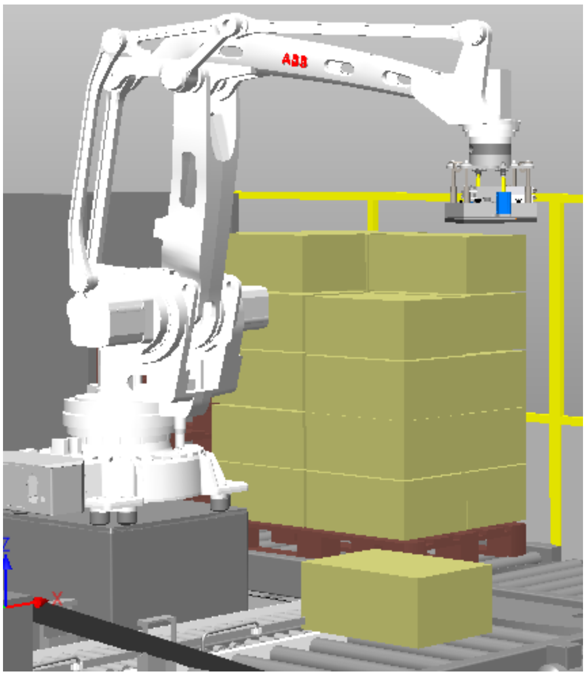

Container Unloading using Robotized Palletizing

– A study for automation of Container Unloading at Elgiganten’s central warehouse

Master of Science Thesis in the Production Engineering Programme

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Caption:
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Preface

This Master of Science thesis work was performed during the spring term of 2012 at the department of Product and Production Development at Chalmers University of Technology in Gothenburg. The thesis covered 30 credits and is the final examination in the master program, Production Engineering. This project is carried out in collaboration with Front Automation AB in Jönköping and one-third of the time has been spent at the site and the rest at Chalmers in Gothenburg.

We want to thank individuals and organisations who have helped us during this project. First of all, we would like to thank Front Automation AB, who has given us the opportunity to perform our master thesis within industrial robotics and for always supporting us with the information needed. We are very thankful for the coaching and guidance provided by our supervisor Jonatan Berglund during the project. Also, we want to thank the examiner, Rolf Berlin, and robot expert, Per Nyqvist, for their knowledge input to specific parts of the project.

Many thanks are also directed to Johan Olsson at Tepro Machine & Pac Systems AB, Jesper Lundstedt at Robotics Division ABB AB, Cuong Lien Elgiganten AB, Andreas Lövgren at DHL Exel Supply Chain AB and Eskil Laago at IKEA Svenska AB.

Gothenburg, Sweden, May 2012

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Abstract

As the globalisation increases and many companies are locating their production in low cost countries, effective logistics becomes more and more important. The automation of distribution centres and central warehouses is a vital topic today. A problematic as well as labour intensive field at central warehouses is the container unloading procedure, which today still often consists of manual work. The container unloading procedure consists of unloading containers, filled with cartons of varying sizes and weights, and placing these in a predetermined pattern on a pallet. To reduce the risk of work related injuries automation is an alternative considered by more and more companies.

The case studied is Elgiganten's central warehouse. Elgiganten is included in the Norwegian cooperate group, Elkjop, which is an actor within the consumer electronics business. This giant warehouse covers 100 000 square meters and serves all Elkjop stores in the Nordic region. The purpose of this study was to evaluate the potential of using robotized palletizing and suitable aids for the application Container Unloading at Elgiganten's central warehouse. This study included an evaluation of the recently developed software, Palletizing PowerPac, which is a software dedicated for palletizing procedures. Analyses of the work environment with regards to ergonomics were made with the purpose to investigate how this could be improved. During the project a suitable gripper has been selected for the large variety of cartons present at Elgiganten.

The results from this study showed that robotized palletizing using Palletizing PowerPac was feasible. With the selected gripper, cartons with weights less than 30 kg and side lengths of 600 mm or less should be handled. Two solutions, ParceLift and Empticon, were evaluated to be most appropriate for Elgiganten to use in combination with robotized palletizing for the application Container Unloading. The major advantage of introducing aids and robotized palletizing was found to be the reduced risk of musculoskeletal disorders.

Keywords: Robotized palletizing, Vacuum gripping, Palletizing PowerPac, Container unloading

Table of Contents

Abbreviations

ISO	International Organisation for Standardisation
NIOSH	The National Institute for Occupational Safety and Health
PzPP	Palletizing PowerPac
REBA	Rapid Entire Body Assessment
TEU	Twenty-foot equivalent unit
TOF	Time Of Flight

1 Introduction

In times of increased globalization the transportation and demand for automatized logistic solutions also increase. Many goods are today transported in containers, by ships, trains and trucks. The management of loading and unloading goods from containers is carried out in different ways depending on type of goods and distance. If the goods have to be transported a far distance the filling degree is important, which in many cases make the loading and unloading process problematic.

The application ”Container Unloading” is common amongst various distribution centres, where goods are reloaded for further distribution to different department stores. The work procedure consists of unloading containers, filled with cartons of varying sizes and weights, and placing these in a predetermined pattern on a pallet for further distribution by truck.

This report starts with a background to the project and the foreseen difficulties that have to be taken into consideration. In the introduction part the purpose and delimitations of the project is presented.

1.1 Background

The case studied is Elgiganten’s central warehouse. Elgiganten is included in the Norwegian cooperate group, Elkjop, which in turn is owned by the British consumer electronics’ company, DSG International. This giant warehouse covers 100 000 square meters and serves all Elkjop stores in the Nordic region [**1**]. Consumer electronic is a tough business, where the actors always compete about having the lowest prices. Because of struggling with keeping low prices the profit margin per unit will decrease. Another problem Elgiganten has to handle is the high absence of employees due to heavy lifts and stressed work environment [**2**]. This problem motivates an automated solution for the manual work of unloading containers. Elgiganten has seasonal variation in demand, which affects the requirements of the central warehouse. At the autumn there is a peak in demand, which in turn affects the central warehouse a couple of months earlier. There is also a peak in the spring when all the grills are arriving for the summer. During other months of the year the demand is much lower, which of course affects the proposed solutions.

This study was also performed in collaboration with Front Automation. Front Automation is a Preferred Partner by ABB Robotics. This means that the work is performed in close collaboration with ABB to develop and supply system solutions where the ABB products are used and integrated. Within the field picking, packing and palletizing Front Automation is the preferred system integrator in Sweden by ABB.

At Elgiganten, the application Container Unloading is divided into two stages, referred to as Stage One and Stage Two. Stage One consists of unloading containers filled with cartons, see number one in Figure 1. Number two in Figure 1 is the telescopic conveyor belt, which transports the cartons from the container to the next stage. Stage Two consists of placing these cartons in a predetermined pattern on a pallet, see number three in Figure 1. This procedure is called palletizing. The pallet and cartons are then wrapped in plastic film, see number four in Figure 1. At Elgiganten today, the application Container Unloading requires four operators per shift and consists of entirely of manual work.

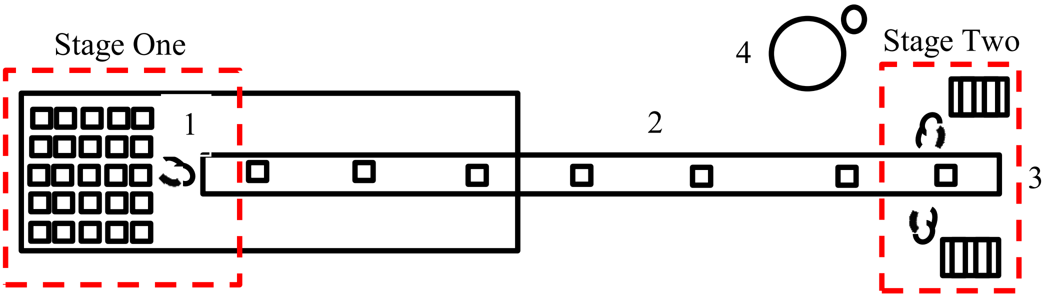

Figure 1: Principle layout of the current environment.

1.2 Problem Formulation

The application Container Unloading is ergonomically demanding. Hence, possibilities for introduction of an automatized solution for Stage One and robotized solution in Stage Two was analysed and evaluated. Since Front Automation is competent and experienced in the field of robotized palletizing, a robotized solution for Stage Two is preferred, see Figure 2.

Regarding programming of robots for palletizing, software specialized to simplify this task have been developed. In a virtual environment, palletizing patterns and robot cell layouts can be simulated in order to estimate and optimise cycle times as well as verified before physical implementation. One of these software is RobotStudio Palletizing PowerPac (here after referred to as PzPP), which has been recently developed by ABB Robotics. It was uncertain if this software was able to meet the demands specified by Elgiganten.

Figure 2: An example of robotized palletizing.

Technology for gripping of cartons is another area that will be highlighted in this study. Due to the broad variety of carton sizes, weights and orientations, the number of required gripping devices and the design of these will be analysed.

At a first glance at a palletizing operation the complexity seems to be low, but there are many factors to consider. The orientation of the cartons, the pick approach and the velocities are some issues to manage. Another factor to consider is the visual appearance of the finished pallets. In some cases the containers at Elgiganten hold more than one type of cartons, which further increase the complexity. Currently, more than hundred different carton sizes are present and approximately hundred new products are introduced every year. This means that the solution must be flexible in order to handle the product variety. It is desirable for operators, with neither technical education nor programming experience, to be able to program new palletizing procedures within 20 minutes. Therefore, high demands on user-friendliness are also required for the proposed solutions.

1.3 Purpose

Due to unsatisfactory work environment, the purpose is to evaluate potential solutions in Stage One and define if robotized palletizing, using Palletizing PowerPac, is feasible and applicable in Stage Two. The study will investigate the possibilities to improve the work procedure of Container Unloading at Elgiganten with respect to cost-effective, ergonomic and technical aspects.

1.4 Delimitations

The software PzPP was used for programming the robot. The reason for selecting this software was based on two factors. Firstly, the software was recently released and therefore no earlier studies exist. This makes software more interesting from an analytical point of view. Secondly, earlier experiences and knowledge in RobotStudio, in which PzPP is integrated, made the selection even more evident. The work procedure of Container Unloading also consists of wrapping the pallets in plastic film and will not be considered in this study.

Since it was complicated to estimate the gains of improved work environment in financial terms, no financial analysis of the ergonomics have been made.

Due to the broad variety in weights, this study only focused on products weighing 30 kg or less.

The following delimitations have been established:

- Programming and evaluation will only be done on ABB’s PzPP and no other similar software.
- No investigation on how to wrap the pallets in plastic film will be made.
- No financial analysis of the ergonomics has been made.
- Products with weight more than 30 kg will not be included in the study

1.5 Specification of Question Formulation

The following questions are established in order to clarify the purpose of this study:

- Is it feasible for an operator with no experience in robot programming to setup a new palletizing procedure in ABB's software within 20 minutes?
- Is it feasible to use robot palletizing for the whole range of products in the case Elgiganten and if not which products are feasible?
- How will the productivity be affected by the introduction of a robot solution?
- How will the work environment be affected at Elgiganten?
- What will the capacity level of the proposed solutions be?
- Is it feasible and cost-effective to unload containers within two hours by using robotized palletizing?

1.6 Report Disposition

The following chapter, Chapter 2, describes the methodology used in the project. In Chapter 3 the basic theory for the analysis is structured. The basic theory consists of e.g. general information about robots, the software used, gripping technologies and ergonomic methods. The situation analysis at the case of Elgiganten is highlighted in Chapter 4, which is the analysis section. Also, the selection of grippers and cartons in focus are motivated in this chapter. The report ends with a discussion and conclusion of the proposed solutions for Elgiganten.

2 Methodology

In this chapter a description of the way data were collected, the software PzPP was evaluated and how the analysis was performed. The methodology is divided in four sections, Collection of Data, Evaluation of Palletizing PowerPac, Verification at Front Automation and Analyses of the Proposed Solutions.

2.1 Collection of Data

As a start, literature studies using Chalmers library and databases served as a base for the collection of data for the theoretical framework. Study visits to and active dialogues with relevant companies were kept in order to obtain expertise information and suggestions on solutions for problems that occurred during the project. Visits to Elgiganten were also made with the purpose of gathering data needed for ergonomic and productivity studies of the manual work. The gathered data consisted of work postures and motions, cycle times and operators' view points on the work environment. The data constituted films, pictures and unstructured interviews with the employees. The ergonomic studies were structured by two methods, Rapid Entire Body Assessment (REBA) and The National Institute of Occupational Safety and Health (NIOSH), and the human simulation software Jack. REBA is used for analysing postures, while NIOSH is focusing on motions and are often used in this type of operations. Jack was used for visualizing the ergonomic problem at Elgiganten and highlighting specific parts of the body that are particularly burdened. Both methods and the software were used because they complement each other. The ergonomic analyses were made in three cases with varying pick approaches. Also guidelines provided by the Swedish work environment authority, Arbetsmiljöverket, were used.

An Excel file containing data about e.g. carton dimensions and quantities was received from Elgiganten, which served as a base in the selection of cartons in focus and gripper. From the Excel file the number of arriving containers each month was established, which indicated a suitable capacity level.

2.2 Evaluation of Palletizing PowerPac

The software PzPP is used for simulating robotized palletizing. Its possibilities and deficiencies were studied by using various carton sizes and pallet patterns that are present at Elgiganten. To verify the simulations, a physical robot station at Front Automation, see section 2.3 was used to test accuracy, repeatability and robustness of the software. For evaluation of user-friendliness, subjective impressions such as logical layout, appropriate warnings and the time constraint of maximum 20 minutes was used. The usability was analysed using simulation and rated upon for which product types robotized palletizing is suitable in both cost-effective and productivity aspects.

2.3 Verification at Front Automation

To verify simulations made in PzPP, investigate robot performance and appropriate robot motion values as well as suitable gripper design, a robot station at Front Automation was used. The layout of the station consisted of two conveyors, a robot and a gripping tool, see Figure 3.

Figure 3: Layout of robot station at Front Automation.

The conveyors constituted in- and out feeders which were arranged perpendicular to each other and have a height of 40 cm. The robot is model IRB460 by ABB and was positioned on a stand with a height of 80 cm. For further specifications regarding the robot, see [**3**].

As gripping tool, a vacuum pad called UniGripper was used. The tool, see Figure 4, had a suction area of 200x300 mm with foam thickness 10 mm and circular suction activators with radii five mm distributed over the pad. The tool was equipped with an optional function called "floating plate", which allowed compensation for variations in carton heights. During verifications, tests were made both with and without the floating plate function.

The verifications were carried out by repeatedly gripping a carton at the in feeder and move it to the out feeder, which created the pallet pattern seen in Figure 3. The cartons had dimensions 400x600x250 mm (width, length and height) with weights ranging from nine kg to fifteen kg.

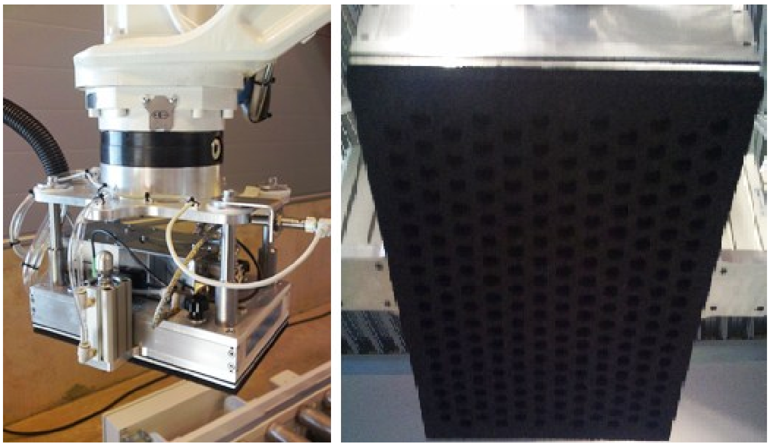

Figure 4: Gripping tool called UniGripper to the left and vacuum pad design to the right.

2.4 Analyses of Proposed Solutions

To analyse the proposed solutions different approaches and methods have been used. The dimensions analysed were productivity, cost-effectiveness and ergonomics. For all solutions, two states were compared and analysed. The Current State refers to the current situation at Elgiganten today, where no automation is present. The Future State refers to when an improvement of the manual work in Stage One and robotized palletizing in Stage Two of the application Container Unloading are implemented. Since no physical implementation was made at Elgiganten in Future State, all analyses were done through simulation in PzPP and verifications at Front Automation’s robot station.

When analysing productivity, changes in output of products and application cycle time between the two states was measured. This yielded a ratio between the states and thus productivity was given.

When the work environment was analysed with regards to ergonomics, REBA and NIOSH lifting equation were used in each state. Note that the ergonomic analysis was only carried out for Stage One because the results for Stage Two will be almost the same. From an ergonomic viewpoint the work procedure is the same in Stage Two even if the procedure is performed in reverse order compared to Stage One.

To systematically evaluate the proposed solutions, two evaluation methods, Pugh matrix and Kesselring matrix was used. The Pugh matrix is a decision-matrix for comparing possible solutions based on given criteria to a reference solution. Solutions considered better than the reference solution are further analysed in a Kesselring matrix, where the criteria are assigned weights.

Regarding analysing the robustness of the solution, this has been made both in the software PzPP and in the physical robot station at Front Automation. The purpose of this analysis was to investigate how robust the solution is concerning disturbance factors, such as operator errors and error detection by the software. The analysis also covers evaluation of PzPP, its robustness and reliability.

3 Theoretical Framework

In this chapter, Industry Characteristics basic knowledge of Industrial Robots and Robot Programming is highlighted. Also, Gripping Technologies and Identification Systems are presented. Last the Ergonomic and Systematic Evaluation methods that are used in this study and Existing Solutions are described.

3.1 Industry Characteristics

To further understand the problem a description of characteristics in the industry is presented. This section begins with general information about transportation of objects by containers and follows by a description of what to consider when palletizing. Finally, a presentation of Elgiganten and their business is made.

3.1.1 Container Transportation

Since globalisation increases, the transportations of finished goods are increasing as well. Many of the fastest growing economies in production are located in Southeast Asia, but the consumption per capita is still highest in the Western world [**4**] [**5**]. The most cost-effective transportation alternative for this far distance is by ship see Figure 5 [**6**].

