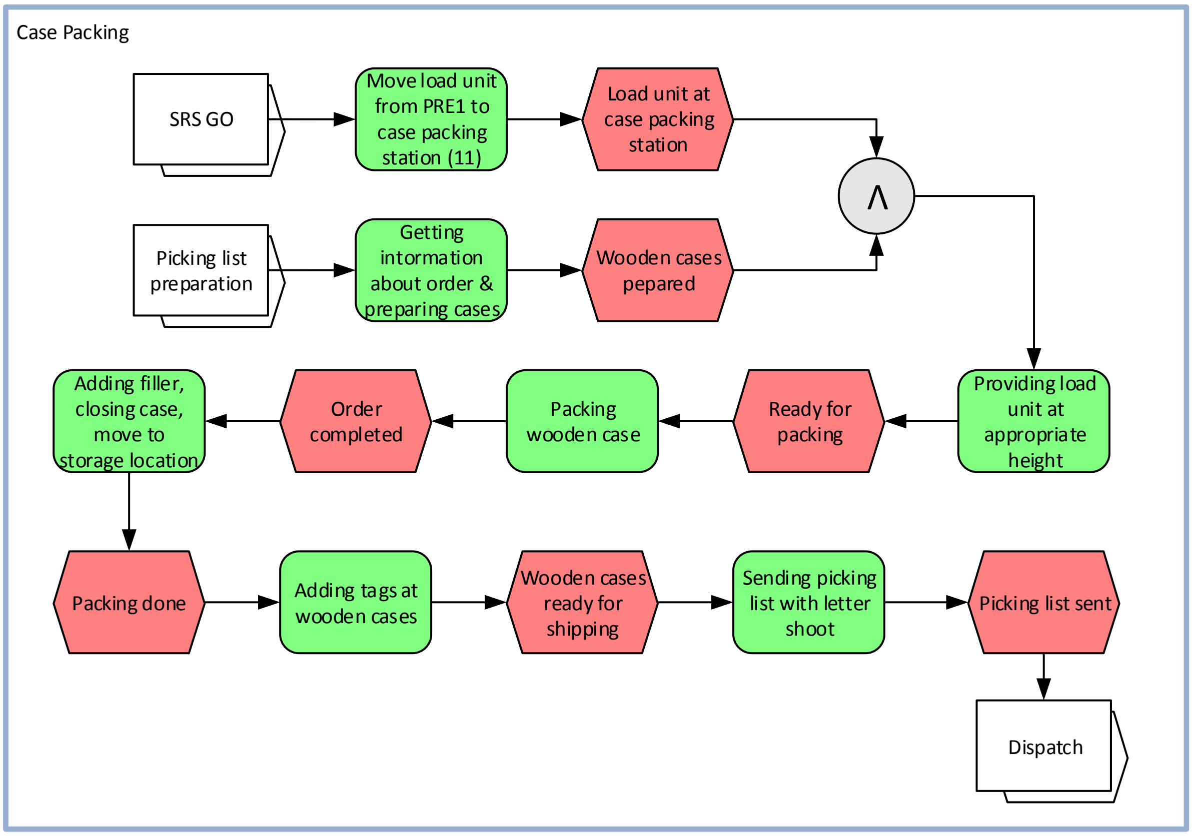

Figure 4-12: Case Packing - Compact Process Chain

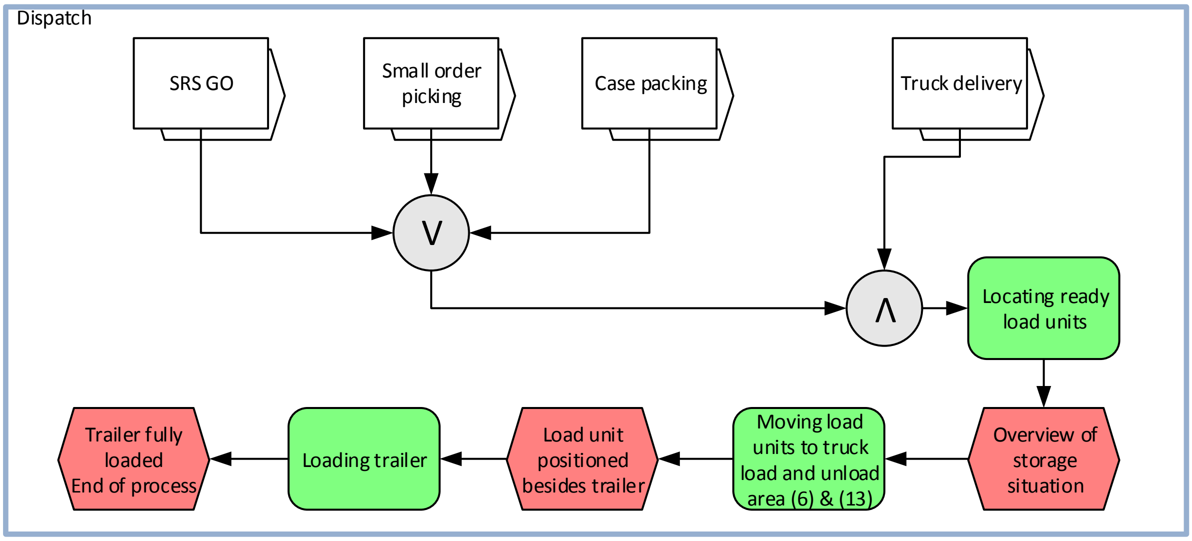

Figure 4-13: Dispatch - Compact Process Chain

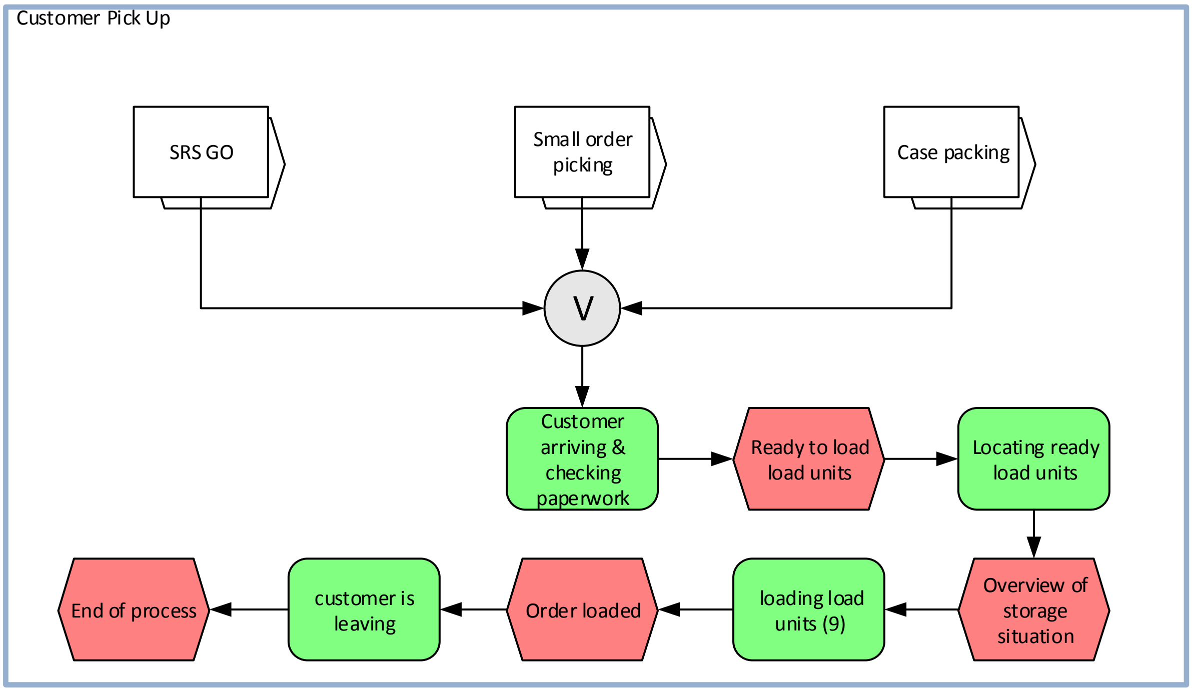

Figure 4-14: Customer Pick Up - Compact Process Chain

4.1.3.4 Process Cost Intensity

As described in chapter 2.3, after a detailed process analysis and the target of 25% cost reduction in consideration, all defined processes are further investigated according to their total cost intensity. In order to determine this all processes are evaluated according to attributes like generated manpower, needed equipment, time consumption and cost affects caused by disruptions. The classification and rating is based on a qualitative point-based system. Separated in four attributes each of them can get a maximum of five points. Points are awarded after a previously defined scale, which can be seen in Table 4-2 (agreed with project partner). By multiplying attribute scores a qualitative illustration of cost intensive processes is given. The totals can be seen in Figure 4-15 and the separate ratings of each process and each cost-attribute are shown in Table 8-2.

The top three processes in terms of cost intensity (truck delivery, SRS goods-out and case packing) are further investigated to find out the root causes of their cost intensity and to define potential savings.

The truck delivery process´ cost intensity derives from handling and control efforts of incoming goods as well as failure dependencies of other processes.

The SRS goods-out process is rated as cost intensive because of expensive hardware and its big influence on other processes. In particular the customer is directly affected by failures, which happens during this process.

Case packing is time consuming. Bad ergonomics and therefore long packing times increase costs. Additionally this process´ failures affect customers directly. No matter if wrong products are packed or wrong package is chosen.

Table 4-2: Grading Key for Cost Intensity

Cost Attribute Classification	1 Point	2 Points	3 Points	4 Points	5 Points
Generated Manpower	0 employees	1-2	2-3	3-4	5 or more
Needed Equipment	no equipment	hand held scanner and gripper	pallet stacker or forklift truck	2 forklift trucks or combination of max 2 vehicles, SRS crane	combination of more than two attributes
Time Consumption	0-5 min	5-15 min	15-30 min	30-45 min	more
Cost Effects caused by disruptions	no effect on other processes and small effect on same process	small effect on other processes or big effect on same process	big effect on other processes and big effect on same process	effect on one or more other processes but no direct effect for customer	effect on several other processes or direct effect for customer

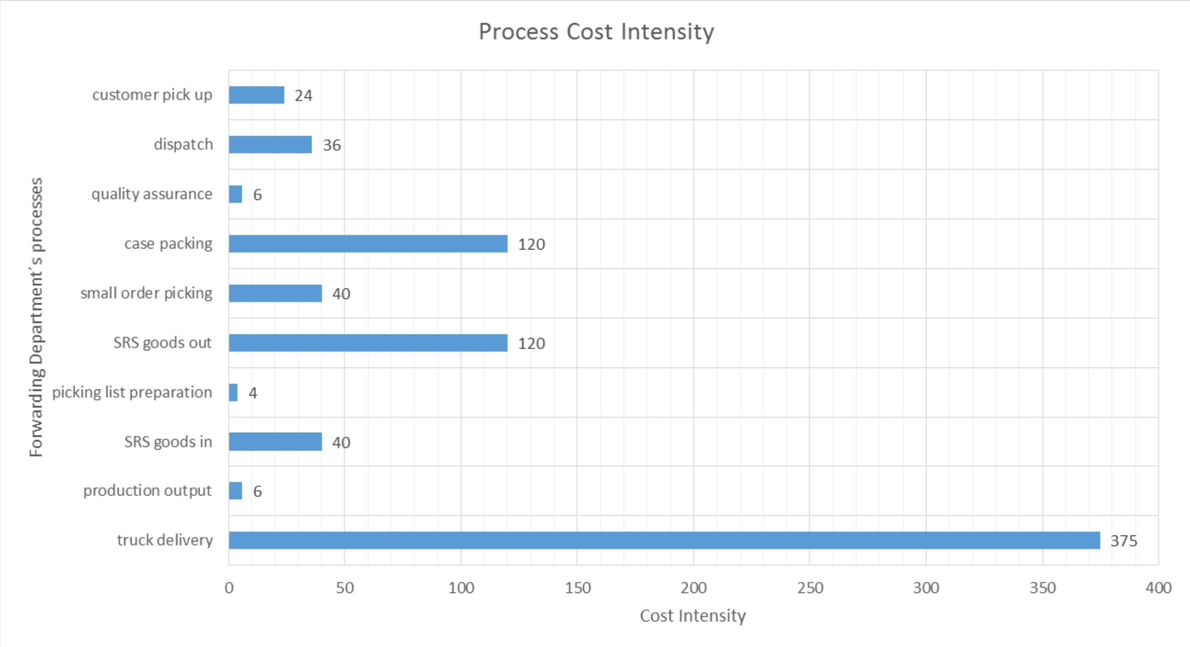

Figure 4-15: Process Cost Intensity

Divided into three types (Goods-in processes, Warehouse processes and Goods-out processes), ten forwarding department´s processes are described, represented in an eEPC chart, discussed and analyzed concerning their cost intensity. The more processes are rather complex and are partially done simultaneously, the more important it is to have clear rules and standardized communication channels.

4.1.4 Data Analysis

Besides a detailed process analysis, an analysis of data is essential for a broad warehouse analysis. As described in chapter 3.2 data has to be recorded and assessed. Chapter 4.1.4.1 shows sources where data is recorded and how this data is recalculated to meet the requirements of investigations shown in chapter 4.1.4.2. Chapter 4.1.4.2 shows material flow analysis, warehouse data analysis and order analysis. Applied methods and tools are described in chapter 3.2.

4.1.4.1 Data Acquisition and Recalculation

The quality and informational value of a data analysis´ outcome strongly depends on the quality of input data and how good the actual state is represented by this input. Therefore it is very important to engage in data acquisition. This section describes data sources used for this project and the chosen period of investigation.

In order to analyze the forwarding department´s data, goods-in documentation, goods-out documentation and warehouse stock numbers as well as lists of all articles with specifications and customer information are chosen as data sources from the project partner´s WMS. Having the principle of benefit effort ratio in mind, the period of investigation of data is defined from 1st of April 2014 to 31st of July 2015, since a financial year for voestalpine Böhler Welding Austria GmbH starts with April. The significance of an analysis increases with the amount of analyzed data. Due to changes in the documentation a lot of incomplete data lines exist in the WMS of the project partner. Therefore five representative dates between first of July and 31st of August 2015 are chosen to give an insight into the warehouse inventory. To ensure the reliability of all data used and also of further calculations as well as outcomes, all inconsistent data is corrected and validated.

Due to different types of data sources, like occupation reports, goods-in lists or goods-out lists, recalculation of data is necessary. Goods-in data are additionally connected with the product´s source data to add missing sources. By recalculating goods-out data two types of goods-out lists (one list includes the number of outgoing pallets, the other list includes pick positions and information about product storage locations) are combined to determine the number of moved units. For all recalculations and data, a plausibility check is done. In order to minimize mistakes, wrong or incomplete data is corrected.

4.1.4.2 Data Analysis

The analysis of all data is separated into three parts. The first part investigates in transportation and material flow outside and around the high rack storage. The second part of data analysis concerns the high rack storage itself and the third part is the investigation of order data.

Material Flow Analysis

One outcome of this analysis is the Sankey diagram, which is shown in Figure 4-16. Shown values are the numbers of all transportations occurring between the previously defined areas (cf. Figure 4-2) during the period of investigation (1st of April 2014 to 31st of July 2015). To improve the readability and significance of this Sankey diagram, material flows with a lower intensity than 1000 transportations are not shown. Therefore Figure 4-16 shows arrows that represent at least four transportations on each working day.

The two truck lanes as well as the end of production lines are defined as sources, where goods are able to enter the system. Different colors represent different types of material flows. Red colored material flow arrows represent goods-out of the production. The green arrows represent delivered goods from suppliers and yellow arrows show transportation of handling units out of intra site deliveries. Blue arrows represent transportation of units, which are already picked and ready to be shipped.

A closer look at the high rack storage shows that there is a difference between the number of in- and outgoing handling units. The reason for this is the fact that orders are picked inside the high rack storage and therefore outgoing handling units are not as dense packed as ingoing units. Similar differences can be seen in the case storage. Additionally capacities of wooden cases are often smaller than the capacity of a pallet. Due to the delivery process, all outgoing handling units are distributed equally on the two alternatingly used truck lanes. Except of deliveries from international suppliers, international dielivries are processed through truck lane one.

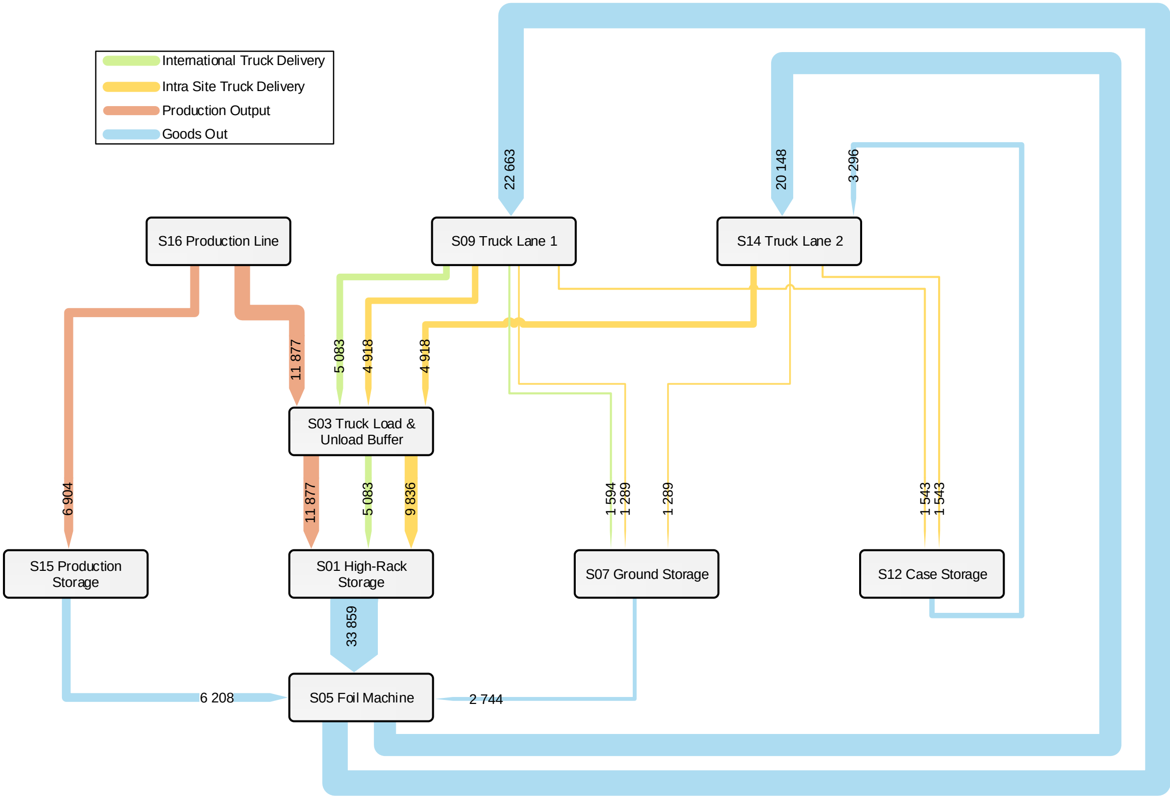

Figure 4-16: Sankey Diagram

More detailed than the schematic illustration of the material flow in the Sankey diagram is the transport intensity figure (cf. Figure 4-18). The storage areas are shown in their real layout and Sankey arrows are added there. Again this figure does not show every single transportation but the most intense ones to enhance the figure´s readability. The color code as well as the arrows width in this figure represent the number of transportations done during the period of investigation. Figure 4-17s shows a legend of this color code. By using the opportunity of having the material flow figures implemented in a real layout, the numbers of transported load units can be connected with the distance they have been moved. All paths of transportations are shown in Figure 4-18.

In order to rate the material flow in a quantitative way, the number of transported units is multiplied by the moved distance in meter. As an outcome the transport intensity number is defined, with pallet meters (Palm) as unit. With this number the actual state is comparable with new designed layouts and their transport intensity. For the current state the material flow´s transport intensity number is calculated to 4,304,383 Palm.

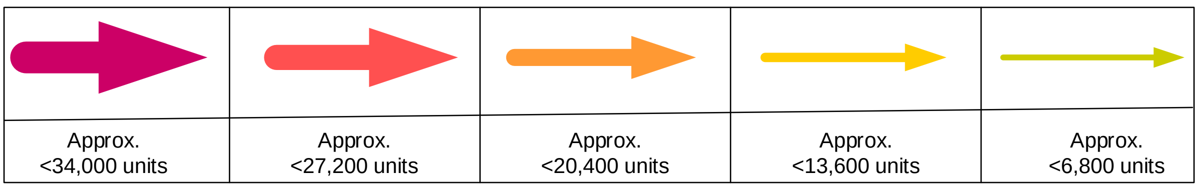

Figure 4-17: Sankey at Layout - Legend

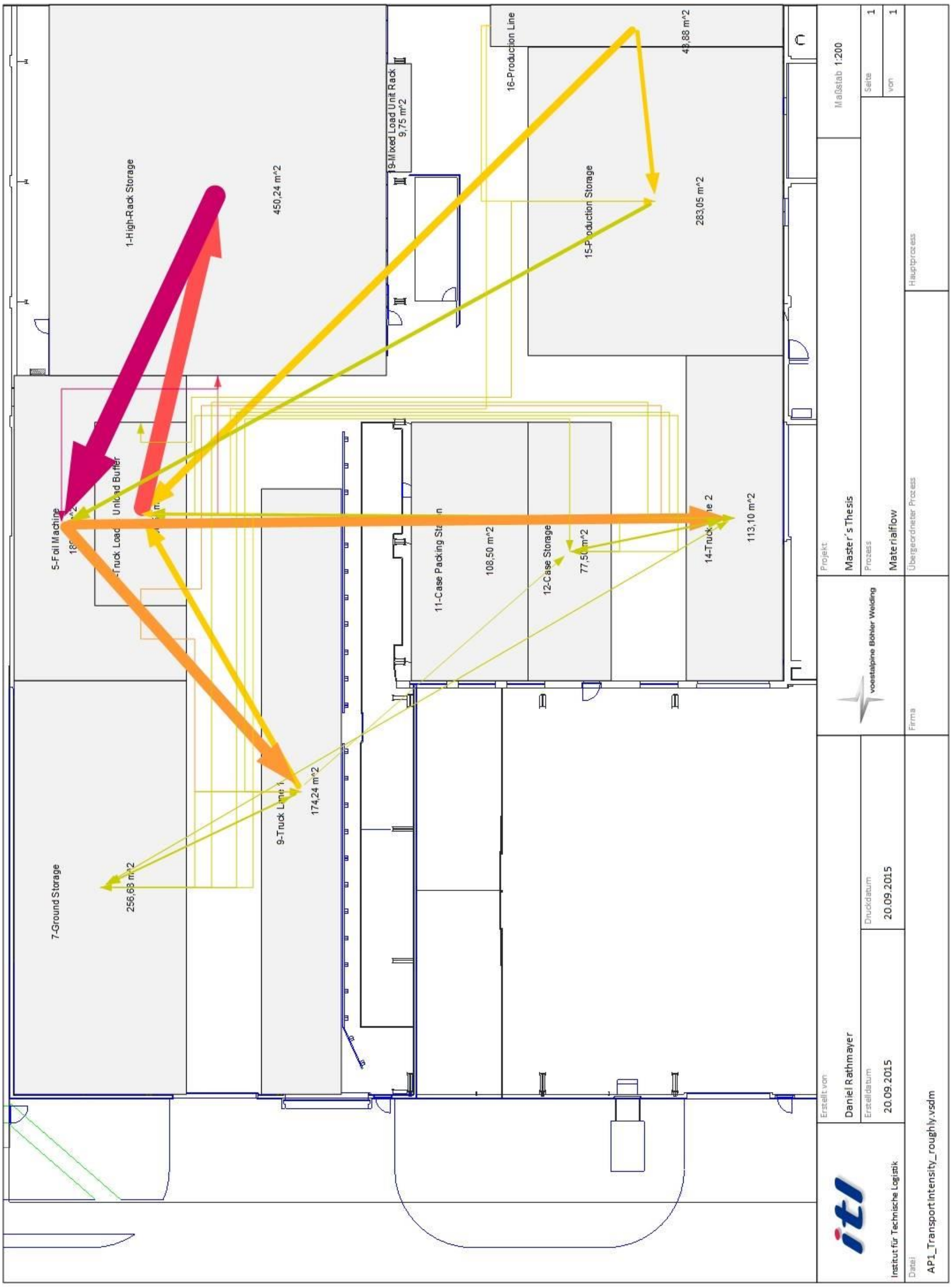

Figure 4-18: Sankey at Layout

Warehouse Data Analysis

The material flow analysis in chapter 4.1.4.2 shows how the analyzation of the material flow in the forwarding department. The warehouse data analysis mainly focuses on the high-rack storage itself. Therefore, the storage´s utilization, each bin´s utilization and cycle rates are calculated and analyzed. Additionally some Key Performance Indicators (KPI) are calculated and presented.

