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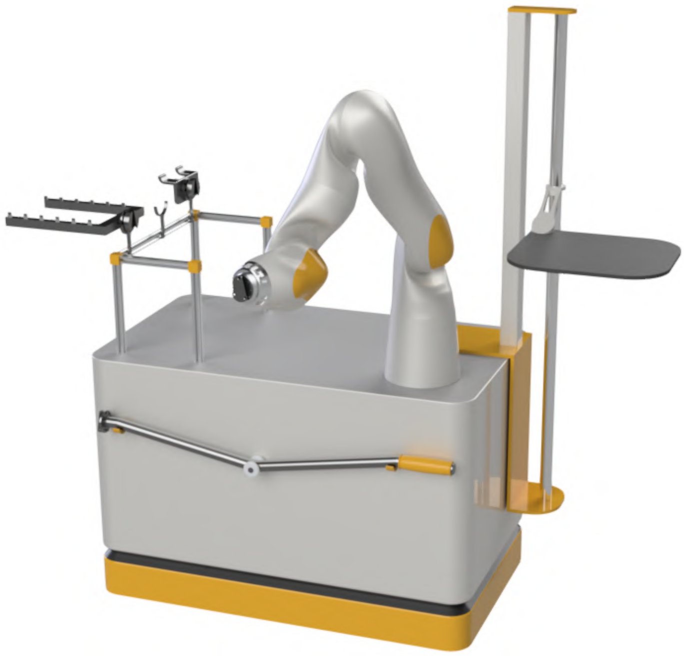

Towards a sustainable automated material handling system within the automotive industry

Master's thesis in Production Engineering

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Department of Electrical Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2020

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Cover: Image of the developed concept for a sustainable automated material handling system

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Abstract

This thesis was accomplished as a part of a global project within Volvo Trucks, whereas several of their production plants currently have issues with poor ergonomics, associated with the material handling of boxes in their supermarket warehouses. In this thesis, an investigation of the current material handling at Volvo production plant in Tuve, Sweden, was conducted together with a market analysis of possible state of the art solutions. Various solutions were evaluated and it was analyzed how these could be adapted in order to resolve the problems and be sustainably implemented. Based on this analysis, a first prototype of an automatic box picking solution for a supermarket warehouse within the automotive industry was developed. The solution consists of a special end effector used by a collaborative robotic system. The concept was developed to enhance the material handling efficiency and eliminate socially unsustainable work procedures. Moreover, the concept would also enable a flexible and reconfigurable production.

Keywords: Material handling, automation, sustainability, internal logistics, collaborative robot, end effector, ergonomics, supermarket warehouse.

Acknowledgements

This project was conducted together with some helpful people and we would therefore like to give some extra thanks to our supervisor and coworker at Volvo Trucks, Erik Dahl. Moreover we also appreciate all the help we have gotten from all of our other coworkers at Volvo Trucks and would like to give extra credit to Erik Bergstrand for his kindness and for being eager to help us with moving the project forward.

Finally we would also give our thanks to our supervisor, at Chalmers University of Technology, Kristofer Bengtsson.

Hugo Månsson Martin Rattfelt, Gothenburg, June 2020

Acronyms

PoC	Proof of Concept
SuMa	Supermarket
MRP	Material Resource Planning
ERP	Enterprise Resource Planning
UP	Use Point
OP	Order Point
SWEA	Swedish Work Environment Authority (Arbetsmiljöverket)
SSIA	Swedish Social Insurance Agency (Försäkringskassan)
ISO	International Organization for Standardization
EN	European Norm
AS/RS	Automated Storage and Retrieval System
AGV	Automated Guided Vehicle
FIFO	First In First Out
VSM	Value Stream Map
N/A	Not Applicable
SBCE	Set-Based Concurrent Engineering
PD	Product Development
SBD	Set-Based Design
CE	Concurrent Engineering

Contents

1
Introduction

1.1 Background

Within the truck manufacturing company Volvo Trucks, many of their manufacturing sites, e.g. the ones in Tuve, Skövde, Ghent, and Curitiba, currently have issues with poor ergonomics associated with their warehouses. More specifically, the ergonomic issues regards the material handling of a certain type of boxes, in a certain type of warehouse, which they want to find a new type of solution for. These specific boxes are internally called as "blue boxes", which are boxes that have a certain type of standard measurements and are used within the whole supply chain for Volvo Trucks.

Regarding the particular warehouse, it is a warehouse of the type called "supermarket warehouse". Meaning that it is constructed similar to the gravity fed conveyor shelves that would be found in a supermarket, used for presenting e.g. milk for the customers. Whereas the articles are being placed from the back and then picked from the front, resulting in a first-in first-out (FIFO) flow. An image of the supermarket warehouse, at the Tuve manufacturing plant, with the regarded "blue boxes", is to be seen in Figure 1.1.

Figure 1.1: Image of the supermarket warehouse, at the Tuve manufacturing plant, with the regarded "blue boxes".

So in order to resolve these problems, Volvo wanted to investigate how a new technical solution could eliminate these issues. A desire for this was more specifically to explore new automatic solutions, that not yet had been tested within their own facilities, and evaluate how these would be a suitable fit for them. Although, they were also open to other less technologically advanced solutions, as long as it would get rid of the problems.

1.2 Aim

The project aimed to perform an analysis of the current state, of the warehouse, which was associated with the previously mentioned poor ergonomics. Furthermore, the aim was also to investigate how a technical solution could eliminate the current problems, in order to establish a more efficient- and sustainable workplace. The plan to achieve this was to perform a market analysis of state of the art solutions and evaluate which one of these that was most suitable for Volvo. If it was necessary for the solution to be reconfigured in some way, in order for it to be adaptable, this was supposed to be developed as well.

A final aim for the project was to desing a proof of concept (PoC) solution. This was thought to be performed by testing and evaluating the recommended solution, at the Volvo Trucks Tuve manufacturing site, within their production logistics test area.

1.3 Research questions

- How should a new technical solution be designed to eliminate a bad ergonomic situation and which will provide a more sustainable material handling?

- What kind of technical solutions, for material handling, are available on the market today?

- How could an automatic solution be adapted in order to enable high flexibility and high product variation for material handling?

1.4 Delimitations

Throughout the project, it was discovered that the warehouse workers were performing several manual operations. However, for the project to be feasible, the scope was limited to two specific operations, namely the picking and placing of the boxes into the storage racks at the supermarket warehouse.

Further on the project was more focused on the technical solutions and market investigations rather than analyzing the daily organization, change management, work training, etc.

However, it should also be specified that there was no intention of constructing a complete new technical solution from scratch, whereas the main focus was to perform a market analysis and thereafter configure the technology to be a suitable fit.

Another delimitation was also to not collaborate with the material suppliers, meaning that the boxes had to be handled as they are delivered today.

1.5 Report outline

Throughout the report, the different chapters have been divided into multiple focus areas. In Chapter 2, some of the current warehouse solutions, at Volvo Trucks in Tuve, will be introduced. It will mainly describe the supermarket warehouse, which is also mentioned as the "SuMa" warehouse throughout the report. This SuMa warehouse will be investigated in detail, as the automatic warehouses only will be briefly discussed upon.

Continuously the Chapter 3 regards the boxes, which in the report more generally will be called as "blue boxes" or "V-EMB and its specific model number". These name descriptions will be further explained, in the same chapter, and the boxes' technical specifications and measurements will be specified.

In Chapter 4 the ergonomic situation is processed. A deeper background about ergonomic issues and its potential harms and effects are reflected upon. Moreover, the ergonomic situation, by handling the blue boxes, is analyzed and evaluated.

Within Chapter 5, the company vision of Volvo is briefly described as their vision for the SuMa warehouse is more thoroughly specified. Along with the vision, the key findings from the earlier described chapters, are summarized and combined into a list of requirements. This list of requirements was more specifically compiled with needs and wants, which the new solution had to fulfill.

As the list of requirements was apprehended it was used for performing and evaluating the market analysis, which is to be found in Chapter 6. Within the chapter, the evaluation led to the selection of the mobile robot KUKA KMR iiwa.

Further on in the report, there is a deeper investigation of collaborative robots, since this is a part of the KUKA KMR iiwa concept. This is presented in Chapter 7.

As the KUKA KMR iiwa was selected it required further developments to be a suitable fit for Volvo. There was therefore a need of designing a customized end effector. The development and result of this are processed in Chapter 8.

Thereafter the results from the report are discussed upon in Chapter 9, and finally, a conclusion and recommendation is drawn and is presented in the last part of the report, namely Chapter 10.

2

Current warehouse solutions at Volvo Trucks

2.1 Warehouse introduction and methodology

In order to achieve a deeper understanding, of the current issues at the supermarket warehouse, the warehouse required to be further analyzed. This was accomplished by investigating in the material flow, the warehouse layout, and the current- capacity and effectiveness of the SuMa warehouse. Whereas relevant data was collected from the MRP-systems at Volvo Trucks and/or other existing database files and systems. The data was also gathered by performing some measuring activities and for e.g. the layout and dimensions for the supermarket warehouse and its racks, the measurements were taken using a folding rule and a laser distance meter.

2.2 The supermarket warehouse

A growing number of manufacturers have adopted the concept of supermarket warehouses, in order to follow just-in-time principles. These supermarket warehouses are generally located nearby the assembly lines and are intended to supply these with parts. This enables the inventory at the lines to be reduced as it also avoids long-distance deliveries from a central receiving storage. The parts are typically delivered in appropriate containers, by operators using small towing vehicles connected to wagons. These types of warehouses usually have to enable fast and ergonomic material handling and therefore often consist of special storage equipment such as gravity shelves and flow racks [1].

Regarding Volvo Trucks in Tuve, the SuMa warehouse was introduced as a manual alternative to the automatic warehouse when a wider range of material boxes was implemented in the production. Since the automatic storage could not handle the new boxes a more flexible solution was needed. Moreover, the manually operated warehouse would allow for more flexibility as well as it would result in cheaper and faster implementations of changes.

This SuMa warehouse and its associated areas make up the limits of the project's scope. Whereas the area consists of a delivery area, an intermediate buffer, a manual picking table, and three pallet racks mixed with flow racks.

The delivery area is located in connection with a gate where trucks from outside the factory have access to the inside. An image of this area, where the trolley just been unloaded, is to be seen in Figure 2.1. This is the first step of the workflow which could be seen in Figure 2.11.

Figure 2.1: Image of the delivery area for the material which comes from the goods receipt. On the picture the trolley have just been unloaded.

Continuously the intermediate buffer, or the unloading area, is a designated floor area of 6x4 m, marked up with tape. The main purpose of the buffer is to function as a quick way to free up the delivery area from material. An image of the buffer area can be seen in Figure 2.2.

Figure 2.2: Buffer area for pallets with material.

Moreover, the manual picking table consists of a conveyor as well as unloading areas for returning empty boxes. The picking table and its work procedure are shown in Figure 2.12 and Figure 2.13.

However, the majority of the designated floor space, of the SuMa warehouse, consist of three pallet racks, with aisles in between them. They are arranged in three columns, covering an area of 26x13.8 m. An illustration of these racks, seen from above, is to be found in Figure 2.4. The racks consists of four levels, see Figure 2.3, the upper three levels are used to store full pallets, while the lowest level stores individual blue boxes in four layers of gravity-fed conveyors. In order for the boxes to stop at the end of the gravity-fed conveyors, there is a stop edge of the height of 2 cm to 3.6 cm, which is seen in Figure 2.9. The edge is also used for displaying material information such as article number and component descriptions.

Figure 2.3: A pallet rack in the SuMa warehouse, the bottom level consist of four gravity-fed conveyors, while the upper three levels stores pallets with blue boxes.

Additionally, there are two kinds of pallet racks, one kind with yellow features, visualized in Figure 2.3, as well as another one with red features, visualized in Figure 2.10. Henceforth referred to as yellow racks and red racks. The distribution of the different kinds, as well as their measurements, are visualized from above in Figure 2.4. Whereas the measurements for the red racks, seen from the front and the back, are illustrated in Figure 2.6 and Figure 2.8. The dimension of the yellow racks vary relatively much and illustrations of these racks, seen from the front and the back, are to be seen in Figure 2.5 and Figure 2.7. The rack variations include the height of the different shelves, the spacing between them as well as the inclination of the gravity-fed conveyors. The red racks however show no major variations between themselves (or themshelves for that matter).

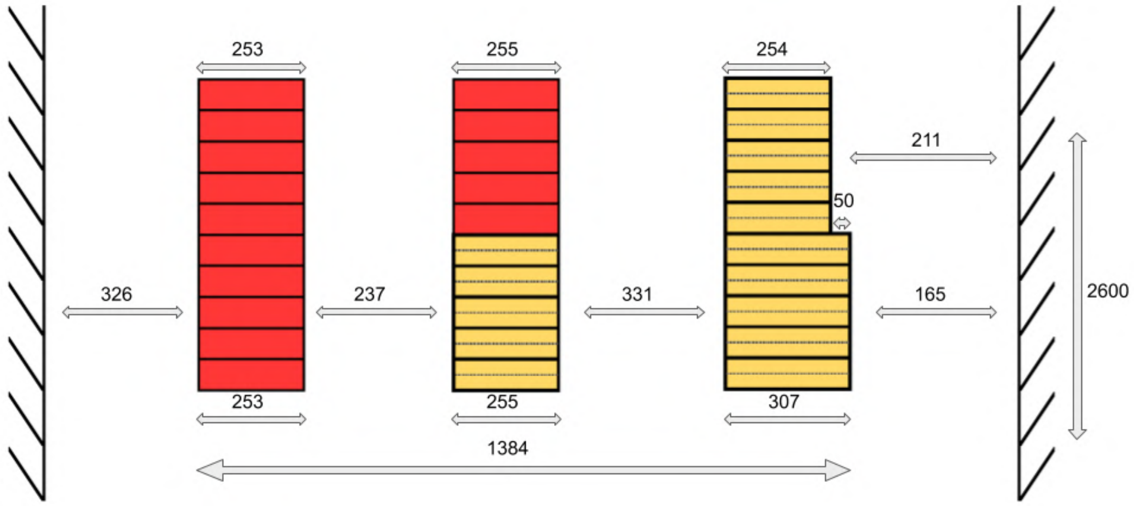


Figure 2.4: An overview of the dimensions as well as the distribution of pallet rack types, seen from above. The yellow racks show significant variance between themselves, while the red ones have consistent dimensions. The measurements are given in cm.

The given dimensions of the pallet rack facades are; the height of the lowest and highest shelves, the spacing between the shelves as well the height necessary to lift the box in order to overcome the box stopper. The width of the racks is also shown. The yellow racks consist of two subunits, and are divided by a beam in the middle, while the red racks do not have any major interruptions.

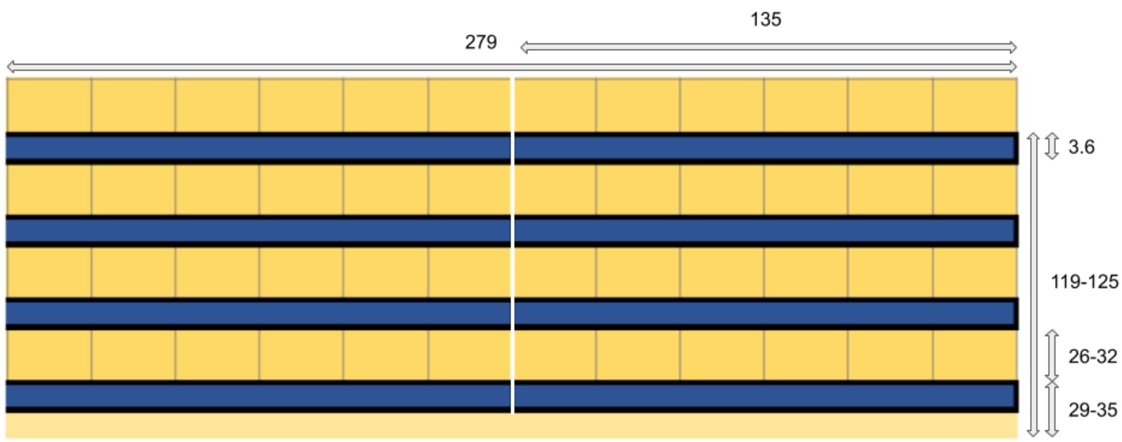


Figure 2.5: The dimensions of a section of the yellow racks front side. The yellow racks show some variance in between themselves. The measurements are given in cm.

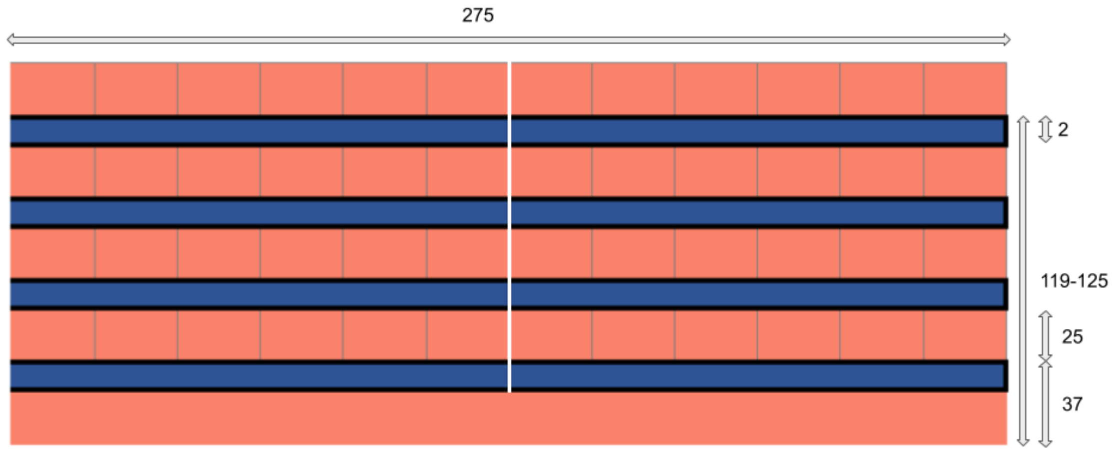


Figure 2.6: The dimensions of a section of the red racks front side. The measurements are given in cm.

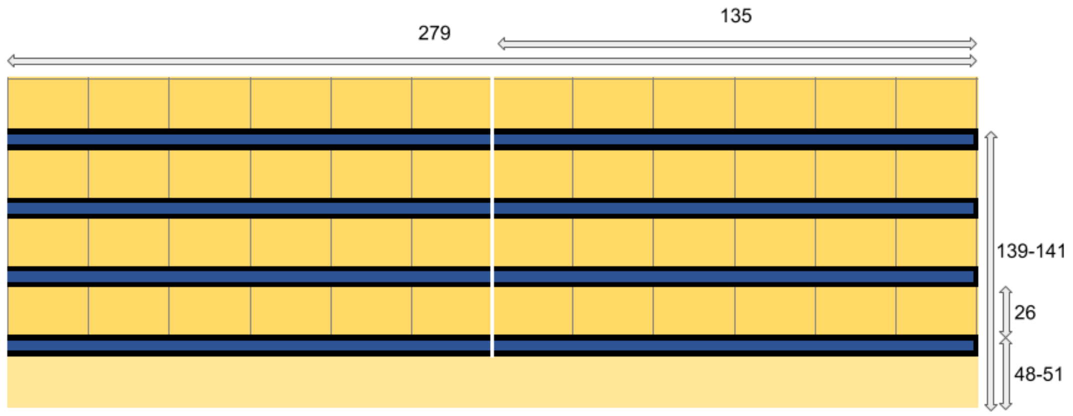


Figure 2.7: The dimensions of a section of the yellow racks back side. The yellow racks show some variance in between themselves. The measurements are given in cm.