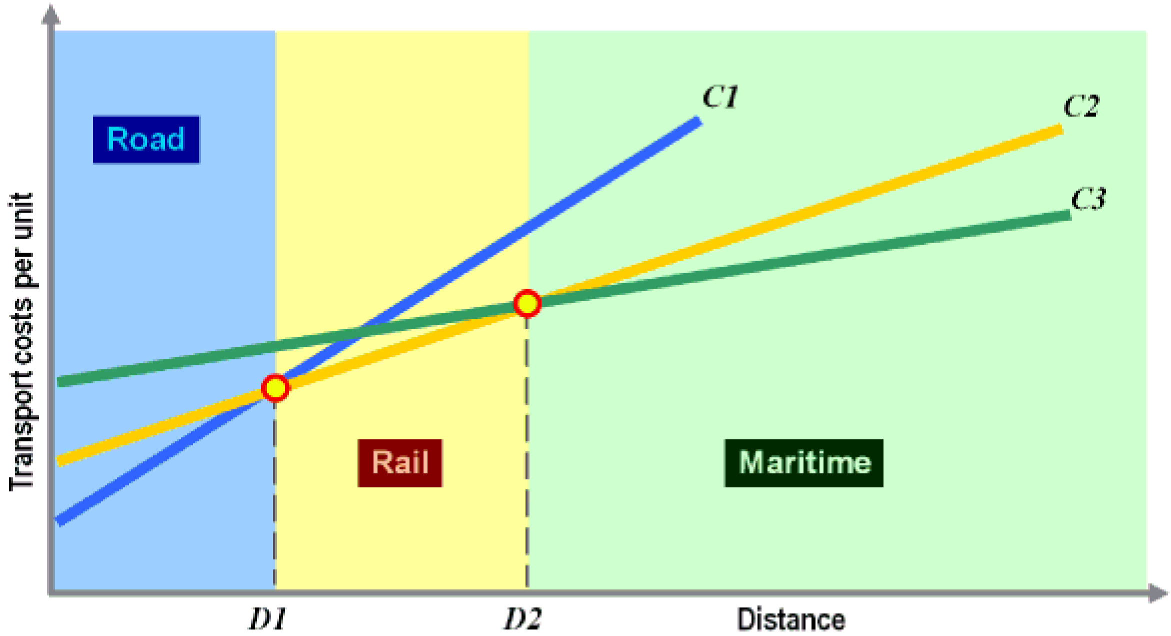

Figure 5: Transportation costs per unit over distances.

When the distances are shorter it is more cost-effective and flexible to transport by truck or by train. The figure covers the three most common transportation systems, where C1 is the cost for transporting one unit by truck, C2 is the cost for transporting one unit by train and C3 refers to cost for shipping transportation of one unit. The distance D1 is normally located between 500 and 750 km from departure while D2 is near 1500 km. Noteworthy, this figure is simplicity of the reality and for a further analysis of transportation situation in a particular case a more exactly calculated version is needed.

In year 2009 the transportation by ship amounts to over 27 million TEUs [**7**], where one TEU is equal to one 20 foot container. In transportation of goods by ship the most common way is to use containers. A main advantage of using ships instead of trains is transportation volume, which are significantly higher for ships. Products not dependent on time are also beneficial to transport by ship. There are mainly three different types of standard containers, 20 foot, 40 foot and 40 foot High Cube [**8**].

3.1.2 Pallets and Palletizing

Palletizing refers to the placing of cartons, bags or other packaging in a predetermined pattern on a pallet. A pallet, see Figure 6 [**9**], is equipment used to facilitate material handling. It also protects the goods from dirty and damp floors during transportation and storage.

Figure 6: A pallet.

In the US alone, over 400 different pallet dimensions were used in 2002 [**10**]. The International Organisation for Standardisation (ISO) has tried to standardise one pallet dimension, but have failed to do so. Instead of having an international standard for pallets, six pallet dimensions have been defined in ISO 6780:2003 and the different dimensions are more or less common depending on which continent pallets are being used [**11**]. In Europe, pallets with dimensions 1200 x 800 mm are most common, whereas dimension 1100 x 1100 mm is most used in China [**10**]. This of course causes problems when exporting and importing between continents. Since different dimensions are used, material handling equipment such as forklifts and storage systems may not be compatible with differing pallet dimensions. This in turn increase the total transport cost of the goods, due to the need for de-palletizing and re-palletizing, and also creates a less time-efficient logistic chain [**10**]. Also, regulations for phytosanitary control add difficulties when exchanging pallets from other regions [**12**].

The filling degree is of great importance. Since pallets occupy volume in the container, which preferably should be used for goods instead, pallets are not common in container shipping. This is to fully utilise the container volume, thus maximising the value of goods [**10**]. Instead, palletizing is performed at the receiver to avoid the material handling problems mentioned earlier and to minimise costs. The value of the products differs a lot between businesses and in some businesses, like electronic, it is not even cost-effective to palletize the finished goods before loading the container [**13**].

3.2 Industrial Robots

Industrial robots have been used since year 1961, when the first robot was implemented at the General Motors plant in New Jersey [**14**]. Today industrial robots are applied in work environments that are uncomfortable or hazardous for humans. Where high degree of accuracy and repeatability is required, e.g. in arc welding, robots are also favourable to implement.

The difference between accuracy and repeatability is illustrated in Figure 7 [**15**]. The definition of repeatability is the ability of the robot to reach a certain position over and over again. Accuracy of the robot specifies how closely it can reach this position.

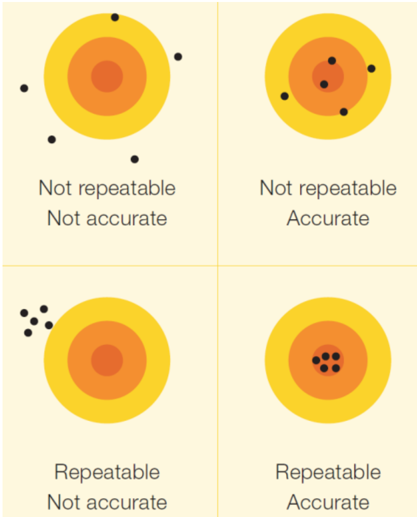

Figure 7: Illustration of accuracy and repeatability.

Robots are constructed of joints and links, which can easily be compared to the human body. Each link is connected with another link by a joint. Each joint, or axis, provides the robot with the degrees-of-freedom of motion and the number of degrees-of-freedom often classifies the robots. Joint types can exist in form of both translational and rotational characteristic. Almost all industrial robots are made up using one or more of these five joint types, see Figure 8:

- *Linear* – The axes of the input link and output link are parallel. It is translational sliding motion.
- *Orthogonal* – This joint type is the same as the linear joint type, but the output link is perpendicular to the input link during the movement.
- *Rotational* – In this rotational motion, the rotation is around an axis which is perpendicular to the axes of the input and output links.
- *Twisting* – Same as the rotational joint type but the rotary motion is around an axis which is parallel to the axes of the links.
- *Revolving* – The joint motion of this joint type is the same as the twisting joint type but the output link is perpendicular to the input link during the move.

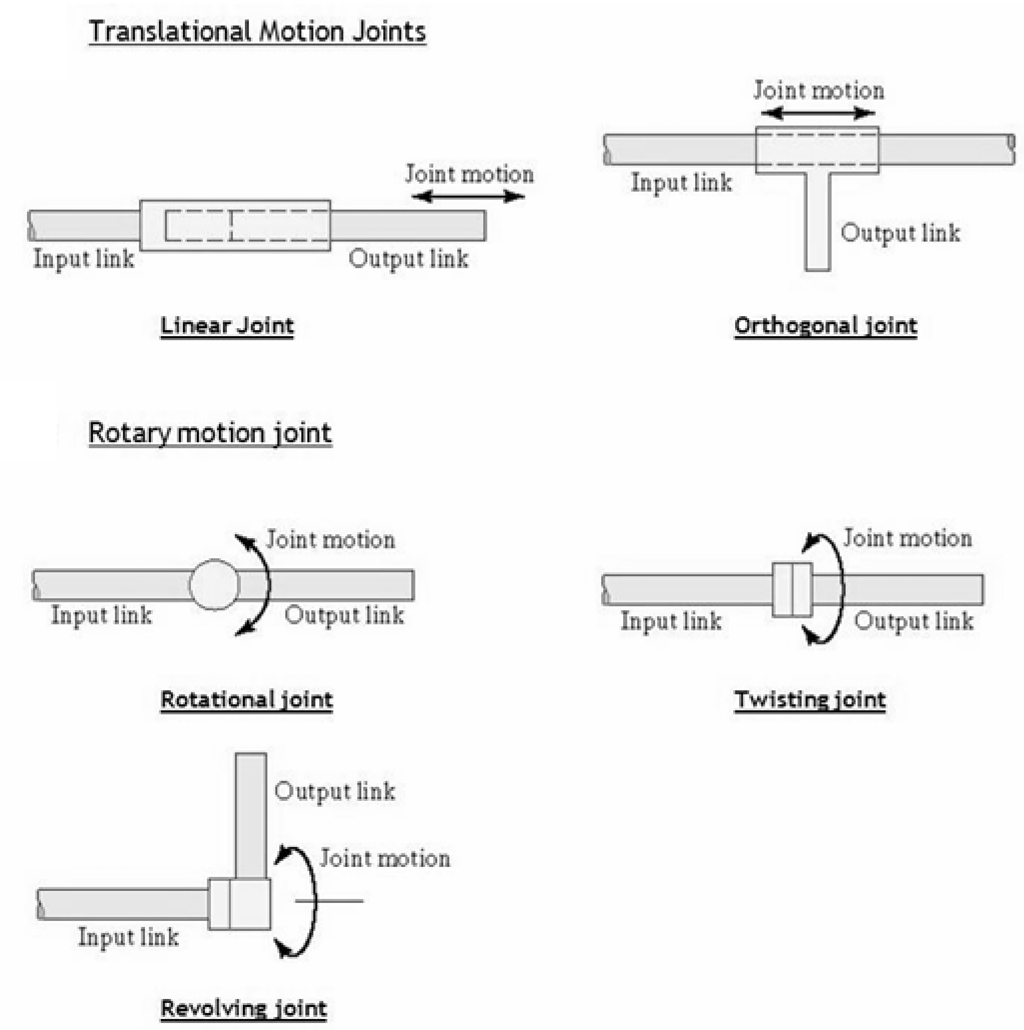

Figure 8: Illustration of the five joint types.

Industrial applications for robots are mainly classified into three different categories: material handling, processing operations and assembly and inspections. In the material handling category there are two types of handling; material transfer and machine unloading and/or loading. Material transfer refers to pick-and-place operation and palletizing, where the robot picks parts, cartons or other objects from one position and places them in a specific pattern on a pallet. These operations are mainly performed by four axis robots, which consist of two rotational joints and two twisting joints see Figure 9 [**16**] [**17**]. When it comes to machine loading or unloading a more flexible robot is required and therefore six axis robots are more commonly used in this kind of operations. A six axis robot consists of three rotational joints and three twisting joints and is more suitable in complex environments.

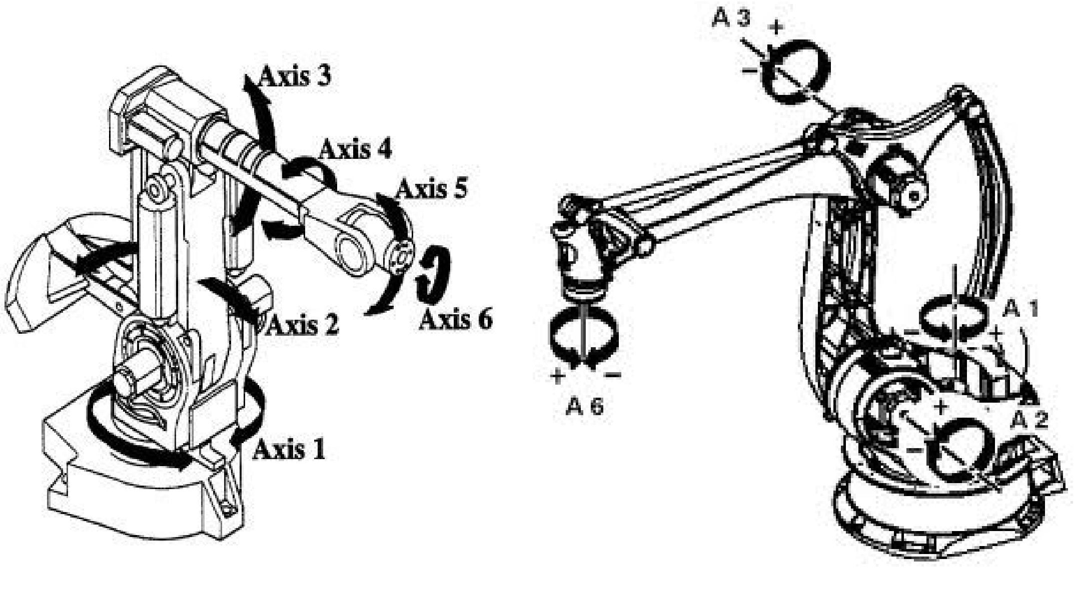

Figure 9: A six axis robot to the left and a four axis robot to the right.

In process operations like spot welding, arc welding, spray coating, robots are preferably implemented because of the level of quality and the repeatability a robot can achieve. In this kind of operations the possibility to adjust the angle of the tool is important and therefore 6 axis robots are mainly used.

Assembly and inspection is a combination of the two previous categories. In more simple and frequent operations it is cost-effective to implement a robot instead of having employees perform these operations with risk of getting ergonomic injuries. In operations where high degree of flexibility is required humans are still the most preferred solution [**14**].

3.2.1 Robot Programming

Each robot needs a program to follow when performing the motions for the operation. The program is established either by online or offline programming or a combination of them. In online programming the program is established by moving the robot to the desired positions, called jogging. This jogging operation is performed by a handheld device called TeachPendant [**14**]. In this device it is also possible to, for example change digital inputs and digital outputs manually, adjust in the program and get instructions when problems occur. In online programming you are basically teaching the robot a sequence by moving the robot to different positions in the sequence.

In offline programming, on the other hand, computer software is used for establishing the program for the robot. One benefit of offline programming compared with online programming is downtime in production while new program is constructing. The program is made in the computer software and the production is just stopped during implementation of the new program or verification of positions between the virtual model and the reality. Another benefit with offline programming is the ability to test the program before implementation.

3.2.2 Palletizing PowerPac

This section will describe the way of working with ABB RobotStudio's add-in PzPP in order to create pallets with products as specified by the user. The purpose with the software is to create and simulate palletizing processes in an easy, quick and flexible way without the need of any robot programming skills. Rather than *programming* pick-and-place sequences, conveyors and gripping tools, the system is *configured* in a window based environment. Compared to traditional methods this will radically reduce programming time [**18**].

PzPP is a further development of ABB's palletizing software PickMaster5 with the aim to simplify the simulation of palletizing processes even more. The main difference between the software, see Figure 10 is that PzPP offers a visualised simulation environment for the whole palletizing process, whereas in PickMaster5 this is not available [**19**] [**20**]. Also, PzPP is integrated in RobotStudio instead of being a stand-alone application [**21**] [**19**].

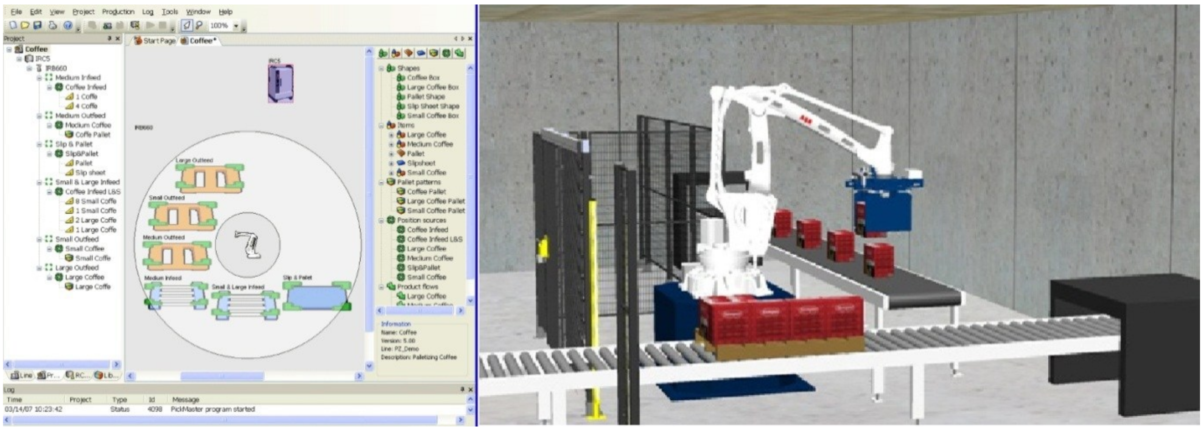

Figure 10: PickMaster5 to the left and its successor PzPP to the right.

Before any work with PzPP can take place, the virtual controller for the robot system in RobotStudio must be prepared in order for all necessary signals used to be included. This is done when a new robot system is created and is called the "Prepare for PickMaster"-option. ABB has included most of their four- and six axis robots to choose from. Once a robot has been chosen and the system is created, the PzPP is ready for use.

The PzPP menu tab in RobotStudio is seen in Figure 11. It contains ten different categories with different build components, where the following five categories are necessary in the workflow of creating a simulated palletizing process:

Build Cell → Product Data → Programming → Validate → Simulation

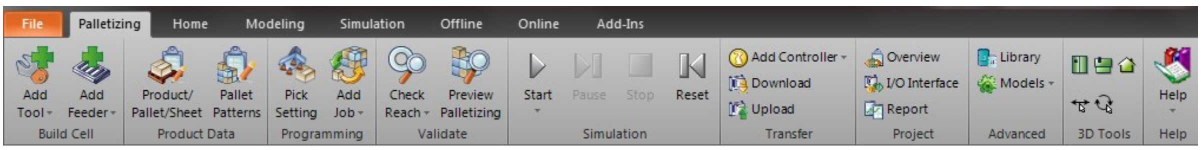

Figure 11: The PzPP menu tab in RobotStudio.

In the "Build Cell" category, tools and product feeders are imported and added to the robot and robot cell respectively. ABB has included five standard tools as SmartComponents to choose from. These tools contain functions such as vacuum picking for cartons, claw gripping for bags and pallet searching. Since there are standard tools, editing of tool signals is not needed [**21**]. For transportation of products and pallets in and out of the robot cell, conveyor tracks called feeders are used. Three types of feeders are commonly used; in-, out- and pallet feeder.

Dimensions and weights of products and pallets are defined in the “Product Data” category, see Figure 12. When products and pallets are defined, pallet patterns based on data in the previous step are automatically generated. The generated patterns are then added to the pallet layer by layer, see Figure 13.