Five representative storage situations are chosen to be investigated (01.07.2015, 20.08.2015, 21.08.2015, 24.08.2015, 25.08.2015). These dates of investigation are chosen randomly because a reflection of the high-rack storage´s inventory can be shown for the certain moment in time when it is recalled and no recalculations of earlier points in time are possible. Figure 4-19 represents the storage occupation. Out of 4,500 bins about 4,100 to 4,400 are occupied at the chosen moments. This results in an occupation of 91% to 99%, which is recommended to be changed to improve the storage.

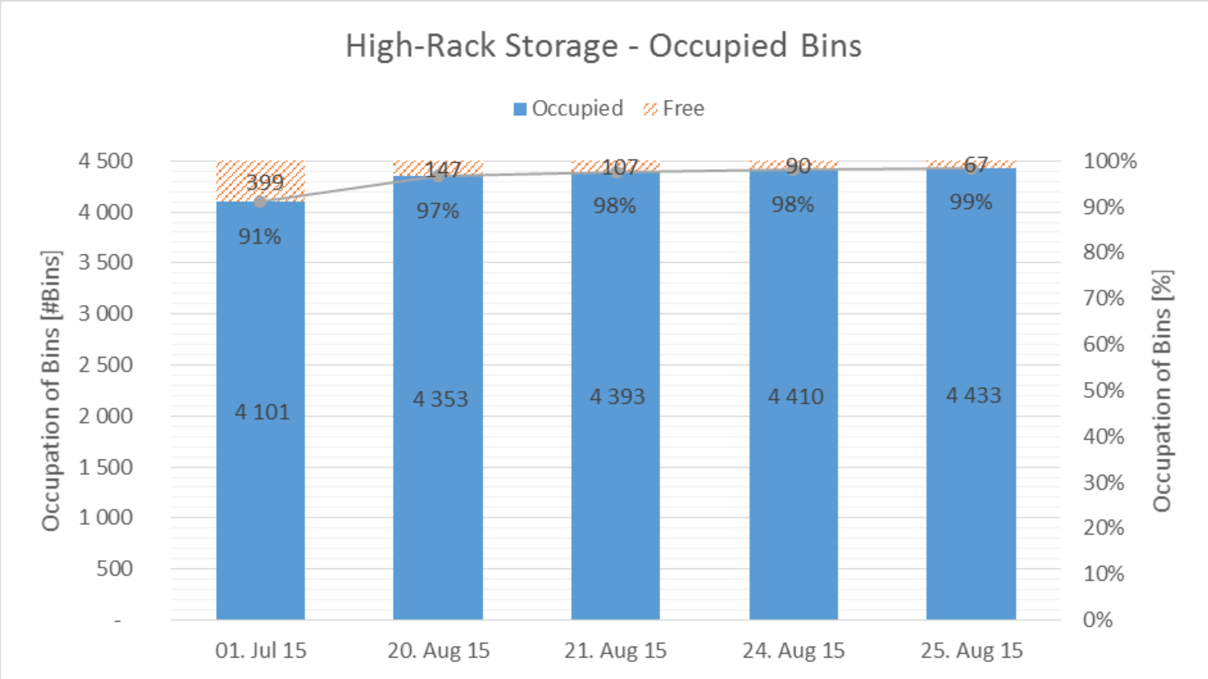

Figure 4-19: High-Rack Storage Occupation

Besides the filling rate in terms of occupied bins, also the filling rate in terms of weight is investigated. In this case, rates are much lower than in the previous case. Bins are not fully loaded because filling rates fluctuate in a range between 36% and 40% (cf. Figure 4-20). Therefore, the weights of pallets inside the high-rack storage are analyzed.

Figure 4-21 shows the distribution of weights stored in each bin (the average of the five investigated days). The weights are represented in classes of ten kilograms.

A number of 75 bins are defined with 0kg. These bins do have the status "work in progress", which means they have been moved or changed in the very moment of data documentation. Due to this fact, these 75 bins are not included within the orange cumulative percentage line in Figure 4-21. However, this orange cumulative percentage line shows that about 22% of all occupied bins have stored 300kg or less instead of possible 1,500kg. This means in average just 10% of the possible stored weight is used for these bins. More than half of all bins occupied have less than half of the potential weight (750kg). Having realized the reason of bad weight potential usage inside the high-rack storage, classifications are done to separate all occurring bin weights into meaningful and for further investigations reasonable classes. So six classes are elaborated on Figure 4-20 and are shown in Figure 4-22.

As described in chapter 4.1.2 quality assurance products are stored in the high-rack storage too. On average 144 bins (3% of all 4,500 bins) are occupied with QA products and 68% of them are stored longer than one year. The QA-bins´ majority (87%) weight is smaller than 450kg.

Chapter 1.3 shows the big variety of products that are handled by the project partner. To determine the number of cardboard boxes on each loaded bin, a virtual standard cardboard box is calculated. To generate a virtual standard cardboard box the most likely used boxes are measured to document their weight and dimensions. Table 4-3 shows these values and defines the virtual standard cardboard box. With the virtual box´s weight the number of boxes stored inside the high-rack storage is calculated to more than 150,000. Each pallet has got between 1 and 75 virtual boxes on it. The frequency of pallets loaded with the same number of virtual boxes is shown in Figure 4-23. As expected concerning outcomes of Figure 4-21, about a quarter of all pallets have about 21 or less cardboard boxes on them.

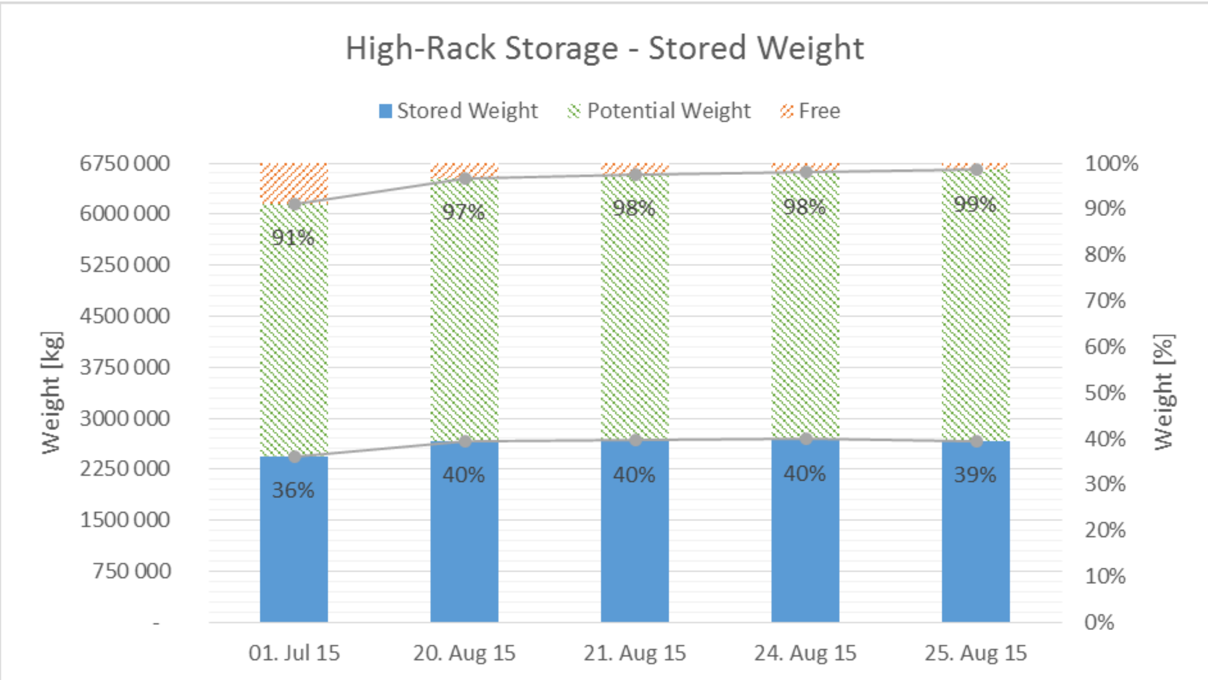

Figure 4-20: High-Rack Storage Stored Weight

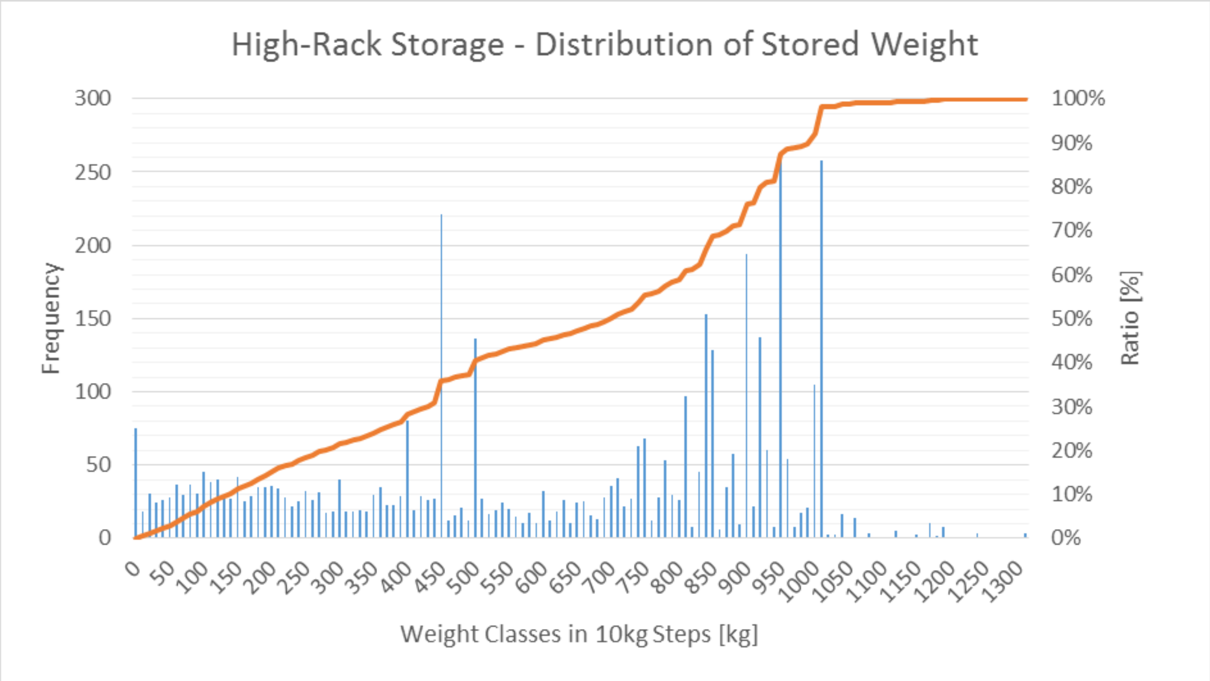

Figure 4-21: Distribution of Stored Weight

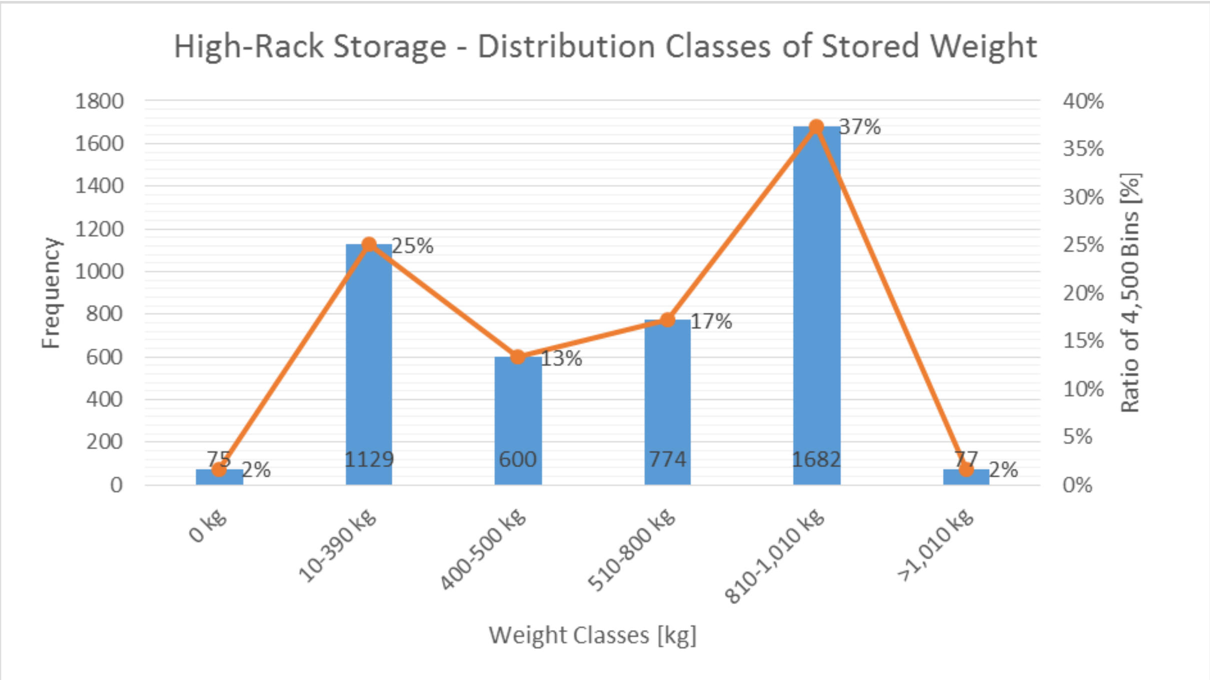

Figure 4-22: Weight Classes

Table 4-3: Virtual Box Standard

Boxes	Length [m]	Width [m]	Height [m]	Weight [kg]	Density [kg/m³]
Type 1	0.400	0.280	0.110	17.50	1,217.53
Type 2	0.325	0.325	0.120	17.50	1,577.91
Virtual Standard	0.363	0.303	0.115	17.50	1,397.72

A closer look at the material flow of goods entering or leaving the high-rack storage shows the number of cycles per hour done to proceed all movements of the specific days in two shifts (16 hours). Employees work in three shifts to proceed peaks, but this does not happen frequently and can only be taken into account when assessing the peaks (cf. Figure 4-24). While having just single cycles due to the actual processes, an average of about 12 cycles per hour for two cranes results out of calculations. Peaks do not exceed 21 single cycles per hour so the crane drivers as well as the cranes do not work at their capacity limit.

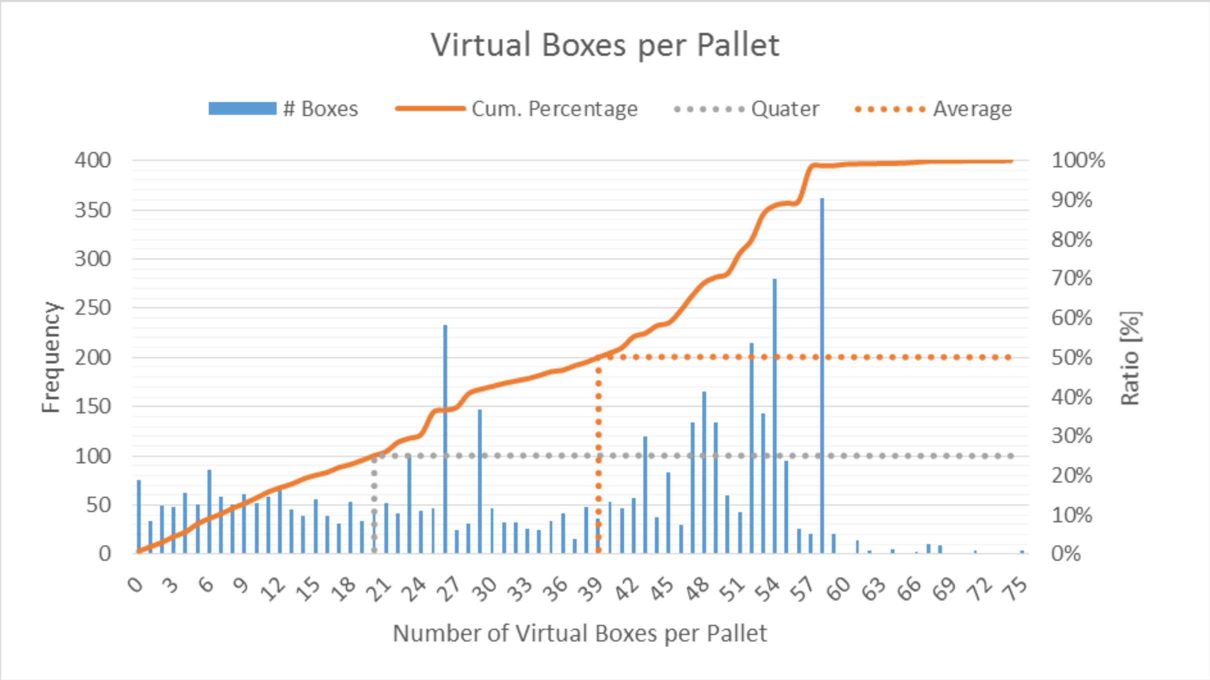

Figure 4-23: Virtual Boxes per Pallet

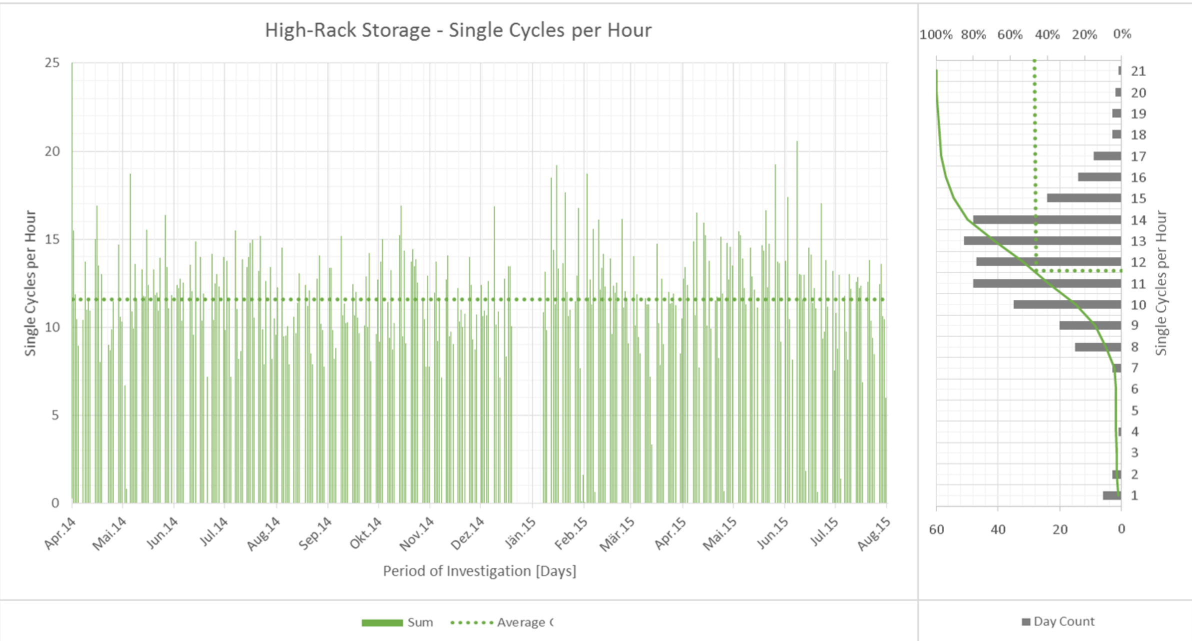

Figure 4-24: Single Cycles per Hour

Chapter 3.2 describes key figures and their equations. Table 4-4 shows calculations concerning the key figures from chapter 3.2.

A weekly calculated GI-GO Ratio and therefore a time depended behavior is shown in Figure 4-25. A ratio equal one shows that all goods-in movements are covering goods-out movements. A ratio bigger than one indicates an increase of stock, but if the ratio is smaller than one, more goods are retrieved than stored. In Table 4-4 the GI-GO Ratio is calculated in two different units because of the ratio´s dependency on pallet´s weight. Usually goods-in pallets are heavier than picked goods-out pallets. Therefore, in goods-out processes more pallets are needed to move the same weight and this results in a ratio smaller than one regarding the number of pallets. (cf. Table 4-4)

Having a GI-GO Ratio calculated out of numbers of pallets of less than one does not mean less bins are occupied over time. The GI-GO ratio calculated out of weight is bigger than one and therefore the storage is getting slightly more occupied in average. Weekly GI-GO Ratio´s values are strongly changing over time (cf. Figure 4-25), but it is independent form the total moved weight.

Table 4-4: Key Figures

Name	Equation	Unit	Calc.	Value
Storage Capacity	-	-	-	*4,500* Bins
Product Range	-	-	-	*1,129* Products
Warehouse Occupancy	$\frac{Number\ of\ Occupied\ Bins}{Warehouse\ Caparity} \times 100$	$\frac{[Bins]}{[Bins]}$	$\frac{4{,}338}{4{,}500}$	*96.40%*
Range of Storage	$\frac{Average\ Inventory}{Average\ GO\ per\ Time}$	$\frac{[kg]}{\left[\frac{kg}{Day}\right]}$	$\frac{2{,}631{,}108}{54{,}560}$	*48* Days
Inventory Turnover	$\frac{GO\ per\ Time}{Average\ Inventory}$	$\frac{\left[\frac{kg}{Day}\right]}{[kg]}$	$\frac{54{,}560}{3{,}631{,}108}$	*0.02* Turns per Day
		$\frac{\left[\frac{kg}{Year}\right]}{[kg]}$	$\frac{13{,}299{,}055}{3{,}631{,}108}$	*5.05* Turns per Year
GI-GO Ratio	$\frac{GI}{GO}$	$\frac{[kg]}{[kg]}$	$\frac{18{,}767{,}622}{17{,}732{,}073}$	*1.06*
		$\frac{[Pallet]}{[Pallet]}$	$\frac{27{,}782}{33{,}858}$	*0.82*

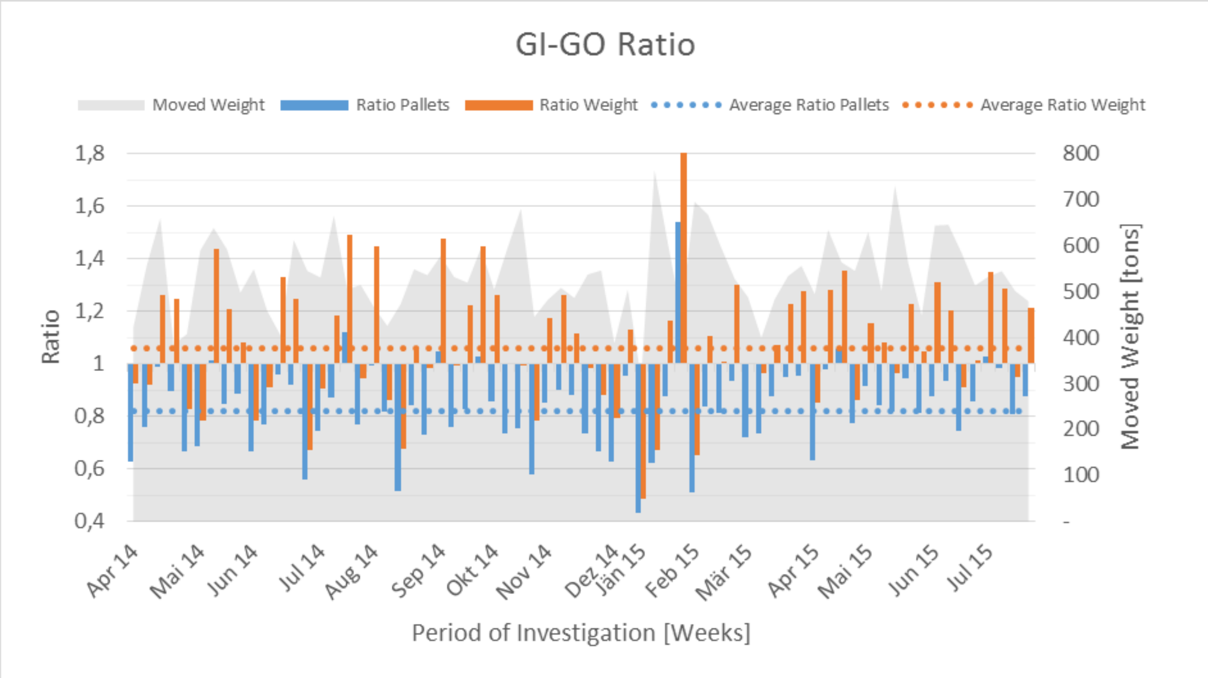

Figure 4-25: Goods-In – Goods-Out Ratio

Order Analysis

Having analyzed warehouse data like capacity and occupancy, orders in the period of investigation (April 2014 – July 2015) are analyzed in this section. When creating a new or improved storage- or material flow system it is necessary to know the real requirements of the system. Therefore, it is indispensable to know customers´ behavior and the resulting order composition.