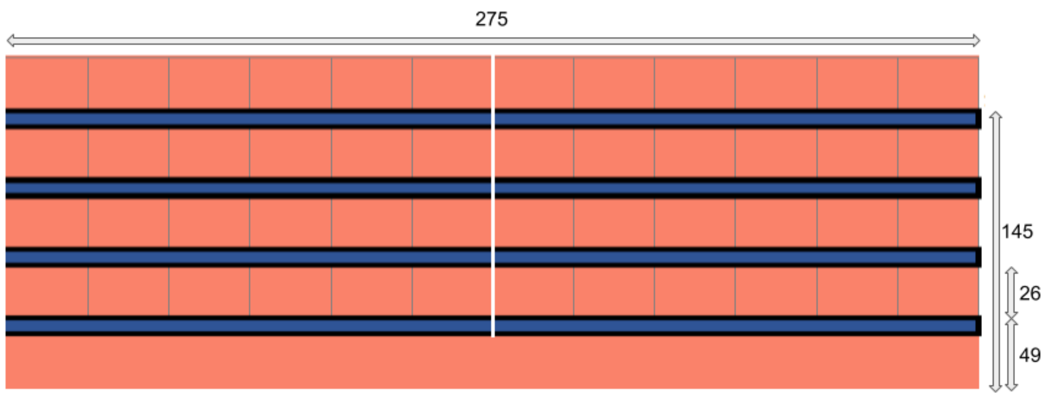


Figure 2.8: The dimensions of a section of the red racks back side. The measurements are given in cm.

Figure 2.9 shows the boxes in their idle position, resting against the box stopping edge. It can also be seen that the boxes have been equipped with a black plastic tag, attached with a cable tie. However, the plastic tag is only attached to some of the boxes, and as seen in Figure 2.10, there are boxes without this tag.

Figure 2.9: An image of two of the four layers of gravity-fed conveyors with boxes and the stop edges.

Additionally, it could be mentioned that the boxes are prioritized to be distributed in ergonomically friendly heights, depending on the material consumption frequency and weight. These different heights have been colorized in order to visualize the ergonomic zones, which are seen in Figure 2.10, and will be further described in Chapter 4.2.

Figure 2.10: An image of four layers of gravity-fed conveyors, for the red racks, with boxes and stop edges. Where the edges have been colorized in order to visualize the ergonomic zones, which will be further described in Chapter 4.2.

Regarding the turnover capacity for the SuMa warehouse, at the Tuve manufacturing plant, the warehouse is set to be distributing approximately 800 boxes per day. Which is done by two shifts, 8 hours each, resulting in a total of 16 hours.

2.3 SuMa Workflow

The material flow, regarded in the project, starts at the unloading area. The material is delivered to the area in blue boxes stacked on top of pallets via a trolley train, whereas the boxes are stacked on top of each other on each pallet. The stack of boxes is secured to the pallet by two plastic ties surrounding the pallet and the boxes, as well as a wooden lid at the top of the stack. An overview of the material flow is shown in the form of a value stream map (VSM) in Figure 2.11.

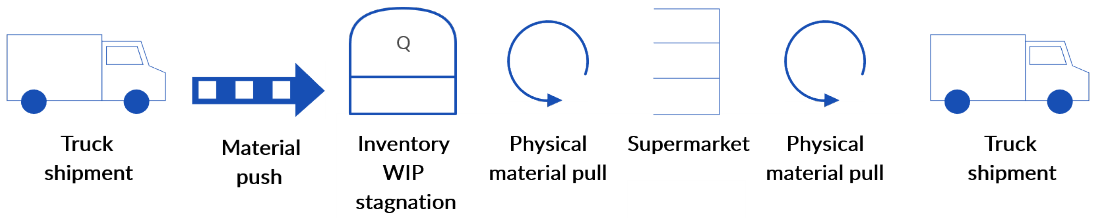
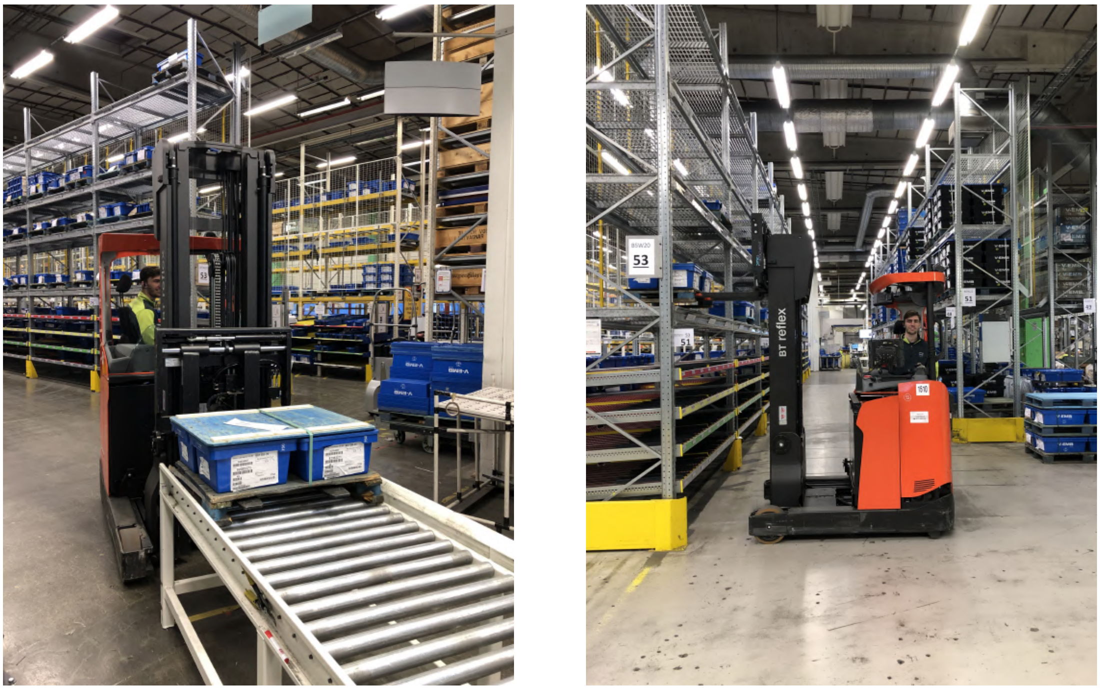


Figure 2.11: Simplified VSM for the SuMa storage workflow

After the material has been delivered, the pallets are pushed and transported by truck to an intermediate storage area, named B5W20, in order to clear the delivery area.

From the area B5W20 the pallets can take one of two paths, either go directly to the picking table for processing, or to storage in pallet racks for later use, see Figure 2.12. In both of the cases, the pallets are transported by forklift.



(a) Moving pallet to the picking table. **(b)** Storing the pallet in pallet racks.

Figure 2.12: Current work procedure in the SuMa warehouse at the Volvo manufacturing plant in Tuve. Initial transportation of pallets with boxes of material.

At the picking tables, the plastic ties are cut and the wooden lid is removed in order to free the Blue boxes, as seen in Figure 2.13. The boxes are then placed on a motorized trolley for transport to the SuMa storage, alternatively the boxes are placed on a larger pallet that can be transported to the SuMa storage with a forklift.

(a) Cutting the plastic ties and removing the wooden lid.

(b) Loading the blue boxes to a pallet that can be transported with truck.

Figure 2.13: Current work procedure in the SuMa warehouse at the Volvo manufacturing plant in Tuve. Depalitization of blue boxes and loading for transportation to the gravity-fed conveyors.

A worker then refills the SuMa racks from the back, see Figure 2.14, allowing the different materials to be pulled in a supermarket FIFO flow, as seen in the VSM in Figure 2.11. The racks are refilled manually by a worker placing the boxes in racks at four different heights. The boxes are scanned in order to keep track of the material in the Volvo MRP-system.

The last step in the scope of the SuMa warehouse workflow is the delivery to the use point (UP). This happens as the material is picked from the SuMa storage by a worker driving delivery milk runs around the factory. The worker lifts the box manually, scans the bar-code on the box and then places it at one of four levels in the trolley. The material is then transported to its UP, which is the end of the scope processed in this project.

(a) Loading the gravity-fed conveyors with blue boxes.

(b) Picking blue boxes from the SuMa warehouse in order to load a trolley for transportation to UP.

Figure 2.14: Current work procedure in the SuMa warehouse at the Volvo manufacturing plant in Tuve. Loading and picking from the gravity-fed conveyors.

2.4 Current automatic warehouses at Tuve production plant

As it is today, Volvo production plant in Tuve has two different automatic warehouse solutions, provided by the company Swisslog. The warehouses are internally called V01 and V03 and are to be seen in Figure 2.15 and Figure 2.16. V01 is handling whole pallets for the whole factory whereas V03 is handling the three different box types V-EMB 460, V-EMB 780 and V-EMB 840 and is dedicated to only supply certain areas of the factory. Further description of the different box types will be found in Chapter 3.

Figure 2.15: Image of the automatic warehouse, internally called V01.

Figure 2.16: Image of the automatic warehouse, internally called V03.

As seen in Figure 2.15 and Figure 2.16, both of the warehouses are of the traditional automated storage and retrieval system (AS/RS) type, using aisle cranes and conveyor belts and are therefore both very locked installations to their current locations. Due to the massive crane solution and conveyor belts, they become very hard and expensive to relocate. Which however also results in a very rigid- and precise system with very high box- and pallet handling capacity. Both of these automatic warehouses existed before the SuMa warehouse was constructed, which is only dedicated and prioritized to a specific section of the factory.

Another important aspect is that both of the automatic storages generally has a longer traveling distance from the warehouse location to the use points, compared to the SuMa warehouse. Which results in more time-consuming delivery rounds for the operators. So when combining the fact that the automatic warehouses handle material for several factory sections, which means that it does not only prioritizes the orders from the specific area which the SuMa warehouse does, it results in a longer lead time, from the automatic warehouses to use point, than it does for the SuMa warehouse. Another reason for the automatic warehouse (V03), which results in longer lead time, is that it usually waits until it has fully loaded a rack of ten blue boxes before it is transported out to use point.

The SuMa warehouse was first constructed as a response to the introduction of more blue box variants. As the automatic warehouse, at the time, only was able to handle two different box types, there was a need for something more flexible which also could handle more variation.

3

Description of the blue boxes handled at Volvo Trucks

3.1 Usage area

Within the supply chain of Volvo Group, there are ten types of standardized boxes that are being used for transportation for smaller- and more lightweight material/-components/articles. By lightweight means that these types of boxes only handle loads from 0 kg - 50 kg. The boxes are made of plastic, are reusable, and are officially called "V-EMB small plastic containers". However, due to their characteristic blue color they generally go by the more simplified name "blue boxes".

The SuMa warehouse at the Tuve plant handles seven of these ten different boxes, whereas the distribution could be seen in Table 3.10. However, the plants at Curitiba, Ghent and Skövde are also using the 787- and 840-box at their SuMa warehouses, and a suggested solution for the project should therefore be able to handle nine of these different types of boxes. The box which could be neglected is the V-EMB 1200.

(a) Stacked inside of each other **(b)** Stacked upon of each other

Figure 3.1: Visualization of the blue boxes.

3.2 Technical specifications

The blue boxes could be stacked inside of each other, and by using associated lids they could also be stacked upon of each other. They exist in ten different shapes and measurements which are visualized and described in Figure 3.1 and Table 3.1.

Table 3.1: Overview measurement specifications for the blue boxes.

Name	LxWxH [mm]	Inner top [mm]	Inner bottom [mm]	Inner height [mm]
V-EMB 460	600x400x200	546x370	510x335	185
V-EMB 500	300x200x150	229x174	198x150	138
V-EMB 600	600x200x150	508x142	477x174	138
V-EMB 750	400x300x200	345x265	315x235	185
V-EMB 757	400x300x100	345x265	315x235	93
V-EMB 780	600x400x200	537x362	510x335	185
V-EMB 787	600x300x100	537x362	510x362	93
V-EMB 800	800x300x200	745x265	710x235	185
V-EMB 840	800x600x200	745x565	710x535	185
V-EMB 1200	1220x270x200	1190x240	1150x220	185

Further on the boxes within the SuMa warehouses are only allowed to have a maximum weight of 12 kg - 15 kg. 12 kg is the current maximum weight allowed at the Tuve plant, which has been decided according to an older ergonomic analysis method, called SARA, according to the Volvo ergonomist, Michael Schröder [2]. Whereas the other plants have allowed 15 kg, based on the standardized recommendations for manual handling: ISO 11228-1 [3], ISO 11228-2 [4], ISO 11228-3 [5] and EN 1005 [6].

3.2.1 Flange measurements for the blue boxes

In order to design a well functional and suitable grasping tool for the blue boxes, there was a need to analyze the boxes' measurements and shapes further. Therefore, the boxes V-EMB 460 to V-EMB 840, and specifically its flanges, will be deeper analyzed and described. This has been performed by measuring the boxes with a sliding caliper where all of the measurements have been taken at the inside of the flanges. The sliding caliper has an error tolerance of 0.02 mm, but since the boxes show some variance, measurements will be presented with an accuracy of 1 mm.

Further on the "corner sections" or "corner ribs" have been neglected as they were considered to be of a too complex and diverse shape and would presumably not contribute to the interface between the boxes and the handling solution. This has therefore been excluded from the compilation of measurements.

Moreover the "section divider" or "ribs divider" has also been left out from the following figures of measurement descriptions, as it was measured to be around 2 mm for all of the boxes.

Additionally, it could be mentioned that the boxes have a conical shape, with tapered sides, leading to wider box measurement at the top than for the bottom. Whereas the inside of the flanges also is tapered, but the other way around, meaning the depth (D) measurement gets narrower, the further within the flange, as the measurement is taken. The measurements presented in the following tables represent the depth at its widest point, meaning at the beginning of the flange.

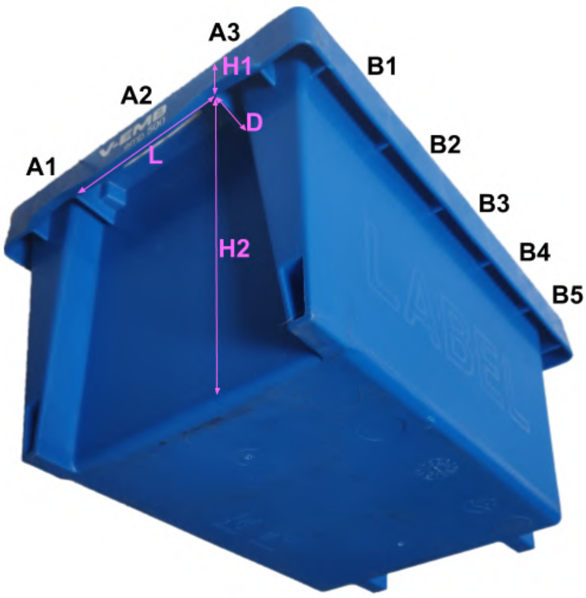
V-EMB 500

The V-EMB 500 is an asymmetrical box and can be seen oblique from above in the Figure 3.2. Due to its' asymmetric shape, the V-EMB 500 therefore consists of three different types of flanges. These flanges will be further described in this paragraph.

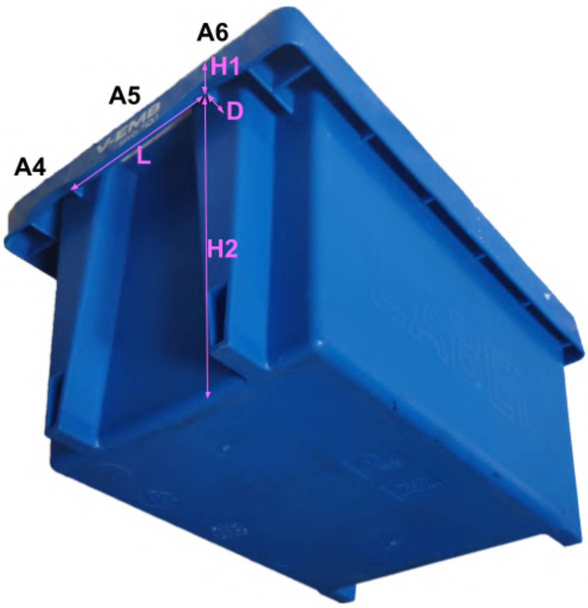
(a) The V-EMB 500 front-side.

(b) The V-EMB 500 backside.

Figure 3.2: The V-EMB 500, seen oblique from above.



(a) The V-EMB 500 front-side.



(b) The V-EMB 500 backside.

Figure 3.3: The V-EMB 500 front-side seen oblique from below. A1 to A3 represents the different sections for the box front-side flange and A4 to A6 the sections for the backside flange. B1 to B5 represents the sections of the box side flange. The measurements for these sections are described in height (H1 & H2), length (L) and depth (D), as vizualized in pink, which can be seen in Table 3.2.

Table 3.2: Flange measurements for the V-EMB 500

Flange section	Length [mm]	Height 1 [mm]	Height 2 [mm]	Depth [mm]
A1	25	23-27	121-124	8-28
A2	91	24-27	121-124	28
A3	25	23-27	121-124	8-28
A4	25	23-27	121-124	8-28
A5	91	24-27	121-124	8-28
A6	25	23-27	121-124	8-28
B1	49	27	121	7-21
B2	49	27	121	7
B3	50	27	121	7
B4	49	27	121	7
B5	44	27	121	7

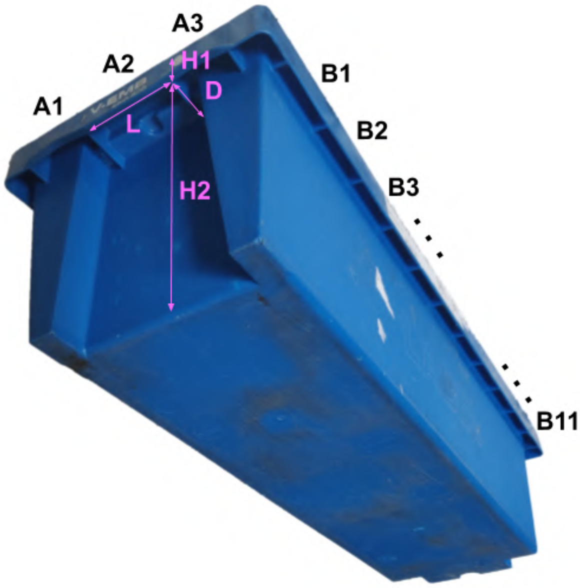
V-EMB 600

The V-EMB 600 is an asymmetrical box and can be seen oblique from above in Figure 3.4. Due to its' asymmetric shape, the V-EMB 600 therefore consists of three different types of flanges. These flanges will be further described in this paragraph.