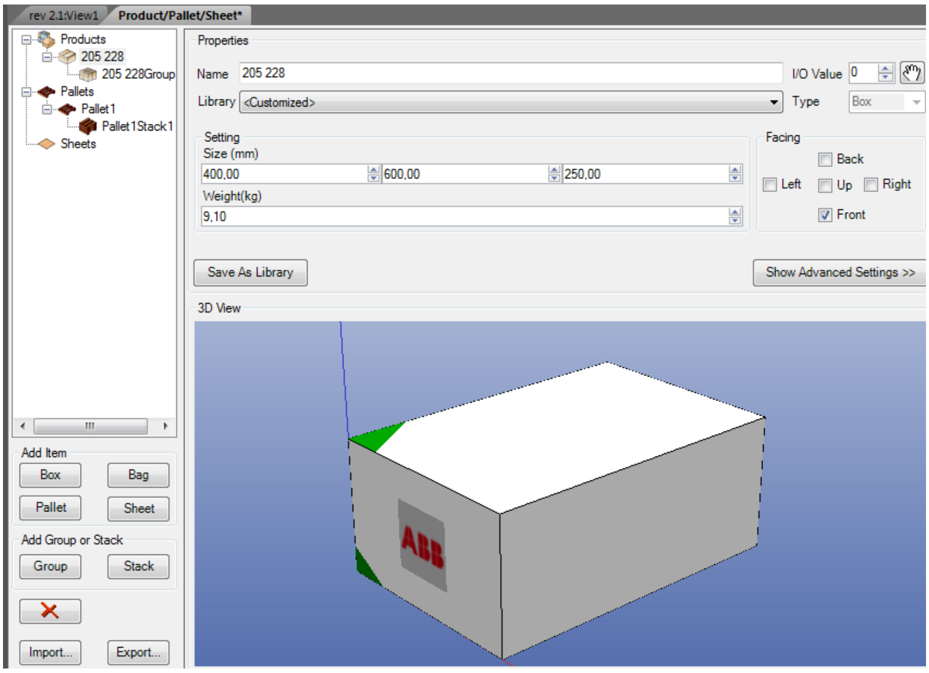

Figure 12: Definition of dimensions and weight of a carton.

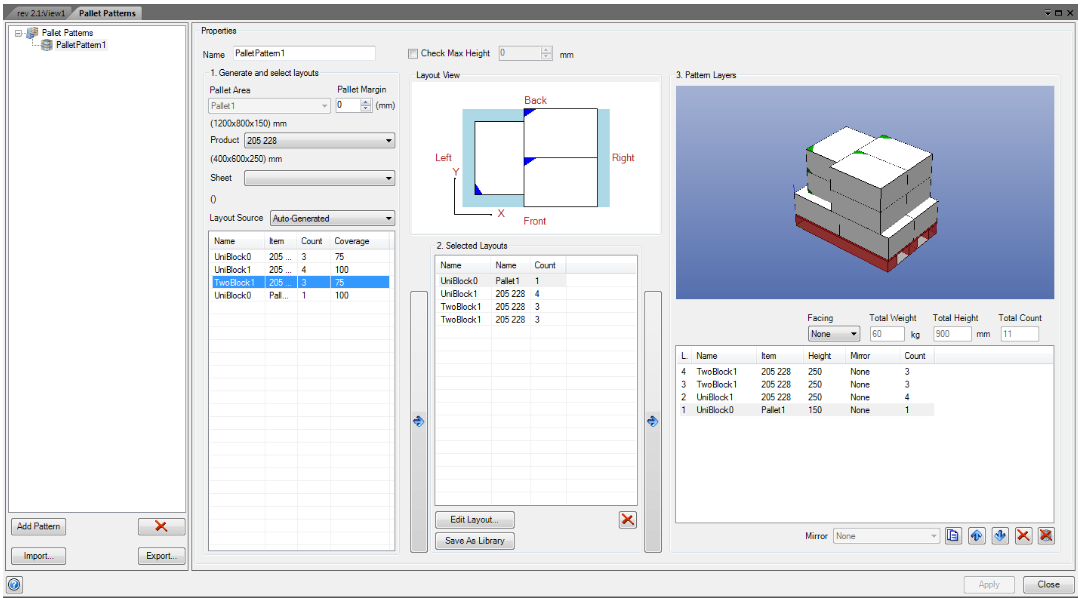

Figure 13: Selection of automatically generated pallet patterns

The next category, “Programming”, handles how the tool should pick products and how the palletizing job is to be performed. In Pick Setting, the orientation and displacement of the tool, see Figure 14, with respect to the product is specified.

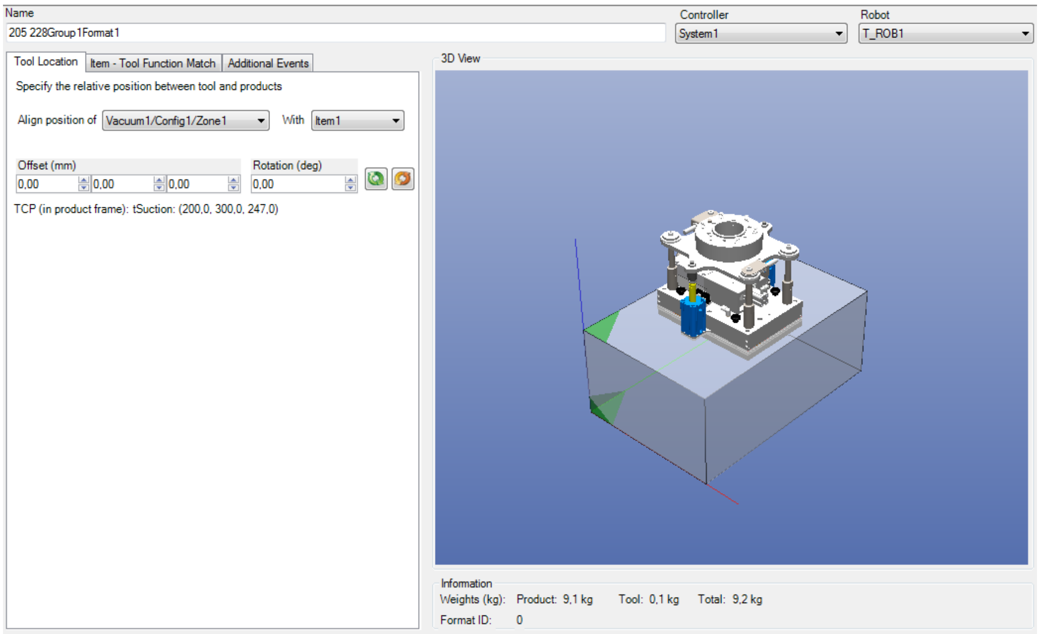

Figure 14: Orientation and displacement of tool.

To create the palletizing process, a job is added using the “Add Job”-button, where feeders for feeding the robot with products are assigned and which feeder to use for placing the pallet pattern is defined.

The last category before simulation, “Validate”, is used to ensure that the robot is able to reach all pick and place targets. This is done by using the “Check Reach”-button. Optionally, the palletizing process can be previewed before actual simulation takes part.

In “Simulation” the palletizing process is downloaded to the virtual controller in RobotStudio and simulated, see Figure 15, before any implementations to the physical robot controller are made.

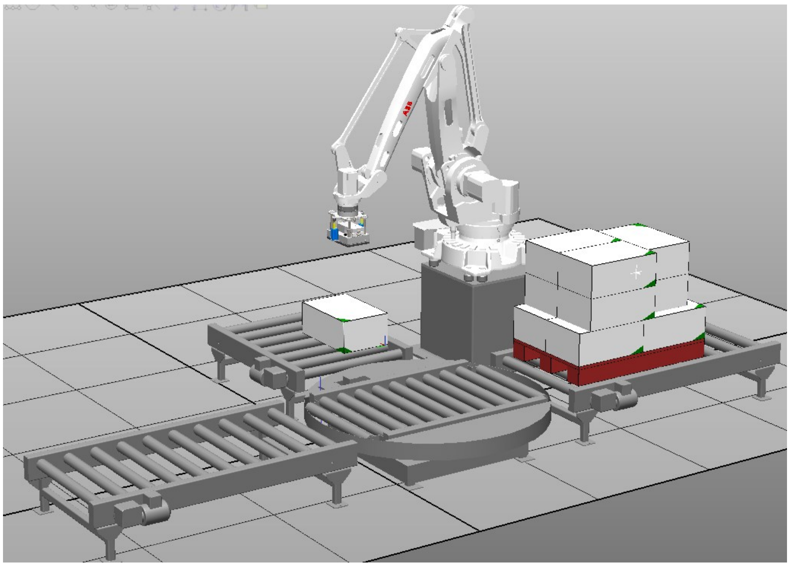

Figure 15: Snapshot of the simulated palletizing process.

After all steps have been completed and the simulation generated a satisfactory result, the palletizing project is complete and can be applied in the real robot cell.

3.3 Gripping Technologies

This section will describe what the definition of a gripper is, give examples of different types of gripping technologies used in automated systems and define the requirements put on a gripper. A deeper explanation of vacuum grippers and how to achieve vacuum will also be provided.

3.3.1 Classification of Grippers

Grippers are defined in one way as [**22**]:

> “Grippers are subsystems of handling mechanisms which provide temporary contact with the object to be grasped. They ensure the position and orientation when carrying and mating the object of the handling equipment”

There are different ways for gripping an object. Figure 16 shows gripping of a spherical object using six variants of grippers [**22**].

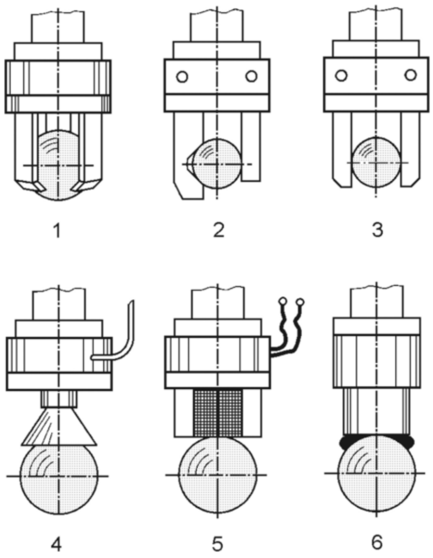

Figure 16: Six different ways of gripping a spherical object.

The classification of grippers can be made into four different categories as per below:

- Impactive mechanical grippers
- Ingressive grippers
- Contigutive prehension
- Astrictive grippers

Impactive mechanical grippers, for example gripper two and three in Figure 16, use mechanical force to grip the object. These grippers are the most frequently used types and consists normally of two or four fingers depending on the object to be gripped. In order to manipulate the fingers, different drive systems are used. Drive systems are of mechanical, pneumatic, hydraulic or magnetic types. The choice of appropriate system depends on criteria and rankings of these, such as gripping force, costs, maintenance and controllability. Typical object materials for impactive mechanical grippers are rigid objects.

Ingressive grippers are used for objects that made of non-solid materials, such as textiles. By using serrated edges, gripping in a pinch-like manner is achieved. In contrast to impactive grippers, ingression is applied on one surface and the object can be held without the need to continuously apply force.

Contigutive prehension includes grippers that use either chemo- or thermo adhesion, see gripper six in Figure 16. For chemo adhesion, tapes which are spun upon spools or permanently tacky pads are utilized to attach the object to the gripper. This requires changing the tape or cleaning the pads after a number of cycles in order to obtain the same retention force. Thermo adhesion uses small droplets of water in combination with liquid carbon dioxide. As the water freezes, an adhesive layer is formed between the object and the gripper.

Astrictive grippers have the ability to provide retention force without the need of any compressive stresses. Vacuum suction, electro- and magnet adhesion, see gripper four and five in Figure 16, are examples of this type of gripping technology. Grippers of this type require, a continuous stream of energy, i.e. air or electricity, to preserve the retention between object and gripper [**22**].

3.3.2 Requirements on a Gripper

When selecting a gripper, four characteristics and requirements come into play [**22**]:

- Technological requirements
- Effects of gripped objects
- Handling equipment
- Environmental parameters

Prehension time, gripping path and number of objects gripped per cycle is defined as technological requirements. Effects on gripped objects include mass, type of material, temperature and tolerances of the object. One example is that grippers using magneto adhesion are limited to magnetically susceptible objects, such as iron and steel. There are correlations between gripper and object, such as object mass and gripping force needed, object position and gripping, that need to be taken into consideration. Factors regarding handling equipment are what type of connections, mechanical, electrical or fluidic, are desired as well as the positional accuracy of the object required by the application. The environmental parameters include ambient temperature and humidity, vibrations and possible contaminations.

3.3.3 Vacuum Gripping

In automated processes with short cycles times where the object is relatively rigid and has a non-porous surface, vacuum gripping is suitable [**23**]. Depending on the design of the vacuum gripping tool, plastic bags and objects with curved surfaces is also subject to this type of gripping [**22**]. There are different types of gripping approaches where either suction cups or vacuum pads as depicted in Figure 17 are used [**24**]. A vacuum pad comprises of mainly three parts, but the design of parts and additional features vary depending on manufacturer [**24**] [**25**]. The top part in Figure 17 is the housing for the vacuum generator and a manometer for measuring of the obtained vacuum. The middle part is a valve module which contains vacuum regulation valves. A foam sealing mat is used at the bottom for secure gripping of objects and to reduce sliding.

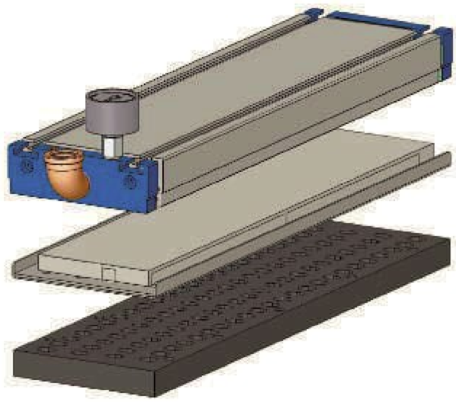

Figure 17: Exploded view of a vacuum pad.

3.3.4 Vacuum Theory

At sea level, the atmospheric pressure is 101,325 kPa or 1013 mBar. As the altitude increases, the atmospheric pressure decreases. For vacuum to occur, a difference Δp in atmospheric pressure and applied vacuum pressure must exist. The prehension force F_p on an object has a proportional linear relationship to these pressures and the prehension surface area A as, Eq. 5.3 [**22**]:

$$F_p = (\sigma_0 - \sigma_u) * A = \Delta p * A \quad [1]$$

where,

σ_0 = atmospheric pressure [bar]
σ_u = applied vacuum pressure [bar]
A = effective interface area between suction cup and object surface [m^2]

For astrictive grippers using vacuum suction, the vacuum is created by a vacuum generator which clears the air between the pad and the object. Since the pad and the object are in contact, no air can enter and vacuum is created.

When prehension is achieved, additional factors have to be considered. The following equation gives the effective suction force F_s with respect to these factors, Eq. 5.4 [**22**]:

$$F_s = (\sigma_0 - \sigma_u) * A * n * \eta * z * \frac{1}{s} + m * g \quad [2]$$

where,

n = deformation coefficient for suction cups
η = system efficiency considering leakage losses
z = number of suction cups [pcs]
s = safety factor
m = mass of object [kg]
g = force of gravity [m/s^2]

further parameters are described in equation [1].

s is given as [**26**]:
1: For very controlled conditions with very little risk for injury and/or machine failure.
1.5 Default value.
3-5 High or very high risk for personal injury and/or machine failure

3.4 Identification Systems

Several approaches and possibilities to robot vision systems are available. This section will first present the steps performed in a general machine vision system and then two different technologies used.

There are three steps performed by a machine vision system, see Figure 18, when transforming an image of a physical object into information that can be used by a robot or other industrial applications [**27**].

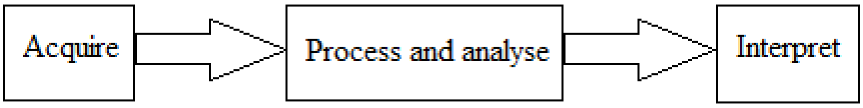

Figure 18: Steps performed for image transformation into data used by application.

By using a camera and a digitizing system, the image of the object is acquired. The image is divided into discrete sub-frames, called pixels. Each pixel corresponds to a light intensity with respect to its surroundings, which is converted into a digital value by an analogue-to-digital converter. Depending on the system used, the light intensity is classified into levels. The most basic system, binary vision, uses a two-level classification, where pixels are either white or black. More sophisticated systems use up to 256 intensity levels.

Cameras used to, *acquire* image data typically have resolutions of 640x480, 1024x768 or 1042x1392 pixels [**27**]. Higher resolution generates more pixels and a better image of the object at the cost of a more expensive camera and longer processing time. Another aspect to consider during image acquisition is the illumination. Since the ambient light may differ or not be sufficient enough for the cameras to operate, different techniques are used. One technique is structured light, where a well-defined pattern of pixels are projected on to the object. The vision system is then able to calculate information about the object, such as depths.

In the next step, *process and analyse*, the digital values created in the previous step are processed using different techniques. The object's features, such as length and width, are identified in this step and analysing and comparing pixel intensities.

The last step, *interpretation*, the image is compared to known computer models in a database. If there is sufficient correlation between the image and a model, the vision system can then determine what type of object the image is referring to. This gives decisions and actions, which is then interpreted and used as input to, for example, a robot controller.

Two technologies used in machine vision systems are stereoscopic 3D-vision and Time of Flight (TOF), see Figure 19 [**28**].

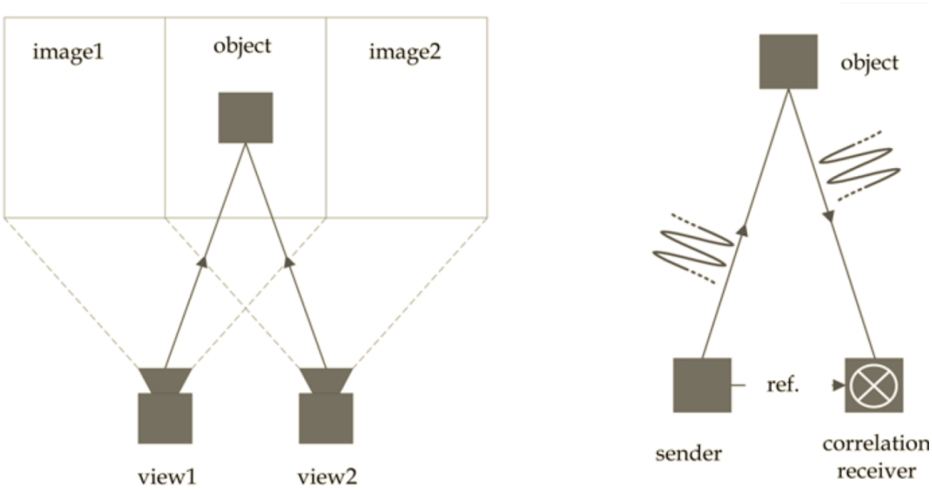

Figure 19: Stereoscopic vision system to the left and TOF vision system to the right.

Stereo vision systems use two cameras to acquire a physical point of an object. If a pixel is present in both images taken by the cameras, the distance can be calculated by using triangulation [**28**].

The TOF-system contains a sender, which emits a near-infrared light. The light collides with the object and is then transmitted to the correlation receiver. By calculating the time it takes for the light to travel from the sender to the receiver, the distance at where the object is placed can be calculated. This sequence is repeated over the object´s surface area until the entire object has been scanned.

Since TOF is an active range system it needs an illumination source, whereas the stereoscopic system is passive [**29**]. The TOF-system is insensitive to inferior lighting conditions and shadows, which are often present in containers [**30**].