Similar to the distribution of stored weight (shown in Figure 4-21) the weight distribution of goods-out movements in the high-rack storage are shown in Figure 4-26. These movements derive out of picking list lines, like one line of customer order “a” is 399kg of material “b”, batch “c”, from storage bin “x-y-z”. This line is one count in the 390-400kg weight class, which counts 787 lines in total. The cumulated ratio of weight classes shows that 50% of all picked lines in the SRS GO process have 200kg or less while the weight class with the highest frequency is 10-20kg (7,334 occurrences in 80,053 cases, 9% of all picking lines). The second frequency peak in Figure 4-26 appears in the weight range between 370kg and 540kg. Taking the virtual standard box´s density (cf. Table 4-3) into account, in average a fully loaded storage bin contains about 870kg. Due to the density of products the maximum capacity of 1,500kg cannot be reached. This means the second frequency peak describes half loaded pallets, which cause the most handling effort while picking inside the high-rack storage. To pick half loaded pallets cause the most picking effort because, orders with less amount create less effort. In case of orders with more than half of a pallet to pick, employees just pick the amount of products which would be left in the storage to exchange the picked pallet with the stationary one. With this procedure picking effort is reduced. The second frequency peak of weights represents about 13% of all picking list lines. Picking list lines with the smallest handling effort are lines of almost fully loaded pallets of 870kg and more (14% of all picking lines).

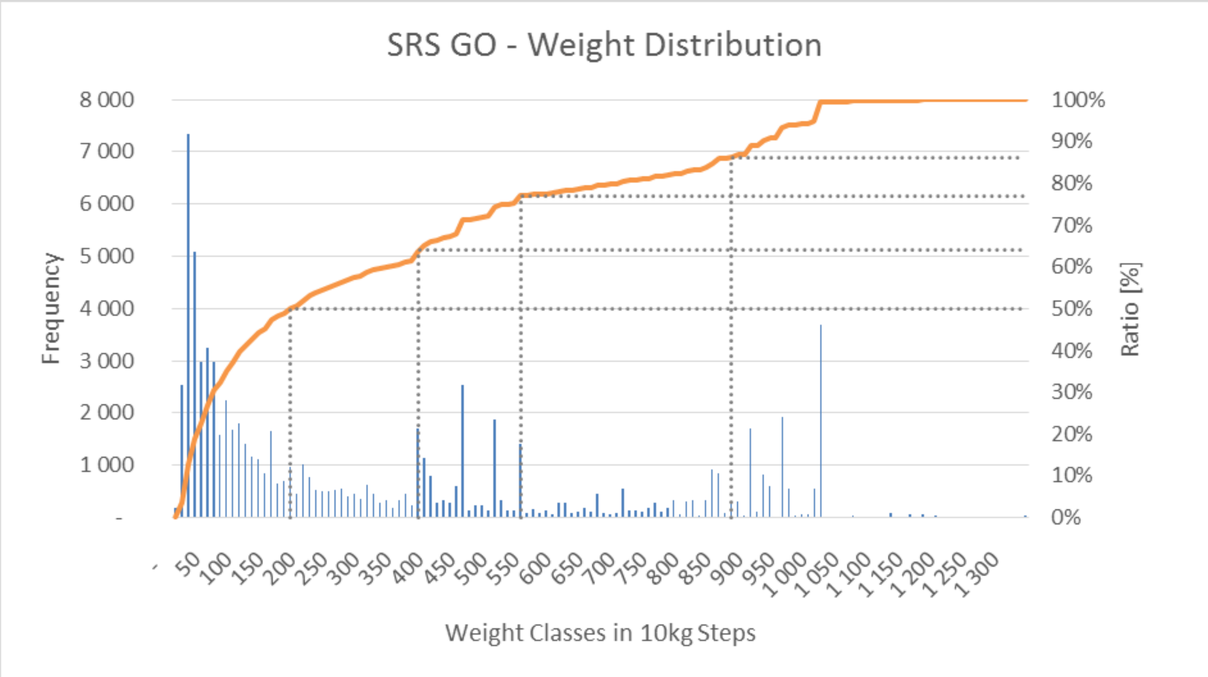

Figure 4-26: SRS Goods-Out Weight Distribution

Picking list lines are not equal to order lines. An order of 800,000kg of a product is completed with a single order line but results in for example ten lines in a picking list. Therefore, ordered weights of different materials are further investigated. In Figure 4-27 a graph shows the investigation´s outcome. Even 71% of all order lines are below 300kg. Again a peak at 1,000kg and also small peaks at 2,000kg, 3,000kg, 4,000kg and 5,000kg occur.

Because of the varying combinations of total order weight and number of picking lines Figure 4-28 shows the picking list´s number of lines over its total weight. With the cumulated ratio over weight it is shown that 80% of all orders have total weight of less than 1,405kg and a maximum number of four lines for about 90% of all orders it is proven that the majority of orders have low weights and low numbers of picking lines. The ratio of orders with only one line can be determined as 67%. This customer behavior of ordering different products with low quantities is one of the main reasons for the current usage of weight potential inside the high-rack storage.

In the current situation, products are packed into cardboard boxes and stacked on pallets during manufacturing. These fully loaded pallets are further processed, stored or shipped. Due to the outcomes of the previous investigations and order analysis (cf. Figure 4-20, Figure 4-21, Figure 4-25, Figure 4-26), it is recommended to omit loading products on pallets because this creates unnecessary handling effort. In upcoming planning processes for new overall logistics solutions further investigations are recommended be done to determine whether a pallet based system is reasonable. If so, a clear specification of products that have to be processed on pallets or not has to be created. Classifications of products used for different kind of orders are recommended to be implemented. These further investigations and order analysis are not part of this Master´s Thesis and are recommended to be discussed in following projects. This order analysis shows the customer´s ordering behavior is one of the main reasons of the current usage of weight potential inside the high-rack storage.

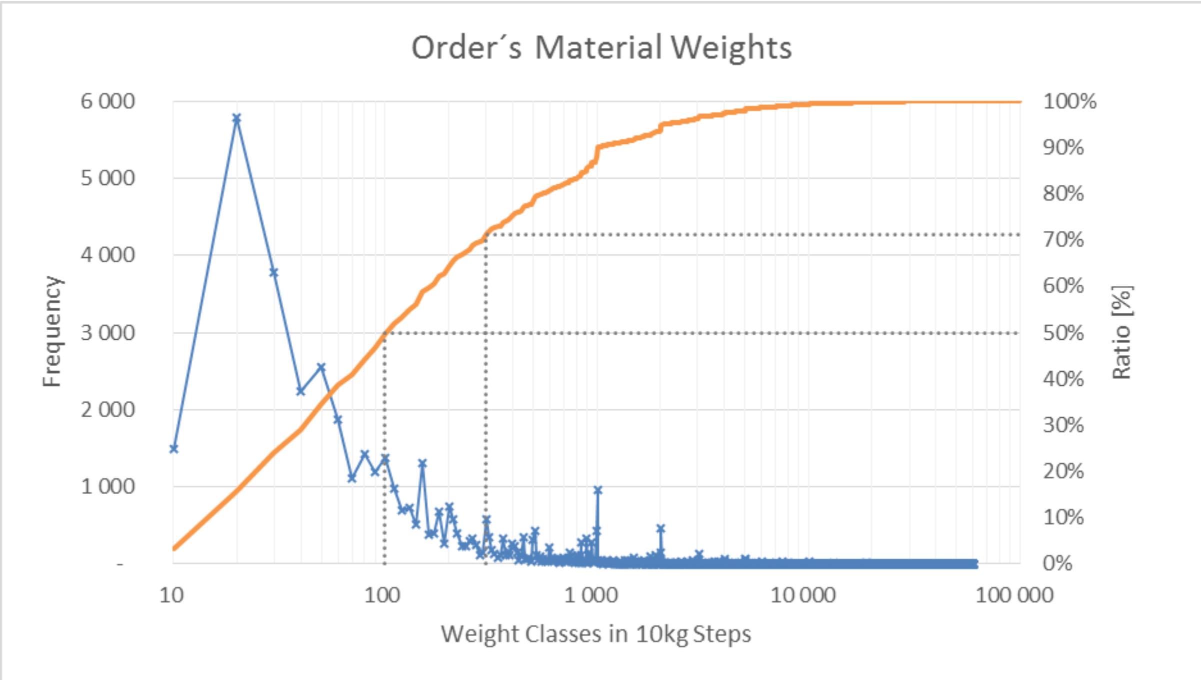

Figure 4-27: Order´s Material Weights

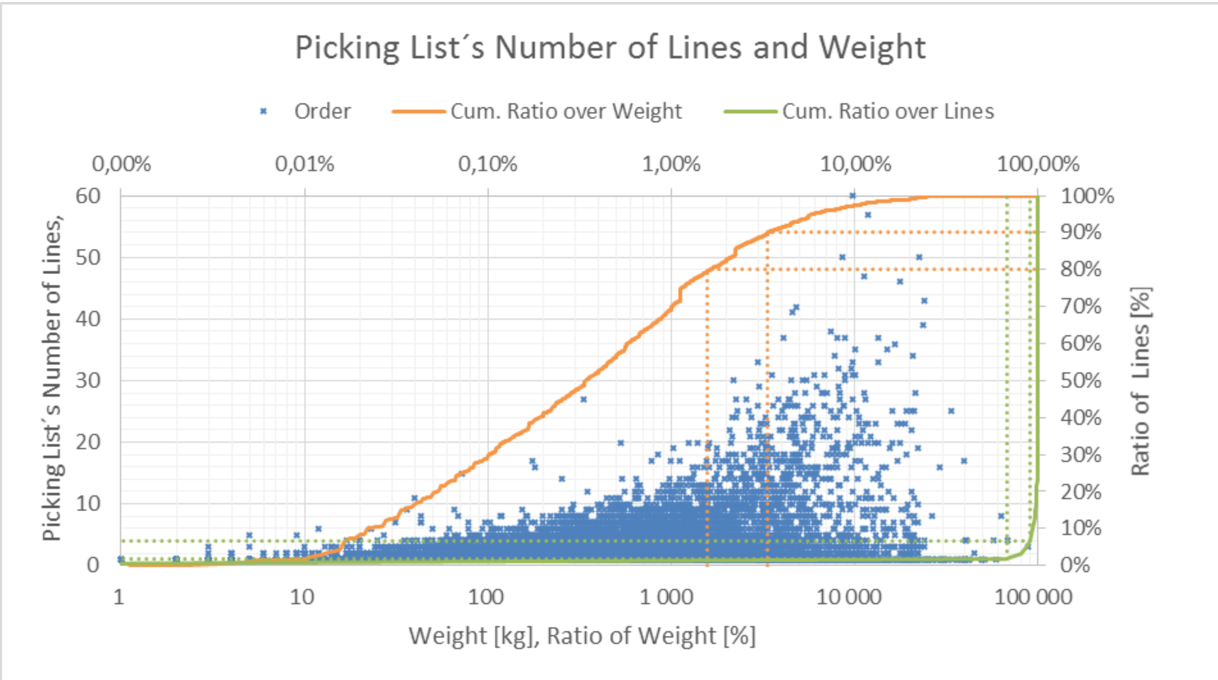

Figure 4-28: Picking List´s Number of Lines and Weight

4.1.5 Expert Analysis – SSI Schäfer

After having analyzed all current data to have a clear overview of ongoing processes in the forwarding department, it is essential to assess the currently used hardware. In order to value machines in use according to their reliability and sustainability a lot of experience is needed. The company SSI Schäfer represents a large conglomerate of such specific experience and pleasantly supported the high-rack storage´s technical validation. After discussions and a site visit an expert analysis is carried out. With best thanks to SSI Schäfer and special thanks to Mr. Totz and Mr. Roitner appreciations come to a conclusion as described in the following.

Despite of rather high age of the high-rack storage it is in a good shape. Changes and improvements are recommended be done when it comes to software, process and organizational matters. Modern storages are able to store several different products at one single bin at the same time. With regard to upcoming changes in production rearranging actions are definitively necessary. The whole logistic system in its actual state has reached its physical and systematic limit. Not even additional layers can be added to the storage, which usually is a common way to enlarge capacities. Also an ABC-Classification and Zoning is already implemented as far as possible. An essential improvement is to change the system´s man-to-goods strategy into a goods-to-man strategy and to create ergonomic order picking zones. At least the warehouse management system´s software has to be adapted but better to be replaced. Also building an additional modern high-rack storage next to the existing one is possible. This is recommended to be used to buffer previously picked orders and pallet flow racks provide pallets for trucks. In this case, one crane is for goods-in and a second one for goods-out movements. Besides these changes, organizational improvements are recommended to be focused. Changing the existing warehouse management system will result in large programming effort and high costs. If the strategy is changed into a goods-to-man, a modern software like "SAP EWM" is recommended. In such a new software it is easy to implement automation, whereas systems like the actual "WMS" are made for simple storage processes. The project partner´s "WMS" is an expiring software and a lot of programming effort is necessary to adapt systems for automation. There are companies offering those "WMS" changes but also these companies are using "EWM" more often. Costs for reprogramming are up to €300,000 or more. In a modern warehouse, management system software functions like automatic compaction of goods are implemented and storage maintenance can be scheduled in daily business. Orders can be sorted according to their priority over the workday and an automated permanent inventory is possible. A storage optimization or rearrangement of organization will improve the situation. However, if all forecasted changes in production are implemented, these actions are not enough to continue with shipping. After two or three years, when the new production´s output capacity is on maximum, a significant rebuilding will be necessary. Such a rebuilding takes a lot of time in planning, preparation and building therefore projects are recommended to be started in 2016 to deal with preparation and possibilities. The construction of a new storage is recommended to be started at the latest in 2017 because of the type of rebuilding this process lasts for 12 to 16 months. The truck transport between the buildings (explained in chapter 4.1.3) generates "artificial peaks" which have to be buffered and processed unnecessarily.

In order to have a more continuous material flow between the buildings (explained in chapter 4.1.3) automated guided vehicles (AGV) are recommended be used. They position themselves with laser beams and three-point navigation by using reflectors along their way. Such systems are very common in industry. With this technology an automated logistic train can replace trucks between the buildings. If transportations between 50 and 200 pallets per hour occur, also electric monorails are recommended to be implemented. The existing basement is recommended to be used to implement shuttles and simple guiding. In this case, additional elevators and buffers for three or four pallets are needed. Out of this, a resulting continuity enables exact calculations of picking and processing times to plan and execute all processes on time.

A strategy change to a goods-to-man system for the high-rack storage increases the SRS crane´s possible performance up to 15 to 20 double cycles per hour. This results in a maximum of 40 double cycles per hour for the whole high-rack storage. In this case, all products in the storage have to be rearranged and fast moving goods have to be at the very front. Distance measurement on lifting- and driving gear and probably at the fork are necessary for an automated positioning of cranes. Additionally, these measurement devices have to be connected with the warehouse software. Positioning with Wi-Fi is also possible with SPS data access. Needed access points cost about €2,000. In any case, the warehouse management system software has to be adapted. An option, in which the crane driver is still driving self-dependently but an assistant positions the crane in front of a bin is easy to apply and does not require software changes. This assistant is started by slowing the crane down to a certain velocity.

The cranes are using direct current motors, which expire in this kind of application because of hardly available drive control systems. Sooner or later, these motors will have to be exchanged.

When building a new storage the current one has to be used too. The existing high-rack storage can be teared down but two aisles remain and be modernized and operated with one crane each. Created areas can be used to enlarge production.

The processing of products on pallets is recommended to be questioned. Depending to orders of full pallets (investigated in Figure 4-26), products are recommended not to be packed on pallets, because boxes have to be picked again anyway. Automated transports of single boxes allow significantly higher velocities and cheaper materials handling equipment. An automatic storage and retrieval system (ASRS) is recommended to be implemented. Picking workstations are very flexible, so multiple orders are processed at the same time. Also, cranes drive with higher velocities. The reasonability of changes strongly depends on orders. In this case, if processes are automated all products have to be checked on their automation.

Because of the usage of wooden cases automation is hardly possible. Therefore, also this loading equipment is recommended to be questioned even if it is a customer´s wish.

A strategy change to goods-to-man increases the number of movements inside the high-rack storage tremendously. A performance of 40 double cycles per hour cannot be exceeded, so upcoming challenges have to be compared with this performance.

Another way to solve problems is to store fast moving good outside the high-rack storage where a fork lift truck reach them.

With these conclusions the storage´s hardware is rated and ideas for possible solutions are given. Also necessary actions according to software and hardware changes are described. With this information added to the detailed data analysis in chapter 4.1.4 weak points can be defined. Outcomes will also be integrated in optimization approaches.

4.2 Weak Point Analysis

After a detailed data and observation based analysis of the actual state, weak points are going to be investigated in this section. By identifying, defining and classifying weak points, they are extracted out of previous investigations. The evaluation of weak points, puts weak points into an objective context to enable appropriate and efficient proceeding heading optimization.

4.2.1 Weak Point Definition and Classification

Based on analysis of the actual state in chapter 4.1, weak points in the forwarding department are identified in many different situations and due to various reasons. By defining, naming and simultaneously classifying them a reliable basement for further investigations is created. Weak points arise from issues of the current *Layout*, the way actual *Processes* are defined, from issues with *Machinery & Equipment* and from analysis of *Warehouse Data*-. Figure 4-29 shows an organigram, which represents all defined weak points separated concerning issues they arise from.

Layout

- The location of the forwarding company ESP (opposite side of the forwarding department´s building, which can be seen in Figure 4-1) is one weak point. Because of this location in relation to the forwarding department´s location large transportation distances have to be managed. (cf. Figure 4-29, layout weak points one and two)
- Another problem is that truck lanes enforce opposing material flow on narrow and very busy routes inside the forwarding department (cf. Figure 4-2, area 20 and Figure 4-18). Both truck lanes are also used for goods-in and goods-out movements (as described in chapter 4.1.3), which prohibits a directed material flow. Additionally, these lanes are localized separately. Therefore, the locations of goods-in and goods-out change all the time which makes loading and unloading more complicate. Products have to overcome larger distances until they are stored into the high-rack storage, when they arrive at truck lane two (cf. Figure 4-2, area 14). These longer distances (cf. Figure 4-18) result in bigger transportation efforts. (cf. Figure 4 31, layout weak points three to five)

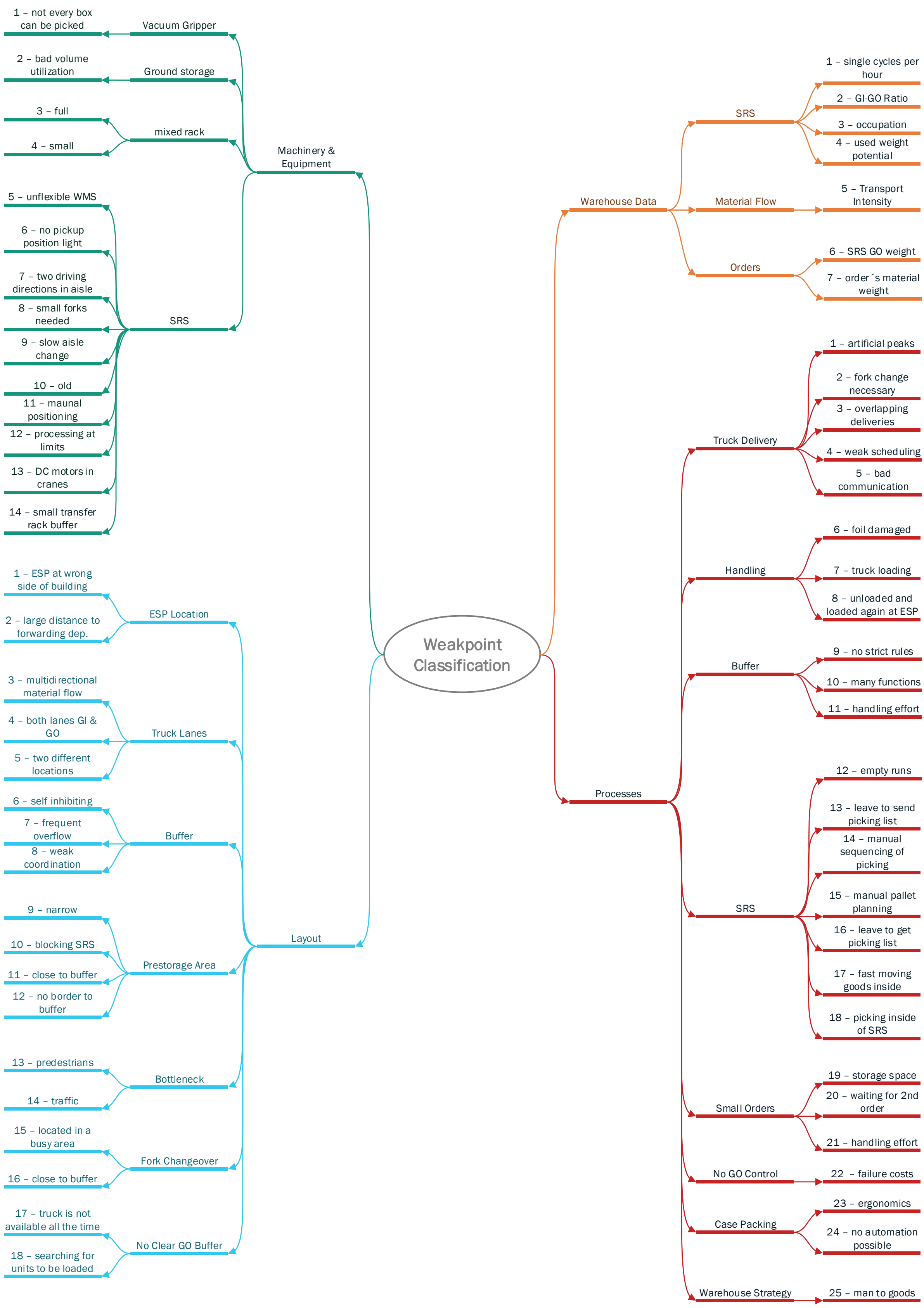

Figure 4-29: Weak Point Classification

- A major reason for problems during forwarding processes is the truck load and unload buffer. Chaotic situations, in which load units are blocking the shrink wrapping machine, or employees load and unload wrong load units occur in the truck load and unload buffer. Additionally, a frequent overflow occurs in in the truck load and unload buffer. Due to overflow and frequent multiple use of this area, self-inhibiting situations occur. As a result, the buffer area is blocked and processes cannot be executed in surrounding areas. (cf. Figure 4 31, layout weak points six to eight)
- The prestorage area is located very closely to the buffer zone (cf. Figure 4-2, areas two and three). There are no physical borders. The prestorage area is also very narrow and problems in this area directly affect the high-rack storage and hinder it from working. (cf. Figure 4 31, layout weak points nine to 11)
- The bottleneck (cf. Figure 4-2, area 20) is very narrow and due to its location very traffic intense (cf. Figure 4-18). Additionally, many of employees have to frequently pass this intersection by foot which is also a safety issue. (cf. Figure 4 31, layout weak points 13 and 14)
- The Fork Changeover area is located nearby the buffer area too (cf. Figure 4-2, areas three and four). So it is also effected by problems happening there. In particular issues in the buffer zone are restriction processes there. (cf. Figure 4 31, layout weak points 15 and 16)
- As products are loaded directly into a truck most of the time (described in chapter 4.1.3), there is no clear defined goods-out buffer. If no truck is available to be loaded the already very frequently used buffer zone is occupied with buffered load units waiting to be loaded. In this case, employees have to search for units to be loaded as soon as an empty truck is available. (cf. Figure 4 31, layout weak points 17 and 18)

Processes

- A major process weak point results out of bad communication in the whole truck delivery process. Truck drivers do not know when deliveries are needed and forwarding department´s employees do not know when they are coming. Overlapping of deliveries occur, which means different deliveries, for example an intra site and an international one, are incoming at the same time. This heavily effects the buffer zone and generates major issues there. An issue that is also deriving from intra site truck deliveries is the creation of artificial peaks of loads to be processed at the same time. These peaks are also worsening the situation in the buffer area. Due to the fact that truck trailers have to be loaded double deep and due to the lack of loading ramps, fork lift trucks have to be equipped with long forks and while feeding the high-rack storage they are not allowed to have long ones. This causes necessary fork changes. (cf. Figure 4 31, process weak points one to five)
- Handling processes of pallets or cases also have their weak points in truck loading. Units have to be placed very accurately inside the trailer and thereby they have to be moved twice. After being loaded in the forwarding

department, pallets are unloaded and loaded again at the ESP. This creates handling effort, which is time and money consuming. Also plastic foils (added in the shrink wrapping machine), in which the loaded pallets are wrapped are damaged due to the high amount of picks. As a result goods are not properly protected during transportation. (cf. Figure 4 31, process weak points six to eight)