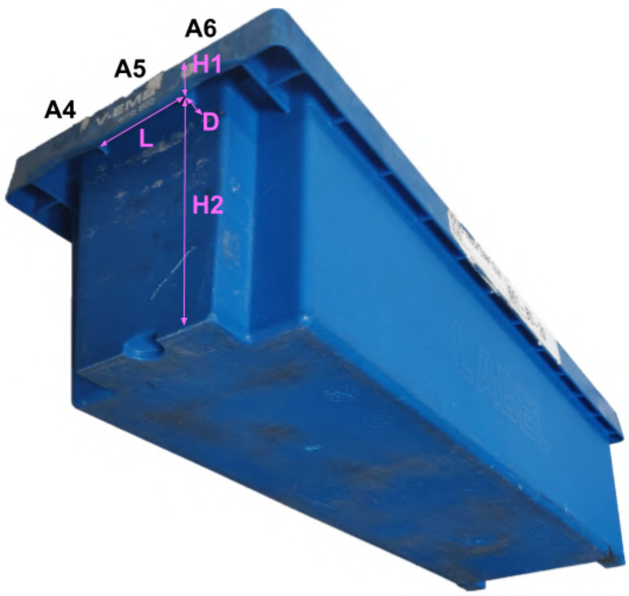
(a) The V-EMB 600 front-side.

(b) The V-EMB 600 backside.

Figure 3.4: The V-EMB 600, seen oblique from above.



(a) The V-EMB 600 front-side.



(b) The V-EMB 600 backside.

Figure 3.5: The V-EMB 600 front-side seen oblique from below. A1 to A3 represents the different sections for the box front-side flange and A4 to A6 the sections for the backside flange. B1 to B11 represents the sections of the box side flange. The measurements for these sections are described in height (H1 & H2), length (L) and depth (D), as visualized in pink, can be seen in Table 3.3.

Table 3.3: Flange measurements for the V-EMB 600

Flange section	Length [mm]	Height 1 [mm]	Height 2 [mm]	Depth [mm]
A1	40	23-27	119-122	14-40
A2	63	26-28	119-120	40
A3	40	23-27	119-122	14-40
A4	40	23-27	119-122	14-40
A5	63	26-28	119-120	40
A6	40	23-27	119-122	14-40
B1	48	28	120	9
B2	48	28	120	9
B3	48	28	120	9
B4	48	28	120	9
B5	48	28	120	9
B6	48	28	120	9
B7	48	28	120	9
B8	48	28	120	9
B9	48	28	120	9
B10	48	28	120	9
B11	37	28	120	9-22

V-EMB 750

The V-EMB 750 is a symmetrical box and can be seen oblique from above in the Figure 3.6. Due to its' symmetric shape the V-EMB 750 therefore only consists of two different types of flanges. These flanges will be further described in this paragraph.

Figure 3.6: The V-EMB 750, seen oblique from above.

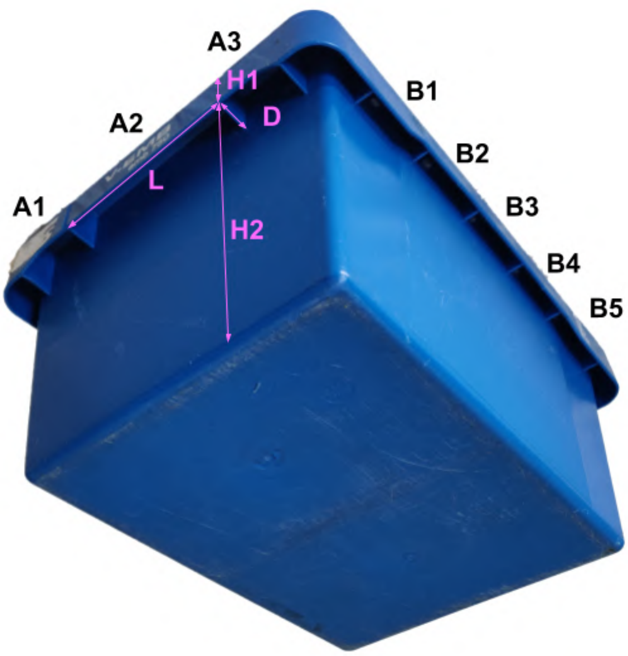


Figure 3.7: The V-EMB 750 bottom seen oblique from below. A1 to A3 represents the different sections for the box front flange and B1 to B5 the sections of the box side flange. The measurements for these sections are described in height (H1 & H2), length (L) and depth (D), as visualized in pink, can be seen in Table 3.4.

Table 3.4: Flange measurements for the V-EMB 750

Flange section	Length [mm]	Height 1 [mm]	Height 2 [mm]	Depth [mm]
A1	45	37-47	150-160	23
A2	137	37	160	22
A3	45	37-47	150-160	23
B1	58	37-47	150-160	13-14
B2	58	37	160	13
B3	58	37	160	13
B4	58	37	160	13
B5	58	37-47	150-160	13-14

V-EMB 757

The V-EMB 757 is a symmetrical box and its' outside measurements are quite similar to the V-EMB 750, besides from the height. A visual representation of the box can be seen oblique from above in Figure 3.6. Due to its' symmetric shape, the V-EMB 757 therefore only consists of two different types of flanges. These flanges will be further described in this paragraph.

Figure 3.8: The V-EMB 757, seen oblique from above.

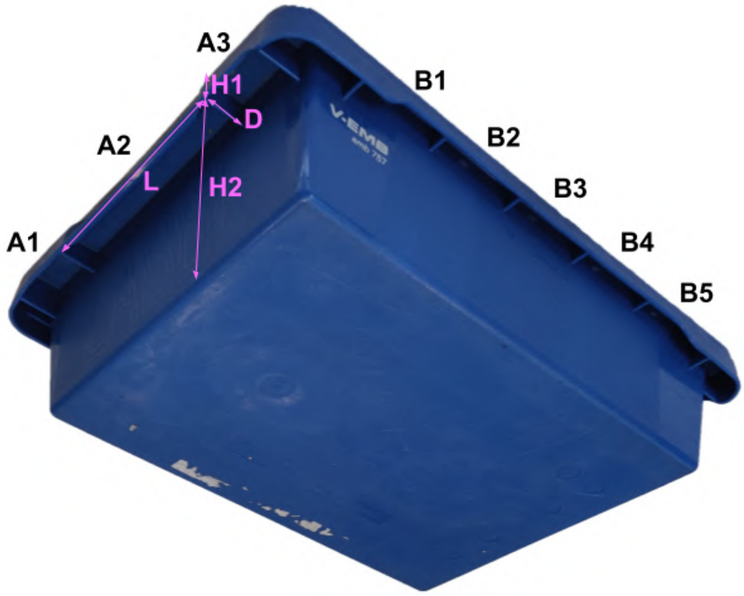


Figure 3.9: The V-EMB 757 bottom seen oblique from below. A1 to A3 represents the different sections for the box front flange and B1 to B5 the sections of the box side flange. The measurements for these sections are described in height (H1 & H2), length (L) and depth (D), as visualized in pink, can be seen in Table 3.5.

Table 3.5: Flange measurements for the V-EMB 757

Flange section	Length [mm]	Height 1 [mm]	Height 2 [mm]	Depth [mm]
A1	44	15-22	73-80	24
A2	151	15	80	18-24
A3	44	15-22	73-80	24
B1	57	15-27	68-80	12-14
B2	57	15	80	12
B3	57	15	80	12
B4	57	15	80	12
B5	57	15-27	68-80	12-14

V-EMB 780 and V-EMB 460

The V-EMB 780 and V-EMB 460 is basically the same box, besides from that the V-EMB 460 is made for better containing electronic articles. Therefore the box is also made of another plastic, and instead of the color blue, it has a black color. The box is of symmetrical shape and can be seen oblique from above in the Figure 3.10. Due to its' symmetric shape the V-EMB 780 therefore only consists of two different types of flanges. These flanges will be further described in this paragraph.

Figure 3.10: The V-EMB 780, seen oblique from above.

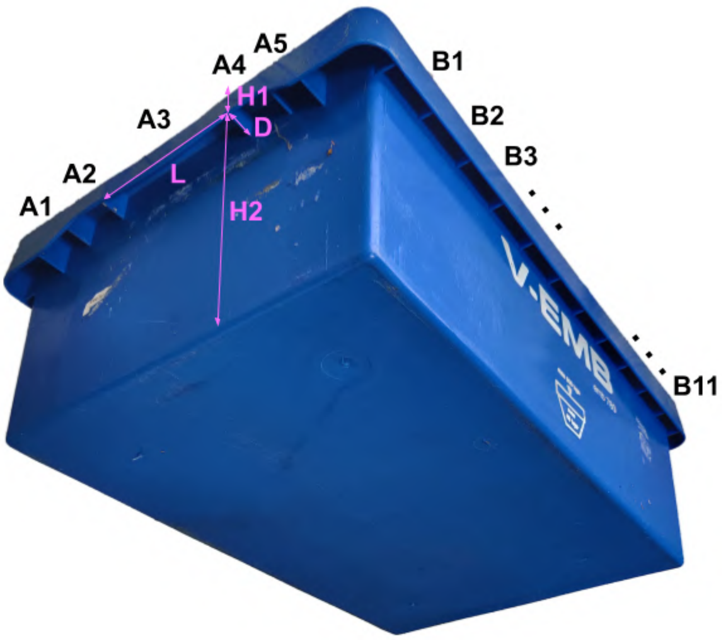


Figure 3.11: The V-EMB 780 bottom seen oblique from below. A1 to A5 represents the different sections for the box front flange and B1 to B11 the sections of the box side flange. The measurements for these sections are described in height (H1 & H2), length (L) and depth (D), as visualized in pink, can be seen in Table 3.6.

Table 3.6: Flange measurements for the V-EMB 780

Flange section	Length [mm]	Height 1 [mm]	Height 2 [mm]	Depth [mm]
A1	27	36-46	150-160	24-25
A2	37	27-33	164-167	24
A3	137	28-35	160-167	20-23
A4	37	27-33	164-167	24
A5	27	36-46	150-160	24-25
B1	43	46	150	12
B2	48	46	150	12
B3	48	46	150	12
B4	48	46	150	12
B5	48	46	150	12
B6	48	46	150	12
B7	48	46	150	12
B8	48	46	150	12
B9	48	46	150	12
B10	48	46	150	12
B11	43	46	150	12

V-EMB 787

The V-EMB 787 is a symmetrical box and its' outside measurements are quite similar to the V-EMB 780 and the V-EMB 460, besides from the height. A visual representation of the box can be seen oblique from above in Figure 3.12. Due to its' symmetric shape, the V-EMB 787 therefore only consists of two different types of flanges. These flanges will be further described in this paragraph.

Figure 3.12: The V-EMB 787, seen oblique from above.

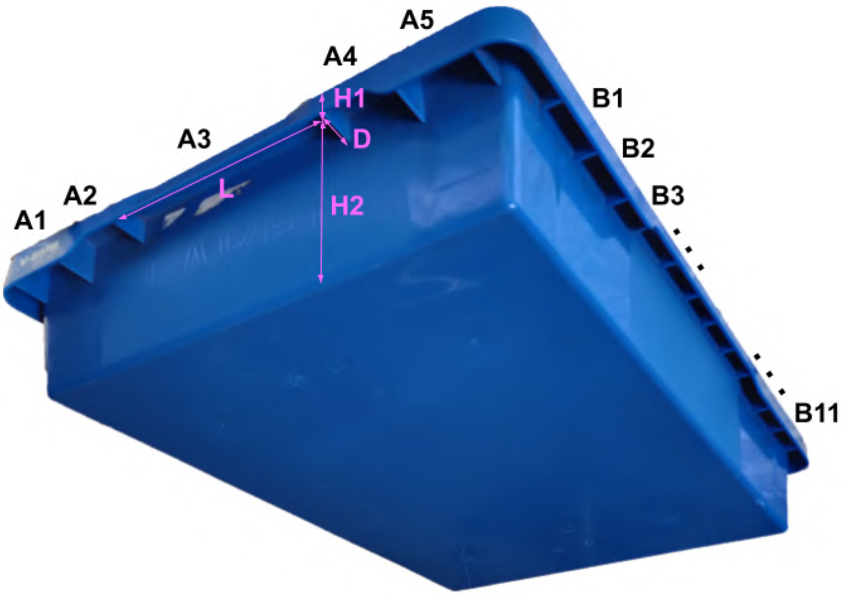


Figure 3.13: The V-EMB 787 bottom seen oblique from below. A1 to A5 represents the different sections for the box front flange and B1 to B11 the sections of the box side flange. The measurements for these sections are described in height (H1 & H2), length (L) and depth (D), as visualized in pink, can be seen in Table 3.7.

Table 3.7: Flange measurements for the V-EMB 787

Flange section	Length [mm]	Height 1 [mm]	Height 2 [mm]	Depth [mm]
A1	43	27	69	25
A2	45	15-27	69-79	23-25
A3	161	15	79	18-23
A4	45	15-27	69-79	23-25
A5	43	27	69	25
B1	43	27	69	13
B2	43	27	69	13
B3	43	18-27	69-78	11-13
B4	43	15	81	11
B5	43	15	81	11
B6	37	15	81	11
B7	43	15	81	11
B8	43	15	81	11
B9	43	18-27	69-78	11-13
B10	43	27	69	13
B11	43	27	69	13

V-EMB 800

The V-EMB 800 is one of the biggest boxes and has a symmetrical shape. A visual representation of the box can be seen oblique from above in Figure 3.14. Due to its' symmetric shape, the V-EMB 800 therefore only consists of two different types of flanges. These flanges will be further described in this paragraph.

Figure 3.14: The V-EMB 800, seen oblique from above.

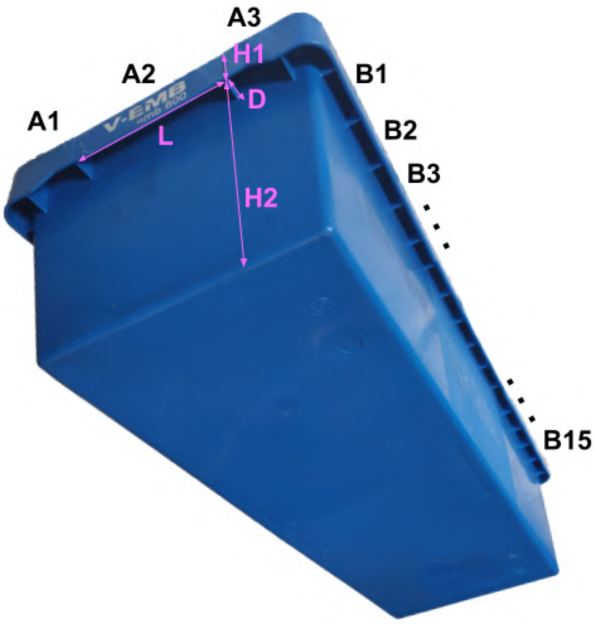


Figure 3.15: The V-EMB 800 bottom seen oblique from below. A1 to A3 represents the different sections for the box front flange and B1 to B15 the sections of the box side flange. The measurements for these sections are described in height (H1 & H2), length (L) and depth (D), as visualized in pink, can be seen in Table 3.8.

Table 3.8: Flange measurements for the V-EMB 800

Flange section	Length [mm]	Height 1 [mm]	Height 2 [mm]	Depth [mm]
A1	44	36-46	149-160	20-22
A2	137	36	160	17
A3	44	36-46	149-160	20-22
B1	46	46	149	12
B2	46	46	149	12
B3	46	46	149	12
B4	46	46	149	12
B5	46	37-46	149-162	11-12
B6	46	37	162	11
B7	46	37	162	11
B8	46	37	162	11
B9	46	37	162	11
B10	46	37	162	11
B11	46	37-46	149-162	11-12
B12	46	46	149	12
B13	46	46	149	12
B14	46	46	149	12
B15	46	46	149	12

V-EMB 840

The V-EMB 840 is the biggest box to be handled in the SuMa warehouses and has a symmetrical shape. A visual representation of the box can be seen oblique from above in Figure 3.16. Due to its' symmetric shape, the V-EMB 840 therefore only consists of two different types of flanges. These flanges will be further described in this paragraph.

Figure 3.16: The V-EMB 840, seen oblique from above.

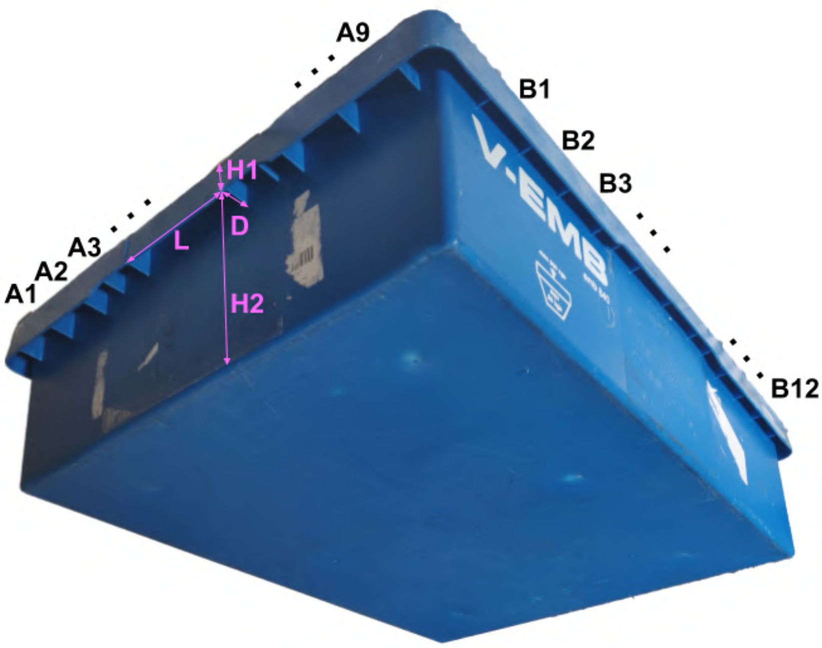


Figure 3.17: The V-EMB 840 bottom seen oblique from below. A1 to A9 represents the different sections for the box front flange and B1 to B12 the sections of the box side flange. The measurements for these sections are described in height (H1 & H2), length (L) and depth (D), as visualized in pink, can be seen in Table 3.9.

Table 3.9: Flange measurements for the V-EMB 840

Flange section	Length [mm]	Height 1 [mm]	Height 2 [mm]	Depth [mm]
A1	57	46	149	25
A2	57	46	149	25
A3	27	38-46	149-159	24-25
A4	37	36	159	24
A5	137	36	159	22
A6	37	36	159	24
A7	27	36-46	149-159	24-25
A8	57	46	149	25
A9	57	46	149	25
B1	57	46	149	13
B2	57	46	149	13
B3	57	46	149	13
B4	37	39-46	149-160	12-13
B5	37	37	160	12
B6	68	37	160	12
B7	68	37	160	12
B8	37	37	160	12
B9	37	37-46	149-160	12-13
B10	57	46	149	13
B11	57	46	149	13
B12	57	46	149	13

Summary findings measurements box flanges

By analyzing the flange shapes for the different boxes it was concluded that the shapes of the boxes have some similarities as they also have many varieties. For example, the V-EMB 840 box has 9 sections (A1 to A9) in the front- and back flange whereas the V-EMB 800 only has 3 (A1 to A3). The side flanges could also vary a lot, as the V-EMB 800 has over 15 sections (B1 to B15) and as e.g. the V-EMB 500 only has 5 (B1 to B5). However, the variation in the number of sections seems to be somewhat relative to the different boxes overall sizes. In the following paragraphs some of the differences and the similarities have been pointed out and described.