A problem, called correspondence problem, occurs with objects of equal grey level values. The stereo vision system will have problems gathering 3D-information about the object due to the lack of active illumination. This problem can be reduced, but requires much more processing power compared with the TOF-system [**28**].

3.5 Ergonomics

As mentioned in section 2.1 two ergonomic methods and one human simulation software are used for the ergonomic analysis; REBA, NIOSH and Jack.

3.5.1 REBA

Rapid Entire Body Assessment is a method for analysing postures of the entire body [**31**]. The method considers for example how easy an object is to grip and positions of the upper extremities. The bad ergonomic posture obtains a higher score than a less harmful posture. If there is a large difference in postures the method will also consider that. REBA is easy to use because no advanced equipment is required [**32**].

REBA consists mainly of four steps:

1. Select a sample principle
2. Collect body postures
3. Analyse the postures
4. Compile the result

The sample can be selected by identification of bad work postures, analysis of time sampling or through task analysis. In identification of bad work postures the whole work cycle is observed and some hazardous work postures are selected. Analysis of time sampling refers to the posture a worker/operator has at a specific time for example every tenth second during a period of ten to twenty minutes. For the task analysis the work cycle is divided different operations were each operation's posture can be analysed.

In collection of the body postures a video camera is commonly used but just photos works well when identifying work postures.

When analysing the postures and compiling the results it is important to explain and motivate why a posture causes a certain score. This will facilitate the improvement work of the operations.

3.5.2 NIOSH

The Revised NOISH Lifting equation is a method for analysing motions during lifting [**31**] [**33**]. Experts from The National Institute of Occupational Safety and Health in USA have developed an equation, which considers factors related to workload tolerances in order to identify limiting values of the maximal load that should be handled. Two common limiting values are: Action Limit (AL, which is recommended lifting limit) and Maximum Permissible Limit (MPL, which is maximum lifting limit). Values lower than AL can be performed by 99 % of all men and 75 % of all women without risk of injury. Work situations, which give values higher than MPL-level, indicates that there are high risks of getting hurt and these situations must be improved immediately.

The equation of Recommended Weight Limit (RWL) is:

$$RWL = 23 * H_m * V_m * D_m * A_m * F_m * C_m \; kg$$

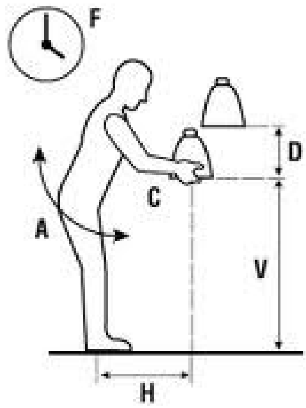

Figure 20: Definition of the lifting variables H, V, D, A, F and C.

where,

H_m = a horizontal factor = 25/H, where H is the horizontal distance from the operators' feet to the gripping position of the object.

V_m = a vertical factor = 1-0,003 | V-75 |, where V is the vertical distance from the operators' feet to the gripping position of the object.

D_m = a distance factor = 0,82 + 4,5/D, where D is the lifting distance.

A_m = an asymmetric constant = 1-0,0032A, where A is the asymmetric angle relative upper body when lifting.

F_m = a frequency factor and has a value between zero and one. This value could be found in Table 6 in Appendix – Ergonomics.

C_m = a coupling factor, which has a value between zero and one and is also received from Table 7 in Appendix – Ergonomics.

3.5.3 JACK

The Centre of Human Modelling and Simulation at the University of Pennsylvania began to develop Jack in mid-1980s. During the beginning of the development they had significant support by the US Army and NASA, but today it is marketed and developed by multinational conglomerated company, Siemens.

Jack is a human modelling tool suitable for ergonomic analysis in production environments. The representation of the model has developed during the years and is currently based on anthropometric, anatomical and biomechanical data, see Figure 21 [**34**]. The human, also called mannequin, has restrictions of motions of joints which closely corresponds to a real humans motions. For example the shoulders are based on inverse kinematic algorithms in order to make sure that the body is not moveable into strange postures. The software supports different kind of CAD-files, which facilitates the arrangement of the work environment where the mannequin acts. Other analysis tools are also available, e.g. collision detection and reach envelope, in order to support when designing the workplace.

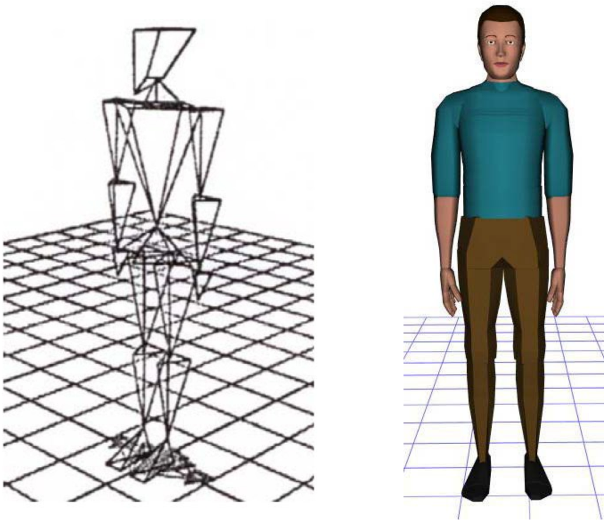

Figure 21: A human representation in Jack from 1980s to the left and current representation to the right.

The software enables creation of animations in a Task Simulation Builder. In the builder it is possible to put together different tasks, e.g. put, go and reach, into a sequence. From this sequence it is possible to acquire an ergonomic report consisting of joint angles, joint torques and percentage of the population who is capable of executing the sequence without risk of injury.

3.6 Systematic Evaluation

For selecting the most appropriate and applicable solution for Elgiganten two systematic evaluation methods, Pugh matrix and Kesselring matrix, has been used. In the Pugh matrix the different solutions is compared to a reference, which often constitute of the existing solution. This comparison is based on the predetermined criteria. Solutions better or worse than the reference in the specific criteria get a plus respective minus. If it is impossible to separate the solution and the reference a zero is marked. The solution/-s with the highest net value is passed to the further development process.

The second method used, Kesselring matrix, uses the same criteria but in this matrix the criteria is weighted. The weighting varies between one and five and if a criterion is important the assigned value is five. The total score from the solutions are compared to an ideal solution.

3.7 Existing Solutions

In this section several existing solutions for the application Container Unloading is presented. The four following solutions refer to Stage One, which is unloading the cartons from the container to the conveyor belt. Stage One is further described in section 1.1. After these four solutions, two solutions for both Stage One and Stage Two are presented. This section is ended with a description of the Container Unloading procedure at Attends and IKEA.

3.7.1 ParceLift

ParceLift, manufactured by Vaculex, is a non-automatic lifting aid based on vacuum and helps the operator with the lift. This lifting aid can be applied to the existing conveyor belt at

Elgiganten, see Figure 22. ParceLift is specially developed for loading and unloading containers [**35**]. From an ergonomic point of view this helping device is better than manual work [**36**]. The tool can be attached to the cartons from all sides, which increase the flexibility of it.

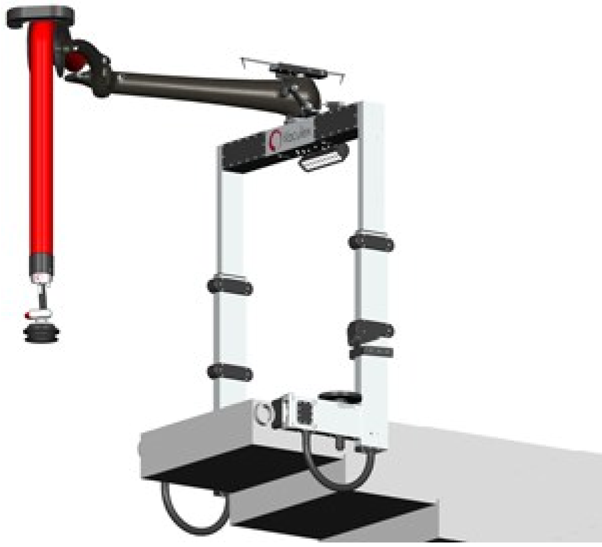

Figure 22: The ParceLift.

ParceLift has a recommended max load of 40 kg and the unloading capacity is limited by the operator. It is suitable for both 20 foot and 40 foot containers because it is applied to the conveyor belt. The investment cost, which includes full installation, is 250 000 SEK [**37**].

3.7.2 Empticon

Another existing solution for unloading a container, without palletizing the products, is Empticon [**38**].

Figure 23: The Empticon.

It is manufactured by Univeyor in Denmark and facilitates the picking of cartons from the container to the conveyor. Empticon is based on telescopic conveyor, which is able to reach all cartons in the container. At the front of the conveyor, Empticon is equipped with seven arms. Each arm, in turn, is provided with a suction cup. These arms attach to the carton/-s and pull it/them to the conveyor and drop down in slots of the belt in order to not hinder the cartons. Then the employee operates Empticon to the next carton by a wireless control desk, see Figure 24.

Figure 24: A wireless control desk.

Cartons, which can be handled by Empticon, have to have dimensions larger than 150x150x150 mm in length, width and height and smaller than 1000x800x800 mm. The maximum weight of the handled carton is 40 kg. Empticon can be used for both 20 and 40 foot containers and also for high cube container of 40 foot size. By using Empticon a skilled and trained operator is able to unload 600 cartons per hour and even more if it is possible to pick two or three cartons at a time. The investment cost of Empticon is 1 000 000 SEK, but note that this price includes education, delivery and installation.

3.7.3 ParcelRobot

Another machine, which is not manually operated, is the fully automated ParcelRobot, see Figure 25 [**39**]. This system is based on a 3D laser scanner, a computer and a robot. The procedure begins with the laser scanner scans the pattern of the cartons and transmits the data to the computer, which in turn calculates the gripping position and the trajectory to this position. The system also considers reachability of the gripping position and avoidance of collisions. The robot grips the carton with a vacuum pad called UniGripper and when the robot has picked the carton it places the carton on the conveyor belt [**40**]. When all the reachable cartons are picked, the telescopic conveyor belt can be extended further into the container. This system can be used for both 20 foot and 40 foot containers.

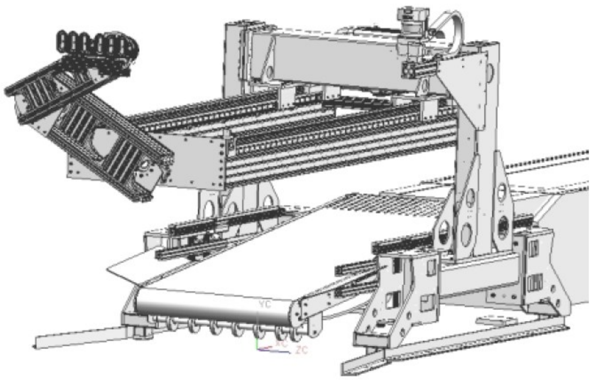

Figure 25: The ParcelRobot.

The ParcelRobot enables unloading of up to 500 cartons per hour and cartons up to 60 kg can be handled. Dimensions of the cartons can differ between 200 to 600 mm for each edge length [**41**]. The investment cost of this system is 2 500 000 SEK.

3.7.4 Random Box Mover

The company Universal Robotics has developed an application called "Random Box Mover" (RBM) for detection, identification and moving of cartons distributed in a random pattern. RBM uses structured light and low-cost cameras for stereoscopic 3D-vision, see Figure 26.

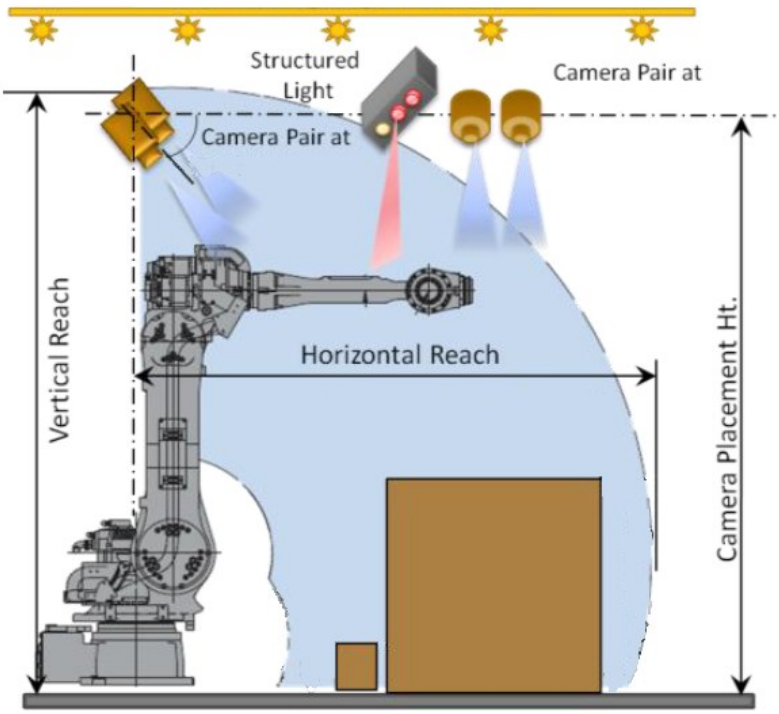

Figure 26: Principal layout of Random Box Mover.

The image processing is managed by the company's own software, Spatial Vision Robotics, which generates the position of the carton by using the coordinates (X, Y and Z) together with the rotation of the carton in a given coordinate frame. This serves as an input to the PC-based software where the information is converted to suite chosen robot controller and as a result, the robot knows where the carton is located.

The system is universal in the sense that it works with several different robot brands and models. Combined with a Motoman MH50-20 robot using the DX100 controller, RBM has the capacity to move 720 cartons per hour that are positioned in any orientation. The application manages cartons with dimensions varying from 152 x 152 x 3 mm to cubic cartons with side lengths of 1219 mm. The accuracy can be varied between ± 0.5 mm to ± 5 mm depending on the requirements of precision [**42**].

A typical scenario with cartons in a container can be seen in Figure 27**Error! Reference source not found.**. The cartons are positioned in various orientations and at different depths in the container.

**Figure 27: Top, cartons in various orientations in the container.
Middle, Geometry of cartons is identified as a whole.
Bottom, each box is identified as an entity.**

Firstly, the software detects and generates an overall three-dimensional view of the cartons, see Figure 27. Since there are several cartons in this case, the software chooses cartons that are closest to the robot. If all cartons are to be positioned at the same distance, the highest located cartons will be chosen.

Secondly, each carton and its spatial position regarding a defined coordinate frame are identified. This is shown in Figure 27 and since the uppermost, left carton is closest, this carton will also be picked first.

Using the calculation software, 3D Calculator, provided by Universal Robotics it is possible to estimate at which distances the cameras should be placed in order to have desired field of vision. As input, carton dimensions, robot reach, size of work envelope as well as location and type of cameras are defined.

3.7.5 TEUN

Developed by Ergolog B.V, TEUN is a fully automatic system solution for unloading floor loaded containers, palletize the cartons and finally wrap these in plastic film [**43**]. Figure 28 shows TEUN in operation. TEUN is offered as a service and price per unloaded container varies between 500 SEK and 2000 SEK. The varying price depends on added services like weighing, wrapping, labelling and more.

Figure 28: TEUN with integrated unloading, palletizing and wrapping of cartons.

The system consists of a Stäubli TX200 six-axis robot with a payload of 125 kg together with a vision system for detection of cartons. TEUN can handle cartons with surface dimensions between 100x100 mm and 600x600 mm.

First, the robot scans the content of the container. Cartons are then gripped using a vacuum gripper and placed in a programmed pattern on a pallet. When the pallet is finished, it is automatically transported to the next station for wrapping. Since it is an automatic system, the only manual labour needed is to serve TEUN with new pallets and transport finished pallets. As a result, it is an optimum solution with respect to ergonomics.

3.7.6 Copal

Copal is a semiautomatic solution engineered by Copal Development BV for unloading cartons from a container, see Figure 29. The unloading procedure begins with an operator manoeuvres the manipulator to the cartons. When the manipulator is in gripping position the operator enables the suction cups to attach to the cartons by pushing a button. Then the operator operates the arm to the conveyor belt, where the cartons are released. After that the cartons are palletized automatically in a predetermined pattern by the machine.

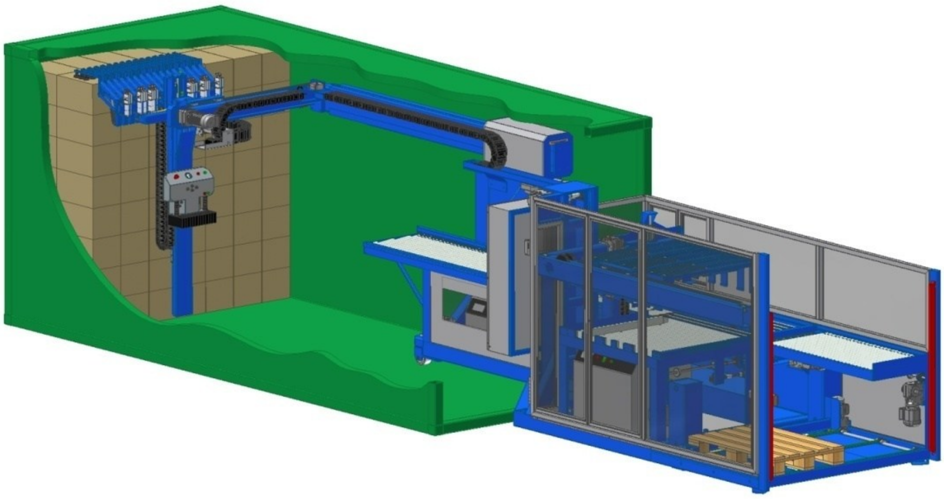

Figure 29: The Copal.

It consists of an arm, which turns the cartons in the right direction before the cartons are arranged in the predetermined layer. The whole layer is arranged in a buffer zone before it is moved to the pallet. Copal supports both stringer pallets and block pallets and can palletize the cartons to a height of 185 cm [**44**]. Copal can be used for both 20 foot and 40 foot containers and has a capacity of unloading and palletizing 1500 cartons per hour. The investment cost for this system solution is 3 475 000 SEK.

3.7.7 IKEA

At IKEA Distribution Central in Torsvik cartons are unloaded from containers in order to reload other containers for further distribution. Approximately 100 containers each week are unloaded and the procedure of doing that differs from other companies' way of handling the problem. They transport their goods on small cardboard pallets, which enable the unloading procedure by truck. A 40 foot container is unloaded within one hour and requires only two operators.

3.7.8 Attends

Another company, which has faced the problem of unloading containers, is Attends Healthcare in Aneby. At Attends 60 containers arrive and being unloaded each month and approximately fifteen cartons with different sizes are represented. The unloading procedure consists of manual handling of carton from the container to a conveyor belt. Before it is palletized by IRB 460 robot the cartons are arranged in different formations on the conveyor belt. The whole system requires three operators. The tool used for gripping the cartons is ABB's standard tool for palletizing operations, Flexgripper [**45**]. Flexgripper consists of 40 suction cups divided by ten zones and has a maximum weight per lift of 40 kg. The tool can handle cartons with the maximum size of 1200x500x300 mm and the minimum size of 240x240x100 mm. The gripper its self has a weight of 75 kg.