- No clear process rules are defined to execute tasks in the buffer area and also processes with a big variety of functions have to be done there. Also the fact that pallets are buffered on ground to get counted and checked in and afterwards getting picked up again to be moved into the high-rack storage creates a lot of time and workforce consuming handling effort in the buffer area. (cf. Figure 4 31, process weak points 9 to 11)
- Processes inside the high-rack storage are also afflicted with problems. First of all, employees have to pick boxes manually inside the storage by using the cranes without any other mechanical picking assistance. Ergonomics during this process and working conditions due to dirt and lighting are not proper for picking tasks. A man-to-goods strategy and separated goods-in and goods-out processes generate many empty runs for cranes. Even though electric hand held scanning devices are used during picking, employees have to use hard copy picking lists to pick orders. Employees have to plan the pallet occupation on their own which means employees decide on their own which products they put on which pallet. Moreover they also sequence patterns manually. Employees decide which order line they pick first. As a result of hard copy picking lists, employees have to leave their cranes to get and send picking lists. While they are gone their crane blocks an aisle. Another weak point is that fast moving goods are stored into the storage although they are going be put out again very soon. (cf. Figure 4 31, process weak points 12 to 18)
- The way small orders are proceeded also creates weak points. In order to give customers the opportunity to order twice a day and get just one pallet, picked pallets are buffered and waiting for a second order. This occupies storage capacity unnecessarily and creates additional organizational as well as handling effort. (cf. Figure 4 31, process weak points 19 to 21)
- The absence of a goods-out control results in failure costs in some cases and lots of rework to be done. (cf. Figure 4 31, process weak point 22)
- Processes that require goods to be packed into wooden cases do not have proper ergonomics for employees. Although they are using vacuum grippers, working steps last long in comparison to picking processes inside the high-rack storage. Also, automation of these process steps is hardly possible due to the usage of cases. (cf. Figure 4 31, process weak points 23 and 24)
- A major weak point is the warehouse strategy of moving man-to-goods instead of goods-to-man. (cf. Figure 4 31, process weak point 25)

Warehouse Data

- Three main topics for weak points come up in warehouse data. The material flow is defined with a transport intensity of 4.3 million pallet meters. Because of the will of continuous improvement the actual transport intensity is defined as a weak point. (cf. Figure 4 31, warehouse data weak point five)
- Data from high-rack storage processes (cf. Figure 4-19) shows a very high occupation, which makes the storage incapable of action. Additionally, data (cf. Figure 4-20) shows that the usage of each bin´s weight potential is low and therefore some bins are almost empty but occupied. A goods-in – goods-out ratio´s average of more than one, in relation to moved weights enforces the weight potential usage getting worse. Further investigations show that the high-rack storage´s performance is limited with 40 single cycles per hour, which is not enough for upcoming requirements in the future. (cf. Figure 4 31, warehouse data weak points one to four)
- Because of the customer´s behavior in ordering, goods-out movements from the high-rack storage have low weights most of the time (cf. Figure 4-26). This causes lots of picking, because whole pallets are picked rarely. Also the stored weight per bin is decreasing while having nearly the same storage occupation (described in chapter 4.1.4.2). Analysis also shows that customers order just a few kg per product most of the time (cf. Figure 4-27). (cf. Figure 4 31, warehouse data weak points six and seven)

Machinery & Equipment

- Weak points created by used machinery and equipment occur in the high-rack storage, in the mixed rack area, in the ground storage and in the case packing area. The high-rack storage and the operating cranes are not up to date any longer (cf. chapter 4.1). Software and hardware problems like missing spare parts, hardly possible automation are outcomes of that. Also velocities during aisle changes are very slow due to old switches. The transfer rack´s buffer capacity is too low to balance performance differences of in- and outside the high-rack storage. Another weak point is the time consuming manual positioning of cranes in front of bins as well as the positioning of pallets at the bins. The transfer rack at the storage´s front side needs to be filled by using short forks, which creates the necessity of a fork change for trucks. The manually driven cranes can enter aisles driving forward and backward in combination with naming bins left and right. This causes be the major reason for wrong picks because left and right depends on the driver's driving direction. Employees filling the transfer rack do not know which aisle is full or which aisle is optimal to be used for next goods-in movements. They just choose an empty transfer bin. So in case of storing a load unit in the transfer rack, in front of a fully occupied aisle, crane drivers have to change aisle with very low velocities. DC motors are used in the cranes, which is a problem in purchasing spare parts because in this type of application they are expiring. (cf. Figure 4 31, machinery weak points five to 14)

- The used mixed rack (cf. Figure 4-2, area 19) improves the situation inside the high-rack storage but it is fully occupied and therefore too small. (cf. Figure 4 31, machinery weak points three and four)
- In the ground storage the available volume of this tall building is badly utilized because only three layers of pallets are stacked at maximum. (cf. Figure 4 31, machinery weak point two)
- Another weak point is the used vacuum gripper in the case packing area. Not every box can be picked although various adapters are used. As a result, packing is inefficient and exhausting. (cf. Figure 4 31, machinery weak points one)

Weak points discovered in this sections are defined and classified. All of them can also be found in Figure 4-29. To specify these weak points´ root causes and their severity chapter 4.2.2 shows further investigations.

4.2.2 Weak Point Evaluation

Evaluating weak points is as important as defining them. It is crucial to know possible failures´ severities, their likelihood of occurrence or their chance of detection in order to set right measures. Also specifying root causes of issues is part of this evaluation.

The five whys is applied to specify the root causes. As an outcome Table 4-5 shows the ten different root causes derived from the five whys method´s application at the in chapter 4.2.1 defined weak points. In appendix Figure 8-12 and Figure 8-13 the five whys method´s table is shown. All weak points are identified with an abbreviation containing a letter describing the section (L – Layout, P – Processes, W – Warehouse Data and M – Machinery & Equipment) and a number (identification number from Figure 4-29). The root cause for 16 out of 64 weak points is the historically grown layout. Not less severe is that 15 out of 64 weak points derive from the current situation of picking orders inside of the high-rack storage and a lack of applied technical solutions to enable an ergonomic and efficient picking outside. Having the delivery company ESP in another building that is located at the other side of the forwarding department´s entrance is ten times a root cause for weak points as well as the used software, a lack of functions within it and difficulties in changing it. Other root causes do not appear that often but are of high relevance too.

Table 4-5: Root Causes and Occurrence

Root Causes	Abbr.	Occ.	Root Causes	Abbr.	Occ.
Layout	LAY	16	bad communication	BC	1
ESP Location	ESP	10	no alternative to wooden case	WC	2
Software	SW	10	customer's behavior	CB	3
no technical solution to pick outside SRS	NTS	15	ground storage	GS	1
paper based system	PBS	3	cost-benefit ratio	CBR	3

To further investigate defined weak points a method is applied which usually is used in risk assessments. The failure mode and effects analysis (FMEA) (cf. chapter 3.2) is used as an objective method to rate the previously defined weak points (cf. chapter 4.2.1) according their severity, their rate of occurrence and their likelihood of detection during processes.

Through risk priority rating (done with the FMEA method), a risk priority number for every single weak point is calculated (cf. Table 4-6). The risk priority number represents the priority and relevance of specific weak points to be changed. Rating values for severity, occurrence and detection are agreed with the project partner. The severity´s rates depends on process cost intensities, which have been defined and investigated earlier in this thesis (see chapter 4.1.3.4). Figure 8-14 shows all weak points connected with processes they affect and these processes´ cost intensities are summed up to a total cost intensity. In Figure 4-30 risk priority numbers are visualized in a diagram. Weak points marked with "*" directly affect the customer, which is the worst case scenario and therefore they have a severity of ten. Rates for occurrence and detection are chosen because of observations during process execution. In order to connect this data with weak points´ root causes, calculated risk priority numbers applied on root causes are shown in Figure 4-31.

Concerning the FMEA and the included RPN (cf. Table 4-6) the first five weak points are further discussed.

- It is important to avoid artificial peaks in truck transportation. A high RPN results because of their potential to confine almost every ongoing process, their frequent occurrence and their weak predictability.
- It is important to improve the transport intensity to be able to run at higher performance levels.
- Mistakes during picking and therefore failure costs have to be avoided. They are affecting customers directly and therefore issues concerning this weak point are recommended to be improved.
- Another very important weak point that needs to be improved is that processes are executed at their performance limits.
- Two driving directions are possible in aisles. Due to the bin´s naming and process of picking failures occur.

With the ranking of weak points (cf. Table 4-6) a broad analysis of the actual state is finished. After having analyzed the forwarding department's layout, processing areas and ongoing processes have been defined and rated and visualized. The detailed data analysis comes up with visualized material flows and a total transport intensity and investigations of daily movements in different areas. Moreover the high-rack storage´s occupation and weight potential usage as well as further key figures have been defined. Also investigations of customer orders give interesting information about the system´s behavior and requirements (cf. chapter4.1). Weak points are named, defined, evaluated and ranked to complete the actual state´s analysis and weak point analysis.

In the following sections optimization approaches are discussed.

FMEA - Failure Mode and Effects Analysis				Risk Priority Rating			
Weak Points	Abbr.	Causes	Effects	Severity	Occurrance	Detection	RPN
artificial peaks	P-1	ESP	unnecessary workload peaks, mistakes	8	8	5	320
transport intensity	W-5	LAY	high costs, poor performance	6	10	5	300
failure costs	P-22	NTS	customer satisfaction	10	2	10	200
processing at limits	M-12	NTS	chaotic situations, blocking, mistakes	8	8	3	192
two driving directions in aisle	M-7	NTS	mistakes, rework, customer effected	10	2	9	180
single cycles per hour	W-1	NTS	limit reached soon	3	10	5	150
foil damaged	P-6	ESP	customer effected, rework	6	8	3	144
used weight potential	W-4	NTS	less products in full storage	3	9	5	135
weak coordination	L-8	LAY	chaotic situations, blocking, mistakes	6	4	5	120
blocking SRS	L-10	LAY	poor performance	10	4	3	120
GI-GO ratio	W-2	CB	worsening used weight potential	3	8	5	120
SRS GO weight	W-6	CB	GI-GO Ratio	2	10	5	100
order´s material weight	W-7	CB	handling effort	2	10	5	100
unflexible WMS	M-5	SW	hard to change things	10	10	1	100
frequent overflow	L-7	LAY	chaotic situations, blocking, mistakes	8	4	3	96
no strict rules	P-9	LAY	chaotic situations, blocking, mistakes	8	4	3	96
fast moving goods inside	P-17	BC	higher occupation, additional handling	3	7	4	84
narrow	L-9	LAY	chaotic situations, blocking, mistakes	8	10	1	80
close to buffer	L-11	LAY	blocking, mistakes	8	10	1	80
traffic	L-14	ESP	poor performance, safety issues	8	10	1	80
many functions	P-10	LAY	chaotic situations, blocking, mistakes	8	10	1	80
handling effort	P-11	PBS	additional handling	8	10	1	80
weak scheduling	P-4	SW	chaotic situations, blocking, mistakes	6	4	3	72
predestrians	L-13	LAY	safety issues	8	8	1	64
ESP at wrong side of building	L-1	LAY	handling effort, foil damage, waiting, peaks	6	10	1	60
large distance to forwarding dep.	L-2	LAY	handling effort, foil damage, waiting, peaks	6	10	1	60
multidirectional material flow	L-3	ESP	transport intensity, traffic	6	10	1	60
both lanes GI & GO	L-4	ESP	multidirectional material flow	6	10	1	60
two different locations	L-5	ESP	transport intensity, traffic	6	10	1	60
no border to buffer	L-12	LAY	blocking, mistakes	6	10	1	60
located in a busy area	L-15	LAY	blocking	6	10	1	60
close to buffer	L-16	LAY	blocking	6	10	1	60
fork change necessary	P-2	ESP	additional process step	6	10	1	60
truck loading	P-7	ESP	additional handling	6	10	1	60
small forks needed	M-8	ESP	additional effort	6	10	1	60
small transfer rack buffer	M-14	SW	full racks, waiting cranes, poor perf.	10	6	1	60
unloaded and loaded again at ESP	P-8	LAY	additional handling	5	10	1	50
man to goods	P-25	NTS	bad ergonomics, poor performance	5	10	1	50
searching for units to be loaded	L-18	ESP	poor performance, mistakes	6	7	1	42
self inhibiting	L-6	LAY	blocking, mistakes	10	4	1	40
truck is not available all the time	L-17	SW	buffering elsewhere	8	5	1	40
empty runs	P-12	NTS	poor performance	3	10	1	30
leave to send picking list	P-13	PBS	poor performance, safety issues	3	10	1	30
manual sequencing of picking	P-14	NTS	no optimal planning	3	10	1	30
manual pallet planning	P-15	NTS	no optimal planning	3	10	1	30
leave to get picking lilst	P-16	PBS	poor performance, safety issues	3	10	1	30
picking inside of SRS	P-18	NTS	handling effort, unergonomic conditions	3	10	1	30
old	M-10	CBR	tech. problems, hard to change, poor performance	3	10	1	30
manual positioning	M-11	SW	poor performance	3	10	1	30
DC motors in cranes	M-13	CBR	hard to get spare parts	3	10	1	30
occupation	W-3	NTS	fully occupied storage	3	9	1	27
slow aisle change	M-9	CBR	long picking time	3	9	1	27
overlapping deliveries	P-3	SW	chaotic situations, blocking, mistakes	6	4	1	24
bad communication	P-5	SW	overlapping deliveries, no trucks available	6	4	1	24
handling effort	P-21	NTS	capacity occupation	1	8	3	24
no pickup light	M-6	SW	unnecessary aisle changes	3	7	1	21
ergonomics	P-23	NTS	bad ergonomics, poor performance	2	10	1	20
no automation possible	P-24	WC	manual work necessary	2	10	1	20
full	M-3	SW	chaotic situations, blocking, mistakes	3	6	1	18
small	M-4	SW	chaotic situations, blocking, mistakes	3	6	1	18
not every box can be picked	M-1	WC	tech. problems, hard to change, poor performance	2	5	1	10
bad volume utilization	M-2	GS	fully occupied storage	1	10	1	10
storage space	P-19	NTS	handling effort, capacity occupation	1	8	1	8
waiting for 2nd order	P-20	NTS	handling effort, capacity occupation	1	8	1	8

Table 4-6: Weak Point FMEA

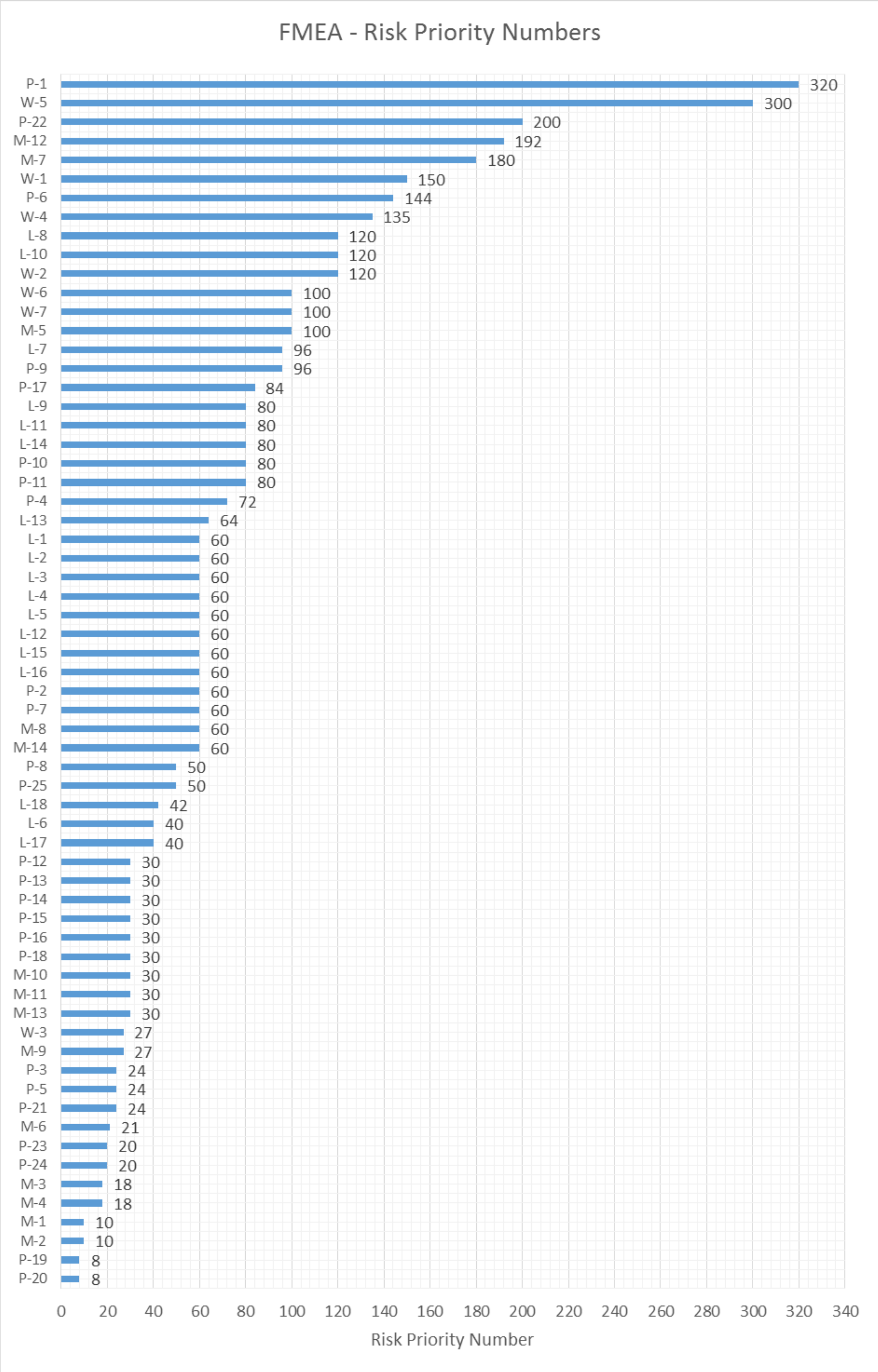

Figure 4-30: Risk Priority Numbers

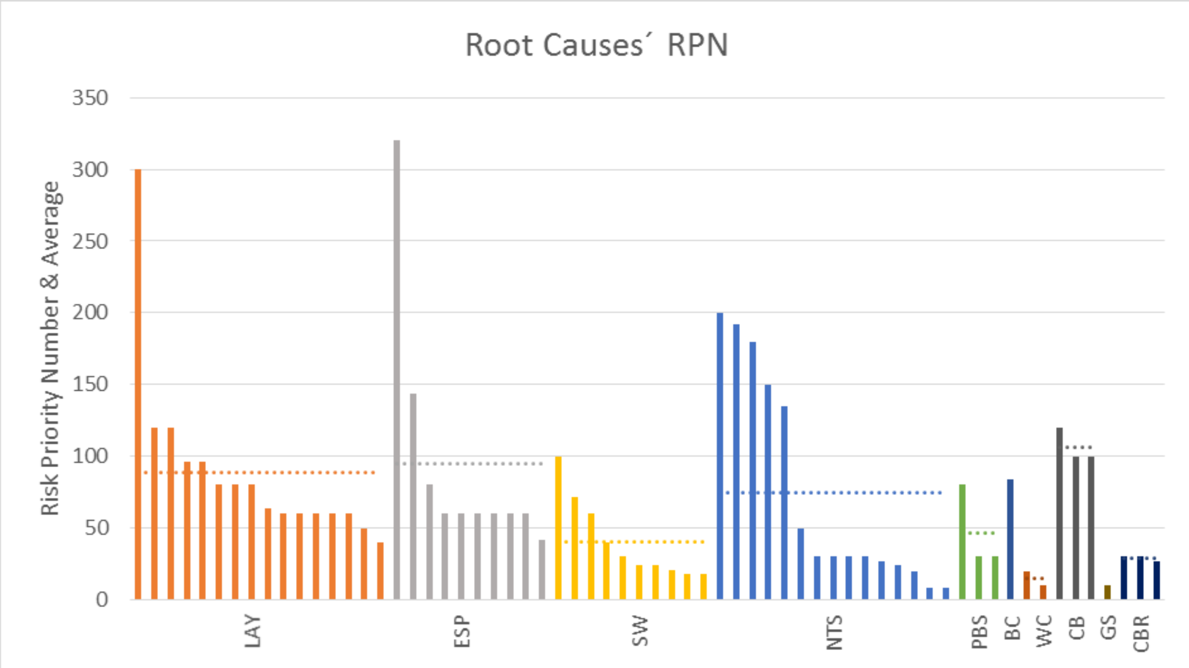

Figure 4-31: Root Causes´ Risk Priority Numbers

4.3 Optimization Approach Development

To optimize the weak points defined in chapter 4.2.1 approaches are developed. They represent a basis for development of solutions. The field of investigation of this master´s thesis is restricted to the forwarding department´s processes and areas (cf. Figure 4-32). Nonetheless, some optimization approaches exceed these boundaries to illustrate that some weak points have to be improved by global approaches (marked with "*"). Figure 4-33 shows which optimization approach affect which weak point.

Customer Education*

Customer education means to influence customer´s habits without limiting satisfaction while improving internal processes.

- Developing alternatives for used wooden cases improves customer´s as well as internal processes in terms of automation. (cf. Figure 4-32, customer education weak point one)
- A modified product pricing in terms of economies of scale (EOS) forces customers buying quantities creating less effort and less costs in production and logistics processes. Cheaper prices if whole pallets are ordered, is a way to influence customers´ habits as well as offering better prices for more flexible delivery dates. (cf. Figure 4-32, customer education weak point two)

Relocating Departments*

To relocate departments exceeds this master´s thesis´ investigation boundaries. Therefore, these approaches are discusses briefly.

- The relocation of test laboratories, forwarding department´s GI & GO areas and high-rack storage creates a new material flow system. Extensive optimizations can be achieved with this comprehensive approach. (cf. Figure 4-32, relocate departments weak point two to six)

- Also a new automated storage and retrieval system (ASRS) creates a new a significantly higher performance level, well adapted for modern requirements. (cf. Figure 4-32, customer education weak point one)

Software Update

An updated software is crucial for most of the optimization approaches. Also, several other improvements derive out of a new EWM system.

- A scheduling tool informing the forwarding department as well as ESP and truck drivers improves process timing and prevent overlapping of deliveries. (cf. Figure 4-32, software update weak point one)
- Checking products into the WMS or EWM by scanning products in production instead of scanning and checking products in the forwarding department creates better data for production as well as for logistics and a logistics process step of checking products into the system is omitted. (cf. Figure 4-32, software update weak point two)
- Improved internal communication between departments improves availability and utilization of machines. (cf. Figure 4-32, software update weak point three)
- A forecasting tool to predict GI & GO movements prevents unnecessary movements in and of storages, because in the current situation every single delivered load unit is stored into the high-rack storage, no matter if is going to be shipped the same day. (cf. Figure 4-32, software update weak point four)
- Reprogramming the existing WMS or implementing a new EWM system is necessary for optimization. (cf. Figure 4-32, software update weak point six and seven)
- Multiple order picking is possible when using a goods-to-man strategy. Reprogramming software enables to store random multiple items per bin. This results into better usage of storage space and improved occupation rates. (cf. Figure 4-32, software update weak point eight and nine)
- Continuous warehouse maintenance creates empty pallets inside the storage, because items are rearranged on pallets when they fall below a certain weight limit. (cf. Figure 4-32, software update weak point ten)
- By picking and simultaneously tagging products an actual state and location of every product is known. (cf. Figure 4-32, software update weak point 11)

Reorganize Layout

Reorganizing the current layout means to change area´s locations inside the forwarding department´s boundaries.

- To create a new layout the approaches to separate GI & GO and implement a one way material flow to avoid multidirectional one are recommended. (cf. Figure 4-32, reorganize layout weak point one to three)

Additional Machinery & Equipment

New machinery and equipment improve weak points, but creates investment costs.

- A new vacuum gripper simplifies packing processes. (cf. Figure 4-32, additional machinery & equipment weak point one)
- Positioning lights at the transfer rack visualize the availability of empty bins in the aisles behind, which reduces aisle changes. (cf. Figure 4-32, additional machinery & equipment weak point two)
- Additional QS racks outside the high-rack storage improve the storages occupation rate. (cf. Figure 4-32, additional machinery & equipment weak point three)
- Racks in the ground storage areas improve volume utilization. (cf. Figure 4-32, additional machinery & equipment weak point five)
- An additional rack for fast moving good outside the high rack storage relieves the high-rack storage. (cf. Figure 4-32, additional machinery & equipment weak point six)
- By adding a GO inspection scale every outgoing unit is able to be monitored and failure costs are be minimized. (cf. Figure 4-32, additional machinery & equipment weak point seven and eight)
- Additional racks for low weight pallets as well as for mixed pallets are recommended to be installed. (cf. Figure 4-32, additional machinery & equipment weak point nine and ten)
- By adding racks in front of the transfer racks (cf. Figure 4-2, area one and two) the transfer rack´s capacity is increased. (cf. Figure 4-32, additional machinery & equipment weak point 11)
- By implementing crane positioning assistant picking times are reduced. (cf. Figure 4-32, additional machinery & equipment weak point 12)
- With an order picking system, ergonomic and fast picking outside the high-rack storage is possible and crane performances increases. (cf. Figure 4-32, additional machinery & equipment weak point 13)

Reorganize Processes

Reorganizing processes means to add, delete or modify processes.