Front/back flanges The position of the front flange section dividers in relation to each other from all box types are visualized in Figure 3.18, where a bar represents a section divider while the long bar represents the edge of a box. By analyzing the position of the dividers in relation to each other, similarities and differences can be found amongst the boxes.

Figure 3.18: The positions of all front flange section dividers, overlaid on top of each other. Each bar represents a divider, while the longer bars represents the edge of a box.

By grouping together similar boxes some interesting patterns are found, such as shared free spaces. V-EMB 500 and V-EMB 600 are the boxes with the shortest middle section, by grouping them together, seen in Figure 3.19, three major shared free spaces are found.

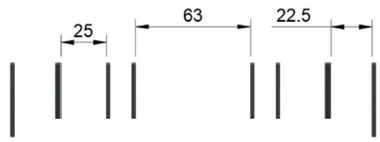


Figure 3.19: The position of the section dividers for V-EMB 500 and V-EMB 600, the measurements are given in mm.

The rest of the boxes can be subdivided into two additional groups. One group would be with the V-EMB 750, the V-EMB 757, the V-EMB 780 and the V-EMB 800 shown in Figure 3.20, while the other one would be with the V-EMB 787 and the V-EMB 840, shown in Figure 3.21. Both of these groups share the free space of 137 mm in the middle, while also having some smaller shared free spaces off-center.

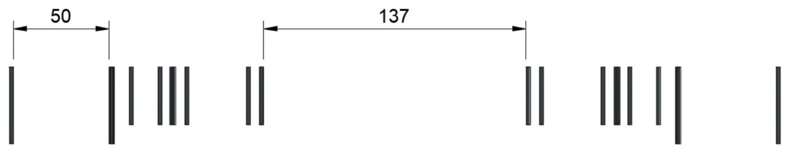


Figure 3.20: The position of the section dividers for V-EMB 750, V-EMB 757, V-EMB 780 and V-EMB 800, the measurements are given in mm.

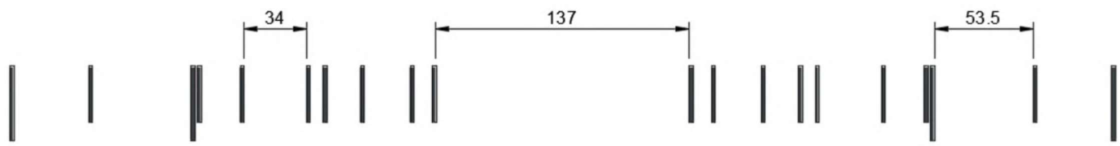


Figure 3.21: The position of the section dividers for V-EMB 787 and V-EMB 840, the measurements are given in mm.

Side flanges The side flanges are generally shallower than the front/back flanges, providing less space for an eventual tool. However, they do have a relatively consistent spacing of the section dividers, compared to the front/back flanges.

Differences The position of the section dividers varies slightly between all boxes, meaning that there is a few free spaces shared across all box types, which is seen in Figure 3.18. As an example, the V-EMB 500 and the V-EMB 600, have asymmetrical front and backsides, while the remaining boxes are symmetrical in this regard.

Another identified difference is that the V-EMB 500, the V-EMB 600 and the V-EMB 780 have asymmetrical features on the side flanges, while the remaining boxes are symmetrical in this regard. Moreover, the side flange of the boxes V-EMB 750, V-EMB 757, V-EMB 787, V-EMB 800 and V-EMB 840, have a cutout, seen in Figure 3.22, resulting in smaller flanges towards the middle. The rest of the boxes have straight side flanges without interrupting features.

Figure 3.22: The position of the section dividers for V-EMB 787 and V-EMB 840, the measurements are given in mm.

Similarities All of the boxes have a symmetrical setup of sections mirrored through the middle of the front and back flanges, with a central section. This central section guarantees that a section divider never obstructs the middle of the flange. The middle section varies from 63 mm to 161 mm. However, if the two smallest boxes V-EMB 500 and V-EMB 600 are disregarded, the minimum middle section width across the remaining boxes reaches 137 mm.

3.3 Distribution of the box variation at the SuMa warehouse

The distribution of the variation of the boxes, for the Tuve SuMa warehouse, could be seen in Table 3.10 and what to be highlighted is that the blue box V-EMB 750 is the most common box, with 39 % of overall occurrence. In second place, of most common boxes, is the V-EMB 500 with 26 % and thirdly is the V-EMB 600 with 19 %. Together these three types of box variations consist of 84% of all the boxes within the SuMa warehouse and should therefore be considered to be of most importance to find an alternative solution for.

Table 3.10: Distribution of blue box variation for the SuMa warehouse at the Volvo manufacturing site in Tuve.

Name	% of box distr.	Max. cap. per SuMa rack
V-EMB 460	3 %	2
V-EMB 500	26 %	4
V-EMB 600	19 %	2
V-EMB 750	39 %	3
V-EMB 757	1 %	3
V-EMB 780	10 %	2
V-EMB 787	0 %	2
V-EMB 800	3 %	1
V-EMB 840	0 %	1
V-EMB 1200	0 %	1

4

Ergonomic situation at the SuMa warehouse

4.1 Introduction ergonomics

As a big manufacturing company and organization, such as Volvo Trucks, they have a huge responsibility for taking care of their workers and employees. One of these is to ensure that the work can be carried out in a healthy and socially sustainable way, according to the Swedish Work Environment Authority (SWEA) or "Arbetsmiljöverket" [7].

Continuously, even though humans are optimal to keep high flexibility and problem-solving skills for material handling and manufacturing operations, there is a risk for them to develop work-related musculoskeletal disorders [8]. This as a result of the physical work that has to be performed and could potentially lead to discomfort, pain and recurring injuries. Consequently, this could lead to operators being unable to work and would then result in high costs for the company as they would need to compensate the personnel, productivity losses and the need of replacing the workforce [8].

According to SWEA, there was 8900 reported sick leaves to the Swedish Social Insurance Agency (SSIA) or "Försäkringskassan", in Sweden in 2018, that were caused due to shorter or longer harmful work activities. Whereas 34 % of these were assumed to be caused due to bad ergonomically loading factors such as heavy lifts, bad working postures and/or monotonous work [9].

However, it is not only the health for the operators that could be of harm. Bad ergonomic situations, without considering health factors, could potentially lead to the occurrence of serious errors which could cause material harm [8] and might result in high costs for the company.

4.2 Ergonomic analysis method

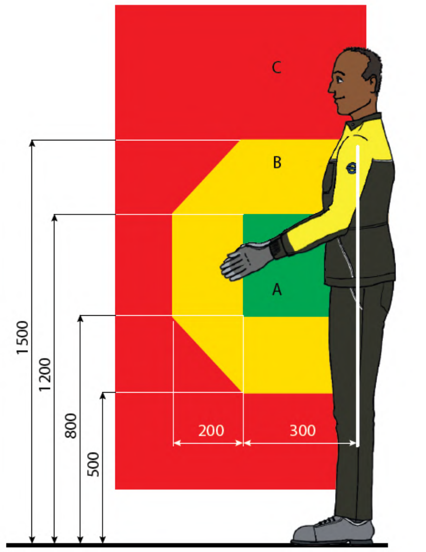
In order to achieve a deeper knowledge of what it is that causes the poor ergonomic situation for the workers, and to evaluate how severe the situation actually is, an ergonomic analysis was carried out. The intention of this was to pinpoint the specific moment that is required to handle the boxes and give insight into what type of movement that needs to be resolved.

The ergonomic analysis was performed by Volvo personnel, who are experts and works as ergonomists, and was then used for further investigations. The analysis was carried out by following the "Ergonomic Guideline Manufacturing", which is one of Volvo's own developed ergonomic analysis methods. These guidelines were constructed in 2017, with the purpose of creating a higher lowest level for all of their global manufacturing sites. Within the guidelines, they have constructed several different forms of tools, which could be used for different types of factory areas, e.g logistics and manufacturing [2]. The tool which was used, for evaluating the current situation at the SuMa warehouse, is simply called "Weight handling frequency".

4.2.1 Weight handling frequency

This ergonomic evaluation method is used to define how severe the ergonomic situation actually is. The approach of the method is to investigate in what type of handling areas the operator is operating in, how heavy the loads are and how frequently the operator is performing the lifts. Depending on what zone the operator is operating in, a coefficient between 1 - 2.5 is established and will later be used for the evaluation method. The coefficient values and the different zones could be seen in Figure 4.1. The green colored zone is called "Zone A" and is the acceptable handling area and requires the operator to work within the height of 800 mm to 1200 mm and with its arms within 300 mm from the body. The measurements are based on a European normal population [2].

Continuously, "Zone B" is marked with yellow color in Figure 4.1 and is considered to be a bit worse than "Zone A" but not as bad as "Zone C" which is marked with red in Figure 4.1. "Zone B" has therefore only a slightly higher coefficient, relatively to "Zone A", whereas "Zone C" has been considered to be a 2.5 times worse handling area than "Zone A".



(a) Handling area evaluation model

HANDLING AREA	COEFF
A	1,00
B	1,25
C	2,50

(b) Work coefficients for the different zones

Figure 4.1: Weight handling frequency evaluation tools.

Along with coefficients, the weight of the load and the frequency per hour is combined to achieve a result of the ergonomic situation. These results are displayed in an evaluation diagram, later seen in Figure 4.2, where the vertical axis shows the weight of the lifted object, while the horizontal axis shows the total weight handled per hour by a worker. If the result was to be within the green area the work situation is considered to be good. However if it would be within the yellow or red area, the result of the work situation would be considered to not be ergonomically acceptable.

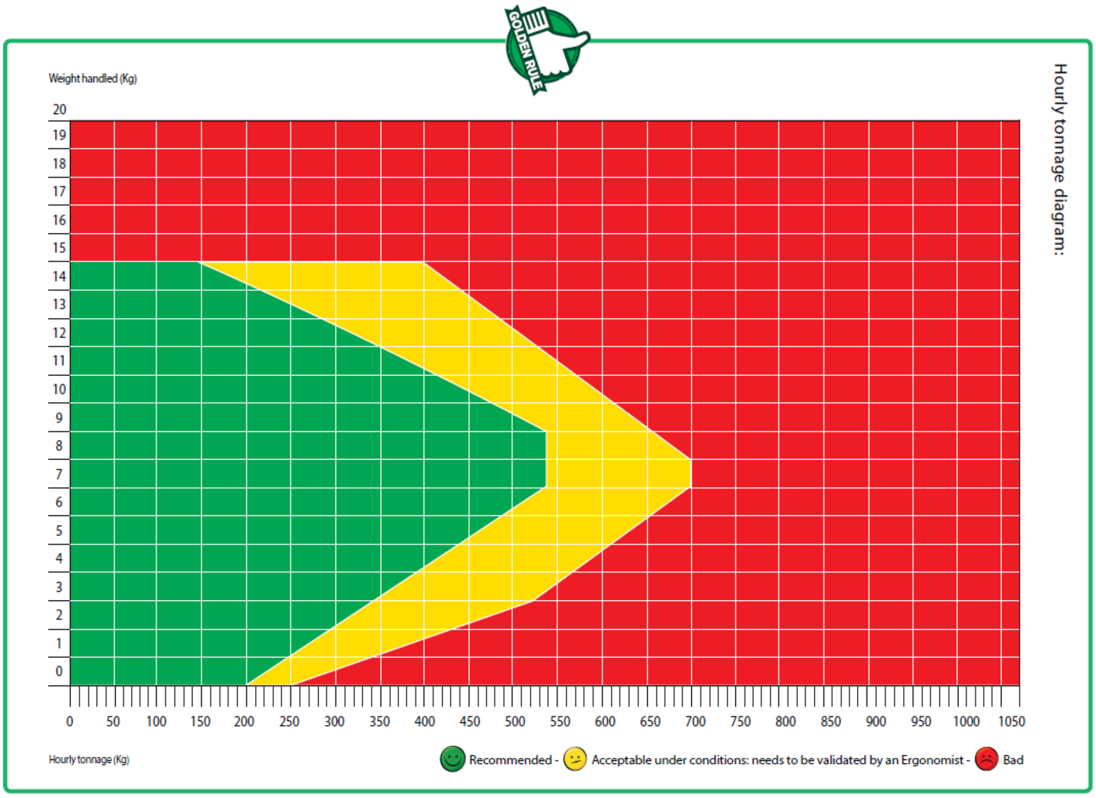


Figure 4.2: Weight handling frequency evaluation diagram

4.3 Ergonomic situation

After the ergonomic analysis had been performed, which was previously described in Chapter 4.2, the data of the SuMa work procedure was gathered and could be seen in Table 4.1. Some of the different working positions, for the operators, could be seen in the earlier SuMa Workflow Chapter 2.3.

Table 4.1: SuMa ergonomic evaluation

SuMa Evaluation	Return of empty boxes	Refill boxes	Pick boxes	Total
No. boxes handled/h	40	40	20	100
No. heaviest boxes handled/h		6.8	3.4	10.2
Avg. weight of the boxes	1.5 kg	6.9 kg	6.9 kg	
Max. weight of the boxes		12 kg	12 kg	
% of work in Zone A (Coeff. 1)	0 %	24 %	32 %	
% of work in Zone B (Coeff. 1.25)	0 %	48 %	36 %	
% of work in Zone C (Coeff. 2.5)	100 %	28 %	32 %	
Summarized avg. coeff.	2.50	1.54	1.57	
Tot. max. weight handling/h		81.6 kg	40.8 kg	122.4 kg
Tot. weight handling/h	60 kg	275.6 kg	138 kg	473.6 kg
Tot. max. weight handling/h * summarized coeff.		125.66 kg	64.06 kg	189.72 kg
Tot. weight handling/h * summarized coeff.	150 kg	424.15 kg	216.66 kg	790.81 kg

By translating the data from Table 4.1 into the Weight handling frequency evaluation diagram, seen in Figure 4.2, the following result was achieved and is to be seen in Figure 4.3.

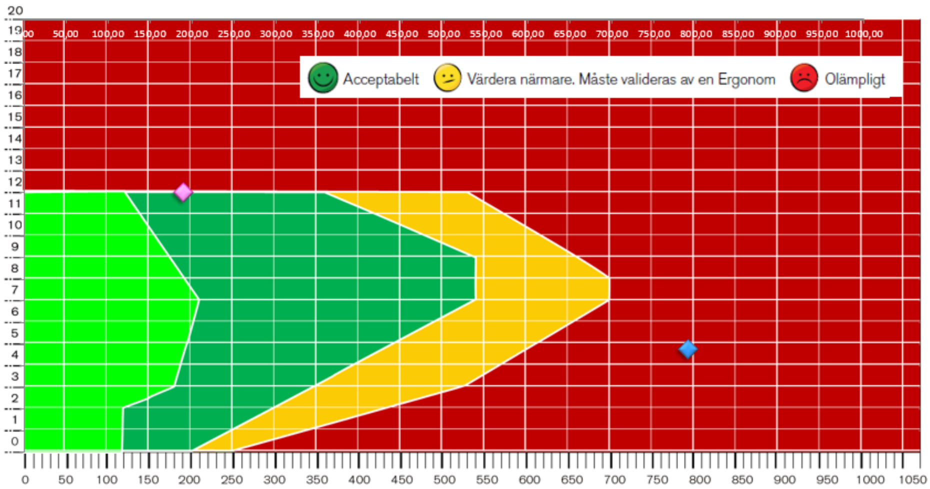


Figure 4.3: Results from the ergonomic analysis of the weight handling frequency for the SuMa warehouse. The Y-axis represents the average weight of the box and the X-axis represents the total weight handling per hour

In Figure 4.3, a pink- and a blue diamond can be seen. The pink diamond represents the maximum weight handling, in Tuve, at 12 kg and the blue diamond represents the average weight handling of 4.736 kg. The pink diamond has received its Y-axis location as the weight of the heaviest boxes of 12 kg and the X-axis as the maximum weight handling per hour multiplied with the summarized average coefficients, which equals to 189.72 kg.

Consequently, the pink diamond is then located within the green area the result is that the maximum weight handling is currently acceptable as it is today. It should however be considered that it is just on the limit to be acceptable and if a box would weigh slightly more than 12 kg it would instead be considered as unacceptable.

However, for the blue diamond, which represents the average weight of the boxes in the SuMa Warehouse, it could be seen that this one has been placed within the red area. The Y-axis placement (the average weight handling for the SuMa warehouse) of the blue diamond was calculated as:

$$\frac{\text{Total weight handling per hour}}{\text{Number of boxes handled per hour}} = \frac{473.6 \text{ kg}}{100} = 4.736 \text{ kg}$$

Whereas the X-axis represents the sum of the total weight handling per hour multiplied with the summarized average coefficients, equals 790.81 kg. This results in a placement, of the blue diamond, outside of acceptable areas within the evaluation diagram. The average weight handling frequency is therefore currently considered to be an unacceptable work situation that needs to be redesigned.

5

Specification of Volvo's needs and wants

5.1 Methodology and information gathering approach

To be able to identify the needs and wants for Volvo, a more qualitative study approach has been followed, whereas several meetings have been performed. These have both taken place locally in the Tuve plant, as well as globally within the global network of Volvo Trucks. More of the qualitative study approach will be found in Chapter 5.1.1. Additionally, information has been gathered by examination of the annual report, from Volvo Group, and different research papers.

5.1.1 Qualitative study

The qualitative study has been following a more flexible research design and functioned as a deeper investigation method and was based on ongoing data collection and analysis. Which is the recommended approach, for a qualitative study, according to Taylor, Bogdan and DeVault [10]. This study has been performed by conducting interviews and observations, both at the different Volvo Trucks plants but also with other relevant stakeholders. Moreover, Taylor, Bogdan and DeVault [10] express the importance of having strategies of how to identify these and how to obtain the right access. Mostly these interviews and conversations have been held with stakeholders that will be affected and/or could have something to say about the problem identified and give some input about the advantages and disadvantages of possible solutions.

The people that have been interviewed and settings that have been observed have mostly consisted of different operators and different responsible logistics engineers. These observations and interviews have been conducted through Skype calls and/or personal contact/observations and have been documented with notes, photos and/or videos. Further on, the data has been analyzed considered to the suggested solution and has given input to project decisions.

This qualitative study has been held continuously during the project and has been a part of understanding different current state issues and has resulted in wishes of how a future state should be designed.