4 Analysis

In this chapter the analysis of the Container Unloading is presented. The first section describes the work procedure at Elgiganten where ergonomic results are presented. In the second section the software, PzPP, is evaluated and its applicability to the case Elgiganten is presented. The third section covers the key factors for a solution at Elgiganten such as carton dimensions and characteristics and gripper design. The fourth section describes systematic evaluation of suitable solutions. Finally, two proposed solutions are presented together with a robotized palletizing solution

4.1 Work Procedure at Elgiganten

In this section a deeper analysis of the situation at Elgiganten is presented. The situation analysis will cover the operators' work methods and the ergonomic situation.

The principle layout of the Container Unloading procedure is presented in Figure 1 in section 1.1. When the operator unloads the container, see number one in Figure 1, there is no lifting aid available for facilitate the managing of cartons. The telescopic conveyor is adjustable further into the container as the number of cartons decreases. This means that the operator does not have to carry the cartons far distances. The conveyor is also adjustable in height in order to minimise the required lift, but still a lifting aid would be desirable from an ergonomic point of view. The fact that the operator is working under stressful conditions means that the possibility to adjust the height of the conveyor belt is not frequently used. A stressful environment usually deteriorate ergonomic situation [**46**]. The operator tend to stand on the cartons when unloading the container in order to easily reach cartons high up even if it is clearly marked that this is not allowed. If this leads to more cassations is not shown but damaged cartons are harder to sell. During winter the operator needs to work under cold conditions, which further affects the ergonomic situation negatively [**47**].

At the other end of the telescopic conveyor the cartons have to be placed in a pattern on the pallet. This palletizing procedure also has several ergonomic shortages. The roller conveyor, which is connected to the telescopic conveyor, is not adjustable in height, which means that a short operator has to work at the same height as a tall operator. When the cartons are placed on the pallet the operator needs to bend over the pallet and has to place the cartons with precision, which is not desirable from an ergonomic point of view [**48**]. The filled pallet is picked up by a truck driver, but a new pallet has to be manually handled from stack of pallet nearby. There are lifting aids available but not used, because they are not easy enough to use and there is no clear directive from the management team that the aids should be used. At the palletizing operation there is no possibility to stop the conveyor which means the operator in the container determines the work speed.

Since Elgiganten today has a telescopic conveyor at the manual workstation for Unloading Container, it is reasonable to include it in the proposed solutions. The layout of the robot cell should be arranged so the conveyor is moveable to another arriving gate, which it is today.

When analysing the work procedure from an ergonomics point of view by the ergonomic tool, REBA and NIOSH, the results indicate bad work conditions. The results from the REBA analysis show that a redesign of the workstation is necessary soon or immediately because the risk is high or very high at the moment, see Appendix - Ergonomics. Also, the method of NIOSH confirms the bad ergonomic conditions, see Appendix - Ergonomics. According to the method the maximum weight that is acceptable to handle in those conditions is always less than fifteen kg. In the worst case, which is gripping cartons from the floor and gripping cartons at a height of around 1,75 meters above floor level, the maximum acceptable weight is around five kg. Those specified weights are lower than what a large part of the cartons weigh, which is a severe problem for Elgiganten, see Figure 36. According to guidelines provided by Arbetsmiljöverket, the maximum allowed weight is fifteen kg when the lift is executed 45 centimetres out from the body. The third most injured body part is the back, which is endangered during manual managing of cartons [**49**].

4.2 Palletizing PowerPac

This section will firstly highlight the strong points in PzPP. Secondly various problems with the software are given. These problems arose after having used the software and analysed it more thoroughly. The problems have been categorized as deficiencies and teething problems. Deficiencies are considered as more severe problems than the teething problems, since the teething problems can most probably be fixed until the next software update release. Finally, the applicability in the case Elgiganten and how well suited PzPP is in this case will be analysed.

4.2.1 Strong points

There are several strong points to PzPP. The software environment in PzPP has a logical layout with symbols that are easy to understand, see Figure 11. This makes it quick for the user to get familiar with the different steps needed in the make of a palletizing process. The approach of not having to do any otherwise necessary traditional text-based robot programming is neat and makes the software easier to understand for a non-experienced user. To be able to export product data and pallet patterns as XML-files is a time-saving feature, since this eliminates the need to re-enter data for all products if these are to be used in another robot station. Also, if there are many different products with various dimensions and weights, it is not desirable to have all these product data imported in PzPP at the same time. This leads to a lot of scrolling and searching for the right type of product in the Product Data window. Thus, having each product as an XML-file and only importing the products needed at the time simplifies this matter significantly.

There are options to manually edit and customise the patterns e.g. adjusting each products individual position and orientations on the pallet see Figure 30. Pallet patterns are shown graphically in a three-dimensional view which can be rotated and zoomed as the user wishes. This gives good feedback and makes it easier to control and verify that the correct patterns have been created. If pallet filling degree is an important parameter, the automatically generated patterns can be sorted on filling degree and the maximum value can easily be found. Feedbacks to ensure that maximum height and weight of the pallet is not exceeded are also available.

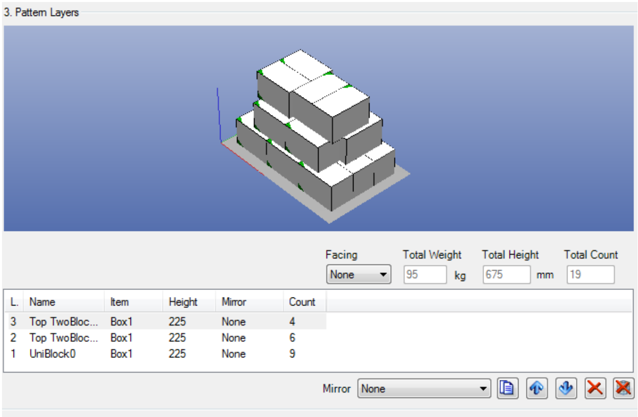

Figure 30: Customisation of patterns.

If a tool with multiple suction cups is used, zones containing one or more suction cups can be created. Activation and deactivation of zones i.e. cups depending on product dimensions can be made. This enables the use of a tool i.e. vacuum pad larger than the surface area of the product without the risk of adjacent products getting attached to the tool. The active area of the tool can simply be customised to fit the product area. Also, if a standard tool from ABB, such as the FlexGripper is used, all tool signals are already prepared and defined in the robot controller.

No pick and place targets, robot axis configurations or programming instructions need to be defined. These are dynamically created by PzPP based on product dimensions and feeder positions. This further saves programming time and makes the setup almost plug-and-play. During the simulation phase it is a main advantage to be able to visually see all motions and actions performed by the robot and tool. This helps in the detection of any eventual collisions between already palletized products and products held by the robot to be palletized.

4.2.2 Deficiencies and Teething Problems

Regarding the deficiencies and teething problems, these mostly concern tool functions, velocity settings and palletizing pattern options.

When creating a new tool out of an existing CAD-model, tool functions such as vacuum needs to be defined. There are six predefined tool functions which are designed to be used with ABB's standard tools. A tool function needs one or more control- and tool signal depending on what type of function is used. This creates a problem when using a non-standard tool, since every input- and output signals that need to be defined in the tool function may not exist in the non-standard tool. As a consequence, the tool function will not perform as expected. There are also no possibilities to import or create own tool functions in PzPP, which is an obvious drawback.

When using the "Check Reach"-function, only the robot's reachability of pick and place positions are checked. Hence, any intermediate positions between these pick and place positions are not checked. As a result, PzPP will state that the robot is able to perform the whole palletizing process without complications. However, when the palletizing process is simulated in the software or downloaded to the physical robot controller, an error message about the inability to reach an intermediate position will occur. In order to discover this problem the whole palletizing process has to be executed before any detection of the mentioned problem is made, since the problem will start to occur for pallets with heights close to the robot's work range limit. To solve this problem, a certain amount of modifications in a routine used in PzPP to calculate intermediate positions is needed. Due to this the purpose and robustness of simulating the palletizing process to discover eventual problems before a physical implementation will be made is lost. Hence, an option in the "Check Reach"-function to enable checking the reachability of intermediate positions is desirable.

When values for robot velocities, accelerations and decelerations called motion values, are defined in PzPP, these values are only possible to define for a certain product. If a new product is created and the user wishes to use the same motion values as for the previous product this cannot be done. Instead, the whole procedure must be repeated for every new product that is created. Often it is possible to use the same velocities, accelerations and decelerations whether a product's dimensions and weight are similar to a product with already defined motion values. It would therefore be more efficient to be able to create a group of products where all products in that group use the same motion values.

The defined motion values can be tuned online at the physical robot station by using a Tuning-function provided by PzPP on the TeachPendant. This is to create a smooth flow of motions between the pick and place positions as well as the motions values when the robot approach and depart defined targets. However, it is only possible to tune motion values for the states when the robot is holding a product. Thus, motion values when the robot approaches a product for picking or departs after placing a product is not possible to tune. Instead these values have to be set offline in PzPP. This makes the Tuning-function a half-measure and less capable of fulfilling desired settings.

Regarding the palletizing pattern options, a deficiency is that it is only possible to rotate a product around the Z-axis. In addition, all products belonging to the same layer on the pallet have to have the same orientation with regards to the X- and Y-axis. Therefore, if it is desired to have every other layer with the product rotated around the X- and/or Y-axis, see Figure 31, a new product has to be created. The products are identical with the only difference that the sizes in Y and Z have been shifted, yielding a standing product instead of a lying product. As the number of products increases so does the number of XML-files, which might be a problem for a company like Elgiganten with a large variety of products.

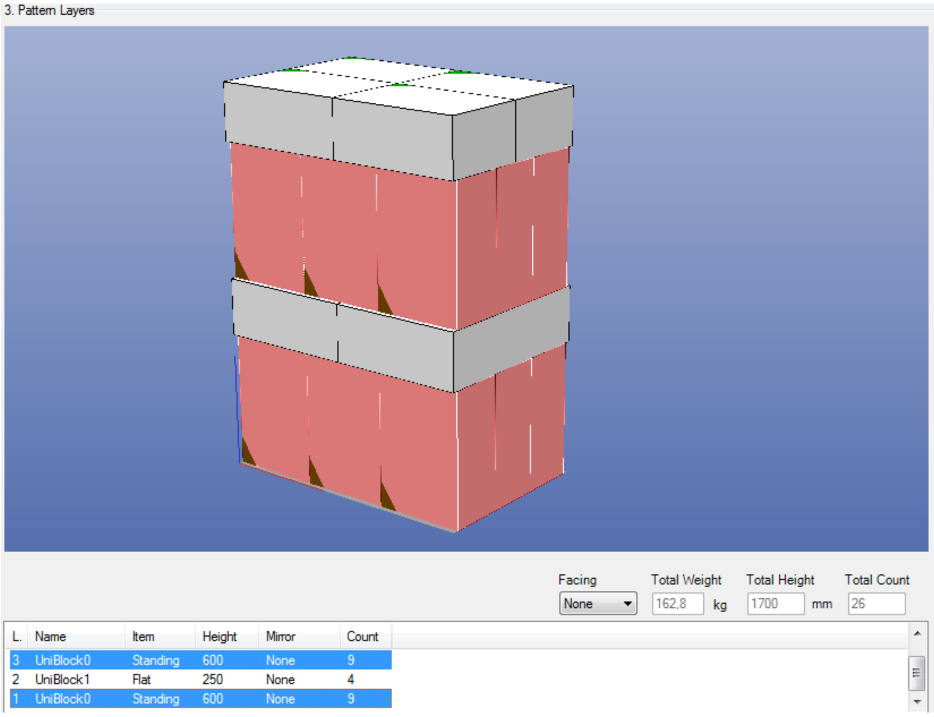

Figure 31: A pallet pattern consisting of products with identical dimensions. The products in red are rotated around the X- and Y-axis.

Since there is no physics integrated in PzPP, irrational palletizing patterns can be created, see Figure 32. No feedback or warnings are given if this type of pattern is created, which makes PzPP less robust towards human errors and mistakes. Desirably, a warning could appear if a product is placed more than 5 cm above adjacent products.

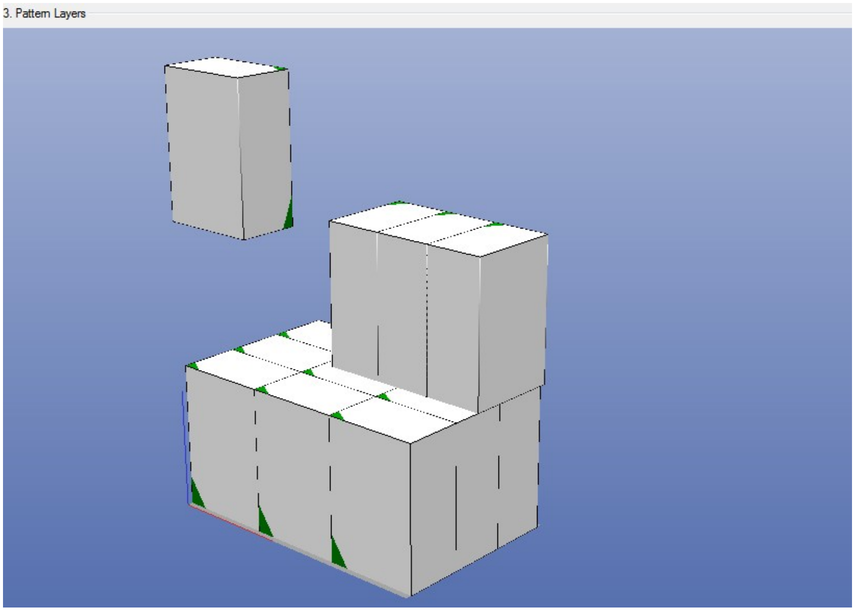

Figure 32: An example of an irrational pallet pattern where a product is placed without contact to adjacent products.

The following teething problems are considered less serious than the deficiencies, but still cause complications when using PzPP. Firstly, all products and pallets defined in PzPP are lost if the robot station is closed before PzPP is deactivated. To avoid this problem, the following procedure has to be done:

- Open station
- Activate PzPP
- (Work with PzPP)
- Deactivate PzPP
- Close station
- (Quit RobotStudio)

If the user forgets to perform this procedure and a lot of different products and pallet sizes have been defined, everything has to be defined once again, which is an outermost tedious and time consuming work. XML-files are not affected by this teething problem.

Secondly, when creating and using a non-standard tool from a CAD-model, input and output signals need to be specified for the tool. The number of input and output signals depend on what functions are included in the tool. Connections of signals are made between tool and controller, which are then saved in a so called “tool profile”. The purpose of the tool profile is that the connections do not have to be made every time PzPP is started. However, the problem is that this does not always work as intended. During the use of PzPP and also when PzPP is restarted, the connections are lost which resulted in error messages and the connection procedure had to be done again. Also, set values, such as bit values, are not always applied for certain tool functions. Due to this, the user is uncertain which values are current and if the tool will perform as expected. This further decreases the robustness and reliability of the software.

Finally, the graphics in the visual simulation sometimes behave irrationally. An example of this behaviour can be seen in Figure 33.

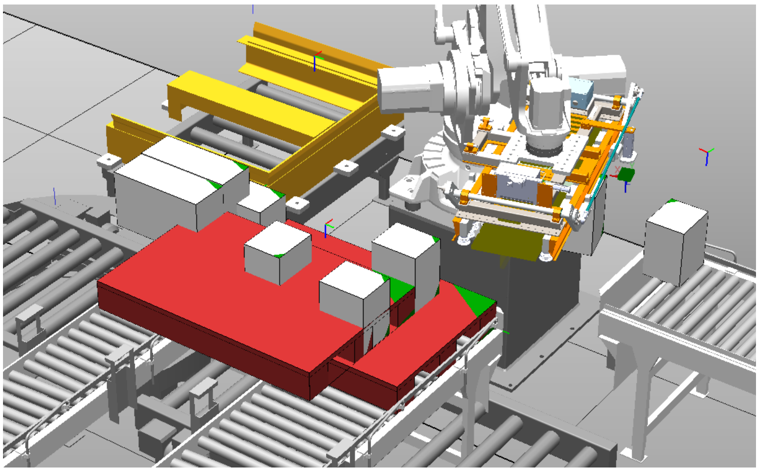

Figure 33: Graphics problems when running simulation in PzPP. Products and pallets appear in random places.

The aim is to create the same pallet pattern as in Figure 31. As seen, products and pallets appear in irregular positions. Though the robot, by analysing robot movements, appear to be picking and placing pallets and products in correct positions, the final graphical positions of these objects are not correct. Furthermore, the robot graphically fails to attach and release products during the picking- and placing sequences. This behaviour also appears in a random pattern and cannot be traced to any specific settings in PzPP.

Other problems that can be characterised as a more of a subjective issue is firstly that PzPP gets slower and slower the more it is used in a session. Frequent restarts of both PzPP and RobotStudio are needed in order to speed up the software. Secondly, due to hidden and read-only modules and routines in PzPP, it is somewhat problematic to modify programming code if needed. Finally, in the "Pallet Pattern" window, an option to ensure that the total pallet height do not exceed a height set by the user. This option does not fully function, since it is possible to set a maximum height, create a pallet pattern that exceeds this height and then download and run the palletizing process to the real robot. From a safety viewpoint this is not desirable.

Though PzPP simplifies steps in the palletizing procedure, such as calculations of robot movements and pallet patterns, other steps are more difficult to modify. These steps are mainly related to tool functions and events, where modification of the programming code generated by PzPP is often needed.

4.2.3 Applicability in the case Elgiganten

In this section, the suitability of implementing PzPP as part of a solution for robotized palletizing will be analysed. The strong points and deficiencies mentioned earlier in section 4.2.1 will serve as a base for this analysis.

When new products arrive at Elgiganten, these have to be defined in the "Product Data" category and a pallet pattern has to be created. This process is done within minutes and needs no direct prior knowledge about PzPP. Therefore it is believed that a non-experienced operator can learn and perform these steps quickly. Regarding the pick settings, these may cause difficulties if several products are to be picked at a time. The orientation and displacement of the tool need to be changed, which in turn requires knowledge about how the tool is configured and designed. Due to the unstable behaviour of PzPP, some experience in this process is essential.

As stated in [**18**], no robot programming skills are needed, but it was shown during the analysis that these skills indeed are needed. When, rather than if, a problem occurs in PzPP knowledge in robot programming to derive and solve the problem is required. The documentation provided with PzPP is at the moment not circumstantial, which further complicates the troubleshooting procedure.

The aim of having operators with no previous experience in this field to create a new palletizing procedure within 20 minutes using PzPP is therefore assumed to be not fulfilled. Instead, one operator needs to be trained in PzPP and responsible for the creation of new palletizing procedures. This should also create consistency and make the procedure efficient and effective.