- To identify and store low weight pallets outside the high-rack storage is a new process. (cf. Figure 4-32, reorganize processes weak point one)
- Load trailers as they are shipped from ESP is a new process to avoid additional handling. (cf. Figure 4-32, reorganize processes weak point two)
- New picking processes outside the high-rack storage, as well as the resulting double cycle processing inside the SRS derive from a new order picking system. (cf. Figure 4-32, reorganize processes weak point three and four)
- A GO inspection process is new, if there is a GO inspection scale added. (cf. Figure 4-32, reorganize processes weak point five)

Reorganize Transportation

Moving goods between buildings in another way than with trucks and trailers improves the material flow as well as situations in buffer and storage. A certain possibility is discussed in chapter 4.4.2.

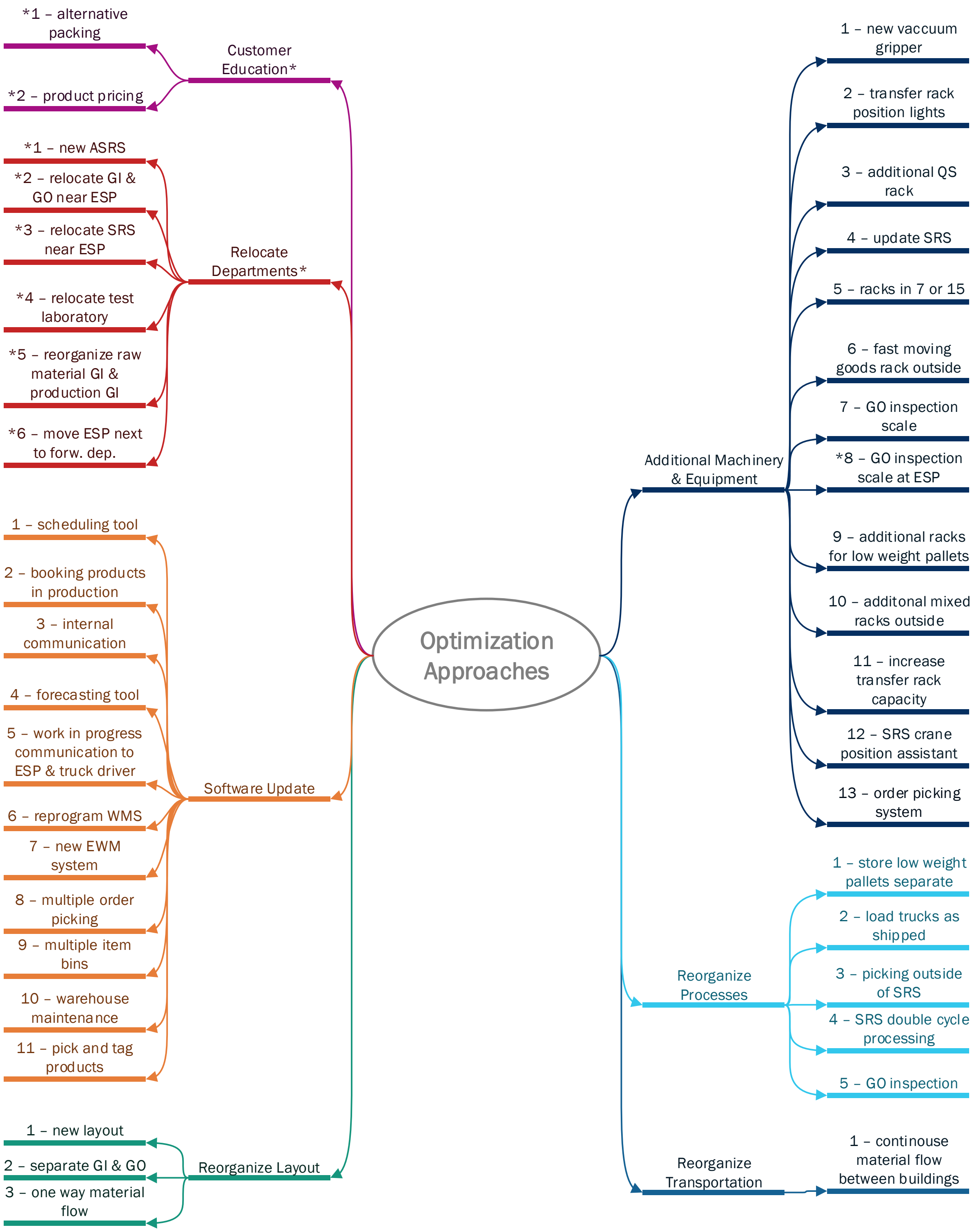

Figure 4-32: Optimization Approaches

	Optimization Approaches	alternative packing*	product pricing*	new ASRS*	relocate GI & GO*	relocate SRS*	relocate test lab*	reorganize raw mat GI*	move ESP*	scheduling tool	booking products	internal communication	forecasting tool	WIP communication	reprogram WMS	new EWM system	mutiple order picking	multiple item bins	warehouse maintenance	pick and tag products	new layout	separate GI&GO	one way material flow	new vaccuum gripper	transfer rack pos. Lights	additional QS rack	update SRS	racks in 7 or 15	fast moving goods rack	GO inspection scale	GO inspection scale at ESP	add racks for low weight pal	add. Mixed racks	increase transfer rack capacity	SRS crane position assistant	order picking system	separate low weight pallets	load trucks as shipped	picking outside of SRS	SRS double cycle processing	GO inspection	continouse material flow
Weak Points	**Abbr**	CE-1	CE-2	RD-1	RD-2	RD-3	RD-4	RD-5	RD-6	SU-1	SU-2	SU-3	SU-4	SU-5	SU-6	SU-7	SU-8	SU-9	SU-10	SU-11	RL-1	RL-2	RL-3	AM-1	AM-2	AM-3	AM-4	AM-5	AM-6	AM-7	AM-8	AM-9	AM-10	AM-11	AM-12	AM-13	RP-1	RP-2	RP-3	RP-4	RP-5	RT-1
artificial peaks	P-1							•	•																																	•
transport intensity	W-5			•	•	•	•	•	•												•	•	•																			
failure costs	P-22														•	•			•	•										•	•					•					•	
processing at limits	M-12			•	•	•	•			•	•	•	•				•																		•	•			•	•		
two driving directions in aisle	M-7			•	•	•	•								•	•				•																						
single cycles per hour	W-1			•	•	•	•																												•	•			•	•		
foil damaged	P-6							•	•																													•				•
used weight potential	W-4		•	•	•	•	•								•	•	•	•	•													•	•			•	•					
weak coordination	L-8							•	•					•	•	•					•	•	•													•						•
blocking SRS	L-10			•	•	•	•	•	•	•	•	•		•							•	•	•											•		•						•
GI-GO ratio	W-2		•																																		•					
SRS GO weight	W-6		•														•																									
order´s material weight	W-7		•																																							
unflexible WMS	M-5			•	•	•	•								•	•																										
frequent overflow	L-7			•	•	•	•			•	•			•							•	•	•																			•
no strict rules	P-9							•	•												•	•	•													•						•
fast moving goods inside	P-17			•	•	•	•					•	•																•							•			•	•		
narrow	L-9			•	•	•	•														•															•						
close to buffer	L-11			•	•	•	•														•															•						
traffic	L-14			•	•	•	•														•		•																			
many functions	P-10			•	•	•	•	•	•		•										•	•	•													•						
handling effort	P-11							•	•		•																									•						
weak scheduling	P-4							•	•	•	•	•	•	•	•	•																										•
predestrians	L-13			•	•	•	•														•																					
ESP at wrong side of building	L-1			•	•	•	•	•	•																																	
large distance to forwarding dep.	L-2			•	•	•	•	•	•																																	
multidirectional material flow	L-3			•	•	•	•														•	•	•													•						
both lanes GI & GO	L-4			•	•	•	•														•	•	•																			
two different locations	L-5			•	•	•	•														•	•	•																			
no border to buffer	L-12			•	•	•	•														•															•						
located in a busy area	L-15																				•															•						•
close to buffer	L-16																				•																					
fork change necessary	P-2			•	•	•	•	•	•																																	•
truck loading	P-7			•	•	•	•	•	•																																	•
small forks needed	M-8			•	•	•	•																		•									•								•
small transfer rack buffer	M-14			•	•	•	•																											•		•				•		
unloaded and loaded again at ESP	P-8				•	•	•	•	•																													•				
man to goods	P-25			•	•	•	•								•	•																				•			•			
searching for units to be loaded	L-18																				•	•						•														
self inhibiting	L-6									•	•										•	•	•													•						•
truck is not available all the time	L-17				•	•	•	•	•	•		•	•	•														•														•
empty runs	P-12			•	•	•	•								•	•	•	•	•																	•			•	•		
leave to send picking list	P-13			•	•	•	•								•	•											•									•						
manual sequencing of picking	P-14			•	•	•	•								•	•																				•						
manual pallet planning	P-15			•	•	•	•								•	•																				•						
leave to get picking lilst	P-16			•	•	•	•								•	•											•									•			•			
picking inside of SRS	P-18			•	•	•	•								•	•																				•			•			
old	M-10			•	•	•	•								•	•																										
manual positioning	M-11			•	•	•	•								•	•																			•							
DC motors in cranes	M-13			•	•	•	•																																			
occupation	W-3			•	•	•	•								•	•		•	•							•		•	•			•	•	•		•	•		•			
slow aisle change	M-9			•	•	•	•								•	•									•																	
overlapping deliveries	P-3							•	•	•		•	•	•	•	•						•																				•
bad communication	P-5							•	•			•	•	•	•	•																										
handling effort	P-21			•	•	•	•								•	•	•										•									•			•			
no pickup light	M-6			•	•	•	•								•	•									•											•						
ergonomics	P-23																																			•			•			
no automation possible	P-24	•																																								
full	M-3			•	•	•	•								•	•		•															•									
small	M-4			•	•	•	•								•	•		•															•									
not every box can be picked	M-1	•																						•																		
bad volume utilization	M-2																											•														
storage space	P-19														•	•	•																			•			•			
waiting for 2nd order	P-20														•	•	•																			•			•			

Figure 4-33: Weak Points & Optimization Approaches

With these investigations (cf. Figure 4-32) 41 optimization approaches are developed. Optimization approach effects and feasibility differ from each other. To ensure further investigations are focused on effective and feasible approaches, they are rated in Figure 4-34. Approaches are arranged depending on affected weak point´s risk priority numbers (0 – low RPN, 1 – high RPN) and possible solutions´ feasibility (0 – hard to realize, 1 – easy to realize). Sizes of areas A, B and C in Figure 4-34 are defined with the project partner´s agreement.

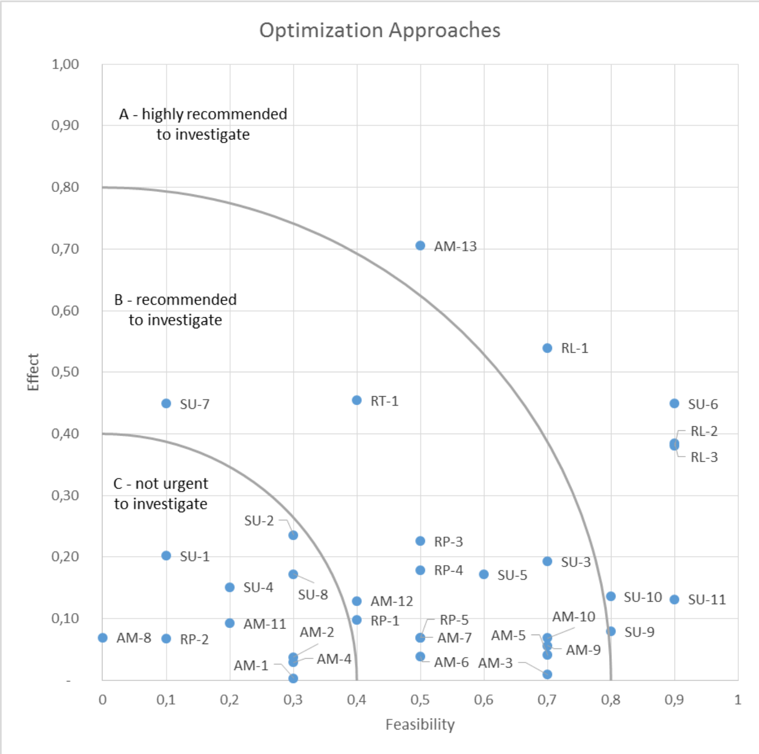

Figure 4-34: Optimization Approach Rating

Technical and practical solutions of optimization approaches are described and discussed in chapter 4.4 as well as the solutions´ consequences on the material flow system.

4.4 Solutions

Solutions derive out of all optimization approaches (cf. Figure 4-32). Optimization approaches are summarized to solutions because of similarities and dependencies between optimization approaches. Based on Figure 4-34 approaches, which are highly recommended or recommended to be investigated in detail are summarized in following solutions:

- New Layout
- Logistic Train
- Multiple Item Bins
- Additional Racks
- Order Picking System
- Goods-Out Inspection Scale

4.4.1 New Layout

Rearranging areas in the layout will lead to a reduction of transport intensity and therefore to higher performance and cost savings. Figure 4-35 shows a new layout, in which the goods-in areas (GI Lane, GI Buffer) is moved into the former area 14 (cf. Figure 4-2). With this improvement a directed material flow is realized, which reduces traffic and distances. The area in front of the high-rack storage is relieved and blocked areas due to overloads are not likely anymore. The calculated transport intensity of 3.6 million pallet meters generates a saving of 16%. This improvement reduces costs directly. In order to realize this new layout no investment is necessary and cost reduction happens immediately.

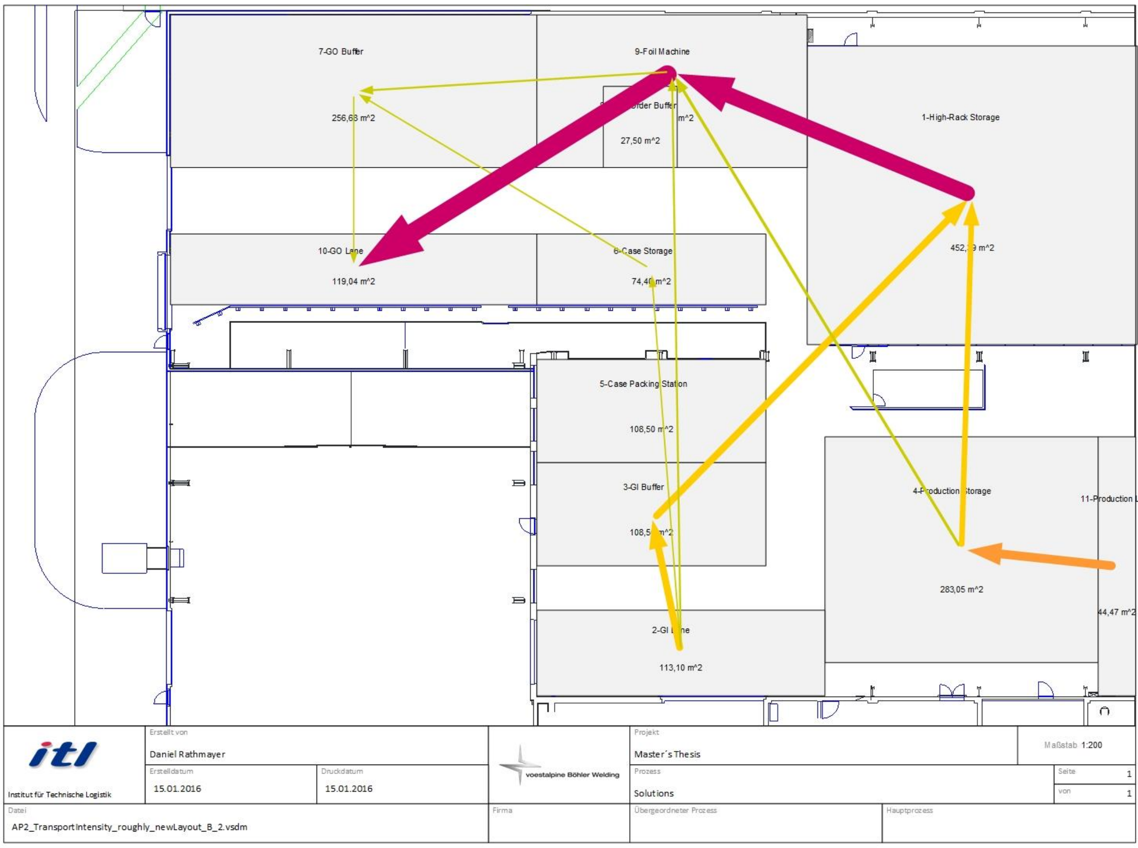

Figure 4-35: New Layout

4.4.2 Logistic Train

A logistic train (cf. Figure 4-36) transportation between the external forwarding service provider and the forwarding company, realizes a reduction of peaks in transportation and workload. A continuous material flow reduces overflows as well as buffer capacities and enhance error free processes. Also pallet handling is faster and a higher goods-out performance is achieved. With an investment of about €100,000 (concerning an offer form the company STILL) an appropriate tow tractor and carriers are purchased and implemented.

Figure 4-36: Logistic Train (cf. [LIN16])

4.4.3 Multiple Item Bins

Loading bins with multiple items reduces the occupation of the high-rack storage. For example 25% of all occupied bins are currently loaded with 390kg or less (cf. Figure 4-21). By mixing products on pallets and creating a minimum load of 810kg per bin, all these light weight bins are saved and pallets with two different materials on them are created. Figure 4-37 shows the split of light pallets. Differently chosen minimum weights per pallet inside the high-rack storage create other savings. Table 4-7 shows recommended possibilities. No investments are necessary for this solution, however the current warehouse management software has to be modified. While picking inside the high-rack storage the single product´s accessibility decreases with increasing minimum weight per pallet. To use this solution´s saving potential a goods-to-man strategy is reasonable (cf. chapter 4.4.5).

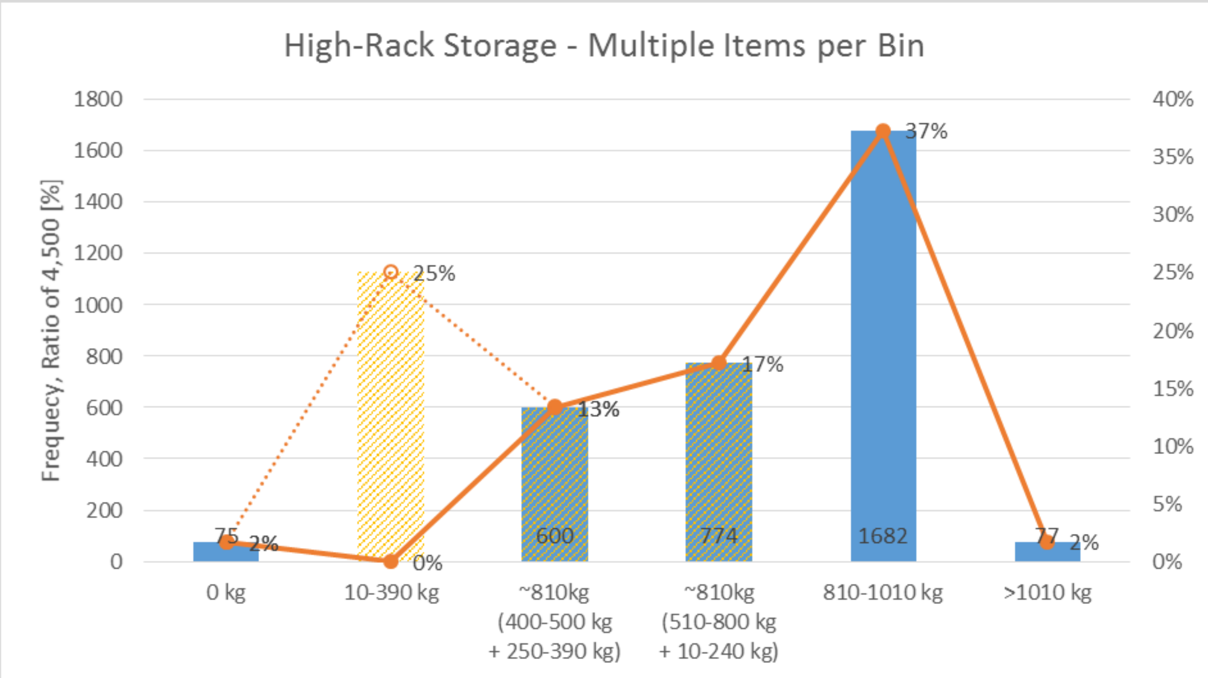

Figure 4-37: Multiple Items per Bin

Table 4-7: Occupation Savings

min. Weight	New Occupation	Savings
310 kg	84%	11%
460 kg	79%	17%
610 kg	74%	21%
770 kg	70%	26%
810 kg	70%	26%

4.4.4 Additional Racks

Light weight pallets removed and stored in additional racks prevent hardly accessible products by achieving lower degrees of occupation inside the high-rack storage. In an additional rack pallets have minimum weights too while being stored more compactly in comparison to the current high-rack storage. For example all pallets up to a weight of 300kg are removed from the high-rack storage, rearranged to pallets with a minimum of 310kg and stored in a new push back rack with a bin´s height of about 500mm. Also QS products are stored outside the high-rack storage. Additional racks are placed on several locations. Figure 4-38 (Mixed- and QS Storage) shows one possibility. A combination of additional racks and multiple items per bin is a solution. Table 4-8 shows savings and additional needs of capacity. Depending on the minimum weight of pallets in additional racks, a certain number of layers of boxes stored on them derives (cf. Table 4-9. Table 4-10 shows savings when products are stored outside the high-rack storage in combination with a minimum weight inside the high-rack storage. Depending on storage types (conventional pallet storage, live storage, push back storage) and capacities, an investment between €5,000 and €50,000 (concerning bin prices of the company SSI Schäfer) is necessary. To use potential of the solution a goods-to-man strategy is reasonable (cf. chapter 4.4.5).

Table 4-8: Occupation Savings with Additional Racks

Number of bins in add. rack	Out up to	300 kg	400 kg	460 kg
	Savings	21%	28%	36%
min. weight in additional rack	150 kg	910	1,621	2,604
	310 kg	440	785	1,260
	460 kg	297	593	849
	610 kg	224	529	641
	770 kg	178	399	508
	920 kg	149	316	425

Table 4-9: Number of Box-Layer on Pallet

Out up to	Number of Layers
150 kg	1
310 kg	2
460 kg	3
616 kg	4
770 kg	5
924 kg	6

Table 4-10: Combined Occupation Savings

Savings	min. Weight Inside				
Out up to	460 kg	610 kg	770 kg	810 kg	920 kg
300 kg	23%	28%	32%	33%	38%
400 kg	-	32%	35%	37%	40%
460 kg	-	37%	40%	41%	44%

4.4.5 Order Picking System

One of the major weak points (cf. Figure 4-34) in the forwarding department´s current status is the man-to-goods strategy, which results in picking inside the high-rack storage. By implementing an order picking system, a goods-to-man strategy is possible. Higher picking performances, monitoring and controlling during picking as well as better work ergonomics are results. Also the high-rack storage cranes´ limited performance is raised up to 40 double cycles per hour. This is a theoretical increase of 400% or more. Additional conveyors connecting the goods-in area with the order picking system forklift truck, decrease traffic drastically. Figure 4-38 shows a layout with such an order picking system and its material flow. Figure 4-39 shows a picture of the picking order system. The resulting transport intensity is 1.8 million pallet meters, which is a reduction of about 57% compared to the current state. An approximately investment of €200,000 (according to estimated costs of €1000 per meter of transportation elements) is necessary to implement this solution. With such a system accessibility of all products is ensured, even though they are stored on multiple item pallets. Also goods-out controlling and monitoring are implemented easily in this system. The goods-in control and booking process happens on an extended conveyor, which is reaching into the goods-in area. Figure 4-39 shows a possible realization of such an order picking system.