5.2 The vision by Volvo

In order to achieve a more efficient- and sustainable workplace, for the SuMa warehouse, Volvo wanted to evaluate and investigate new technical solutions that had not yet been used within their own facilities. A wish was also to keep the advantages you would get from a manually handled supermarket warehouse, in order to keep the high flexibility and adaptability. Whereas they also would like to obtain the benefits you would get from an automated box lifting process. However, the technology does not need to be a fully automated box picking solution but could also be of a lower level of an automation solution.

Further on, a vision by Volvo is to develop the production to remain cost-efficient and to be flexible enough to quickly meet customer demand. In the annual- and sustainability report of 2019 [11], Volvo makes the following statement:

"To secure robust profitability and meet future demands, the Volvo Group has developed a mindset of continuous improvement as well as tools, processes and production systems that contribute to cost efficiency. We strive to meet customer expectations by focusing on quality, flexibility, lead times, delivery precision and availability of parts, while simultaneously working to ensure health, safety and well-being for our employees."

Specifically, Volvo is very keen to keep their production flexibility and adaptability in order to be able to manage fluctuations in the customer demand. This could be interpreted as that a desire from Volvo is to rather invest in flexible production solutions, which are easily movable, reconfigurable and scalable. Rather than solutions that require heavily locked installations, which are both expensive and time consuming to relocate. As this would be a move in the wrong direction for the vision of the company.

Additionally, it could be mentioned that the Tuve factory was initially just a regular warehouse which was later turned into a production facility. Meaning that the space is quite limited and in order to avoid huge cost for investments in new facilities, Volvo needs to try to work with what they have.

Continuously, Volvo Group is heading towards a future where autonomous-, electrical- and connected trucks will be produced at the manufacturing sites. Meanwhile the regular trucks will still have to be produced. This means that not only will the production complexity increase but also the requirement of higher product quality. Consequently, this puts certain demands on the future production, whereas the logistic systems, production processes and final assembly must be developed and transformed into collaborative and intelligent automation systems [12].

Correspondingly the new technology must be able to be agile and be easily adapted and implemented at several of the Volvo manufacturing sites.

5.3 List of requirements and design specifications

By evaluating the current analysis and following the vision from Volvo, there are some key findings that the new technical solution must be able to handle. Some of them are requirements whereas others are wishes. Below Table 5.1 and Table 5.2 have been compiled with what needs and wants a future solution has to overcome.

Table 5.1: Needs

Needs	Function	Description
N1	Safe to use.	The solution should be safe to use.
N2	Eliminate the bad ergonomic situation.	The solution should eliminate the bad ergonomic situation by either lower the lifting frequency for the operators or make it more sustainable.
N3	Handle individual boxes.	The solution should be able to handle single boxes and not just pallets.

Table 5.2: Wants

Wants	Function	Weight 1-5	Description
W1	Handle loads of 15 kg.	4	Since the blue boxes could weigh up to 15 kg the solution is desired to handle this payload. However, if it is only able to handle e.g. 12 kg the solution would still be of interest if it could help to lower the lifting frequency. The weight constant has therefore been set to 4.
W2	Efficiently handle individual boxes.	5	The solution should be able to efficiently handle single boxes, as it otherwise would require extra manual work. The weight constant has therefore been set to 5.
W3	Handle multiple box variations of all of the nine different types of box sizes.	2	Desirable if the solution would be able to handle nine of the boxes which are described in Table 3.1. Although, since the box distribution, of the SuMa warehouse, described in Table 3.10, mainly consists of three of these boxes, the weight constant has been set to 2.
W4	Handles box variation and the three blue boxes: "V-EMB- 500, 600 & 750".	5	A strong desire for the solution to be considered feasible, is for these three types of boxes to be able to be handled. As they consist of 84% of the SuMa warehouse box distribution. The weight constant has therefore been set to 5.
W5	Flexible in the manner of easily movable, reconfigurable and scalable.	5	In order to easily adapt to change in production demands, the solution should be easily relocated. This one of Volvo's key vision and desire's and consequently the weight constant has been set to 5.
W6	Able to safely- and efficiently work alongside humans.	5	An important wish from Volvo is to keep the flexibility of still being able to use human operators in the SuMa warehouse. The new technology should therefore be able to interact alongside humans. For this reason, the weight constant was set to 5.
W7	New technology within Volvo Trucks.	4	Due to upper management desire of funding the project and wanting to explore new concepts, the technology should not yet have been tested within the Volvo Trucks production facilities. However some variants of solutions might have been tested before but for other purposes, therefore the weight constant is set to 4.
W8	Box handling capacity of 100 boxes/hour.	3	The solution would have to be efficient enough to be considered as a reasonable- and sustainable solution. Although as the importance is to eliminate the bad ergonomic situation this weight constant has been set to 3.
W9	Shortens or remains the lead time to UP.	3	The new solution should make it able to shorten the lead time, from OP, from the SuMa Warehouse to the UP. Not a crucial desire but would however be beneficial. The weight constant has been set to 3.

6
The selection of a suitable future solution

6.1 Market analysis introduction

The desired outcome of performing the market screening was to apprehend information about best practices and investigate how other material handling stakeholders have been solving this issue. Data gathering of what types of technical innovations that have been made within the production logistics-/material handling area and how it could be more efficient.

Thereafter the conducted data has been analyzed and evaluated of what solution that would be best suitable for Volvo's concerned manufacturing sites and how it could be implemented. This was performed by comparing the different solutions to how well they fitted to the list of requirements, which was earlier presented in Chapter 5.3. Thereafter the solutions, which acquired the highest points, were further analyzed, by weighing pros and cons against each other, until only one solution remained.

The market screening was conducted by both performing a literature study on recent research about material handling solutions, whereas the screening has also been to investigate what the market is offering today. In more detail, the investigation has also involved contact with various entrepreneurs and automation related suppliers.

6.2 Market analysis

In order to find a suitable future solution for Volvo, a market screening and a literature study were conducted. The purpose was to investigate what type of current technologies that are available today, what the future may provide and evaluate if something could be applicable in order to provide a more sustainable material handling.

6.2.1 Market analysis and technical investigations

For the market analysis, the different technical solutions have been divided into three more specific technical areas. Firstly the more traditional automated storage and retrieval system (AS/RS) will be described, followed by more mobile robot solutions and thereafter semi-automatic lifting solutions.

AS/RS

Similar to the current automatic warehouse solutions from Swisslog, at Volvo Trucks in Tuve, there are other similar AS/RS. Whereas many of them are based on the same type of traditional solution with aisle captive cranes and-/or conveyor belts and elevators, which requires heavily fixed installations. Further on some of these systems from the biggest manufactures will be described, and a brief analysis of what key benefits and disadvantages these systems could provide.

Swisslog Vectura One of the currently available technical solutions is the Swisslog Vectura [13]. From the fact sheet, found at the website of Swisslog, the system is said to be a fully automated stacker crane which could handle pallets in a high bay warehouse. A visual representation of the crane can be seen in Figure 6.1.

Figure 6.1: Visual representation of the Vectura solution from Swisslog. Source to the image can be found in the references [14].

The solution is designed to be energy efficient, to handle a high variety of pallets and is capable of lifting loads from 200 kg to 3500 kg. Whereas the height of the system could be up to 45 meters high. Moreover, the system provides an emergency cabin which could be used for manual operation but the system is not intended to be used by humans. An URL to a YouTube-video of the system is also to be found in the references [15].

Swisslog AutoStore Another solution from the Swisslog company is the system called "AutoStore" [16]. In a contrast to the Vectura system which uses a stacker crane, this is instead using autonomous robots that are traversing an aluminum grid above stacked storage boxes. An image of the system can be seen in Figure 6.2 and an URL to a YouTube-video is presented in the references [17].

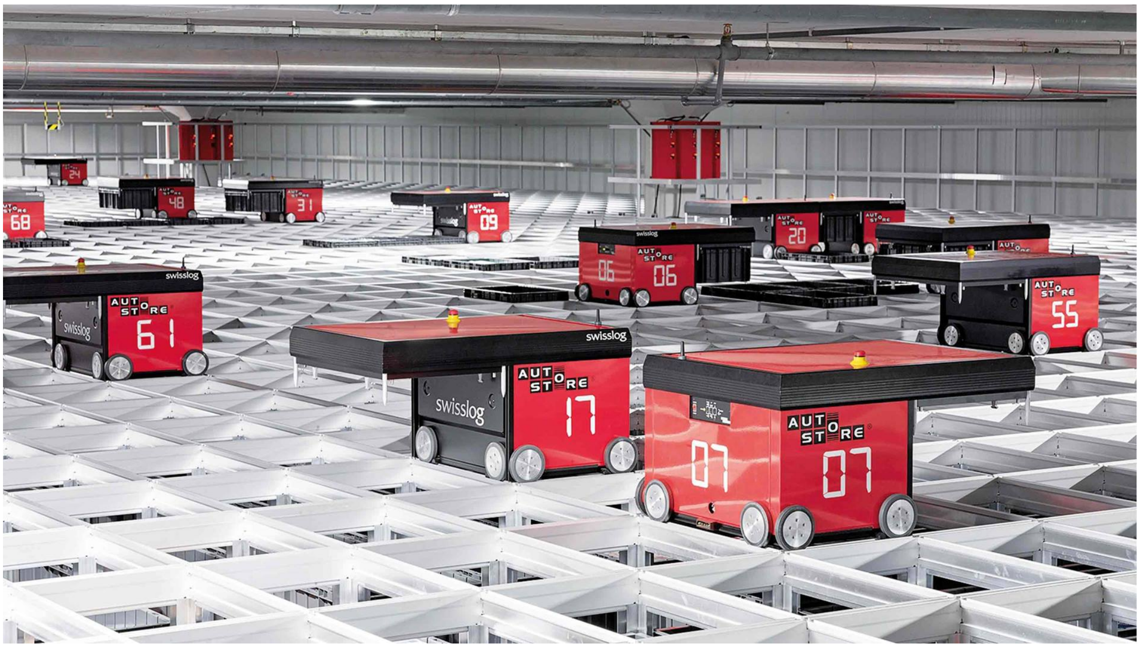


Figure 6.2: An image of the AutoStore solution from Swisslog. Source to the image can be found in the references [18].

According to Swisslog the size and form of the grid could be changed in order to be a suitable fit for any warehouse and simultaneously be of optimal space utilization. Further on the maximum capacity of the system is somewhere between 350-650 boxes/hour per robot depending on what type of robot that is chosen and the maximum height is set to be 5.4 meters. The included boxes for the system come in the three different heights of 202 mm, 312 mm and 404 mm and the inner base size of the boxes is 603 mm x 403 mm and could contain a maximum payload of 30 kg.

KUKA KL + KUKA KR The company KUKA offers various solutions for rail systems which could be combined with their industrial robots. By placing an industrial robot on-top of one of these rails, it enables linear transportation, and according to KUKA thereby a quite mobile solution [19]. An image of this can be seen in Figure 6.3.

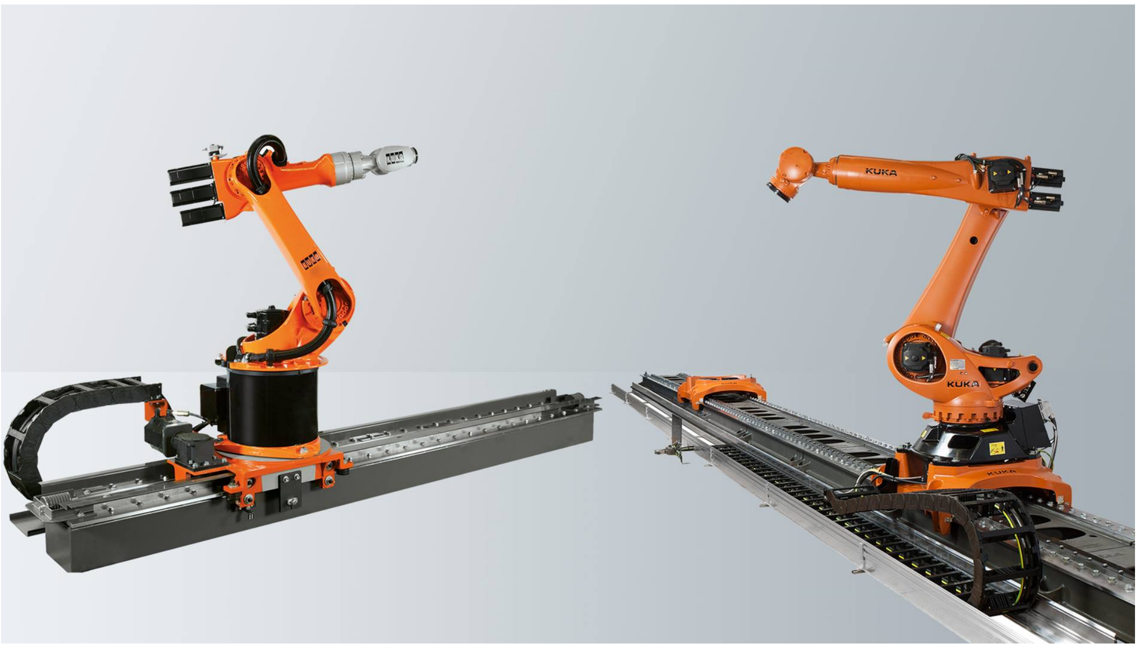


Figure 6.3: An image of linear units from KUKA, whereas a KUKA KL and a KUKA KR has been combined. Source to the image can be found in the references [20].

Depending on what payload that is required a suitable solution could be combined. Whereas with for example the KR 500 Fortec solution, the maximum payload could be up to 500 kg with an operating height of 3326mm. An URL to an example video, of a KUKA robot working with linear transportation, is to be found in the references [21]. Depending on the end effector design, multiple variants of the blue boxes could be handled. However, due to the fixed rail installation and the absence of safety sensors, the solution could be difficult to integrate with human operators.

Standalone mobile robots

Besides the traditional crane systems, there are other solutions that may work as well. The robots described below is of a more mobile style and are easily relocated and gives a high flexibility for Volvo Trucks.

Magazino SOTO The Magazino SOTO is a supply chain solution for production logistics which consists of a mobile transportation robot. At the product website, the company states that the transportation robot uses 3D vision and a gripper tool, which makes it able to pick boxes from shelves, conveyor belts and-/or flow racks [22]. A 2D-vision system is also used to scan barcodes. The maximum box payload for the Magazino to handle is 15 kg and the maximum box measurements are 600x400x300 mm (LxWxH). In Figure 6.4 and Figure 6.5 two product images of the robot are displayed.

Figure 6.4: First product image of the Magazino SOTO. Source to the image can be found in the references [23].

Simultaneously as the robot is picking boxes it could be carrying loads with the capacity of up to 10 boxes, depending on measurements, with a total maximum payload of 150 kg. Moreover, the system is using laser scanners to ensure safe navigation and could be operating alongside humans. An URL to a visualizing YouTube-video, of the system, is to be found in the references [24].

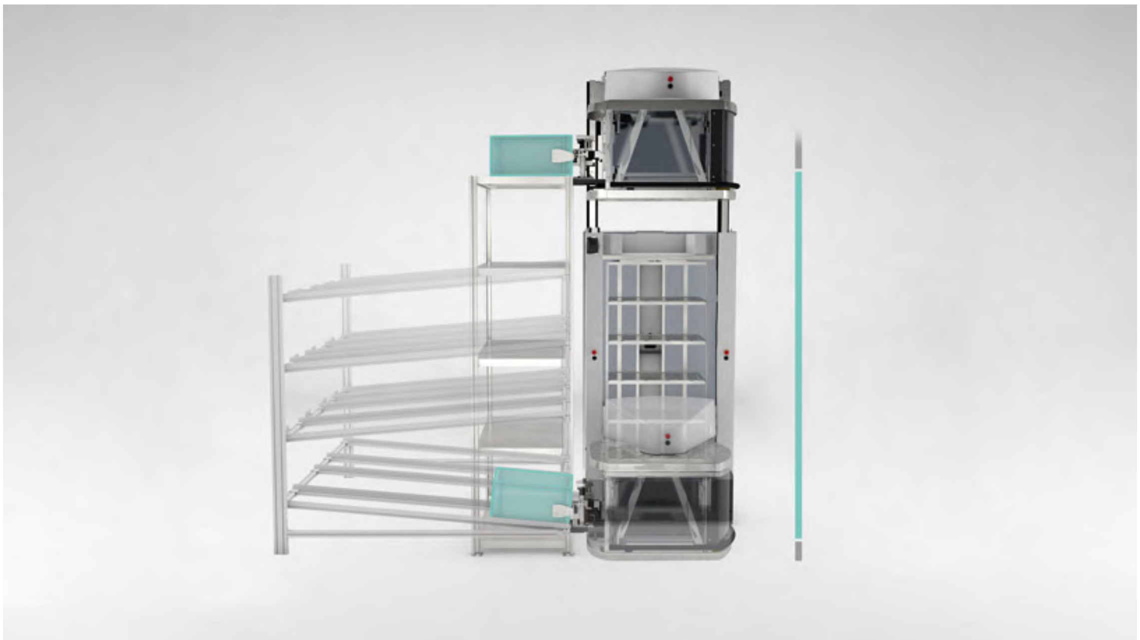


Figure 6.5: Second product image of the Magazino SOTO. Source to the image can be found in the references [25].

In an interview with the CTO, Moritz Tenorth [26], it is stated that the capacity depends on how long transportation the robot has to do. Tenorth explains that the navigation may become more difficult and slow due to longer paths. However, he also states that the pick performance is the most important performance indicator from a business point of view.

KUKA KMR iiwa The KUKA KMR iiwa is a mobile robot with the ability to perform multiple different tasks. The system uses a 70 cm high AGV with a collaborative robot mounted on top of the AGV and has been described as a centaur-looking robot [27] [28]. Two images of the centaur-looking robot are to be found in Figure 6.6 and Figure 6.7.

Figure 6.6: A product image of the KUKA KMR iiwa. Source to the image can be found in the references [29].

Depending on what type of end effector that is chosen, for the robot arm, and what functions the robot is programmed for, the system could be used for several different operations. Whereas the end effector design also impacts on how many variants of blue boxes that could be handled. In the YouTube-video found in the references, an example of the system in use is provided [30].