4.3 Key Factors for a Solution at Elgiganten

Before proposing solutions, key factors need to be considered. In the following section an analysis of the type of cartons to focus on and the cycle time for managing one carton are presented. When the carton dimensions and the required cycle time for unloading a container within two hours are known the selection of grippers is possible to do. The calculation of the capacity level ends this section.

4.3.1 Carton Dimensions and Characteristics

From the Excel-file provided by Elgiganten, container and product data were obtained. Data for containers included arrival dates and products held. Product data consisted of dimensions and weight of products, number of products per carton and volume in cubic decimetres for each product.

Since the containers could hold more than one unique product and cartons could contain more than one product, the following definitions were established:

- Container content C1, C2, …, Cn where C is container and n is the number of unique products/product variants it holds. For example, a C2 container holds two different products, i.e. microwaves and TV stands or two different product variants, i.e. a white and a black microwave.
- Carton relationships 1:1, 1:2, …, 1:n where one is carton and n is the number of products in that carton. For example, 1:4 is a carton containing four identical products.

The weight of the products ranges from 0.2 kg to over 40 kg. After a study visit at a manufacturer of vacuum tools and discussions with corresponding sales engineer, a decision was made to focus only on products weighing less than 30 kg.

Because the Excel-file only provided dimensional data for individual products it was only applicable for cartons of type 1:1, the distribution between width and lengths for 1:2 cartons etc. was not given. Hence, only the dimensions for one product were defined (even if there were more than one in a carton) the volume for the 1:2 cartons was calculated, see Figure 34. The figure shows that the cartons do not tend to be larger or smaller because it contains more than one product. After a discussion with the supervisor at Front Automation the decision to focus on cartons with known length, width and height was made.

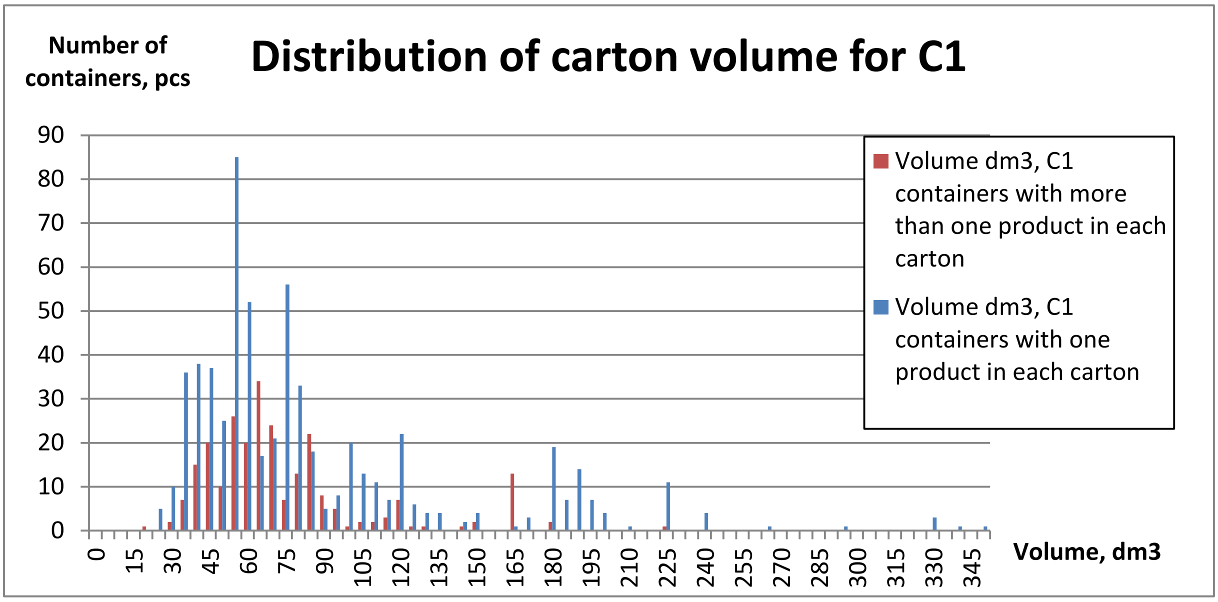

Figure 34: Number of C1 containers distributed among carton volume.

When this decision was made a scatterplot was performed in order to facilitate the choice of an appropriate gripper or grippers, see Figure 35. The figure illustrates the relation between length and width, which is the surface the gripper attaches to. To further facilitate the choice of gripper the distribution of weights for the cartons was established, see Figure 36. As can be seen in the figure most of the cartons have weights ranging from ten to twenty kg, which in theory can easily be handled by a vacuum pad.

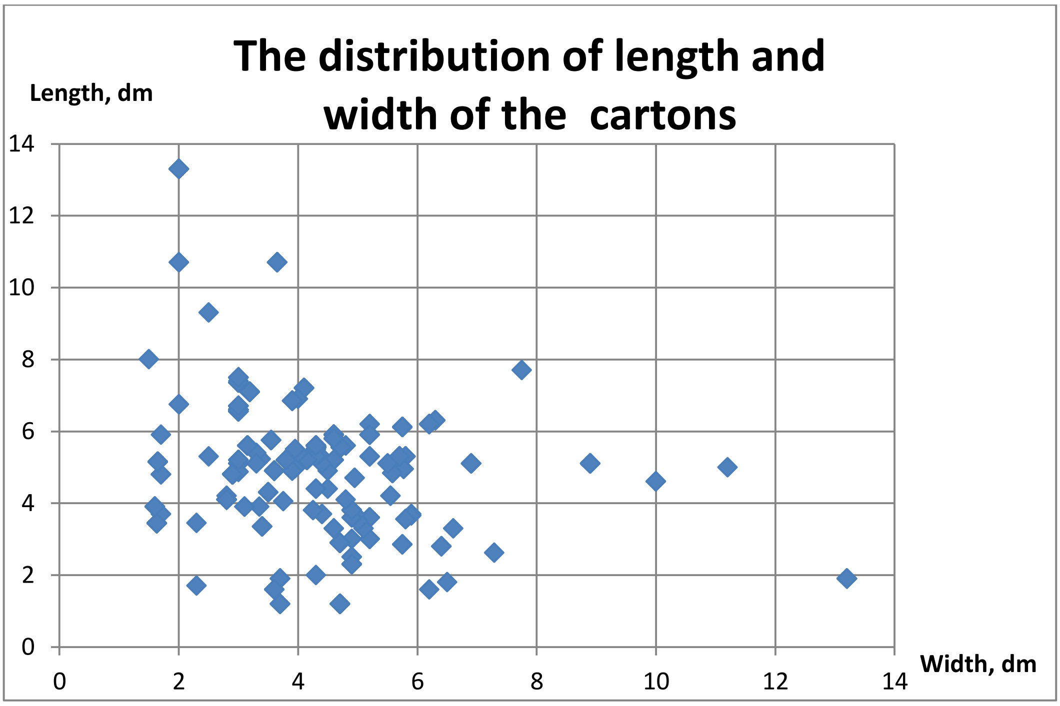

Figure 35: A scatterplot of the length and width of the cartons.

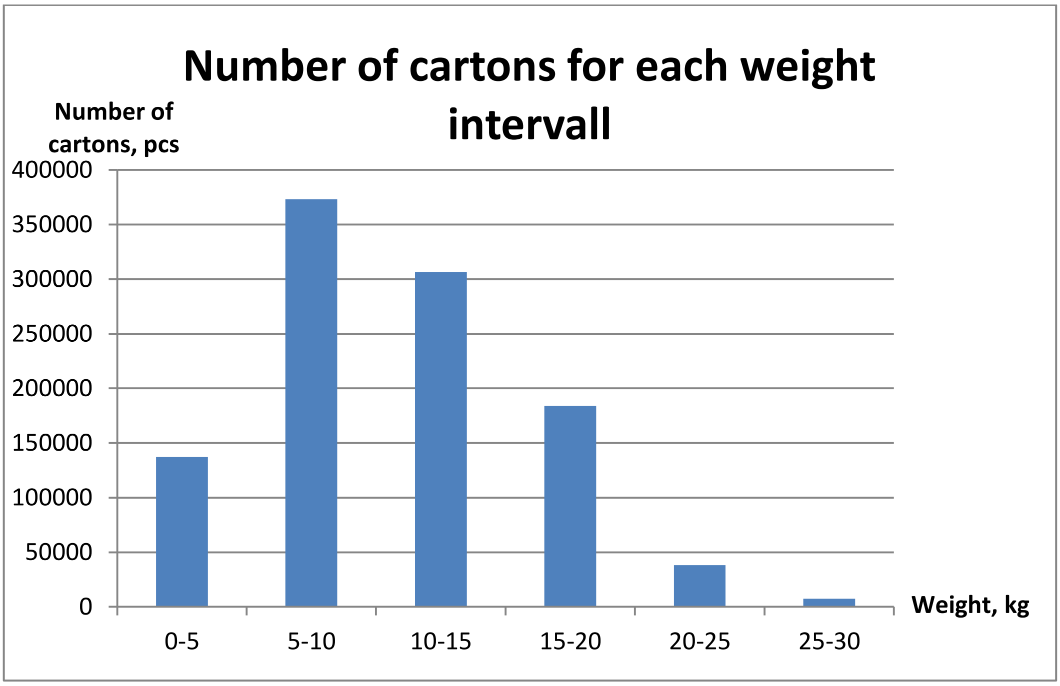

Figure 36: Number of cartons in each weight interval.

The total number of cartons, which are manually unloaded during the last 1,5 years, were calculated from the Excel file. This was done in order to compare number of cartons which could be handled by the robot with the total number of cartons.

To reduce the complexity of the problem, products that would need additional handling equipment during the palletizing process were not included in the analyses. An example of such a product is oil-filled radiators, which have to stand upright on the smallest surface of the carton, thus making the pallet pattern unsteady. Those radiators constitute less than 6% of the total number of cartons.

Since it was impossible, in aspects of both time and availability, to test all different cartons present at Elgiganten, one carton was selected for the verifications at Front Automation mentioned in section 2.3. The carton is representative for a large number of cartons present at Elgiganten in terms of dimensions and weight. A main difference though is that this carton can be seen as a "worst case" scenario with regards to carton characteristics. An ideal carton is a rigid body which do not deform during picking operations and with its weight uniformly distributed over its volume. The carton used during the verifications was far from ideal, as can be seen in Figure 37. Firstly, deformation of the carton's lifting surface during picking as indicated by the red arrows in Figure 37. As a consequence, the degree of compression of the vacuum pad foam differs throughout the tool; see the blue arrow and lines in Figure 37.

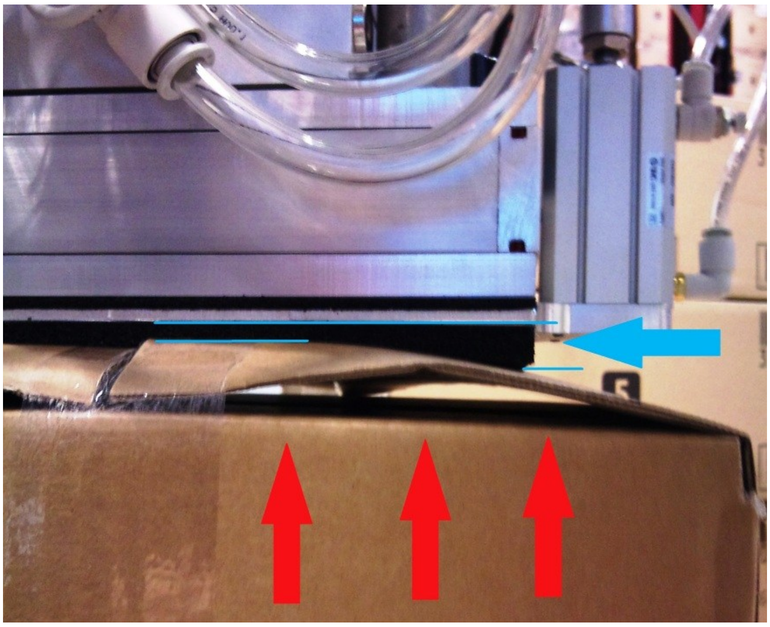

Figure 37: Carton being deformed during picking as indicated by the red arrows. The blue arrow and lines show the difference in compression of the vacuum pad foam.

This leads to lower lifting force of the tool. Secondly, the contents of the carton were soft, which further decrease the carton's ability to withstand deformation. Finally, the carton had an untreated surface instead of a painted, glossy surface. Due to this, the carton is less airproof and this leakage of air results in lower vacuum achieved and thus less lifting force.

4.3.2 Cycle Time

Before the selection of gripper design for the robot in Stage Two can be made, the cycle time for picking cartons from the in feeder and placing these in a determined pattern on the out feeder must be analysed. This analysis was performed by using both a simulation model in PzPP and verifying this model using the robot station and carton described in section 2.3 to find appropriate robot motion values. When the motion values are satisfying, the cycle time per product is given.

Robot motion values, such as acceleration, deceleration, rotational speed of the tool and velocity were varied during the verification process. An important aspect when setting the motion values is that the robot should be able to complete the whole pick and place sequence without dropping any carton. If the robot dropped any carton, the motion values were lowered and a new sequence was run. Also the robot's accuracy and repeatability was analysed during these runs. This was made by looking at every layer of the pallet pattern to spot any differences in orientation of the boxes and if these differences increased with increased motion values.

Another aspect that was taken in to consideration when analysing the motion values was the visual appearance of the robot during palletizing. Fitful motions were not desired and these were minimized by varying the acceleration and deceleration values.

The following motion values with respect to the given aspects mentioned above showed to be appropriate for the 9 kg carton:

- velocity= 2300 mm/s
- acceleration/deceleration = 2.5 m/s^2
- rotational speed = 270 deg/s

When using these values, the cycle time for palletizing 20 cartons was 177 seconds or approximately nine seconds/carton. In PzPP, the same simulated palletizing procedure yielded a cycle time of 175 seconds. This difference is marginal and thus PzPP is regarded as reliable for estimation of expected cycle times for other products and pallet patterns.

Given this cycle time of nine seconds/carton, it is possible to palletize 400 cartons per hour.

4.3.3 Gripper Design

In section 2.3, vacuum gripping is suitable in processes with short cycle times and for objects that are relatively rigid. Therefore, a vacuum gripper was selected as gripping tool and this section will describe the procedure of choosing a suitable design.

As mentioned earlier in section 4.3.1 the cartons in focus have a weight of less than 30 kg. Cartons with weights over 30 kg constitute one percentage of the total volume and are not included because satisfactory gripping cannot be achieved due to the carton characteristics mentioned in section 4.3.1.

A major advantage of using vacuum pads is the ability to manage different sizes of cartons. This flexibility is required in the case Elgiganten, where the variety of carton dimensions is high.

In section 4.3.2 the cycle time for picking and palletize one carton was given as nine seconds. Figure 38 shows the number of cartons per container.

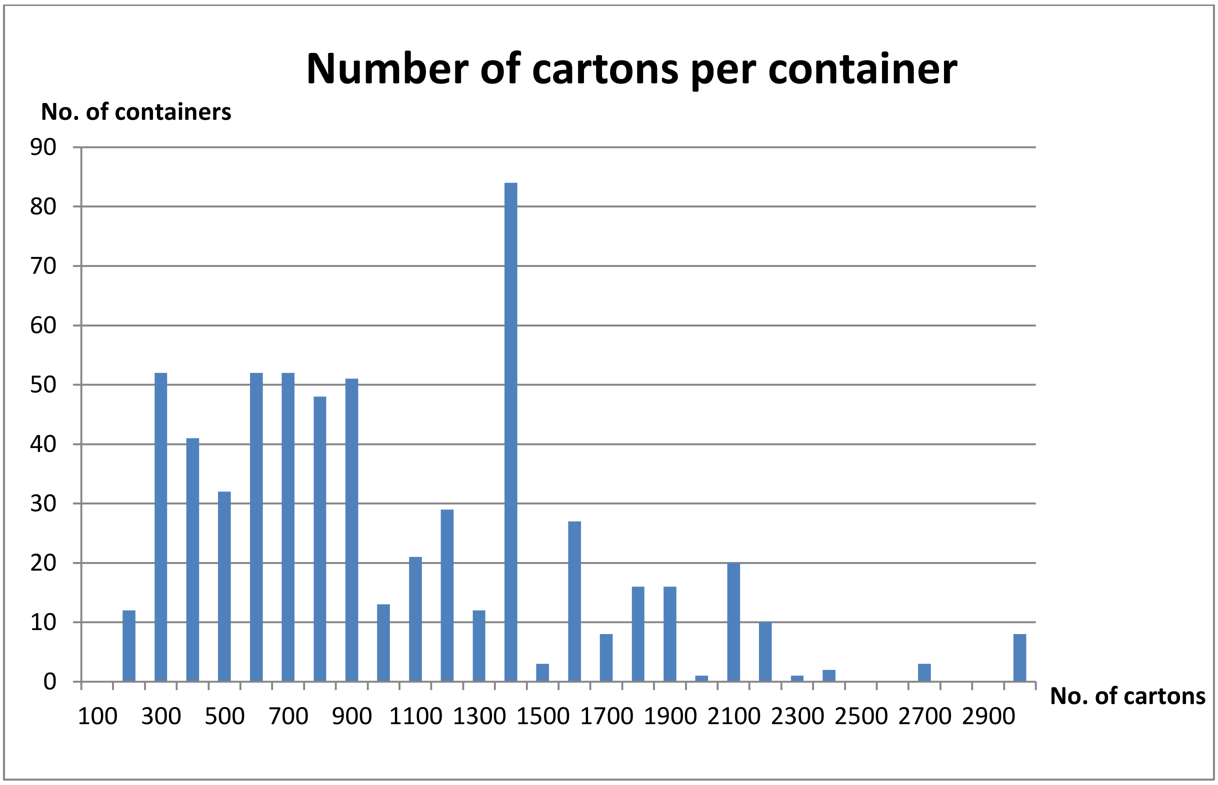

Figure 38: Distribution of cartons per container.

If the desire to palletize all cartons in a container in two hours or less should be fulfilled, the following equation gives how many cartons that can be palletized when the number of cartons picked per cycle, called X, is varied:

$$\frac{7200 * X}{cycle\ time\ for\ one\ carton} = \#cartons\ palletized\ in\ two\ hours$$

For values of X between 1 and 4, Table 1 shows how many nine kg cartons that can be palletized within the given time. Cartons weighing less than nine kg can be palletized using higher motion values, thus decreasing cycle time and increasing output. For heavier cartons, no tests have been performed, but the motion values will probably need to be decreased.

Table 1: Number of cartons palletized in two hours for different values of X.

X:	# cartons palletized in two hours:
1	800
2	1600
3	2400
4	3200

Since most containers hold 2400 cartons or less, picking at most three cartons at a time will be sufficient to fulfil the given time demand. From the Excel-file it could be shown that as the number of cartons per container increase, the volume of each carton decrease. Figure 35 shows that most cartons have a width and length of less or equal than 600 mm.