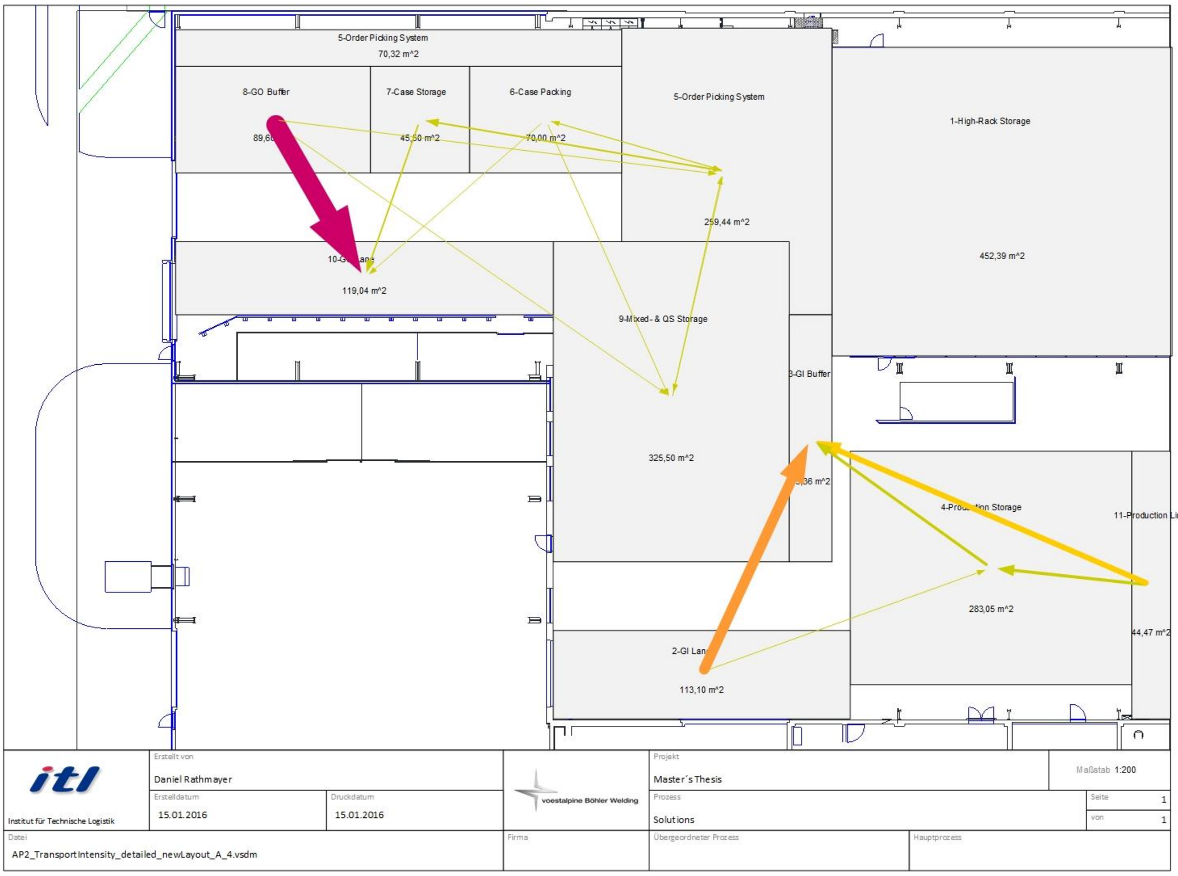

Figure 4-38: New Layout - Order Picking System

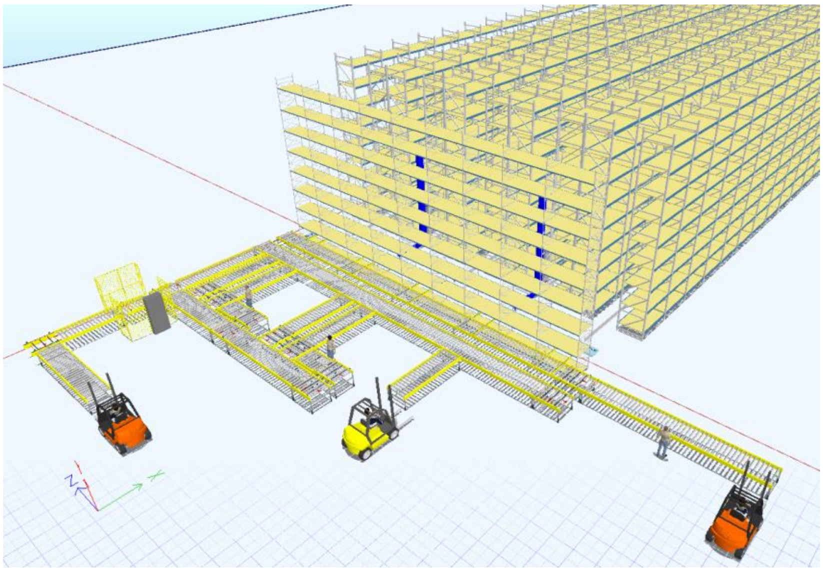

Figure 4-39: Order Picking System

4.4.6 Goods-Out Inspection Scale

An inspection scale implemented in the goods-out process prevents wrong shipments and expensive rework or even more expensive customer complaints. Due to the detailed knowledge of product weights and therefore picked order and pallet weights, every outgoing pallet can be checked. This solution describes two different types of goods-out scales. First, a stationary pallet scale is recommended to be placed in the goods-out area. In this case every packed pallet has to be checked there before it is loaded on a trailer. This is a rather simple solution and comes up with the disadvantage of picking pallets twice before being loaded. The second solution is a scale, which is mounted at a forklift truck´s forks. In this case every forklift truck is equipped with such a scale and additional. Investments for such scales range from €900 for a stationary scale, to €3,500 for a weight fork (prices form BOSCHE Wägetechnik and Gebrüder Schnitt GmbH).

5 Validation & Evaluation of Implementation

In this chapter solutions developed in chapter 4.4 are evaluated based on effects, benefits and investments. Figure 5-1 shows affected weak points´ sum of risk priority numbers (RPN) which derive out of investigations in chapter 4.2.2. The RPN rating "1" in Figure 5-1 represents the biggest sum of RPN and therefore the highest theoretical impact of solutions. The second rating from zero to one derives from a value benefit analysis (VBA). This analysis includes investment costs and improvements of transport intensity, high-rack storage occupation and processes (cf. chapter 4.4). Low investments and high improvements results in a VAB value close to one. Table 8-3 shows details of the VBA. Different possibilities for realization of the solution create differences of the VBA values. They are shown as areas in Figure 5-1. Sizes of areas A, B and C in Figure 5-1 are defined with the project partner´s agreement.

New Layout

Weak points like a non-directed material flow going through narrow and busy routs inside the forwarding department, the simultaneous usage of truck lanes for goods-in and goods-out (cf. chapter 4.2.1), as well as separate locations of the truck lanes which results in bigger transportation efforts (cf. chapter 4.1.2 and chapter 4.1.4.2) are defined and discussed in chapter 4.2.

Chapter 4.3 shows different optimization approaches to improve the current layout and the resulting weak points (cf. Figure 4-32). Out of the connection of weak points and optimization approaches (cf. Figure 4-33) in combination with separate risk priority rating of every single weak point (cf. chapter 4.2.2) defined solutions are risk priority rated and recalculated to values between zero and one (cf. Figure 5-1).

The solution "New Layout" derives out of layout optimization approaches. The more weak points a single solution affects and the higher these weak points´ risk priority numbers are, the higher is a solution´s risk priority number in Figure 5-1. The solution "New Layout" affects many weak points with high risk priorities. In relation to other solutions, Figure 5-1 shows a RPN of more than 0.7 for the solution "New Layout".

A value benefit analysis (VBA) compares solution´s investment costs, the improvement of transport intensity, the improvement of occupation inside the high-rack storage and process improvements. Table 8-3 shows values for every solution. Due to the fact that the solution "New Layout" creates improvements without any investments (cf. chapter 4.4.1), the implementation of a new layout gets the highest VBA value and is highly recommended to be implemented.

Logistic Train

The location of the ESP (cf. chapter 4.1.2) creates a need of transportation between two buildings. The realization of this transportation by trucks and trailers (cf. cf. 4.1.3) results in artificial peaks of work load. Processes have to be done simultaneously and goods-in and goods-out buffer zones are overwhelmed (cf. chapter 4.2.1). Figure 4-31 shows that weak points concerning the ESP location are very crucial.

Optimization approaches which are connected to these ESP weak points (cf. Figure 4-32 and Figure 4-33) are consolidated to the solution “Logistic Train” (cf. chapter 4.4.2). A logistic train harmonizes the material flow and creates a continuous material flows. Due to affected weak points and their risk priority numbers the logistic train solution has a RPN of 0.25 (cf. Figure 5-1) in comparison to other solutions´ RPN. The VBA in Table 8-3 shows a value of 0.25 because of slight improvements connected with investments (cf. chapter 4.4.2). Nevertheless, this solution is recommended to be implemented because of process improvements and an increase of performance.

Multiple Item Bins

The occupation of the high-rack storage is one of the main reasons of this project (cf. chapter 2.3). Data analysis shows high occupation while having low weight utilization inside the high-rack storage (cf. chapter 4.1.4.2). Deriving weak points and their ratings are summarized in the solution “Multiple Item Bins”.

Chapter 4.4.3 describes different possibilities of the multiple item bins solution based on various minimal weights inside the high-rack storage. All these variants with different minimal weights per bin have the same RPN of 0.2 (cf. Figure 5-1) because they are affecting the same weak points. The VBA in Table 8-3 shows different values for every variant, because due to the minimal weight per bin inside the high-rack storage, different improvements of occupation result. The VBA values in Table 8-3 are based on these occupation improvements. Due to this variety of the VBA value the solution “Multiple Item Bins” is represented by a bigger area in Figure 5-1.

To implement multiple item bins is recommended, because it does not require any investments and occupation can be improved up to 26%. This solution is dependent on the solution “Order Picking System”, because high minimum weights per bin are feasible if picking is done outside the high-rack storage (cf. chapter 4.4.3)

Additional Racks

The high occupation of the high-rack storage derives out of low weight utilization (cf. chapter 4.1.4.2). To improve this situation the “Additional Racks” solution merges various optimization approaches described rated in chapter 4.2. Concerning to the weak points´ RPN (cf. Figure 4-30) and their connections to optimization approaches (cf. Figure 4-33) the solution’s RPN is calculated to 0.15.

The additional rack solution is divided into different variants (cf. chapter 4.4.4). Due to these different variants and their different improvements Table 8-3 shows four different VBA values for 0.34 to 0.42 due to investments and high improvements. This results an area in Figure 5-1.

To reach the project goals of reduction of occupation of 25% (cf. chapter 2.3) the additional rack solution is recommended to be implemented. Similar to the “Multiple Item Bins” solution the “Additional Racks” solution is dependent form an implementation of the “Order Picking System” solution´s implementation.

Because without an implementation of an order picking system additional racks cannot be implemented into processes efficiently.

Order Picking System

In the current situation, the picking process is executed inside the high-rack storage (cf. chapter 4.1.3). Low pick performance restricts the forwarding department´s performance because of old and slow cranes inside the high-rack storage, as well as single cycle processing, which results out of a man-to-goods strategy (cf. chapter 4.2).

The implementation of an order picking system affects many weak points with high risk priority numbers and affects the feasibility of other solutions (e.g. multiple item bins) too (cf. chapter 4.4.5). Therefore, the RPN of the order picking system solution is almost one in Figure 5-1. A VBA value of 0.3 in Table 8-3 derives because of improvements of transport intensity and process improvements although a high investment is necessary (cf. chapter 4.4.5).

Goods-Out Inspection Scale

Possible failures during picking inside the high-rack storage lead to high costs (cf. chapter 4.2). Optimization approaches concerning goods-out failures (cf. Figure 4-32) are connected with defined weak points (cf. Figure 4-33).

The solution “Goods-Out Inspection Scale” derives out of defined optimization approaches to prevent goods-out failures. A RPN of 0.1 and a VBA value of 0.31 place the solution in the “not urgent to change” area in Figure 5-1. Due to investments of max. €7,000 and a direct effect on customer´s satisfaction, this solution is recommended to be implemented (cf. chapter 4.4.6). In case of a realization of the order picking system, the goods-out inspection scale is already implemented and no additional scales are needed.

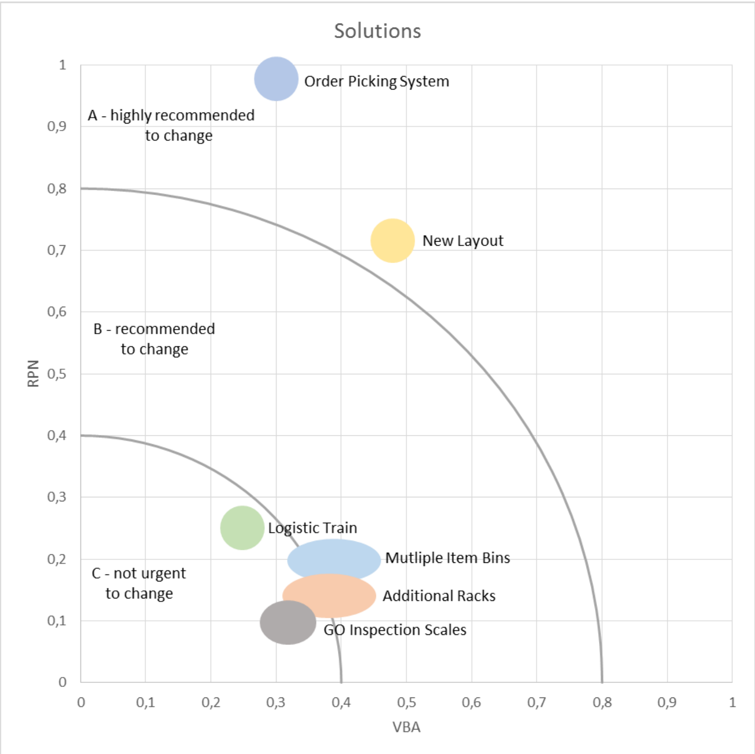

Figure 5-1: Solutions´ Evaluation

6 Conclusion

The analysis of the actual state shows issues in ongoing processes and storage occupation. Future challenges that are defined by changing conditions and changing requirements of customers are not manageable with the current system.

The permanent high occupancy in storages leads to slow and non-controllable processes and mistakes. The sparely usage of information technology and customers´ product order behavior worsen this situation. It is highly recommended to rethink the strategy of storing products on pallets because product boxes have to be picked anyways. Due to the customers´ order behavior a box based instead of a pallet based system is more efficient. Investigations concerning this topic are recommended to done in another project.

Besides an analysis of the actual state of process, material flow and warehouse data, a reduction of the high-rack storage´s filling rate and a cost reduction of both 25% are appointed goals. These goals are achieved with developed and recommended solutions. A reduction of occupancy is assessed quantitatively and theoretically achievable improvements exceed appointed goals. Costs are decreased by reduction of transport intensity, reduction of failure probability and increase of performance. Quantitatively evaluated improvement of transport intensity directly affects cost and therefore also appointed cost reduction goal are achieved theoretically.

Figure 6-1 shows a recommended course of action, starting with rearrangement of the layout to generate benefits without investments and less efforts. Multiple item bins are recommended to be implemented in the high-rack storage because no investments but only some effort is necessary for this step. Then, the logistic train is recommended to be purchased and implemented. This is the first step including a financial investment. Next the decision about the implementation of an order picking system and therefore introducing a goods-to-man strategy has to be done. The author recommends to implement a goods-to-man strategy and to add racks to generate more storage capacity.

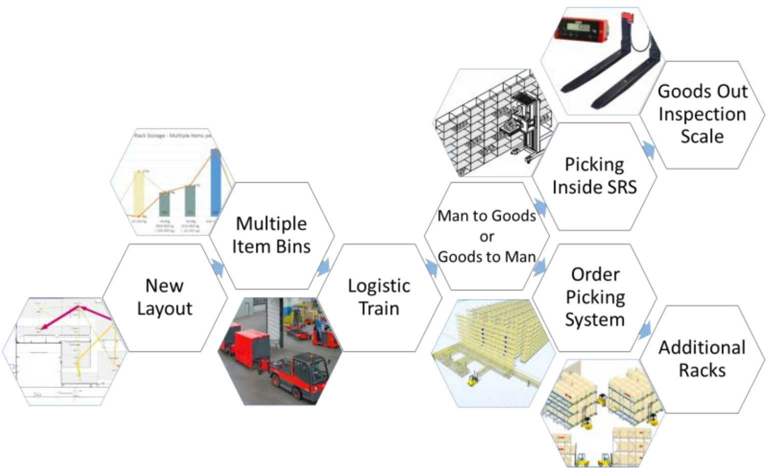

Figure 6-1: Recommended Course of Action

This Master´s Thesis´ recommendation is to set managing actions according the given course of action, to achieve and theoretically exceed appointed goals.

7 Bibliography

7.1 Bibliography.

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7.2 List of Figures

7.3 List of Tables

7.4 List of Equations

8 Appendix

8.1 Appendix A – Published Short Text

Master´s Thesis´ published short text from TUG-online, in English and German.

8.1.1 Abstract

This Master´s Thesis makes a statement about optimization potential of a warehouse in a manufacturing company. This Master´s Thesis shows possible solutions to exploit the potential.

The implementation of this Master´s Thesis is separated into three parts. First a detailed analysis of the actual state is done. In this first part the layout and different areas are analyzed and defined. Also processes are investigated and visualized and a qualitative cost analysis gives insights into the system. Detailed material flow investigations come up with knowledge about transport intensities and weak points. A warehouse data analysis as well as investigations concerning behavior of customers generates important information. Followed by an expert analysis of the current state an adequate basis for further investigations is made. The definition, classification and evaluation of weak points completes the analysis of the actual state.

In the second part a development of optimization approaches shows possible ways to improve the project partner´s forwarding department and gives insights in improvement potentials.

The third part of implementation is the development of specific solutions, which are recommended to be realized in the future. To ensure feasible and effective solutions, the recommended solutions are based on optimization approaches, which are rated concerning specified criteria.

A validation and evaluation of developed solutions comes up with a course of action. This course of action recommends the procedure of implementing solutions, to meet appointed goals.

8.1.2 Kurzfassung

Diese Masterarbeit trifft eine Aussage über das Optimierungspotential eines Warenlagers in einem produzierenden Unternehmen und zeigt Lösungsmöglichkeiten um dieses Potential zu nutzen.

Eine detaillierte Analyse des Ist-Standes geht im ersten Schritt auf den Grundriss des Versandlagers und der umliegenden Bereiche ein. Im Zuge dessen werden einzelne Bereiche definiert und ausführlich beschrieben. Die Erhebung, Darstellung und qualitative Kostenbewertung von Prozessen gibt tiefe Einblicke in Vorgänge. Aus diesen Erkenntnissen und weiteren Datenanalysen werden Materialfluss sowie Transportintensität bestimmt. Diese weisen auf erste Schwachstellen des Systems hin. Auch eine Lageranalyse sowie die Untersuchung des Kundenbestellverhaltens sind Teil dieses Analyseabschnittes. Fachkundige Experten aus der Industrie geben in einem Interview ihre Meinung zu dem vorliegenden Problem ab. Eine anschließende Definition von auftretenden Problemen schießt diesen Abschnitt ab.

Darauf aufbauend werden Ansätze zur Optimierung entwickelt und untersucht. Diese zeigen Möglichkeiten auf, wie das Versandlager und die umliegenden Bereiche optimiert werden können.

Daraus entwickelte Lösungsvorschläge sind Vorschläge, wie das System in Zukunft verbessert werden kann. Diese Lösungen basieren auf den zuvor entwickelten Optimierungsansätzen. Um sicherzustellen, dass die entwickelten Lösungen realisierbar und effektiv sind, werden die zugrunde liegenden Ansätze entsprechend evaluiert und bewertet.

Das Endergebnis stellt ein Vorschlag zu weiteren Vorgehensweise dar. Darin wird empfohlen in welche Lösungen realisiert werden sollen, um die gesteckten Ziele zu erreichen.