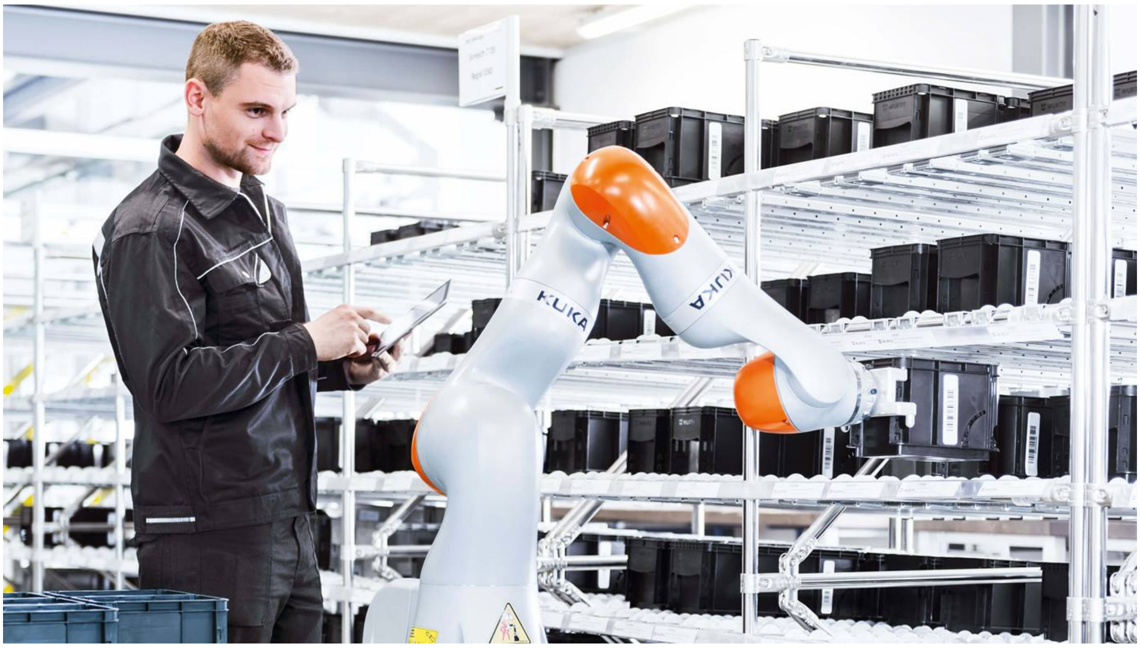


Figure 6.7: An image of the KUKA KMR iiwa in use. Source to the image can be found in the references [31].

Stated at the company website for KUKA, the maximum payload for the robot arm, without end effector, is 14 kg and the maximum payload for the AGV to transport is set to 170 kg and the robotic arm could reach 25 cm below itself and reaches heights of 118 cm [27]. The system is location independent and uses laser scanners to ensure safe navigation. Moreover, the collaborative robot makes it possible for humans to safely interact with the robot if necessary.

Semi-automatic lifting solutions

Moving forward, with less autonomous solutions that still would require human operators but that also would remain easy adaptability and good flexibility.

EksoVest The EksoVest is an industrial upper-body exoskeleton aimed at reducing the strain on workers' arms and shoulders. The solution is provided by the company called Ekso Bionics and at their website, they state the system uses passive springs that support the worker's upper arms and redirects some of the load to the hips [32]. The exoskeleton is visualized in Figure 6.8 and in the references, an URL to a test video at YouTube, made by Quartz, is found [33].

Figure 6.8: A product image of the exoskeleton EksoVest. Source to the image can be found in the references [34].

The lift assistance is adjustable in four steps between 2.2 kg to 6.8 kg per arm giving an operator the additional lifting capacity of 13.6 kg. This solution allows the operator to handle all of the individual boxes. However, by consulting this solution, with the ergonomic specialist Michael Schröder [2], it is said for exoskeletons to have some health issues, as they generally just distribute the load to a different part of the body, and might therefore not be safely sufficient.

2Lift C-150 The C-150 is one of many different lifting solutions from the company 2Lift. The lift is a semi-automatic tool using electric engines as lifting power and a visual representation is to be seen in Figure 6.9. The lifting device is integrated with a mobile platform and easy and flexible to move. On the website of 2Lift they describe that the specific model has a maximum payload of up to 150 kg and could handle various amounts of different tools [35]. The maximum height is set to be 2350 mm and the lowest height depends on the selected tool. The selected tool also defines the possible measurements for the boxes to have.

Figure 6.9: Image of the 2Lift model N-150M, similar to the C-150 model. Source to the image can be found in the references [36].

As a control unit, there is a four-button remote which allows the operator to have full control. When fully charged, after six hours, the device could lift loads of 150 kg up to 60 times with a lifting speed of 130 mm/s.

Summary of specifications from the market screening.

A summary of some of the specifications from the investigated solutions could be found in Table 6.1.

Table 6.1: Summary of specifications from market screening

Available technologies	Payload [kg]	Vertical working range [mm]	Blue box range
Swisslog Vectura	3500	45000	N/A
Swisslog AutoStore	30	5400	V-EMB 460-787
KUKA KL + KR	500	3326	V-EMB 460-1200
Magazino SOTO	15	50-2500	V-EMB 460-787
KUKA KMR iiwa	14	445-2006	V-EMB 460-1200
EksoVest	13.6	N/A	V-EMB 460-1200
2Lift C-150	150	2350	V-EMB 460-1200

6.2.2 Evaluation and discussion of market analyzed solutions

By summarizing the key findings of the current state analysis of what requirements that is needed for a future solution and what technologies that are available today, an evaluation of the most suitable solution was possible to achieve. In Table 6.2 and Table 6.3, evaluation of how well the different technologies fulfill the wants and needs that are required, could be seen. Based on the data from earlier presented information, the score that has been presented in the tables has been discussed upon and decided, as objective as possible, by relevant stakeholders. This has been performed with the focused target of how well the technologies fulfills the different requirements. Additionally, the Y and the N for Table 6.2 represents Yes (Y) and No (N).

Table 6.2: Evaluation of needs

Needs	N1	N2	N3	
Technical solution		Score		Total score
Swisslog Vectura	Y	Y	N	2Y & 1N
Swisslog AutoStore	Y	Y	Y/N	2.5Y & 0.5N
KUKA KL + KR	Y	Y	Y	3Y
Magazino SOTO	Y	Y	Y	3Y
KUKA KMR iiwa	Y	Y	Y	3Y
EksoVest	Y/N	Y	Y	2.5Y & 0.5N
2Lift C-150	Y	Y	Y	3Y

Table 6.3: Evaluation of wants

	Wants	W1	W2	W3	W4	W5	W6	W7	W8	W9	
	Weight	4	5	2	5	5	5	4	3	3	
Technical solution											Total score
Swisslog Vectura	Score	5	1	1	1	1	1	1	5	3	19
	Weighted score	20	5	2	5	5	5	4	15	15	76
Swisslog AutoStore	Score	5	3	4	5	2	2	5	5	3	34
	Weighted score	20	15	8	25	10	10	20	15	9	132
KUKA KL + KR	Score	5	5	5	5	2	2	5	5	3	37
	Weighted score	20	25	10	25	10	10	20	15	9	144
Magazino SOTO	Score	5	5	4	5	4	5	5	3	3	40
	Weighted score	20	25	8	25	20	25	20	9	9	161
KUKA KMR iiwa	Score	4	5	5	5	5	5	4	4	3	40
	Weighted score	16	25	10	25	25	25	16	12	9	163
EksoVest	Score	3	5	5	5	3	3	5	4	4	37
	Weighted score	12	25	10	25	15	15	20	12	9	143
2Lift C-150	Score	5	5	5	5	4	5	5	3	2	39
	Weighted score	20	25	10	25	20	25	20	9	6	160

By comparing the total scores from the Evaluation of needs, seen in Table 6.2, and the Evaluation of wants, seen in Table 6.3, it can be stated that there are three main competitors. Whereas they all fulfill the three different needs and all scores very high in the wants evaluation matrix. Namely the 2Lift C-150, at 160 in a weighted score, the Magazino SOTO, at 161 in a weighted score, and then the winner, KUKA KMR iiwa, at 163 in a weighted score.

Due to the very closeness of the score, with only a difference of 2-3 points, means that all of these three technologies might be very possible solutions for Volvo Trucks. While the reason for the other solution's lower placement, mainly seems to be due to their lack of easy- adaptability and reconfigurability. Whereas those technologies do not allow cooperation with human operators, and requires relatively fixed installations, and has therefore received a low score for W5 and W6.

Meanwhile, the KUKA KMR iiwa remains a multi-functional solution that could be used for other production areas as well, rather than just material handling. This enables production flexibility to a whole new level, as the end effector could just be alternated to what purpose the robot should have. However, it is important to remember that the main problem, as it is today, to be solved, is to handle boxes. Whereas several of the investigated solutions would be a suitable fit. Though the Swisslog Vectura loses its competitive relevance as it designed to only handle whole pallets and not just individual boxes, which was one of the three listed needs.

For this sole purpose, the Swisslog AutoStore would then be of a better choice. As the AutoStore system also would result in high capacity potentials and have good opportunities to easily be scaled up. Its main disadvantage on the other hand is that the system requires to be used with dedicated boxes. This would presumably result in additional material handling, whereas the standard blue boxes would either have to be placed within the enclosed AutoStore boxes or that all of the containing components would have to be redistributed into the AutoStore boxes. The following problem would then be how the containing material would be supplied to the UP? Would it have to be supplied with the AutoStore boxes, forcing Volvo Trucks to have to interchange their whole box handling solution within their whole supply chain? Or would it then once again have to be redistributed into the blue boxes?

Additionally, it could be further researched if the system concept would be applicable for the current existing blue boxes, as they are said to be stackable, which was earlier mentioned in Chapter 3.2. Although this would require the boxes to have their plastic lids kept on, and would therefore require some further research, whether the lids are strong enough to sustain a high number of stacked boxes of heavy payload on top of them. Conclusively, the solution would most likely result in more material handling than it would be beneficially gained.

Another disadvantage for the Swisslog AutoStore is also whether it is possible or not to easily relocate the system. Whereas the construction and assembly of the aluminum racks with its robots seems to make the system to be of a quite locked installation. The system solution would also prevent humans from easily interact with the warehouse and its components. This problem is also one of the main disadvantages for the KUKA KL + KR solution, whereas the placement of the linear transportation path would most likely be in the way of the human operators. As the linear unit and heavy robot also would be more demanding to relocate.

Followingly, since the KUKA KR + KL solution consists of a regular industrial robot, it would not meet the safety requirements to be operated simultaneously as humans are nearby. This solution would therefore need to be complemented with some sort of safety sensors or to be caged in with security fences.

On the other hand, as the KUKA KR + KL solution is designed as it is, with its linear transportation path and industrial robot, the solution gains a lot of benefits. Some of these are mentioned and discussed in personal communication with the two KUKA salesmen, Conny Pettersson and Peter Ljungberg [37]. As an example, the industrial robot could be selected to handle relatively heavy payloads and has in general a much better accuracy and repeatability to handle tolerances, than for example a collaborative robot would have. The potential of interchange and select another end effector is also increasing the system's ability to be reconfigurable and flexible to be used for other production areas as well. Moreover, it could be functioning at a much higher speed than for e.g. a collaborative robot and by using a linear transportation unit it would presumably better tolerate disturbances on the factory floor than a wheel-based solution would.

Further on the EksoVest solution received a quite high score, seen in the evaluation of wants in Table 6.3, and would be a potential choice as well. Whereas the main benefits for the system are for it to be very easily implemented and as it would remain the same flexibility as the human operators provide today. Although it should be further researched on how cumbersome the exoskeleton would be to use, especially as the human operators perform their other daily work tasks. Moreover, some comments, from the Volvo Trucks ergonomist Michael Schröder, should be considered and requires further research. As Schröder was stating that the problem with exoskeletons generally is that they just redistribute the loads to another part of the body, and might therefore not be as suitable as it may seem. Additionally, it should be considered that the EksoVest has no potential of working by itself, such as the other automatic solutions, and Volvo would therefore be forced to continue using human operators.

Similar to have the same advantages as the EksoVest, is the 2Lift C-150 solution, as it is very easily implemented and would keep the same type of flexibility. Even more beneficially than for the EksoVest, is that the 2Lift does not have to be mounted on a human operator, meaning that it would not interfere with the operators' other daily work tasks. Although it is unclear how smooth the interaction of the 2Lift, the blue boxes and a human operator would be. This would therefore require to be tested in order to evaluate its efficiency and user-friendliness. Further on it should be stated that even though the lifting tool seems to be interchangeable, the solution itself is dedicated and focused to only solve lifting issues and shorter transportation. Meaning that its flexibility of reconfigurability would not be as good as for e.g. the KUKA solutions, which potentially could be used for several production purposes. Additionally, the 2Lift would have the same disadvantage as the EksoVest of forcing Volvo to keep human workers for the work task.

Moving on with the solutions, the Magazino SOTO would arguably be of a very good fit for the SuMa warehouse. As it fulfills almost all of the criteria in a sufficient way. Such as having the advantages of being easily relocated, handles the maximum payload of 15 kg, able to safely work alongside humans etc. Whereas it only seem to have two relevant disadvantages, as one of them is that it could not handle the V-EMB 840 box. Although, since the box distribution seen in Table 3.10, of the V-EMB 840, at the SuMa warehouse at Volvo Trucks in Tuve, is set to be zero, the solution could still be arguable to be a very suitable fit. The other disadvantage though is that it does not provide the same type of flexibility in reconfigurability as the KUKA KMR iiwa, as the solution is dedicated to only lifting and transporting boxes.

So as the solutions had been further analyzed, the selection was to continue the project with the KUKA KMR iiwa. Whereas the right type of a designed end effector would be able to handle all of the box types, as the KUKA KMR iiwa also sufficiently fulfills the other listed requirements. The only requirement which could be argued about is that the KUKA KMR iiwa is specified to only handle a payload of 14 kg, whereas the requirement is set to be 15 kg. It should however be mentioned, that this regards the lifting capacity of the KUKA KMR iiwa. Meaning that for e.g. an end effector designed to work more as of "dragging solution", similar to the solution the Magazino is using, seen in the YouTube-video linked in the references [24], the KUKA KMR iiwa would presumably be able to handle even heavier loads. Moreover, other solutions to the problem could be to fully leave the heaviest boxes to the operators, as the ergonomic situation still would be improved due to the low frequency of the heavily loaded boxes, or to interact with the operators using the collaborative mode and get assistance to lift the extra weight needed.

Additionally, it could be mentioned that the development for collaborative robots is continuously moving forward, and by further research, it was found that another collaborative robots manufacturer, called Universal Robots, has quite recently released a model, called UR16, which is able to lift payload up to 16 kg [38]. Further on, a properly designed end effector would also be beneficial, if further research would result in that for e.g. the KUKA KL + KR solution would be of the best choice, as it then easily could be adapted for this solution. The next chapters will therefore focus on how a suitable end effector/lifting tool should be designed for this sole purpose and further research of how collaborative robots works in general.

7

Collaborative robots and end effectors

To achieve a deeper knowledge about collaborative technology in the industry today and how a suitable end effector should be designed, a brief literature study was conducted. The summary of this will be found in this chapter, as it also will present some brief information about bin-picking in general, vision systems, path planning, safety regulations and end effectors.

7.1 Method collaborative robots research

The method for data gathering has mostly been conducted by performing a brief literature study, which will be described in Chapter 7.1.1. However the method has also somewhat consisted of the qualitative study approach, earlier presented in Chapter 5.1.1.

7.1.1 Literature study

According to Tempiler [39] a literature study can serve two different main purposes. Either it functions as the background for a journal or thesis, providing an overview of the current knowledge within the field and identifying eventual gaps. The second type is referred to a *standalone literature review*, and works as a value adding work in and of itself, without presenting any primary data or new analyses. So as for this research purpose, the literature study was conducted to increase the knowledge about collaborative robots and its end effectors.

Moreover Tempiler [39] states that a literature review generally consists of six steps. Although, the steps do not need to be followed in a linear manner, and should rather be seen as part of an iterative process. So for this specific literature study, these six steps have been used as guidelines and inspiration and will be further described down below.

1. Formulating the research question(s) and objective(s)

According to Tempiler, the reviewers should set clear objectives and formulate research questions to base the study on. So as for this the specific study, the main questions that wanted to be answered were the following ones:

- How do collaborative robots work in general and what assisting systems are required?
- What is important to think about when designing an end effector?
- What should be noticed when implementing this type of solution in a factory?

2. Searching the extant literature

To answer the questions, the databases available via Chalmers library were used to find relevant literature.

3. Screening for inclusion

For this step, the applicability of the literature was evaluated. As the literature was screened, according to the following rules and selection criteria:

- No literature published before 2005 would be included.
- Number of citations should preferably be more than five.
- Only scientific sources published in a recognized journal should be included.
- Source should have a clear focus for one of the project's different areas; internal logistics, production, tool construction or automation.

4. Assessing the quality of primary studies

For this step, the quality of the literature, that passed the screening, should be specified and evaluated. However, due to the limited scope, this step was seen as excessive.

5. Extracting data

In this step, the relevant data were extracted from the literature. By using the earlier research questions as a guide, the relevant data were identified.

6. Analyzing data

The final step is to collate, summarize, aggregate, organize, and compare the evidence extracted from the studies. However, as earlier steps were performed with a more lightly approach, it resulted in a more brief analysis of the data. As it was finally summarized in Chapter 7.2.1.

7.2 Collaborative robots and bin picking solutions

To enable the technology of collaborative robots, also called cobots, there are some technological- and industrial areas that need to be inspected. These will be briefly described in the following segments.

7.2.1 Collaborative robots, its features and safety regulations

Robots which enables collaboration with humans are a feature which is becoming more important in order to enhance flexibility and sustainability [40]. However, for the robots to be allowed to work alongside humans, there are certain safety regulations that need to be followed. In the article "Dynamic risk assessment and active response strategy for industrial human-robot collaboration" the authors Z. Liu et al. are treating a risk assessment for the collaborative robot safety specification ISO/TS 15066 [41] and discussing different safety factors and variables. Following, it is said that some of the things that affect the safety of industrial integrators are factors as speed, weight, response rate, robot material and what type of tool it is using [40]. However, Z. Liu et al. are also pointing out that the most dangerous factor, which causes most injuries to people, is the speed of the robot.

7.2.2 Bin picking and optimizing trajectory

In the book "Bin-Picking", by D. Buchholz, the author narrates about how such a simple task for humans, as identifying an object and picking it up from a bin, could be very complex when it comes to automation [42]. So in order for the KUKA KMR iiwa to be able to identify the blue boxes, there is a localization issue that needs to be resolved. Although the KUKA does not need to identify specific complex components and rather just the boxes itself, the same identification problem does exist. However, Buschholz explains an object localization problem to be solvable by using one of three different bin-picking approaches. Where the usage of modern sensors as well as more classic sensor concepts can be applied for enabling a very robust and efficient bin-picking. This could for example be achieved by using 2D-image techniques and combining this with e.g. force and acceleration sensors.

Moreover, the bin-picking along with its tool for grasping the boxes could potentially be further developed for optimized motion planning. This has for example been done by as J. Ichnowski, M. Danielczuk, J. Xu, V. Satish and K. Goldberg describe their work in the report "GOMP: Grasp-Optimized Motion Planning for Bin Picking" [43]. The purpose of optimizing motion planning is for the robot to be able to increase its efficiency by shortening the movement distance and thereby improve the "picks per hour" rate. This could potentially be performed in numerous ways, however J. Ichnowski et al. are using a collaborative robot, by the name UR5, and is utilizing the robot's dynamics and degree of freedom. As they are using sequential quadratic programming to apprehend the fastest trajectory to the regarded object while simultaneously avoiding obstacles in the path.

Additionally, an optimized trajectory planning will not only benefit the pick per hour rate but would also be beneficial for energy efficiency, stability, safety and cost savings [44]. This could be achieved by several different approaches as C. Llopis-Albert, F. Rubio and F. Valero explain how different mathematical approaches and algorithms have different pros and cons. Some of the trajectory approaches could be very smooth and robust, but to the cost of high computation time and high execution time, whereas others have very low execution time but to the cost of not enabling smooth paths [44].