In the analysis of vacuum gripping tools the standard palletizing gripper by ABB, FlexGripper was studied and compared with vacuum pads. The strong points of vacuum pads in comparison with the FlexGripper are the low weight and easier maintenance. The vacuum pad does only use one or two ejectors for each zone on the pad while the FlexGripper uses one ejector for each suction cup. This increases the number of components, which also increase the weight. The primary maintenance that needs to be done on a vacuum pad is cleaning and changing the foam. When the foam is worn the whole bottom of the pad is removed and replaced with a new one. Maintenance on the FlexGripper requires removal and changing of suction cups. Due to the construction of the FlexGripper, see [**45**], the suction cups are aligned much like berries on a straw. That means if the innermost suction cup has to be replaced, every suction cup placed in before must be removed first. The investment cost of having an exchangeable bottom plate is low in compared to increased cost for longer downtime in production when FlexGripper is used.

During the verifications at Front Automation, tests were carried out in order to analyse and find out an appropriate vacuum gripper design. It was discovered early in the tests that the carton height on identical cartons could vary several centimetres. Since the picking position on the in feeder is fixed in height, the robot always went to this exact position. Due to this, and because of the sometimes lower carton heights, the carton could not attach to the vacuum gripper. Therefore, the proposed vacuum gripper should contain a floating plate function as mentioned in section 2.3, to make the gripper robust against differences in carton heights.

When gripping cartons at Front Automation, a vacuum level of 200 mBar was recorded. This level differed from the vacuum levels of 600-800 mBar recorded at a manufacturer of vacuum grippers. The difference was due to the air tubes, which were narrower at Front Automation and therefore limited the airflow. This in turn lowered the vacuum gripper's lifting force. Tests were made where a carton weighing fifteen kg was lifted. The gripper could barely lift this carton. As another test a pallet weighing fifteen kg and two cartons weighing nine kg each was lifted, see Figure 39.

Figure 39: Vacuum gripper successfully lifts pallet weighing fifteen kg and two cartons weighing nine kg each.

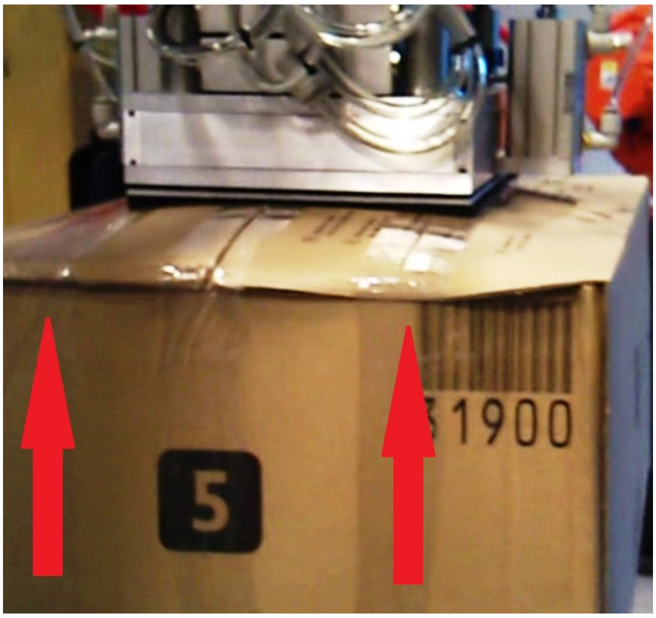

Figure 40: Two additional stripes of adhesive tape on carton as indicated by the red arrows.

This test was successful because the pallet was less deformed compared to lifting the carton. The 15 kg carton was then slightly modified by adding two additional stripes of adhesive tape, see Figure 40. Less deformation during lifting was achieved because of the additional tapes. This resulted in a successful lift, but the carton was not gripped enough to allow any palletizing movements without dropping.

After changing to larger air tubes, a vacuum level of 400 mBar was recorded and the fifteen kg carton was easily lifted even without the additional tape stripes.

Another aspect discovered and analysed during the verifications was how to handle when the area of the vacuum gripper is larger than the surface are of the carton. This caused a problem when the carton should be placed by adjacent cartons. The already placed adjacent cartons got attached to the vacuum gripper during the placing procedure, which resulted in displacements of positions and orientations. An overhang of the vacuum gripper of just three cm was enough to generate these displacements on a carton weighing nine kg.

As stated in section 4.3.1, most cartons at Elgiganten have widths and lengths less or equal than 600x600 mm. This motivates a vacuum gripper with dimensions equal or less to the carton dimensions. In combination with equations [1] and [2] in section 3.3.4, expertise opinions from a manufacturer of vacuum grippers and the verifications made at Front Automation, a recommendation for an appropriate gripper design was made.

The vacuum pad suitable for Elgiganten uses a floating plate, which works like a searcher and compensates for variation in height of the cartons and/or pallet. The pad should have dimensions of 400x600 mm using twin ejectors and air tubes with inner diameter of at least ten mm to ensure that satisfactory vacuum levels can be achieved. Since the vacuum pad used during verification is merely one-fourth in size and successfully managed cartons with poor characteristics weighing 9 kg, the specified dimensions for the pad will work.

To solve the problem with accidently attaching adjacent cartons during placing, the vacuum gripper's suction area should be divided into six different zones, called zoning. Each zone can be either active (vacuum suction possible) or inactive and is independent of the other zones. Six quadratic zones in identical size on the pad means that each zone has sides of 200 mm, which merely a few cartons have, see Figure 35. This means the risk of attaching to another carton while placing is minimal. The zoning is also important when placing several cartons after each other during the same placing operation. For example, it is desirable to grip two cartons at a time and place in an orientation which differs from the gripping orientation. This means that the cartons cannot be placed at the same time but rather one after the other, which requires a zoning tool.

The foam on the tool used in verifications at Front Automation had a thickness of 10 mm. The proposed tool should use thicker foam in order to compensate for the deformations of the carton during lifting operation. This compensation will increase the lifting force, but the thicker foam wears out faster than thinner foam which increases the maintenance.

The ParcelRobot mentioned in 3.7.3 also use the same type of vacuum pad, which strengthen the selection of gripper. The selection of a proven technique further increases the credibility of the recommended gripper.

4.3.4 Capacity Level

Before proposing suitable solutions for the case Elgiganten, the appropriate capacity level must be calculated. The early view of this case indicates about a highly automated solution for Elgiganten. After analysing the number of incoming container and cartons per month, this view was revised. From Figure 41 below a capacity level for the system is approximately 65 000 carton per month and shift. Setup is not considered in the calculation because this time is hard to estimate.

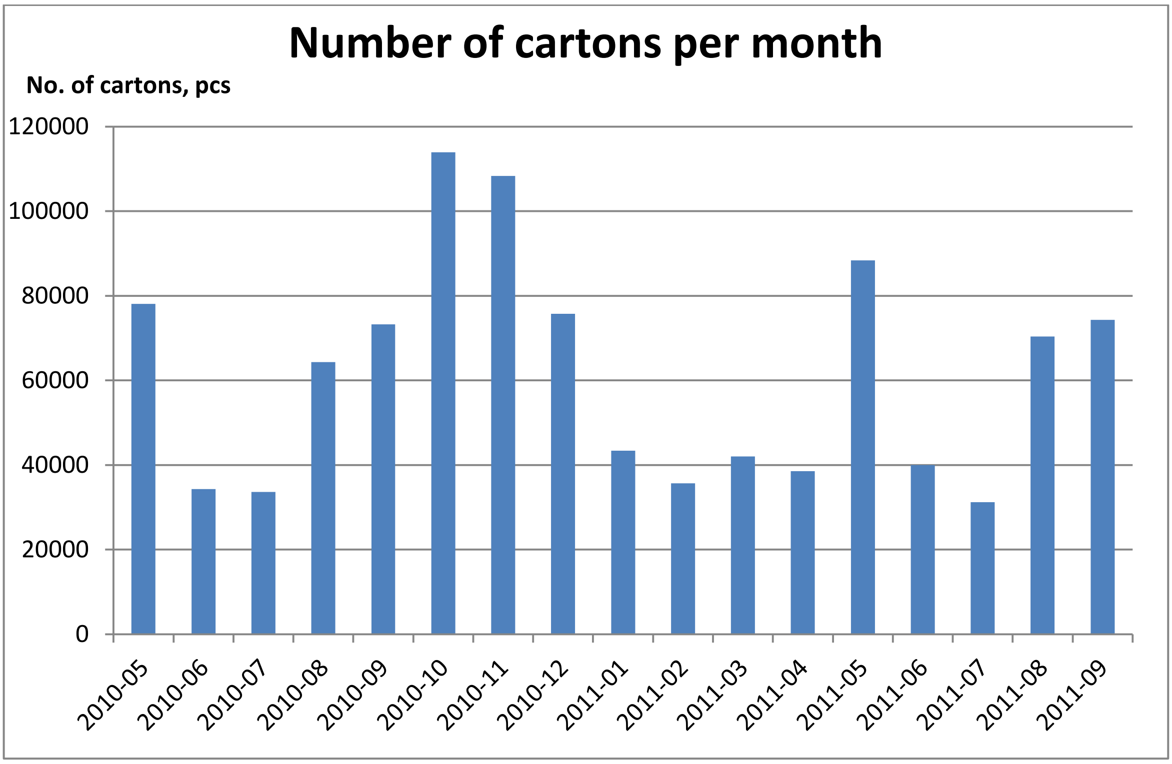

Figure 41: Number of cartons per month.

This calculation assumes that a container always is ready to be unloaded. The setup time consists of docking of the trailer, securing the container, download the project from computer to the controller in the robot cell and doing a trial run of the program.

A capacity of unloading 65 000 cartons a month, leads to that less than 400 cartons must be unloaded each hour. This number of cartons per hour can be handled by all the solutions presented in section 3.7. This is a lower rate than today, which is desirable from an ergonomic perspective. If the robot is the limiting factor there is no point for the operators to stress as today. As mentioned in section 4.1 in a stressed environment affects the operator's physical and mental health.

4.4 Evaluation of Solutions

Based on the factors mentioned in the previous sections, a suitable solution for Elgiganten needed to be presented. The systematic evaluation procedure consisted of two methods, the Pugh matrix and the Kesselring matrix. Before the evaluation procedure, the analysis of the possible solutions is made.

4.4.1 Analysis of Existing Solutions

By using ParceLift the operator is able to unload 600 cartons per hour at normal work rate. The ParceLift has a low investment cost and reduce the ergonomic strain on the operator. An additional advantage of the lifting aid is the applicability to the existing conveyor belt at Elgiganten. The tool is easy to use and learning period is short. An obvious drawback of the ParceLift is that the operators still have to perform all the movements required for gripping the cartons.

A major advantage with Empticon compared with manual container unloading is that no heavy loads have to be handled by the operator. This ergonomic advantage will in the long run end up in lower cost caused by musculoskeletal disorders. Empticon has problem when heavy cartons with a small width should be pulled, because just a few suction cups can attach to the carton, which is not enough to pull it to the conveyor. Also the quality of the cartons is of great importance, otherwise will not the suction cups attach to the carton. The suction cups can also have problem to attach to the carton/-s if Empticon and the container are not aligned parallel.

By using the ParcelRobot the ergonomic problem is eliminated, because no operator is required. The major disadvantages of the system are the investment cost (2 500 000 SEK) and the payback time. The number of cartons, which is unloaded, needed to be high in order to reach a payback time in reasonable time.

For Random Box Mover the feasibility is a problem. For example, if cartons with dimensions 200x400x300 mm (width, depth, height) are placed in a work envelope equivalent to a standard 20 feet sea container, this will result in cameras needing to be positioned at a distance of 4 meters above the container floor. With a height of a standard container being 2 meters, the problem is obvious. Another deficiency is that RBM can only operate with USB-cables of lengths less than 5 meters. As a consequence, the PC must be transported along with the camera system as the robot proceeds into the container. In total, the Random Box Mover application is a potential solution for detection of work objects in space. The advantages are its usage of low-cost cameras and ability to adapt to various robot controller systems. Due to the need for cameras to be placed at vertical distances beyond standard container heights, this is a considerable drawback. Because of additional cost (robot etc.) the total cost for this system is high.

The major advantage of using TEUN is that just a truck driver, which is loading and unloading the machine with an empty respective full pallet, is required. One drawback of the solution is that the system is offered as a service and therefore is the payback time difficult to calculate.

At IKEA the ergonomic problems are low in comparison to Elgiganten because the unloading procedure is managed by trucks. Unfortunately, the cardboard pallets used are not applicable to Elgiganten because it is not cost-effective as stated in section 3.1.1. The number of unloaded containers at IKEA is extensively larger than for Elgiganten. A major advantage of this solution is that it is not sensitive for high product variety, which IKEA also has.

At Attends the number of arriving containers are about 60 a month, which is comparable with Elgiganten. However, the number of variants is fewer and the weight of the cartons is lower at Attends than at Elgiganten. Large part of the system solution is applicable at Elgiganten but the gripper is not, see section 4.3.3.

Generally, an advanced solution for container unloading at Elgiganten is not suitable because of the low number of arriving containers and their current level of automation is low.

4.4.2 Pugh Matrix

The systematic evaluation procedure began with a Pugh matrix, where the different solutions were compared with the reference, the existing solution at Elgiganten. Six possible solutions have been established and are specified in Table 2. Four of those are using an existing solution in Stage One and robotized palletizing in Stage Two, while solution E and F are system solutions for the application Container Unloading.

Table 2: The different solutions.

Solution:	Stage One:	Stage Two:
A	ParceLift	Robotized Palletizing
B	Empticon	Robotized Palletizing
C	ParcelRobot	Robotized Palletizing
D	Random Box Mover	Robotized Palletizing
E	TEUN	
F	COPAL	

The criteria used in the Pugh matrix are; ergonomics, cost, productivity, feasibility safety and applicability. Ergonomics refers to the work environment for the operators in the solution and cost refers to if the solution has a payback time less than five years. The productivity criterion covers the number of cartons that can be unloaded and palletized. Feasibility refers to how easy it is to implement, understand and work with the solution. The prevention of work injuries in the solution is covered by the safety criterion. Applicability refers to how well the solution can handle the high product variety.

Table 3: Pugh matrix.

Chalmers	Pugh matrix					
			Created: 120416			Page 1
			Modified: 120502			
Criteria	**Solution alternative**					
	Ref	**A**	**B**	**C**	**D**	**E**	**F**
Ergonomics		+	+	+	+	+	+
Cost		+	+	-	-	+	-
Productivity		0	0	-	+	-	+
Feasibility		0	0	-	-	-	0
Safety		0	+	+	+	+	+
Applicability		0	-	-	0	0	-
# +		2	3	2	3	3	3
# 0		4	2	0	1	1	1
# -		0	1	4	2	2	2
Net value		2	2	-2	1	1	1
Ranking		1	1	6	3	3	3
Further development		Yes	Yes	No	Yes	Yes	Yes
Decision	Evaluate alternatives A and B using a Kesselring matrix						

A positive net value means that the solution is better than the existing solution at Elgiganten. Solution C had a negative net value and therefore this solution was immediately eliminated.

Solution A, B, D, E and F still had positive net value and since the net value of the solutions differed marginally, further evaluation is needed.

4.4.3 Kesselring

In the Kesselring matrix the five solutions were analysed with respect to the weighting of the criteria.

Table 4: Kesselring matrix.

Chalmers		**Kesselring matrix**											
				Created: 120416 Modified: 120502								Page 1	
Criteria		**Solution alternative**											
		Ideal		**A**		**B**		**D**		**E**		**F**	
Name	w	v	t	v	t	v	t	v	t	v	t	v	t
Ergonomics	5	5	25	4	20	5	25	5	25	5	25	4	20
Cost	3	5	15	5	15	3	9	1	3	3	9	2	6
Productivity	3	5	15	4	12	4	12	3	9	3	9	5	15
Feasibility	4	5	20	5	20	3	12	2	8	2	8	3	12
Safety	4	5	20	3	12	4	16	5	20	4	16	3	12
Applicability	4	5	20	4	16	4	16	1	4	2	8	1	4
Total		30	**115**	25	**95**	23	**90**	17	**69**	19	**75**	18	**69**
Rank					1		2		4		3		4
Decision		Propose both alternative A and B											

Solution D, E and F had the lowest total score, which meant these solutions were eliminated. Solution A and B have a total score close to each other. Because of the subjective impact on the result of matrices and the fact that it is a small difference in total score the decision to propose two solutions was obvious. Note that the values in the matrices are based on the analysis made earlier in chapter 4.

4.5 Proposed Solutions

Based on the analysis two proposed solutions are stated. Using the unstructured interviews mentioned in 2.1 as a support2.1, operators' view points on the current work environment motivate these two proposed solutions. Proposition A and Proposition B are solutions for Stage One. Proposition A includes the semiautomatic Empticon and Proposition B includes the manual lifting aid ParceLift. Each of these solutions can be combined with the solution for Stage Two, Robotized Palletizing, which is further described in this section.

4.5.1 Proposition A: ParceLift

Compared to Empticon, ParceLift requires short education time and is therefore suitable for the high personnel turnover at Elgiganten. Since ParceLift is applicable to the existing conveyor belt at Elgiganten, it could be a first step towards an automatic solution in Stage One as well. By using ParceLift the operator is required to place the cartons in the correct orientation in order to avoid implementation of a steering function.

ParceLift has been successfully implemented at Posten Logistics in Orebro, where a large variety of cartons are handled every day. The relatively low investment cost and the applicability to the existing conveyor belt are two things which support this solution.

The bad ergonomic postures are not improved by implementing ParceLift, but the risk of musculoskeletal disorders is decreased by lowering the workloads, see Appendices NIOSH Analysis Future State and REBA Analysis Future State.

4.5.2 Proposition B: Empticon

The major advantage of implementing Empticon is the ergonomic benefits. The operator does not have to manually lift the cartons but operates the conveyor to the cartons. When the cartons are placed on the conveyor belt, a steering function is needed in order to move the cartons to a predetermined position. This position needs to be the same for all cartons since the robot's picking position is constant. The orientation of the cartons in the container will be the same on the conveyor belt, because it is not possible by Empticon to re-orient the cartons.

To be a skilled driver of Empticon, quite a long time of practice is required. The personnel turnover at Elgiganten is at the moment relatively high, probably because of the heavy lifts. However, if Empticon is to be successfully implemented at Elgiganten, a group of operators need to be educated and trained to operate the machine.

An investment in Empticon will release the existing conveyor belt, which could be used for other gates during the peaks in the seasonal variation.