8.2 Appendix B – Additional Information

8.2.1 Process Illustrations

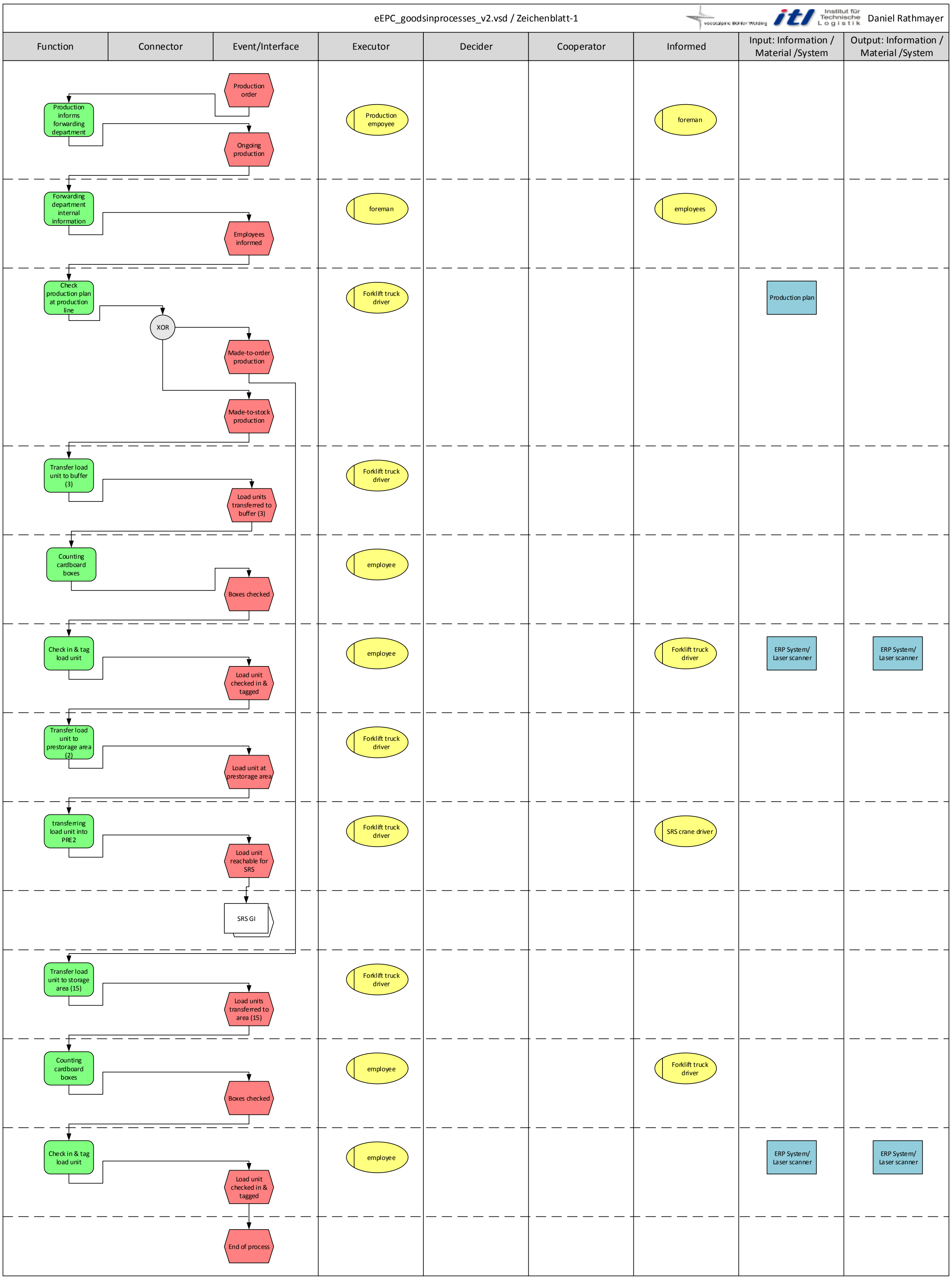

Figure 8-1: eEPC Production Output Process

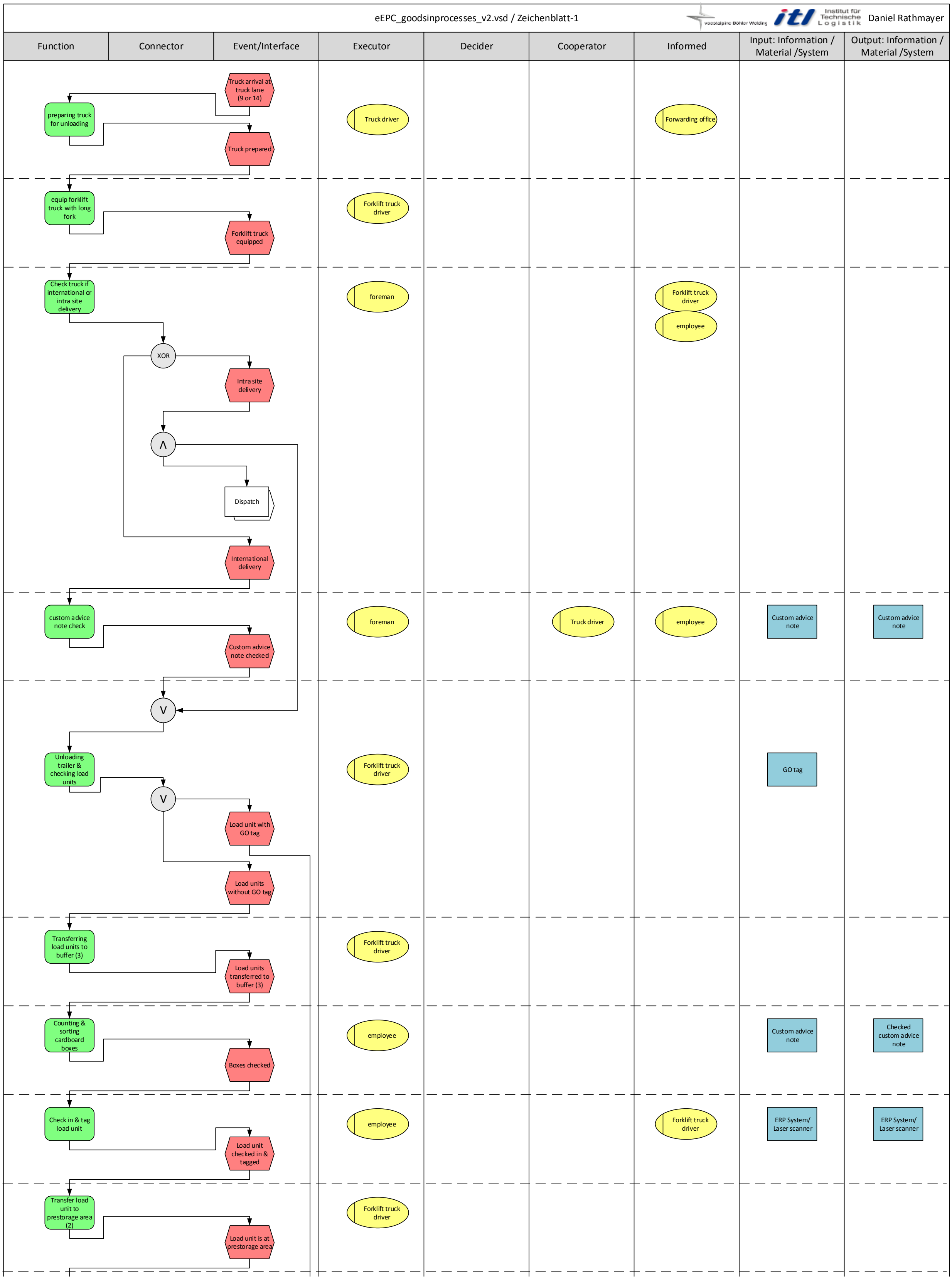

Figure 8-2: eEPC Truck Delivery Process Part 1

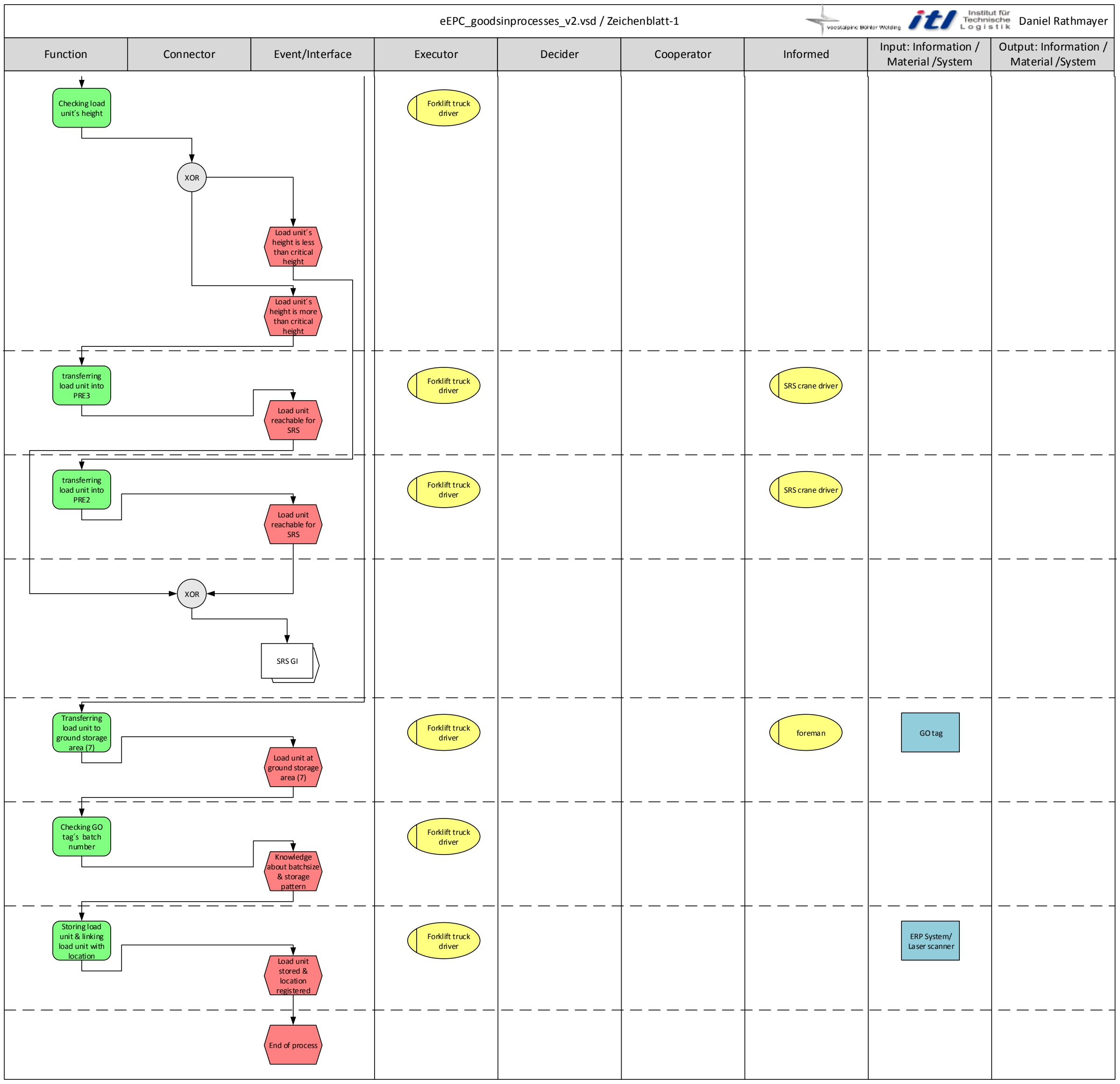

Figure 8-3: eEPC Truck Delivery Process Part 2

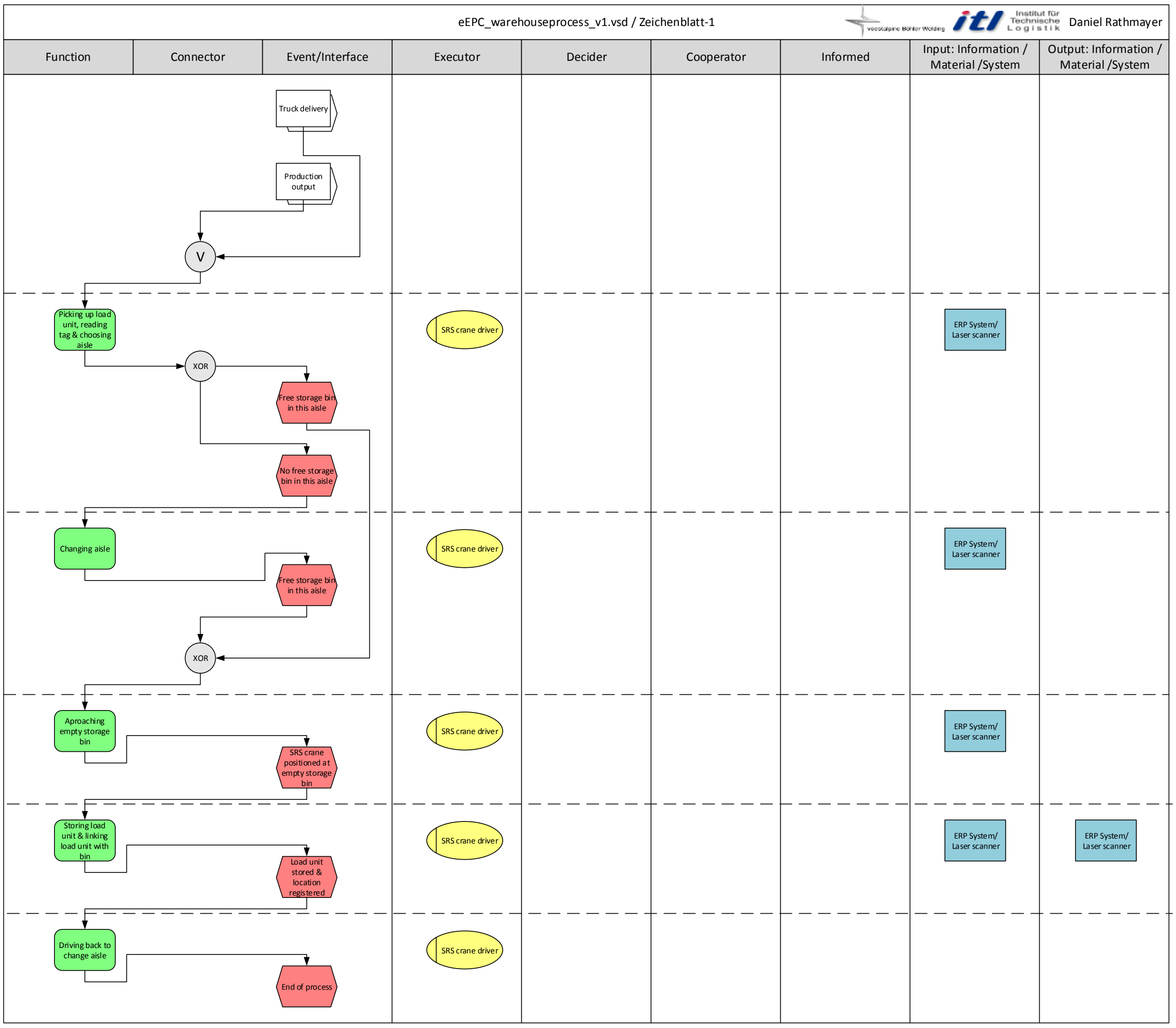

Figure 8-4: eEPC SRS GI Process

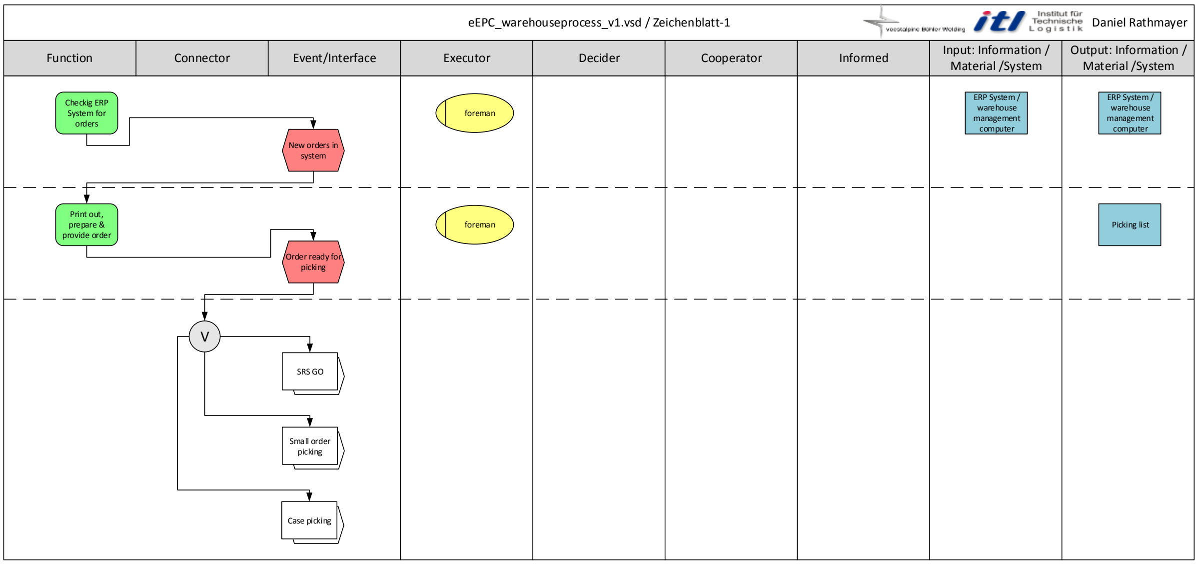

Figure 8-5: eEPC Picking List Preparation Process

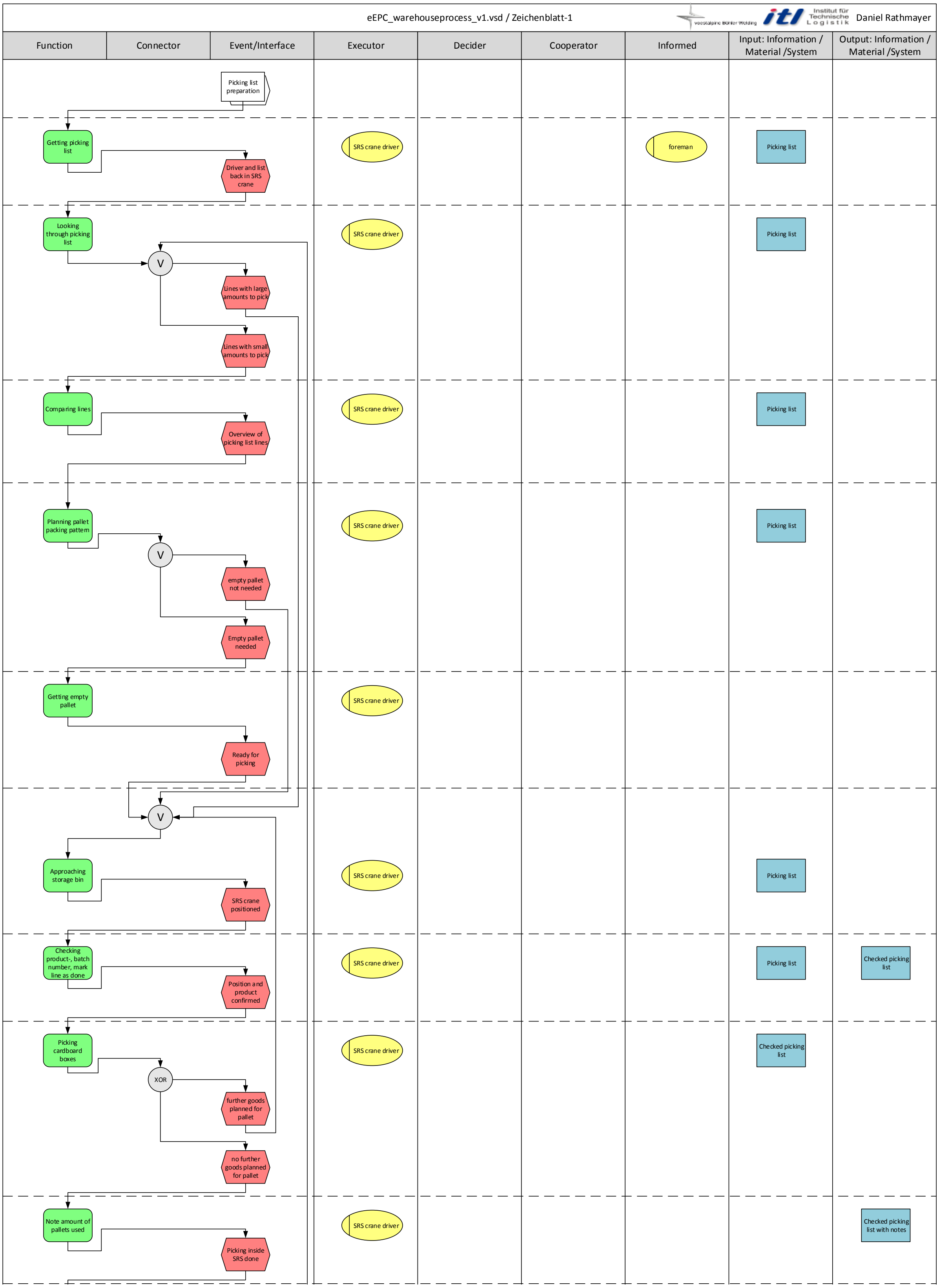

Figure 8-6: eEPC SRS GO Process Part 1

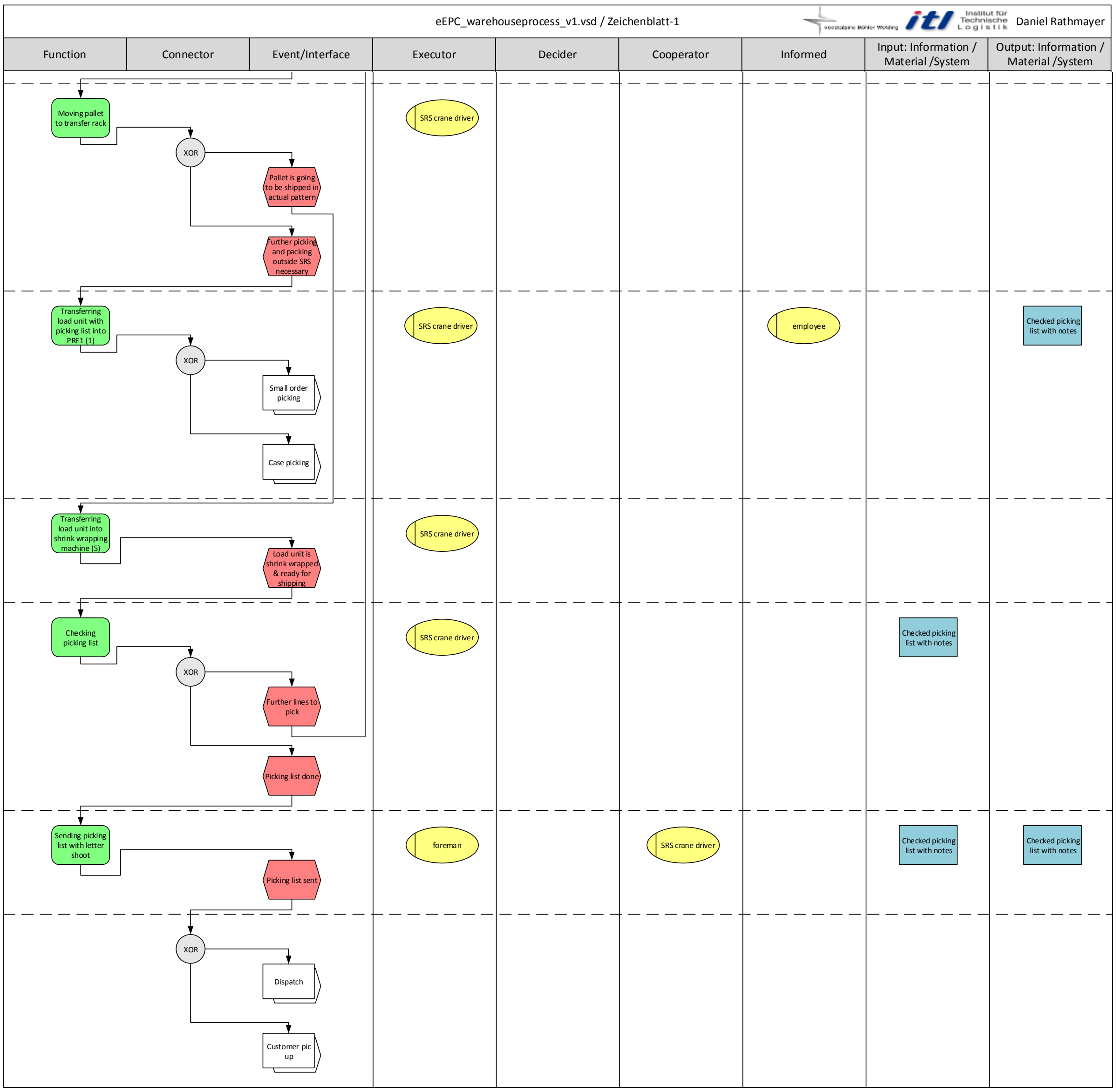

Figure 8-7: eEPC SRS GO Process Part 2

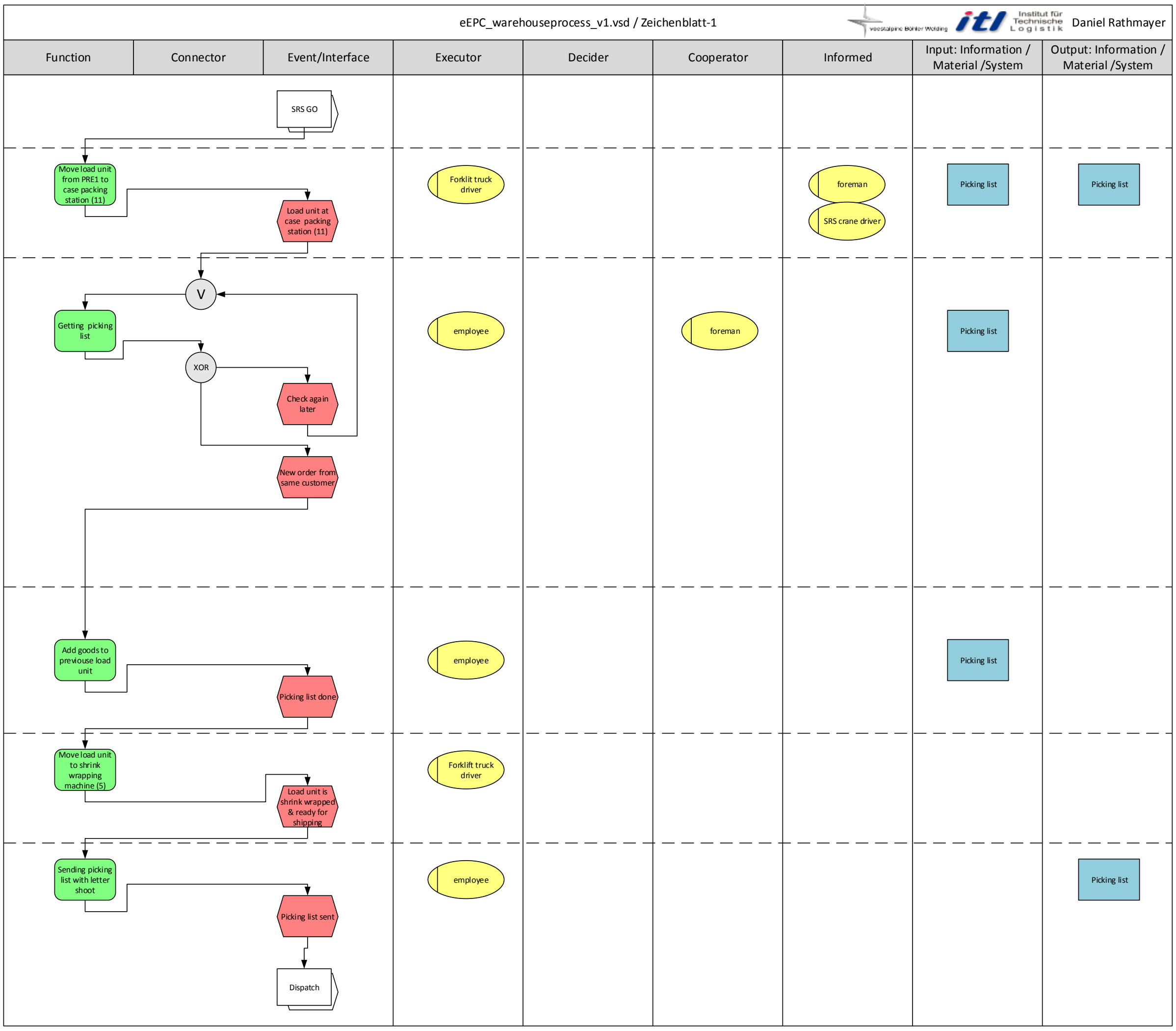

Figure 8-8: eEPC Small Order Picking Process

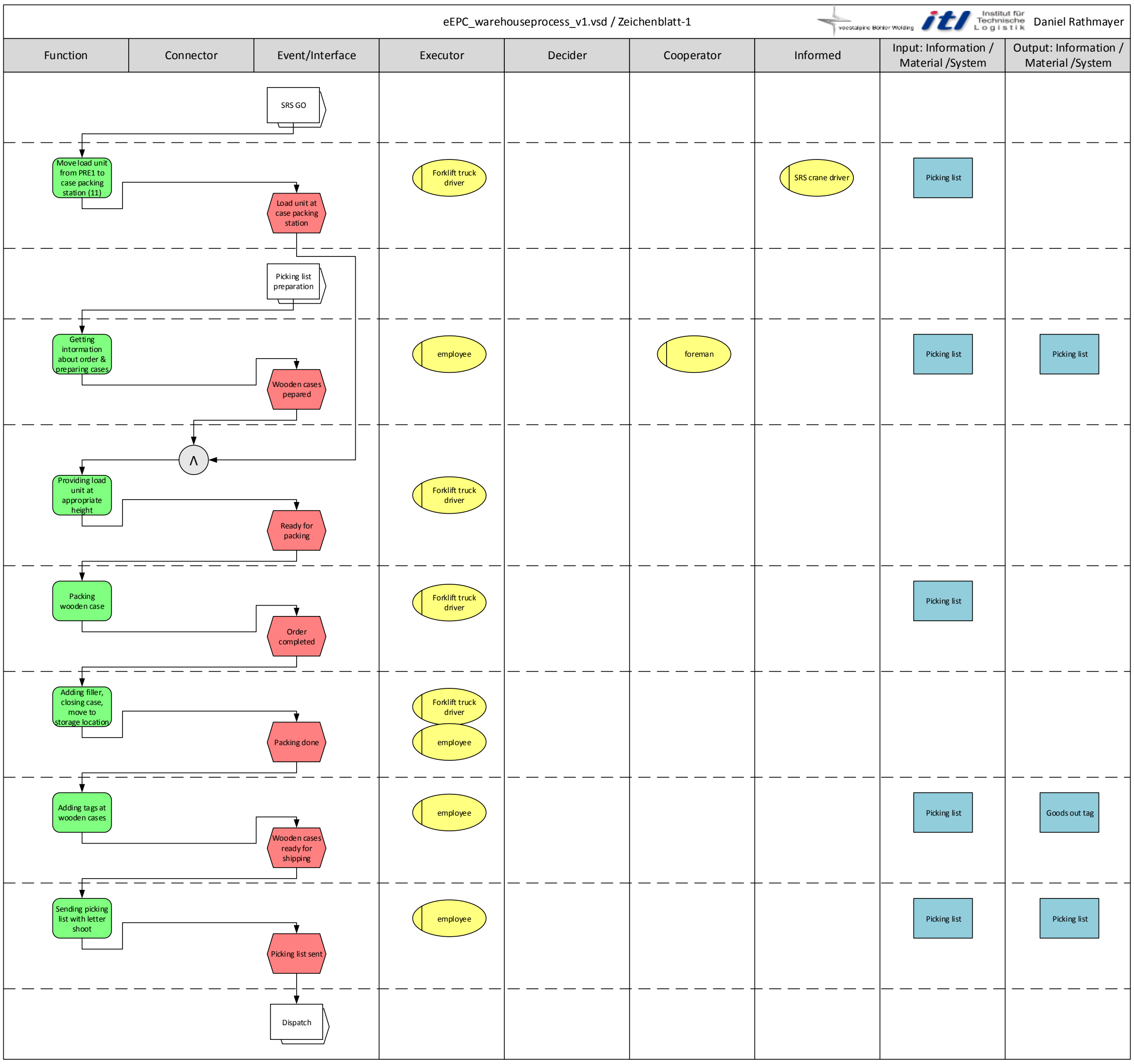

Figure 8-9: eEPC Case Packing Process

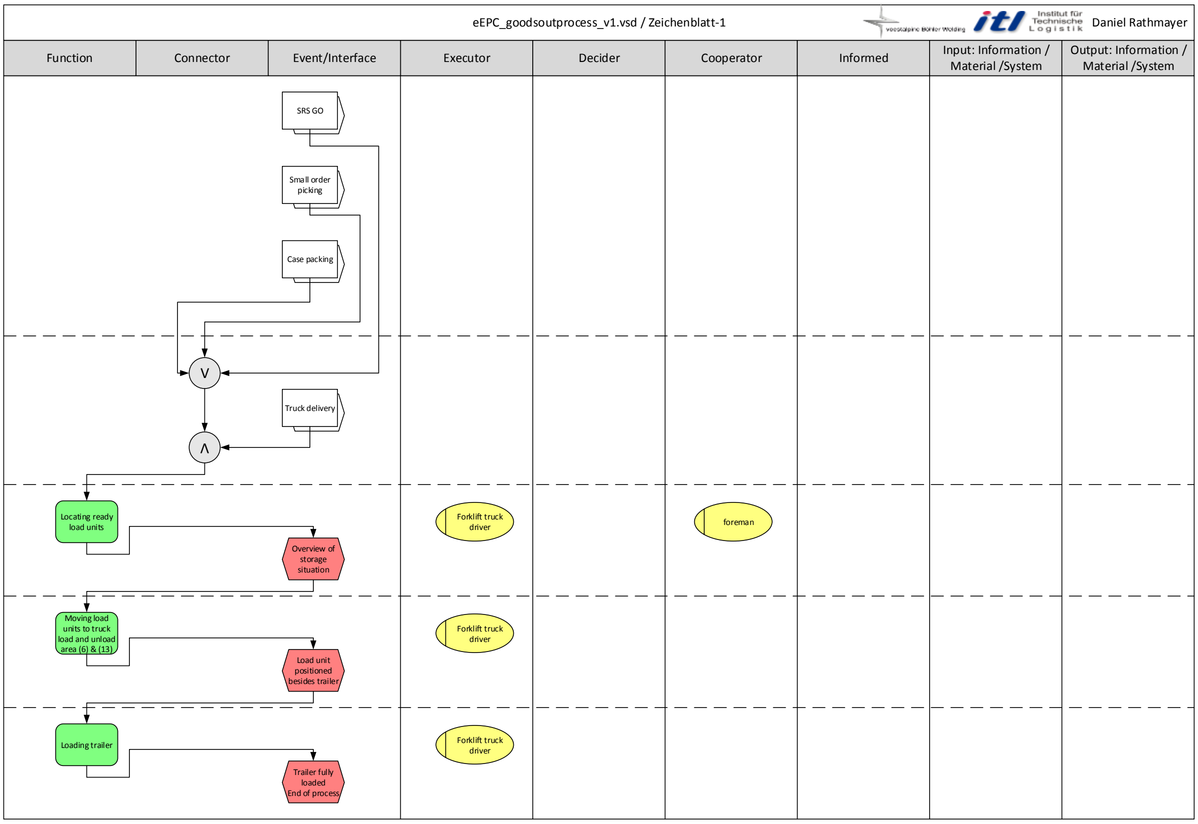

Figure 8-10: eEPC Dispatch Process

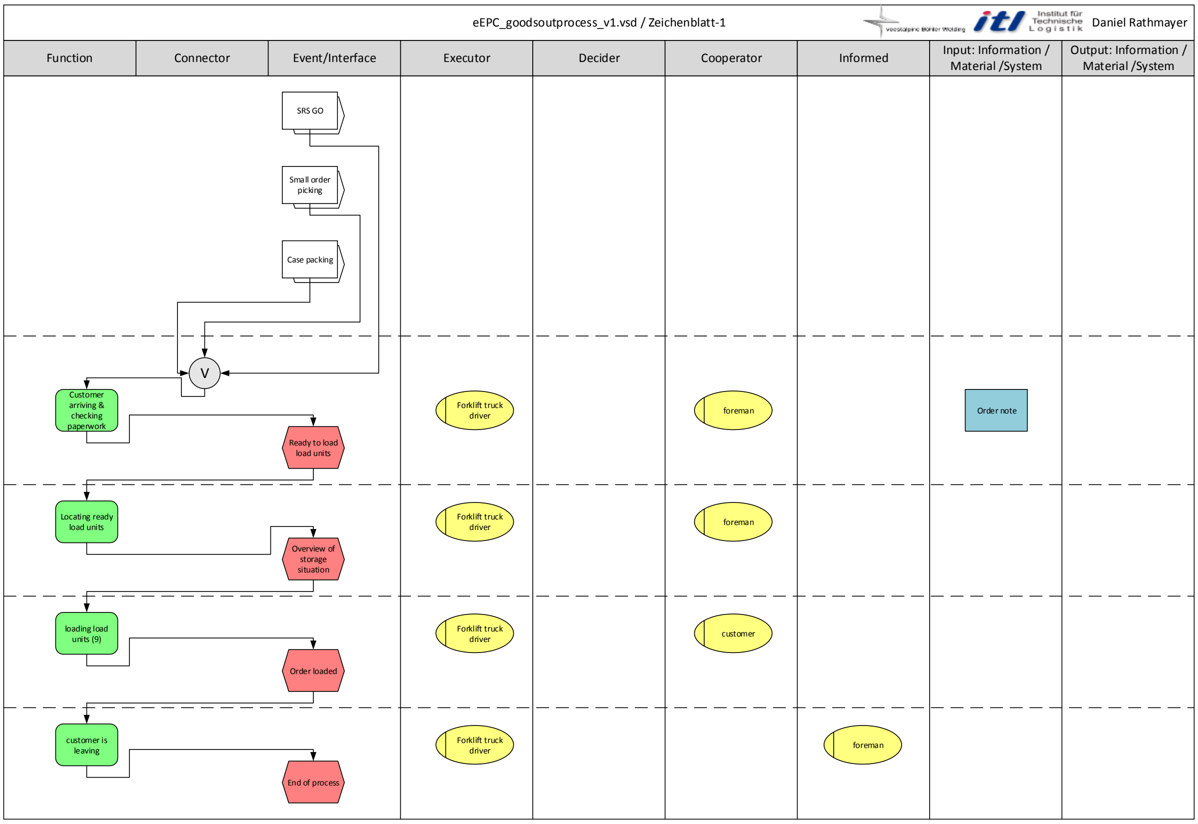

Figure 8-11: eEPC Customer Pick Up Process

8.2.2 Process Cost Intensity

Table 8-1: Process Cost Intensity – Assessment

Processes	Gen. Manpower	Needed Equipment	Time Cons.	Cost Effects
Truck Delivery	6 people	1 truck, 2 forklift trucks, 1 hand held scanning device	15-20min	truck delivery, SRS GI, SRS GO, dispatch, customer
Production Output	2 people	1 forklift truck or 1 pallet stacker, hand held scanner	0-5min	another employee needed, communication with production
SRS Goods-In	1 person	SRS crane, hand held scanning device	0-5min	truck delivery, SRS GI, SRS GO, dispatch, small order picking, case packing, customer pick up
Picking List Prep.	1 person	PC	0-5min	SRS GO blocked
SRS Goods-Out	1 person	SRS crane, picking list	15-30min	truck delivery, SRS GI, SRS GO, dispatch, small order picking, case packing, customer pick up
Small Order Picking	1 person	1 forklift truck or 1 pallet stacker, picking list, additional storage space	5-15min	small effect on case packing, customer directly affected
Case Packing	1 person	1 forklift truck or 1 pallet stacker, picking list, additional storage space, vacuum gripper	30-45min	repacking of goods, picking mistakes directly affecting customer, employee´s health
Quality Assurance	1 person	quality assurance list, 1 pallet stacker	0-5min	another employee needed, communication with quality assurance
Dispatch	2 people	1 forklift truck	10-15min	hindering GI processes, delaying Truck, delaying delivery
Customer Pick Up	1 person	1 forklift Truck	10-15min	customer directly affected but GO control

Table 8-2: Process Cost Intensity

Processes	Gen. Manpower	Needed Equipment	Time Cons.	Cost Effects caused by disruptions	Total
Truck Delivery	5	5	3	5	375
Production Output	2	3	1	1	6
SRS Goods-In	2	4	1	5	40
Picking List Prep.	2	1	1	2	4
SRS Goods-Out	2	4	3	5	120
Small Order Picking	2	2	2	5	40
Case Packing	2	3	4	5	120
Quality Assurance	2	3	1	1	6
Dispatch	2	3	2	3	36
Customer Pick Up	2	3	2	2	24

8.2.3 Weak Point Evaluation

Weak Points	Abbr.	1st Why	2nd Why	3rd Why	4th Why	5th Why
MSG at wrong side of building	L-1	outsourced shipping	no capacity at forwarding department	no space at forwarding department	layout	historicly grown layout, not only a warehouse
large distance to forwarding department	L-2	outsourced shipping	no capacity at forwarding department	no space at forwarding department	layout	historicly grown layout, not only a warehouse
multidirectional material flow	L-3	two separated truck lanes	alternating GI GO process	loading directly into trialer	truck-transportation to MSG	MSG in another building
both lanes GI & GO	L-4	two separated truck lanes	alternating GI GO process	loading directly into trialer	truck-transportation to MSG	MSG in another building
two different locations	L-5	alternating GI GO process	loading directly into trialer	truck-transportation to MSG	MSG in another building	
self inhibiting	L-6	overflow, overloaded	much traffic	weak coordination	many processes in a small area	historicly grown layout, not only a warehouse
frequent overflow	L-7	much traffic	weak coordination	many processes in a small area	historicly grown layout, not only a warehouse	
weak coordination	L-8	many processes in a small area	historicly grown layout, not only a warehouse			
narrow	L-9	multiple usage of area	lack of space	layout	historicly grown layout, not only a warehouse	
blocking SRS	L-10	GI & GO of SRS blocked	overloaded surrounding areas	much traffic	weak coordination	historicly grown layout, not only a warehouse
close to buffer	L-11	multiple usage of area	lack of space	layout	historicly grown layout, not only a warehouse	
no border to buffer	L-12	multiple usage of area	lack of space	layout	historicly grown layout, not only a warehouse	
predestrians	L-13	only connection between two sides	layout	historicly grown layout, not only a warehouse		
traffic	L-14	two different locations of truck lanes	alternating GI GO process	loading directly into trialer	truck-transportation to MSG	MSG in another building
located in a busy area	L-15	between areas where it is needed	multiple usage of area	lack of space	layout	historicly grown layout, not only a warehouse
close to buffer	L-16	between areas where it is needed	multiple usage of area	lack of space	layout	historicly grown layout, not only a warehouse
truck is not available all the time	L-17	communication & scheduling truck	truck driver doing his thing, serving other customers too	no information about trailer loading progress	no software solution to mark goods as loaded	
searching for units to be loaded	L-18	No defined GO buffer area	Usually loading directly into trailer	Truck-Transportation to MSG	MSG in another building	
artificial peaks	P-1	truck-transportation to MSG	MSG in another building			
fork change necessary	P-2	two different fork sizes needed	truck-transportation to MSG	MSG in another building		
overlapping deliveries	P-3	communication & scheduling truck	truck driver doing his thing, serving other customers too	no information about trailer loading progress	no software solution to mark goods as loaded	
weak scheduling	P-4	lack of information	communication & scheduling truck	truck driver doing his thing, serving other customers too	no information about trailer loading progress	no software solution to mark goods as loaded
bad communication	P-5	truck driver doing his thing, serving other customers too	no information about trailer loading progress	no software solution to mark goods as loaded		
foil damaged	P-6	same pallet relocated often after being foiled	loading into trailer reloading at MSG	Truck-Transportation to MSG	MSG in another building	
truck loading	P-7	Usually loading directly into trailer	Truck-Transportation to MSG	MSG in another building		
unloaded and loaded again at MSG	P-8	outsourced shipping	no capacity at forwarding department	no space at forwarding department	layout	historicly grown layout, not only a warehouse
no strict rules	P-9	much traffic	weak coordination	many processes in a small area	historicly grown layout, not only a warehouse	
many functions	P-10	much traffic	weak coordination	many processes in a small area	historicly grown layout, not only a warehouse	
handling effort	P-11	buffering on ground	GI counting, GI GO simultaneously	GI booking into system	paperbased information from production	
empty runs	P-12	blockwise GI GO	slow SRS GO	picking inside SRS	no possibility to pick outside	no technical solution to pick outside SRS yet
leave to send picking list	P-13	get and bring picking list	lists are printed out and provided in office	paper based system		
manual sequencing of picking	P-14	picking inside SRS paper based	no possibility to pick outside	no technical solution to pick outside SRS yet		
manual pallet planning	P-15	picking inside SRS paper based	no possibility to pick outside	no technical solution to pick outside SRS yet		
leave to get picking lilst	P-16	get and bring picking list	lists are printed out and provided in office	paper based system		

Figure 8-12: Five Whys Method I

Weak Points	Abbr.	1st Why	2nd Why	3rd Why	4th Why	5th Why
fast moving goods inside	P-17	everything except of GO tags into SRS	no possibility to store elsewhere	strict & static defintion on fast moving goods	bad communication with other departments	
picking inside of SRS	P-18	no possibility to pick outside	no technical solution to pick outside SRS yet			
storage space	P-19	maybe 2nd order buffering	slow SRS GO	picking inside SRS	no possibility to pick outside	no technical solution to pick outside SRS yet