7.2.3 Research about end effectors

In the article "Methodology for implementing universal gripping solution for robot application", the authors describe several variants and approaches for the usage of end effectors [45]. More specifically they describe the selection of different grippers as an end effector, focused for pick and place operations. The article was released in 2019, and within the paper, the authors make the statement that along with the growth of industrial robots, the market of end effectors also grows and brings new innovation to the area. Some of these innovations are of how to handle a high variation of products and will be further described down below.

To start, it is said that one of these innovations, is to select a gripper that could work as a universal gripping solution, without the need of having to be interchanged for when different components are to be picked. This type of end effector solution could provide extra benefits as it also would save costs [45]. In order for e.g. a gripper to be able to perform this, it could be produced to enable several gripping solutions, like be able to perform inside gripping, outside gripping and grip objects of different shapes.

Moreover, the authors describe that the end effector could be designed and used, with a solution of an easy changing approach. This type of solution is also said to be applicable when the parts have several gripping requirements involved. To efficiently achieve this, different grippers could be placed in a rack and whenever a specific product is going to be picked and placed, the suitable gripper will be selected [45]. However, it is also stated this sort of solution will have an impact on productivity, as the setup time then will increase. Additionally, this type of changing solution will be affected differently, depending on if the end effector changing mechanism could be performed automatically or has to be performed manually. As the manual option most likely would be cheaper to produce but will result in being dependent on human operators, as it most likely also will result in a longer setup time. Whereas an automatic changing mechanism might require higher developing and manufacturing costs, as it generally becomes more complex, but could then also result in a shorter setup time.

A further solution, for end of arm tooling, is to use a method where multiple tools are connected to the one and same frame. The frame would then be assembled to the robot and would carry all of the necessary end effectors for every process. This type of solution would be beneficial as all of the tools would be connected to the robot simultaneously and thereby reduce the setup time to nearly zero. However, the design of this type of end arm tooling is said to be challenging and expensive to accomplish [45].

Regardless of what type of approach that is chosen for the end effector, the first thing to prioritize, in order to design an end effector is to perform a component study [45]. This should be conducted thoroughly and in detail, as the components should be divided into product families. These should then be analyzed and common areas should be identified and grouped together. Relevant to this project, this part of the process has been earlier described in Chapter 3, which was about the blue boxes, whereas similar measurements between the flanges were identified.

Further on, the authors state that it is important to identify other factors, such as the weight of the components, temperature tolerance, and applicable force to the components. As these things will impact whether what type of gripping mechanism the solution could be solved with and what width the tool has to work within and how high the gripping force has to be or could be.

7.2.4 The implementation of collaborative robots

When it comes to proceeding with the implementation of cobots, for a production environment and manual assembly, there are some aspects and requirements which should be considered. In the conference paper "Industrial Challenges when Planning and Preparing Collaborative and Intelligent Automation Systems for Final Assembly Stations" the authors mentions five different requirements, whereas one of them is that smart tools should be able to be used both by cobots and human operators, in order to enable flexibility and robustness by interchangeability [12].

This means that the development of a suitable end effector or box lifting device, for the cobot, could beneficially be designed to also be able to be apprehended by a human operator. Moreover, the authors of "Industrial Challenges when Planning and Preparing Collaborative an Intelligent Automation Systems for Final Assembly Stations" states that a planning and preparation phase is important in order to enable a reconfigurable modern factory.

8

Tool- design and development

8.1 Method and design approach

When designing the required end effector for the KUKA KMR iiwa, the method of Set-Based Concurrent Engineering was followed. This was performed in order to achieve such a lean development phase as possible and in the following section, the method approach is being further described.

8.1.1 Set-Based Concurrent Engineering

The design and development process of the required tool followed the Set-Based Concurrent Engineering (SBCE) approach. This is a part of the lean product development (PD) process and was firstly introduced in the early 1990s, based on the Toyota PD system [46]. This lean approach is claimed to be one of the reasons for Toyota's success within the automotive industry [47].

The SBCE method could be divided into two different concepts, Set-Based Design (SBD) and Concurrent Engineering (CE). Whereas the SBD concept is to remain all potential design solutions as long as possible, within the process, before they are being excluded due to that it is not working [47]. Regarding the CE concept, the approach is to simultaneously, as performing the SBD, design several different subsystems for the solution which later all will be integrated into the final product [47]. The CE approach requires good communication skills between the design teams but is also one of the reasons why it is possible to shorten the lead time for the developing phase [47].

Continuously the SBCE method could be divided into five different stages of how the design process should be carried out. These are being described by Al-Ashaab et al. [47] and are the following:

1. Value Research
The key thing to start with, following a lean approach, is to identify the customer value. This will later be translated to align with the design and company strategy.

2. Map design space
Thereafter the level of innovation should be decided and how much design work that is required. The identification of subsystem targets is also of importance.

3. Concept set development
Further, design concepts and sub-systems should be created. These should then be simulated and-/or prototyped and tested. This process should then result in knowledge of what is working and what is not.

4. Concept convergence
During this phase, an optimal solution should be sought, whereas the weaker system alternatives should be eliminated. The elimination process should consider facts such as evaluating the robustness and costs of the concepts.

5. Detailed design
The final solution is concluded with details and specifications.

8.1.2 Concept and prototype development

Along with the knowledge gained from the research about collaborative robots and end effectors, found in Chapter 7, several prototypes were developed. These were apprehended through brainstorming activities and resulted in simpler sketches, drawn with pen and paper.

However, in order to achieve the prototype concepts to be more visualizing and apprehendable, they were constructed in "Autodesk Fusion 360". This is a 3D-modelling software that works as a cloud-connected tool and integrates several functions such as CAD, CAM and CAE [48].

Additionally, it was decided that the different concepts were needed to be visually mounted on the KUKA KMR iiwa. It was therefore required to construct a digital model of the KUKA KMR iiwa. This digital model was constructed by following the available dimensions given in a datasheet, of the product, found at their website [27]. Most of the dimensions were given, such as the size of the AGV, as well as the length of each limb of the collaborative robot. However, some dimensions had to be estimated, such as the shape of each limb, although these dimensions do not have a direct impact on the actual function of the KUKA KMR iiwa.

8.2 Tool and end effector design

As the end effector was going to be constructed, it followed the earlier described method of SBCE development. Exactly how this was achieved will now be further described in more detail.

8.2.1 SBCE development phase for the KUKA KMR iiwa end effector

1. Value research

When conducting the current state analysis, while simultaneously considering the earlier presented background, the customer value began to be identified. The key findings that were identified for Volvo were to enable a high production flexibility and reconfigurability, in order to adapt to variation in the customer demand. Whereas this had a huge impact on what type of solution that would be the most beneficial one. This resulted in the automatic solution of the KUKA KMR iiwa.

However for KUKA KMR iiwa to be a suitable solution there are requirements for the end effector to follow the same type of customer value. Additionally the end effector must be fulfilling the earlier presented needs and wants. Meaning that in order to meet the usage value for Volvo, the end effector should fulfill things as being safe enough, being able to handle the individual boxes etc.

2. Mapping the design space

As the end effector was going to be attached to the KUKA KMR iiwa, it was relevant to adapt the tool to fit this system and follow its' design space. It was therefore constructed a digital model, representing the system, which can be seen in Figure 8.1. The designed end effector system will be attached at the end of the arm and requires to be attached by seven bolts and one guiding pin. The end effector could potentially be designed to use electronics, which is enabled by cables wired within the robotic arm.

Figure 8.1: A digital constructed model of the KUKA KMR iiwa

For the KUKA KMR iiwa to be able to handle the individual boxes, the end effector system would require a subsystem of some type of identification method to locate the boxes. As earlier described in Chapter 7.2.2 this identification method would presumably consist of some type of vision system, such as force feedback sensors, cameras or other relevant types of sensors. This subsystem will however not be included for this design task and requires to be further investigated.

Additionally, the end effector needed to consist of a subsystem that makes it possible to actually grasp the blue boxes and handle them as wanted. This required some sort of tool to be designed and which would be a suitable integration for the whole system. Beneficially, this tool would also be able to be operated by humans if it ever would be necessary needed and in order to enable a higher flexibility. In detail, the tool needed to be designed in that way that it was being able to handle all the different types of blue boxes and its different measurements. The blue boxes measurements and specifications were earlier described in Chapter 3.2. Further on, the end effector required to be designed to fit within the SuMa racks. As earlier described in Chapter 2.2, it could also be seen that these SuMa racks had a stop edge of 2 cm to 3.6 cm height and that if a tool would to lift the boxes, using the flanges, it would have to fit within the area between this edge and where the box flange would be located.

3. Creating concept designs

A media flange is located at the very end of the KMR iiwa, which can be seen in Figure 8.2a this is what the end effector will be attached to. The media flange comes in many different configurations, depending on the use of electrical, pneumatic or other special features in the end effector.

A standardized coupling interface was designed in order to attach the concept designs to the media flange, seen in 8.2b, this coupling only acts as a mechanical fastener, meaning it does not allow for special features such as pneumatic or electrical end effectors.

(a) The media flange used to couple the robotic arm with an end effector.

(b) The standardized coupling interface developed for the prototype tools.

Figure 8.2: The standardized coupling interface developed for the prototype tools.

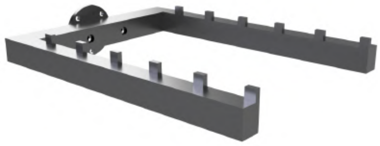
Besides from the required vision system and box identification, the act of lifting the boxes was divided into two additional sub-functions, namely "Mechanically grabbing the box" and "Adjusting the tool". These will be further described below.

Mechanically grabbing the box
Three concepts were designed for the sub-function of mechanically grabbing the boxes. These concepts are static.

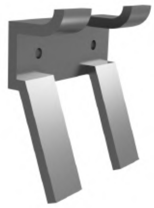
The first concept, referred to as **M1**, uses two arms to reach under the side flanges of the box, see Figure 8.3a. At the top of the arms, there is a row of teeth, which will prevent the box from sliding off of the tool by latching on to the section dividers within the flanges.

The second concept, referred to as **M2**, latches into the front flange of the box, between the section dividers. By lifting the box at an off-centered point like this, momentum is experienced in the box. In order to overcome this momentum and prevent the box from slanting, the tool has two legs which will support the lower part of the box, see Figure 8.3b.

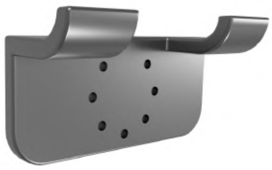
The third concept, called **M3.1**, consists of two parts, a tool which much like the previous concept latches into the front flange of the box, but without the supporting legs, see Figure 8.3c. The difference is that this tool is not made to lift the box, just drag it onto a table, which is the next part of the concept. The table, called **M3.2**, is adjustable along its vertical axis. This means that the table will support the weight of the box, while the tool only needs to output enough force to slide or push the box.



(a) Concept **M1**, the extended arms lift the box under the two side flanges.



(b) Concept **M2**, the upper hooks of the tool latches onto the front flange of the box, while the lower legs provide support on the bottom part of the box.



(c) Concept **M3.1**, a tool that drag the boxes from the shelves

(d) Concept **M3.2**, a table which can support the weight of a box while another tool drags it to the table, its adjustable along its vertical axis.

Figure 8.3: The concepts developed to solve the problem of mechanically grabbing the boxes

Adjusting the tool

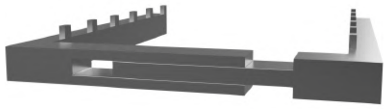
In order to adjust the tool to fit the current box dimensions, four concepts were made. These are both static and dynamic.

The first concept, called **A1**, is to have a tool, with dimensions suitable for many of the section divider groups, found in Chapter 3. An example of this would be a tool with one set of dimensions on one side, which when rotated 180 degrees uses another set of dimensions to latch onto the box, see Figure 8.4a.

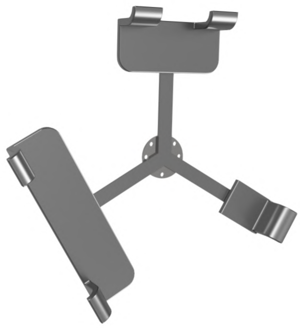
Another concept is to adjust the width of the tool itself, as seen in the second concept **A2**, see Figure 8.4b. This solution requires moving parts, making it a dynamic tool.

The third concept, **A3**, is similar to the concept **A1** in the way that it uses several different tool-interfaces to adapt to different boxes. The difference is that each of the interfaces are attached to a frame, making it more modular, the concept is shown in Figure 8.4c.

(a) Concept **A1**, the tool has one dimension on one side, fitting V-EMB 500 and V-EMB 600, and another dimension fitting the rest of the boxes. By rotating the tool 180 degrees the different parts of the tool can be used.



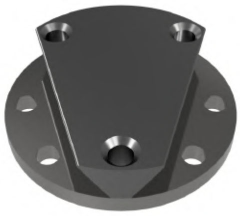
(b) Concept **A2**, the tool has an adjustable width to accommodate for the shapes of the different boxes.



(c) Concept **A3**, known as a frame solution, by attaching a frame with several different tools attached to it, the different tools can be used by rotating the end effector.

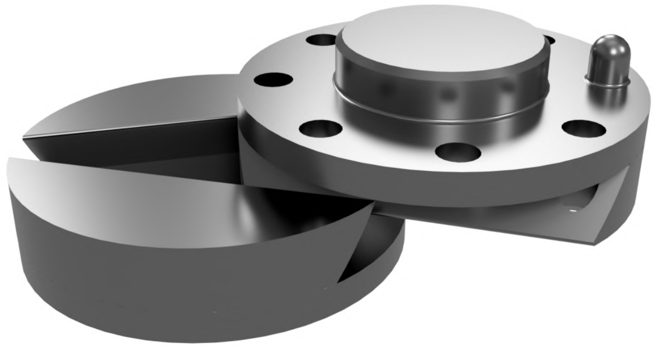
Figure 8.4: Concepts developed to solve the problem of adjusting the tool for different box dimensions.

The fourth concept, **A1**, is based around the idea of easily changing to the correct end effector as the need arises. A metal coupling, see Figure 8.5a, is fitted on the media flange, while inverted couplings, see Figure 8.5b are fitted on each end effector. The couplings are conically shaped, which means they will lock together when slid into each other as seen in Figure 8.5c. The couplings rely solely on gravity to stay connected. Even though the tools themselves do not have to be dynamic, the coupling introduces dynamic elements to the solution.



(a) Concept **A4.1**, a coupling which is fixed directly to the cobot, it has a conical shape which will latch into an inverted coupling located on the different tools

(b) Concept **A4.2**, a coupling which is to be located on the different tools.



(c) A demonstration of the coupling function of **A4.1** and **A4.2**.

Figure 8.5: Couplings which allow the collaborative robot to switch between different end effectors in order to solve the problem of adjusting the tool for different box dimensions.

4. Convergence of the concepts

In this section the concepts will be critically analyzed, addressing weaknesses of the different solutions as well as identifying their different strengths. Ideally, the concepts should have been tested, in order to eliminate the weaker concepts that are not working. However, due to the outbreak of the pandemic disease, Covid-19 [49], complications lead to that physical prototyping and testing with the KUKA KMR iiwa, was not possible to achieve within the project's time frame. Therefore the concepts have only been evaluated and discussed about, with the known information of today.

M1
The concept of lifting the boxes under the side flanges as seen in Figure 8.3a is beneficial in the way that the tool has a large contact area with the box. By lifting the box under both side flanges, the box experiences symmetrical forces, which most likely will reduce the amount of wear on the boxes. However, due to the extra mate-

rial needed to extend the arms under each flange, this tool will be relatively heavy. Also, the center of gravity of the tool would be far away from the attachment to the cobot, which would result in a high momentum. There is also a need for different widths of the tool to accommodate the different widths of the boxes. There would also be a problem to lift a short box with a tool developed for a longer box, since this place the center of gravity of the box at the very tip of the tool, resulting in a big momentum.

M2
This concept allows for a fairly simple tool, in a compact format. However, it puts a lot of stress on the front flange of the box by lifting it at an off-centered position. This might cause wear in the boxes over time. There is also the problem of section dividers being in the way for the tool, as seen in Chapter 3.2.1 meaning several different tools might be needed.

M3
By dragging the boxes instead of lifting them, the system would be able to handle heavier objects. The drawback is that it needs a lifting device to support the weight of the box, adding complexity to the concept, see Figure 8.6.

Figure 8.6: The drag tool working together with a lifting table, this solution ads extra complexity, but can handle heavier objects.

The initial iteration of the lifting table **M3.2**, would not be able to handle boxes located below the AGV. Therefore a new iteration was made that could operate the entire range of the cobots movement. The table would hang on the side of the AGV, and can be seen in Figure 8.7.

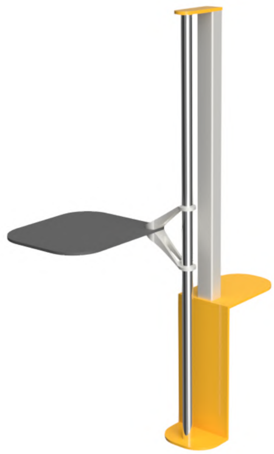


Figure 8.7: The improved side table, able to lift boxes in the entire working range of the KUKA KMR iiwa.

A1
To have several interfaces on the same tool would add some weight, but it could be made in a fairly compact manner. If this sort of adjustability is used together with concept **M3**, the drag tool, it is believed that all of the required tool interfaces would fit into the same tool.

A2
To adjust the width of the tool would allow the solution to handle all boxes. However a dynamic tool introduces more weight, complexity as well as possibly decreasing the robustness of the tool.

A3
The modularity of the frame concept allows for easy change of tools, while also being able to handle all of the boxes. The frame could for instance easily be equipped with other tools if needed. The benefit would also be that the robot could quickly switch to the most suitable end effector, by rotating its' arm and thereby allow for less change over time for different operations. However, this concept would also result in added weight and could be a bit inconvenient in confined spaces, which could therefore be a problem for the KUKA KMR iiwa and the SuMa warehouse racks.

A4
Adding a coupling to the concept adds some weight to the system, however, since each tool can be specified for its' corresponding box, weight is saved since no universal features are needed. Since the coupling works with gravity, it would not be possible to rotate the tool around its' center. This concept could be paired with a tool rack on the AGV as seen in Figure 8.8, or the tool rack could be mounted on a fixed position in a designated area, where the AGV could go to change end effector.