waiting for 2nd order	P-20	maybe 2nd order buffering	slow SRS GO	picking inside SRS	no possibility to pick outside	no technical solution to pick outside SRS yet
handling effort	P-21	repeatedly processing of same pallets	maybe 2nd order buffering	slow SRS GO	picking inside SRS	no technical solution to pick outside SRS yet
failure costs	P-22	no GO control	foiled and loaded after picking	picking inside SRS	no possibility to pick outside	no technical solution to pick outside SRS yet
ergonomics	P-23	lifing and replacing from high to low level	providing goods with pallet stacker	no ergonomic packing station	no technical solution to pick outside SRS yet	
no automation possible	P-24	placing into case´s edge	customer requirement	lack of alternatives for case		
man to goods	P-25	no possibility to pick outside	no technical solution to pick outside SRS yet			
single cycles per hour	W-1	SRS old system	high costs and question of necessity for modernization	no technical solution to pick outside SRS yet		
GI-GO ratio	W-2	customer orders	customer behaviour			
occupation	W-3	used weight potential	bin occupancy getting less over time	no possibility to reorganize pallets	picking inside SRS	no technical solution to pick outside SRS yet & single batch and single product storage
used weight potential	W-4	bin occupancy getting less over time	no possibility to reorganize pallets	picking inside SRS	no technical solution to pick outside SRS yet & single batch and single product storage	
Transport intensity	W-5	high volume long distance transports	tucklanes far apart	layout	historicly grown layout, not only warehouse	
SRS GO weight	W-6	customer orders	customer behaviour			
order´s material weight	W-7	customer orders	customer behaviour			
not every box can be picked	M-1	box getting damaged	boxes have to be lifted	placing into case´s edge	customer requirement	lack of alternatives for case
bad volume utilization	M-2	no racks	enough space for actual usage	only used as buffer for units with GO tag	not enough capacity for more	ground storage
full	M-3	mixed rack area inside SRS and outside to small	single batch & single product storage forced	no hardware or software solution inside SRS		
small	M-4	mixed rack area inside SRS and outside to small	single batch & single product storage forced	no hardware or software solution inside SRS		
unflexible WMS	M-5	made for simple processes	old software	no change of processes	no hardware or software solution inside SRS	
no pickup light	M-6	no hardware or software solution inside SRS				
two driving directions in aisle	M-7	naming left and right & cranes can drive both in both directions into aisle	no GO booking inside SRS while picking	picking inside SRS paper based	no possibility to pick outside	no GO booking inside & no technical solution to pick outside SRS yet
small forks needed	M-8	also long forks needed	loading directly into trialer	truck-transportation to MSG	MSG in another building	
slow aisle change	M-9	manually driven cranes	old SRS	high costs and question of necessity for modernization		
old	M-10	high costs and question of necessity for modernization				
manual positioning	M-11	hard to implement assistants	unflexible WMS	made for simple processes	old software	no hardware or software solution inside SRS
processing at limits	M-12	blockwise GI GO	slow SRS GO	picking inside SRS	no possibility to pick outside	no technical solution to pick outside SRS yet
DC motors in cranes	M-13	old SRS	high costs and question of necessity for modernization			
small transfer rack buffer	M-14	differnet heights & GI GO level seperated	Product geometry & manual driven without optical instruction	no hardware or software solution to mark buffer bins variable as GI or GO		

Figure 8-13: Five Whys Method II

Process Cost Intensity		375	6	40	120	40	120	36	24		
Weak Points	**Abbr.**	**Truck Delivery**	**Production Output**	**SRS GI**	**SRS GO**	**Small Order Picking**	**Case Packing**	**Dispatch**	**Customer Pick Up**	**Total Cost Intesity**	**Severity**
MSG at wrong side of building	L-1	1						1		411	6
large distance to forwarding dep.	L-2	1						1		411	6
multidirectional material flow	L-3	1				1		1		451	6
both lanes GI & GO	L-4	1				1		1		451	6
two different locations	L-5	1				1		1		451	6
self inhibiting	L-6	1	1	1	1	1	1	1	1	761	10
frequent overflow	L-7	1	1			1	1	1	1	601	8
weak coordination	L-8	1	1					1	1	441	6
narrow	L-9	1	1			1	1	1		577	8
blocking SRS	L-10	1	1	1	1	1	1	1		737	10
close to buffer	L-11	1	1			1	1	1		577	8
no border to buffer	L-12	1	1					1		417	6
predestrians	L-13	1	1			1	1			541	8
traffic	L-14	1	1			1	1	1		577	8
located in a busy area	L-15	1	1					1		417	6
close to buffer	L-16	1	1					1		417	6
truck is not available all the time	L-17	1	1			1	1	1		577	8
searching for units to be loaded	L-18	1						1	1	435	6
artificial peaks	P-1	1	1			1	1	1	1	601	8
fork change necessary	P-2	1	1					1	1	441	6
overlapping deliveries	P-3	1	1					1	1	441	6
weak scheduling	P-4	1						1	1	435	6
bad communication	P-5	1	1					1	1	441	6
foil damaged	P-6	1						1	1	435	6
truck loading	P-7	1						1		411	6
unloaded and loaded again at MSG	P-8	1								375	5
no strict rules	P-9	1	1			1	1	1	1	601	8
many functions	P-10	1	1			1	1	1	1	601	8
handling effort	P-11	1	1			1	1	1	1	601	8
empty runs	P-12			1	1					160	3
leave to send picking list	P-13			1	1					160	3
manual sequencing of picking	P-14			1	1					160	3
manual pallet planning	P-15			1	1					160	3
leave to get picking lilst	P-16			1	1					160	3
fast moving goods inside	P-17			1	1					160	3
picking inside of SRS	P-18			1	1					160	3
storage space	P-19		1							6	1
waiting for 2nd order	P-20					1				40	1
handling effort	P-21					1				40	1
failure costs*	P-22	1	1	1	1	1	1	1	1	761	10
ergonomics	P-23						1			120	2
no automation possible	P-24						1			120	2
man to goods	P-25			1	1	1	1			320	5
single cycles per hour	W-1			1	1					160	3
GI-GO ratio	W-2			1	1					160	3
occupation	W-3		1	1	1					166	3
used weight potential	W-4			1	1					160	3
Transport intensity	W-5	1						1		411	6
SRS GO weight	W-6				1					120	2
order´s material weight	W-7				1					120	2
not every box can be picked	M-1						1			120	2
bad volume utilization	M-2							1	1	60	1
full	M-3					1	1	1		196	3
small	M-4					1	1	1		196	3
unflexible WMS	M-5	1	1	1	1	1	1	1		737	10
no pickup light	M-6			1	1					160	3
two driving directions in aisle*	M-7	1	1	1	1	1	1	1	1	761	10
small forks needed	M-8	1	1							381	6
slow aisle change	M-9			1	1					160	3
old	M-10			1	1					160	3
manual positioning	M-11			1	1					160	3
processing at limits	M-12	1		1	1					535	8
DC motors in cranes	M-13			1	1					160	3
small transfer rack buffer	M-14	1	1	1	1	1	1			701	10

Figure 8-14: Determination of Severity for FMEA

8.2.4 Validation & Evaluation of Implementation

Table 8-3: Value Benefit Analysis and Weighting of Aspects

Solutions	Abbr	Investment Costs	Improvement Transport Intensity	Improvement Occupation	Improvement Process	Rating Costs	Rating Transp. Int.	Rating Occupation	Rating Process	Weightet Rating Costs	Weightet Rating Transp. Int.	Weightet Rating Occupation	Weighted Rating Process	Sum
New Layout	Sol-1	- €	16%	0%	100%	1,00	0,28	-	1,00	0,30	0,06	-	0,10	0,46
Logistic Train	Sol-2	100 000 €	0%	0%	100%	0,50	-	-	1,00	0,15	-	-	0,10	0,25
Multiple Item Bins, min. 310kg SRS	Sol-3	- €	0%	11%	0%	1,00	-	0,28	-	0,30	-	0,06	-	0,36
Multiple Item Bins, min. 460kg SRS	Sol-4	- €	0%	17%	0%	1,00	-	0,43	-	0,30	-	0,09	-	0,39
Multiple Item Bins, min. 610kg SRS	Sol-5	- €	0%	21%	0%	1,00	-	0,53	-	0,30	-	0,11	-	0,41
Multiple Item Bins, min. 770kg SRS	Sol-6	- €	0%	26%	0%	1,00	-	0,65	-	0,30	-	0,13	-	0,43
Multiple Item Bins, min. 810kg SRS	Sol-7	- €	0%	26%	0%	1,00	-	0,65	-	0,30	-	0,13	-	0,43
Additional Racks, out 300kg SRS, min. 150kg add	Sol-8	45 500 €	0%	21%	0%	0,77	-	0,53	-	0,23	-	0,11	-	0,34
Additional Racks, out 300kg SRS, min. 310kg add	Sol-9	22 000 €	0%	21%	0%	0,89	-	0,53	-	0,27	-	0,11	-	0,37
Additional Racks, out 400kg SRS, min. 460kg add	Sol-10	30 000 €	0%	28%	0%	0,85	-	0,70	-	0,26	-	0,14	-	0,40
Additional Racks, out 460kg SRS, min. 610kg add	Sol-11	42 000 €	0%	36%	0%	0,79	-	0,90	-	0,24	-	0,18	-	0,42
Order Picking System	Sol-19	200 000 €	57%	0%	100%	-	1,00	-	1,00	-	0,20	-	0,10	0,30
GO Inspection Scale, stationary	Sol-20	1 800 €	0%	0%	25%	0,99	-	-	0,25	0,30	-	-	0,03	0,32
GO Inspection Scale, fork	Sol-21	7 000 €	0%	0%	25%	0,97	-	-	0,25	0,29	-	-	0,03	0,31

Weighting	
Cost	0,30
Improvement Transport Intensity	0,20
Improvement Occupation	0,20
Improvement Process	0,10