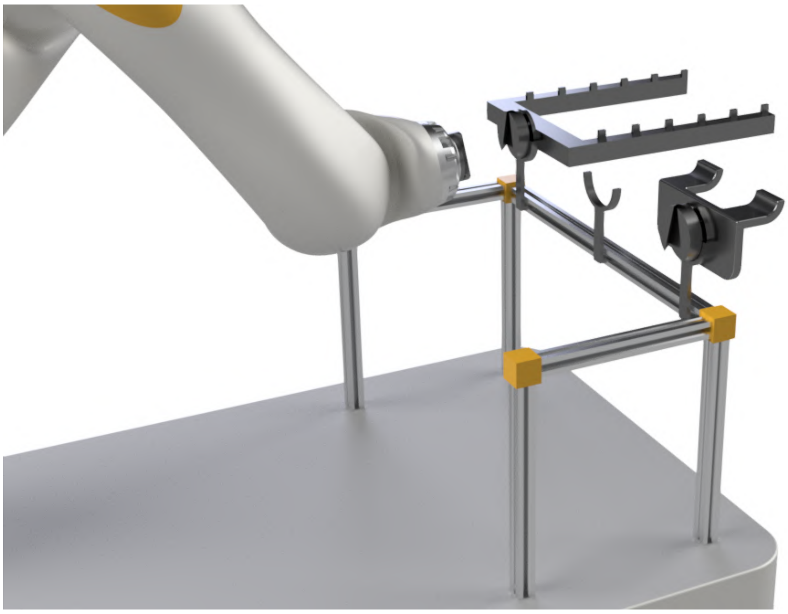


Figure 8.8: The automatic tool changer with a tool rack mounted on the AGV.

As earlier mentioned in Chapter 7, it was stated that it could be beneficial for the human operators to be able to use the tools as well. A concept idea was therefore constructed of how this could be implemented for this case, which is shown in Figure 8.9. In Figure 8.9 it is to be seen that the concept design consists of a long bent shaft, with attached wheels to its' bending point. In the ends of the shaft there has been placed a handlebar at one of the ends and then the automatic tool change concept, called **A4.1** has been placed on the other end. This tool would allow the operators to work with the different designed end effectors as well. Although, it might not be convenient enough to use, for the specific SuMa warehouse, and could be further researched about. It could however be useful to operate, if the boxes ever would get stuck on the gravity-fed conveyors, not rolling all the way to the stopping edge, as the length of the tool would then enable the operator to reach for the boxes and simply drag the box to the stopping edge, using a suitable end effector.

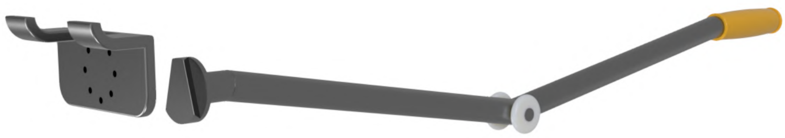


Figure 8.9: A concept of a manual tool which could be used with the designed end effectors, using the automatic tool change concept, called as **A4.1**.

5. Final design

Due to the limited prototyping and testing of the concepts, no final design could be found. Instead, two suggestions of complete solutions will be presented. However, this does not mean that the concepts not included in these solutions have been disregarded, further testing is required before a concept is excluded.

A complete solution, called **S1**, can be formed by combining the drag solution and lifting table **M3**, the ability to change tools automatically **A4**, as well as fitting a tool rack on the AGV. This solution is seen in Figure 8.10. This solution is relatively complex due to a lot of parts, as well as the coupling function.

Figure 8.10: A complete solution able to switch between different tools, as well as using a lifting table to support the weight of the boxes.

A less complex complete solution, **S2**, can be made by combining the lifting table of **M3** with the drag tool with dual flange interfaces in concept **A1**, as seen in Figure 8.11. This would result in a concept that can handle all box types with the same tool, as well as unloading some of the weight on the lifting table. However, the solution would include the drawbacks a general solution has, not being able to use the flange interface of each box type, but rather conforming to the two groups of box interfaces found in Chapter 3.2.1.

Figure 8.11: A complete solution able to alternate between two dimensions of its end effector by rotating it 180 degrees, as well as using a lifting table to support the weight of the boxes.

9 Discussion

Throughout the project, there have been several areas covered and many results have been discovered. These will now be further discussed, within this chapter.

Firstly, the analysis of the current warehouses at Volvo Trucks was presented, as the SuMa warehouse and its' work procedures were being described in detail. From this result, it was found that the blue boxes went through several material handling steps. Whereas some of these could be discussed to be quite unnecessary and non value adding. As an example, the material is today firstly delivered to a delivery area whereas it is quickly unloaded to an unloading area. This unloading area only works as a temporary buffer before it is transported to the picking table but since the unloading area is relatively small, the material could for instance be delivered to the picking table directly instead.

Moreover, it could be discussed if the SuMa warehouse concept even is necessary, as the boxes might as well be stored on pallets in pallet racks and then be picked and transported when requested by the UP. This would then result in less unnecessary material handling, as the storage of boxes in the SuMa racks does not give any direct value itself. On the other hand, the storage in the SuMa racks does provide presentation of the boxes in a more ergonomically friendly way and allows for a deeper storage. Whereas a deep storage, with narrow sections, generally enables for more articles to be placed in a more compact material facade and thereby reduces the distance between different components, which presumably results in time-saving when they are to be picked. This could have been further analyzed but since the objective was to evaluate new technologies, it was decided to neglect investigations in these sorts of solutions.

Additionally, in the investigation of the SuMa warehouse, it was identified that the dimension of the racks could vary relatively much. The variation did also vary depending on different racks, as the yellow type had more variations than the red type. These types of variations are a bit disturbing and could potentially be of a future problem. Whereas this would presumably affect the complexity of the programming of the KUKA KMR iiwa and might put higher demands on a more reliable vision system and end effectors with good tolerances. This would be needed since the rack variation could impact location problems, as the boxes will not always be on the exact same height and could potentially be slightly leaned. In addition, when collaborating with humans within the same warehouse, there is always a risk for boxes to be placed wrongly. This would put even higher demands for the vision system since the robot must be able to know that the correct box is being picked. Supposedly it could be solved by putting higher demands on the box labeling, but this is an area that would require further research .

Another risk within the SuMa warehouse is that since the KUKA KMR iiwa consists of a wheel-based AGV, this put relatively high demands on a clean floor, in order for it to be able to navigate properly. This due to that the boxes are stored without lids and contain loose components and could therefore potentially spill out material on the floor when being handled by the robot or the human operators. Depending on the size of the spilled out components this might then be a problem for the AGV to be able to move. Although, as human operators are working in the warehouse they could supervise the floor and make sure it is clean. Another solution could be to install some other sweeping robots or attach a sweeping solution to the KUKA KMR iiwa, resulting in a robot solution that cleans the factory simultaneously as it performs pick and place operations.

Further on, regarding the boxes' contained components, is how the distributional weight of these would have an impact on the material handling. As the components might be of varying sizes and depending on how these are packaged it could result in uneven weight distribution. Meaning that the center of gravity would not be in the middle of the box, which could potentially impact the lifting operation. This is something that would be required to be tested, in order to evaluate possible effects and achieve a proof of concept.

In addition to testing how the weight distribution will have an impact, there is required future work of analyzing how the different tools would treat the boxes' durability, which is something that has been neglected for this project. This is something to be considered, since the boxes are made of plastics and might therefore not be strong enough to sustain to be lifted, by the robot, in just the boxes' flange middle section.

Continuously, these types of durability tests would be necessary to perform for the end effectors as well. Whereas these also will have to be able to sustain the forces, which occurs when performing the picking operations. This could also be further analyzed in what type of materials the end effector should consist of. As they should be as light as possible, in order to not consume too much of the robot's maximum payload. While the material would simultaneously also have to be durable enough and yet remain safe enough to not endanger any closely working humans.

Besides from the boxes and the end effectors durability and material choices, it could be said that the high flange variation, as summarized in Chapter 3.2.1, for the different boxes are a bit problematic. Since this made the design phase of the end effector very complex. Hopefully, this accomplished research will have some sort of value for future tool development projects, as it also might be of value if the boxes ever are to be redesigned. For instance, the boxes would, in the future, benefit from being designed for automation and it could be beneficial to narrow down these variations, in order to achieve a more simple and higher quality material handling.

Regarding the ergonomics, it was discovered that the main reasons for the bad ergonomic situation, was that the lifting frequency consisted of too many lifts of too heavy average weight, in bad ergonomic zones. The solution of the KUKA KMR iiwa is supposed to eliminate these issues, the question however is how this actually would be practicable implemented. It is no doubt that if the solution itself would be able to perform all of the required SuMa warehouse tasks, it would eliminate the need of a human operator and thereby also eliminate the poor ergonomic situation. Although, this would mean that the KUKA KMR iiwa then must be able to replace all of the human operators, while simultaneously keeping the current capacity, in order to be sustainably implemented. This capacity demand, would then probably require investments of several of these systems, as a single KUKA KMR iiwa would presumably not be efficient enough. The reason for this, is that the system could not just instantly replace a specific number of human operators and their same work tasks, as this would only eliminate the bad ergonomic situation for those specific operators. Whereas the lifting frequency would remain the same for all of the other operators, as the ratio of the number of boxes handled per operator would still be the same. The question would then be if the KUKA KMR iiwa even would be the best suitable fit, as the KUKA KL + KR solution or the Swisslog solutions might be better options for a totally human-free warehouse.

The other option would be to keep the current staff numbers, as well as investing in the new KUKA KMR iiwa solution, as this would then lead to a lower lifting frequency for the operators and the work situation would be improved. However, this would mean a huge investment cost for Volvo Trucks, without any other benefits or savings, rather than "just" improving the ergonomic situation, by lowering the frequency ratio. This could have been more easily solved by just hiring an additional operator. Although, this could potentially also lead to that the operators could work with other value adding operations, such as driving delivery rounds, quality assurance, Kaizen (continuous improvements), supervising, and assistance for the KUKA KMR system.

On the other hand, the solution could also be implemented with a specific plan, of how it should be sustainable implemented, and a solution for this could be to program the robot to only handle the boxes placed in the less ergonomic friendly zones, described as "Zone B" and "Zone C" in Chapter 4. The boxes placed in the "Zone A" would be prioritized for the human operators to handle. This would then allow the operators to only work in the ergonomically friendly zones, which would lower the bad impact for the lifts, and thereby enabling a more socially sustainable work procedure. Additionally, the distribution of the heaviest boxes could be controlled to only be picked by the KUKA KMR iiwa solution. This would then lead to a lower average weight, of the boxes handled by the operators, and the ergonomic situation would be even more sustainable. However, it should be stated that these are just assumptions of a plausible result. The new ergonomic situation would have to be re-evaluated, in order to achieve a definite result for this.

Additionally, this type of inventory control could be further analyzed, in order to be efficiently adapted for the KUKA KMR iiwa. For example, since the system does not suffer from any ergonomic issues, rather than physical strain, the components with the highest turnover should instead be placed with priority to minimize the system's transportation distances. Whereas it today is the high turnover boxes that are attempted to be controlled to the more ergonomically friendly zones. This should be performed as route optimizing with shorter distances, for the AGV, likely would result in shorter lead times, less energy use and an overall higher efficiency. More deeply, the system should also be tested in what box positions the cobot will be able to perform such a short movement distance as possible, regarding both the cobot arm and its' combined AGV.

Another idea of how the system could be implemented, in order to enhance the ergonomics, is if the collaborative robot actually would be used just as a collaborative robot. Meaning that the human operators and the robot actually would collaborate, in the sense that they would handle the boxes together and simultaneously. The robot could then be used to lift in one end of the box as the human lifts in the other end, sharing the weight distribution, and would then result in a lower average weight of the boxes. This sort of collaborative work method could also enable the system to be able to lift even heavier boxes than 15 kg, as the weight would be shared by both the human operator and the cobot. This would however need to be tested and evaluated of how efficient and convenient this type of work operation would be.

Furthermore, the need to specifically using a collaborative robot could be discussed more thoroughly. Since a cobot needs to be safe while used together with humans, they generally consist of more complex designs with higher demands on safety sensors. This generally results in higher costs than a regular industrial robot does. Meanwhile, as mentioned by Conny Pettersson and Peter Ljungberg in Chapter 6.2.2, the industrial robots could also deliver better accuracy, repeatability and higher speed. It should therefore be evaluated of how necessary and advantageous the collaborative mode really is. Otherwise it might be wise to investigate further in other "centaur-looking" systems, consisting of wheel-based robots, and examine what type of solutions that exist. It could be that a system of a regular industrial robot, combined with an AGV, would be a better choice. Although the system would still have to enable human operators to access the warehouse and work closely by the robot, it does not have to be able to actively collaborate with the operators. This means that a system like this would still have to be equipped with certain sensors to ensure the safety of the close working human operators.

The market analysis did result in that other solutions might be suitable fits as well. As the Magazino and 2Lift resulted in being decided as the second and third most suitable choice. These solutions could however have been even more suitable than the KUKA KMR iiwa, and it would be beneficial to test these systems as well and analyze them even further and make an even deeper evaluation. It would also be beneficial to analyze the costs of the different systems, as this has been neglected for the scope of the project. This would be necessary in order to receive a return on investment result and see which one of the systems that would provide the most advantages for the least costs.

Although, the other systems, as described in Chapter 6.2.2, would not allow for the same type of flexibility as the KUKA KMR iiwa with the designed end effectors would. Since this solution would enable the system to be used for several production areas, and not just within the material handling. Along with the automatic tool change mechanism, the robot could be provided with even more different end effectors, and could potentially be programmed to be able to perform a number of various operations. Meaning that, in the best of all worlds, the KUKA KMR iiwa could potentially be working with lifting boxes in the morning, to then roll over to the assembly line, working with other operations after lunch.

One discovered downside though, with the KUKA KMR iiwa, is that since the cobot is placed on a 70 cm high AGV and only has a reach of 25 cm below its' own lowest attachment point, there would be a problem to pick boxes from the lowest SuMa racks. As these specifications would only allow the cobot to pick components at maximum height, above ground, of 45 cm, and as the racks were described in Chapter 2.2, the lowest height of the racks is set to be at 29 cm, for the yellow type, and 37 cm for the red type. Although, as the end effectors have been designed to handle the boxes at the flanges and that these flanges are placed on the top of the boxes, some extra length is achieved. This means that the box flange would have to be at 16 cm height, from the box bottom, for the yellow type and 8 cm for the red type, in order to be able to be handled. Unfortunately, as described in Chapter 3.2.1, the boxes middle flanges are placed, from the bottom, at heights of 7.9 cm (for the V-EMB 787) to 16.7 cm (for the V-EMB 780). This means that depending on the different design solutions, for the end effectors with the KUKA KMR iiwa, some of them might not be able to pick any boxes from the lowest SuMa racks of the yellow type, and will only be able to pick a few from the red type racks.

However, there are some simple solutions to this problem, as for an easy example, the operators could continue to pick the boxes from the yellow racks as they do today. Another solution would be to ensure that the profile, for the designed end effectors, is lowered, in order to achieve the extra needed centimeters. Meaning that the end effector should be lowered from the center of the attachment point at the end of the cobot's arm. Another solution could also be to raise the yellow SuMa racks to be of the same height as the red ones and only allow the boxes, with the highest placed flanges, to be placed on the lowest racks. Whereas the other boxes would have to be distributed to the higher level racks.

Finally, the safety of the designed end effectors and additional tools, such as the lifting table, should be further investigated. Since the lifting table just was developed as a concept of how a lifting procedure eventually could work, there were no investigations about its ability to ensure safety. This could potentially be a huge safety risk, as a close working human might get stuck in-between the lifting table and the KUKA KMR iiwa. However, as the KUKA KMR iiwa system already consists of several safety sensors, to surveil its surrounding, these could potentially be interlinked with a lifting table, ensuring the table to remain still when operators are appearing close-by. Moreover, the other tools would require to be further risk analyzed and ensure that the designs follow certain safety standards.

10
Conclusion

After having finalized the project and discussed the different parts of the report, the research questions are attempted to be answered and will be so within this chapter. Additionally, due the outbreak of Covid-19, complications led to that it was unable to test the designed equipment, in order to achieve a proof of concept. The conclusion will therefore consist of final recommendations, for Volvo, as well as suggestions for further research.

10.1 Answers to research questions

In the first Chapter, three research questions were stated, which now will be attempted to answer.

How should a new technical solution be designed to eliminate a bad ergonomic situation and which will provide a more sustainable material handling?

During the project, it was found that there are several ways in how technology could be designed and used to eliminate bad ergonomic situations. However, it was also discovered that these should be chosen to be able to adapt the company vision in order to be a fully sustainable implementation. Whereas it was also found that it is important to implement technologies with a suitable strategy. Meaning that e.g. for implementing a solution of an automatic box picking cobot, combined with an AGV, it might not just be to easily replace some operators with it, as a clear strategy of how the technology actually would lower the ergonomic issues also is needed.

What kind of technical solutions, for material handling, are available on the market today?

When performing the market analysis, looking for a suitable solution for Volvo, several technical solutions were identified. Some of them have been evaluated and discussed in the earlier parts of this paper, such as the Swisslog solutions, the Magazino, the 2lift and the KUKA KL + KR, whereas other technical solutions were deselected already in the screening phase. Moreover, there have most likely been many other technical solutions, available on the market today, which has been missed out of this project. Additionally, there are several automation companies out there, working with the "engineering to order" approach, meaning that there are certainly many different variants of technical solutions out there that could be suitable designed and applicable. It is therefore hard to answer the question itself but at least the project gave some insights into some of the available technologies of today's market.

How could an automatic solution be adapted in order to enable high flexibility and high product variation for material handling.

As seen in the result in the final design in Chapter 8.2.1, an automatic solution could potentially be looking like the suggested concept solutions **S1** and **S2**. Whereas a cobot, combined with an AGV, has been equipped with suitable tools to be able to handle a high product variation. As the solution also is a wheel based robot (making it easy to relocate), along with the ability to equip the cobot with other tools and end effectors (which could be used for other operations), this type of solution enables a very high flexibility.

10.2 Recommendations for Volvo and suggestions for further research

As a starter, a recommendation for Volvo is to evaluate and investigate further in their unnecessary material handling, for the current material flow, in the SuMa warehouse. Since it is possible that some material handling sweet-spots might could be found here.

Regarding the designed end effector concepts, these should be physically constructed and tested on the actual blue boxes, in order to achieve a proof of concept. Additionally, they should be further analyzed, to ensure that they will fulfill safety requirements. This would also involve the investigation of suitable material choices and durability analyses. As the end effectors also should be tested with boxes containing uneven weight distribution of components, in order to evaluate the impact of this.

Since the development of a vision system for the KUKA KMR iiwa, was ignored, this would have to be further researched. As the need of being able to locate and identify the boxes still exists.

Moving on to a recommendation of how to implement the technical solution, which is to have a clear strategy of how it actually will eliminate the ergonomic issues. If it is decided to move on with the KUKA KMR iiwa, a suggested solution would be to only allow it to operate within the less ergonomic friendly zones.

Furthermore, the market evaluated solutions, of the Magazino Soto and 2lift, are still to be seen as possible suitable solutions. These should therefore be further researched, tested and evaluated.

Finally, as the KUKA KMR iiwa could be the perfect fit, if designed properly, it still has some flaws. For instance its lifting capacity of 14 kg could be a problem, as well as the height of the AGV might be to high to be able to handle all of the boxes on all of the SuMa racks. In addition, it should also be evaluated if the collaborative mode really is a necessary feature. It is therefore recommended to keep the eyes open for other and future centaur-looking systems. As these might develop further with for instance cobots that could handle even heavier payloads.

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