4.5.3 Robotized Palletizing

The robotized palletizing procedure begins with the carton being positioned along two sides, see Figure 42. For the palletizing procedure this positioning is important, because if the carton is not oriented in the same way every time the pallet pattern will be disordered

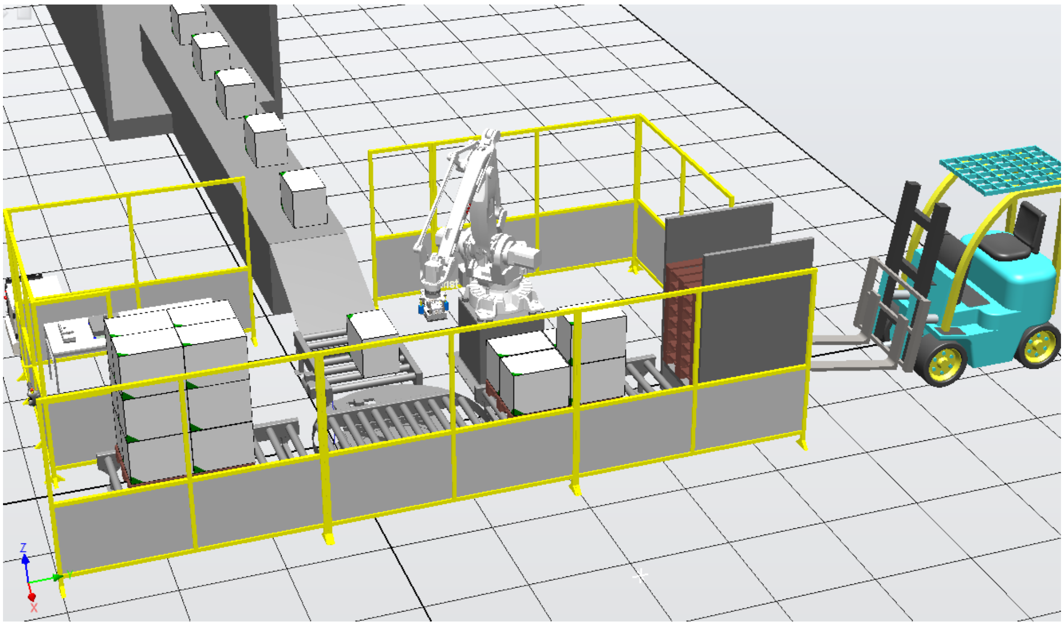

Figure 42: Illustration of the robotized palletizing procedure from RobotStudio.

When the positioning is secured, the robot picks the carton by the vacuum pad and palletizes it on the pallet. As the whole pallet is done, it is transported to the out feeder and a new pallet from a pallet magazine arrives to the palletizing position. From the out feeder, the ready pallet is transported by truck to a machine where it is wrapped in plastic film.

One option could be to implement the stretch wrap machine into the cell, but this option is not chosen because of delimitations earlier in the project.

In construction of a robot cell the safety issues need to be considered. Fences need to be arranged so no employees are able to enter the cell while the robot is operating. Also, the fences must not obstruct the robot.

5 Discussion

At Elgiganten today the ergonomic strain on the operators is obvious. From the ergonomic analyses a redesign of the work stations are required as soon as possible. Both Proposition A and Proposition B decrease the ergonomic strain on the operator, which has been an important factor in the selection of appropriate solutions.

Both propositions have their strengths and weaknesses. By using Empticon in Stage One a trained and skilled operator can unload 600 cartons per hour. If ParceLift is used in Stage One this limitation estimated to 700 cartons per hour. The robotized palletizing in Stage Two has a limitation of 400 cartons per hour when just one carton is picked and palletized at a time. If more cartons are palletized at the same time, the cycle time per carton will decrease and higher productivity is achieved. It is important that Stage Two is the limiting factor. Otherwise, the stress on operators in Stage One will increase which in turn will increase the ergonomic strain.

When analysing other similar cases of Container Unloading, it is obvious that the proposed solutions are successfully implemented, which strengthens the solutions. At Attends, manual unloading containers and palletizing cartons by a robot is performed. Approximately fifteen containers each week are unloaded, which is a volume that is comparable to that at Elgiganten. The reason for not using lifting aids when unloading the container is because of the low weight of the cartons. According to Attends it is preferable and economically viable to implement robotized palletizing even though the carton weights are not as high as in the case Elgiganten. During the study visit at IKEA Distribution Central at Torsvik another interesting Container Unloading procedure was discovered. At IKEA all containers arrive with cartons already palletized on cardboard pallets, which means whole pallets can be unloaded directly by truck. Even though the solution was interesting to analyse further, this type of solution was not considered in the case Elgiganten. This was because of the perquisite from Elgiganten that the cartons will arrive in containers as per today.

Inputs from the study visits at Attends have affected the selection of gripper. An obvious problem with FlexGripper is the suction cups ability to compensate for different height of the products. This deficiency was adjusted by higher suctions cups, but these in turn lead to undesirable swinging motions during acceleration or deceleration. At Attends the variety of carton dimensions is low in compared with Elgiganten. Higher variation of sizes of the cartons needs a more flexible gripper. Thus, selecting a vacuum pad was motivated. When designing a gripper, the variation in carton quality and its ability to withstand deformation are an important factor to consider. At Elgiganten the carton quality differs between the products. Cartons that contain more than one product often have worse quality.

When it comes to managing the seasonal variations at Elgiganten, the best way from an ergonomic perspective is to add extra shifts. This will also increase the utilization rate of the robot. Another alternative is to use two operators in Stage One and decrease the cycle time for the robot by picking several cartons at a time. In the proposed solution, the robot is the bottle neck which is preferable from an ergonomic point of view. If even higher capacity is required other gates can be used manually as today.

The implementation of robotized palletizing at Elgiganten will require efforts from Elgiganten. To get the solution applicable, an operator with technical interests is needed and he or she should be responsible preparations and verifications needed when new products arrive. The teething problems in PzPP need to be eliminated before the software is robust enough to implement at Elgiganten. Also, operators should be trained and skilled in PzPP in order to solve eventual problems that arise. A possibility would be to implement robotized palletizing for approximately five products that represent a major share of the total volume. The number of products can then be increased after the first five products are being palletized without difficulties. In that way, operators get accustomed to both software and the new way of working.

Additional factors that need to be considered on implementation are carton identification systems and conveyor buffers. An identification system, for example bar code reader, is needed if different cartons are to be on the conveyor at the same time. This is to inform the robot about which carton is to be picked. For picking several cartons at a time, a buffer system is needed to provide the robot with the correct number of cartons.

The consequences for the physical workload and musculoskeletal disorders will decrease, according to REBA, when implementing lifting aids and robotized palletizing. Since the characteristics of labour shifts from manual work to partially manual work, the ergonomic strain will decrease [**50**]. The implementation will result in lower movement velocities, which also decrease the ergonomic strains.

By using ParceLift in Stage One the operators' complaint of lower back pain will decrease [**36**]. At a case study at Posten in Orebro the absence due to illness was lowered by 5-10 %. Since Elgiganten today hires its personnel through a staffing company, the absence due to illness is not known. This does not mean that this is not a problem for Elgiganten. If it is discovered that operators from the staffing company got musculoskeletal disorders because of the bad ergonomic work stations at Elgiganten, this is a serious problem.

On the market today interesting solutions for unloading containers exist and therefore the choice of analysing them was made. As mentioned before, not all of them are suitable to Elgiganten, but still interesting if the number of arriving cartons per month at Elgiganten increases. The method to study existing solutions instead of developing totally new concept has its strengths and weaknesses. One strongpoint of studying existing solutions is that the technique is well-tried and tested in reality. If a new concept is proposed, this concept will not be tested in full production, which is a deficiency compared to the existing solutions. A weakness of focusing on existing solutions is the limitation of the possible solutions for Elgiganten. To increase the number possible solutions for Elgiganten further existing solutions of other business could have been analysed.

6 Conclusion

In this section conclusions drawn from the analyses made and from the study in general are presented.

For operators with no experience in robot programming, it is not likely that it will be possible to setup a new palletizing procedure within 20 minutes using PzPP. Instead, Elgiganten need to assign operators educated and trained in PzPP for this task.

It will be feasible and cost-effective to use robotized palletizing at Elgiganten for products weighing less than 30 kg and side lengths of 600 mm when using the proposed vacuum pad. The productivity will be unchanged or improved and depends on how well Elgiganten is able to utilize the robot cell. A capacity of unloading 65 000 cartons a month will be possible if the proposed solutions are implemented. Due to the varying quality of the cartons and the ability to withstand deformation during lifting it is difficult to predict if it is possible to unload containers within two hours. This is because the carton quality dictates the maximum permitted motion values and hence the cycle time.

The work environment with regards to ergonomics will be improved significantly as shown by the analyses if the proposed solutions are implemented. In Stage One, the workload is reduced resulting in facilitation of unloading cartons. In Stage Two, the ergonomic problems are completely eliminated.

The proposed solutions for Stage One and the robotized solution for Stage Two are appropriate levels of automation for Elgiganten. Due to the manual work procedure at Elgiganten with automation present, fully automatic solutions would not have been suitable and was therefore not proposed. If and when the conditions change in terms of containers handled per year, other analysed solutions can be of interest.

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Appendix – Ergonomics

REBA Analysis Current State

Case 1 – Grip a carton at a height of 1,75 meters

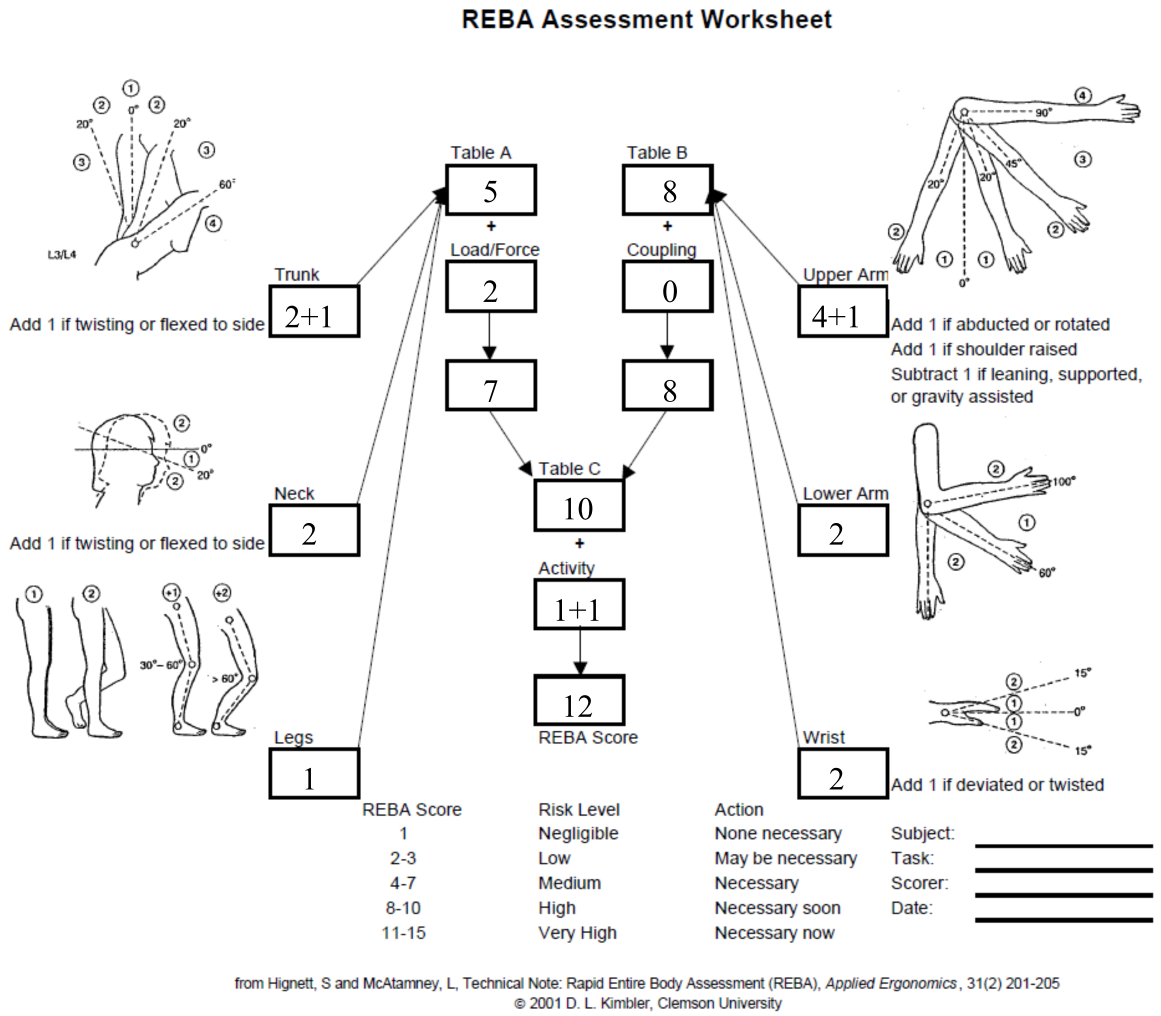
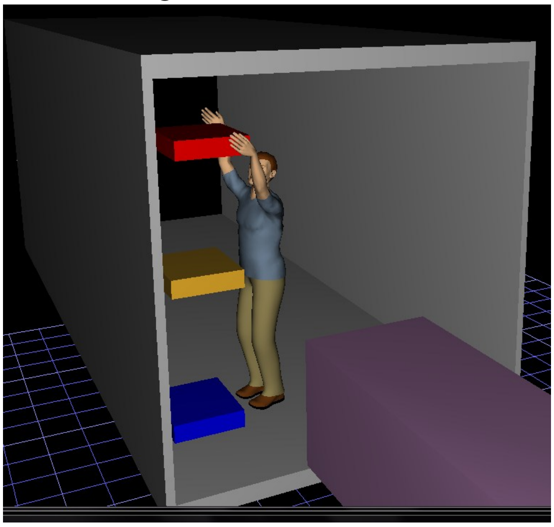


Figure 44: REBA analysis of reaching for cartons at a height of 1,75 cm.

As mention early in section 2.1 three cases are analysed; *Case 1– Grip a carton at a height of 1,75 meters, Case 2 – Grip a carton at a height of 0,9 meters and Case 3 – Grip a carton on the floor*. The REBA score of *Case 1* is 12, which mean that the risk level is very high and a redesign of the workstation is necessary immidiately.



Case 2 – Grip a carton at a height of 0,9 meters

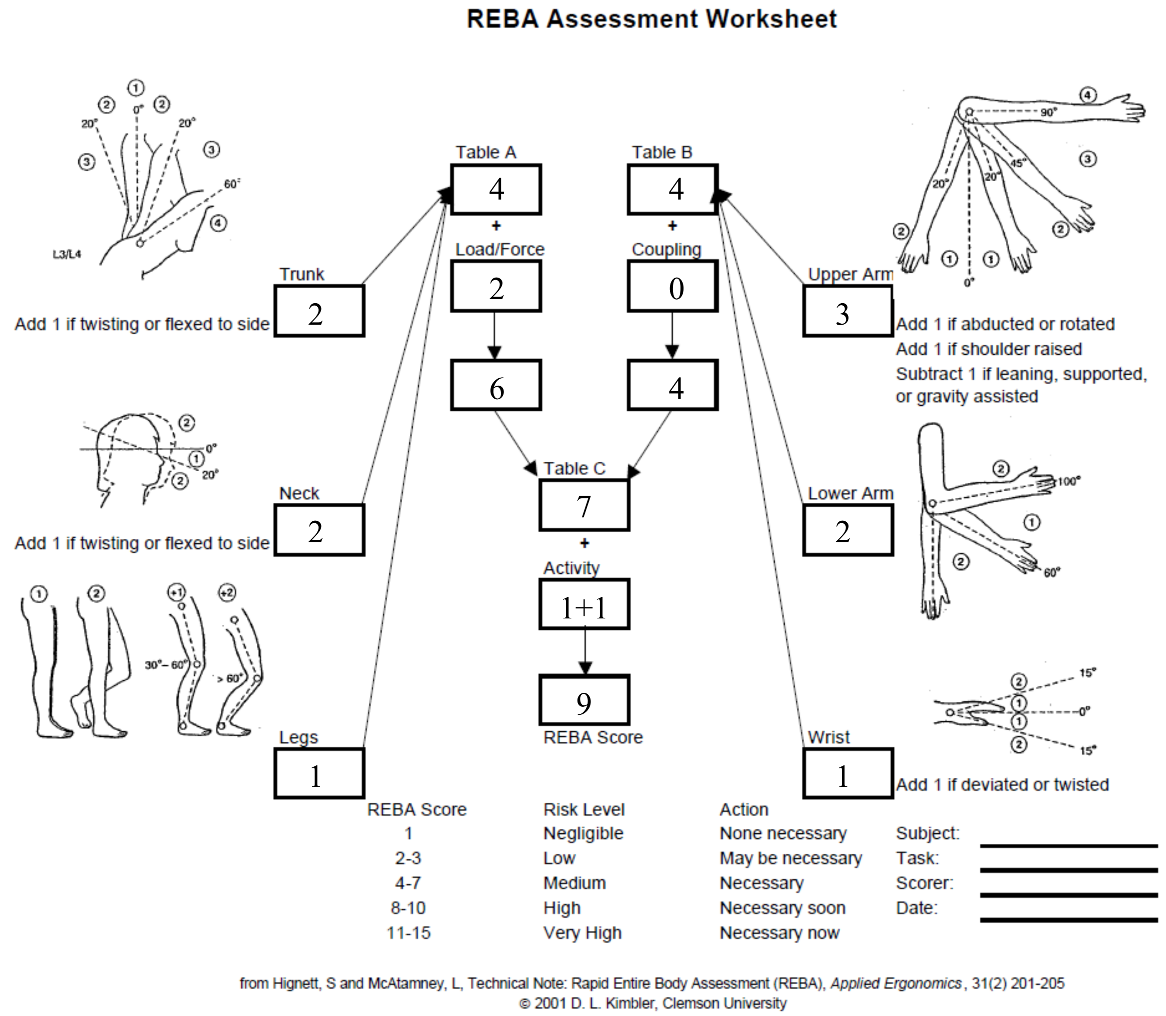


Figure 45: REBA analysis of gripping cartons at a height of 0,9 meters.

For *Case* 2 is the REBA Score 9, which mean a redesign of the workstation is required soon because the risk level is high.

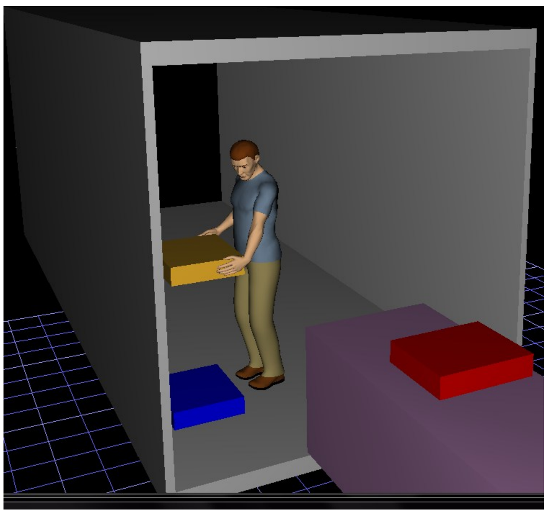


Figure 46:Illustration from Jack.

Case 3 – Grip a carton on the floor

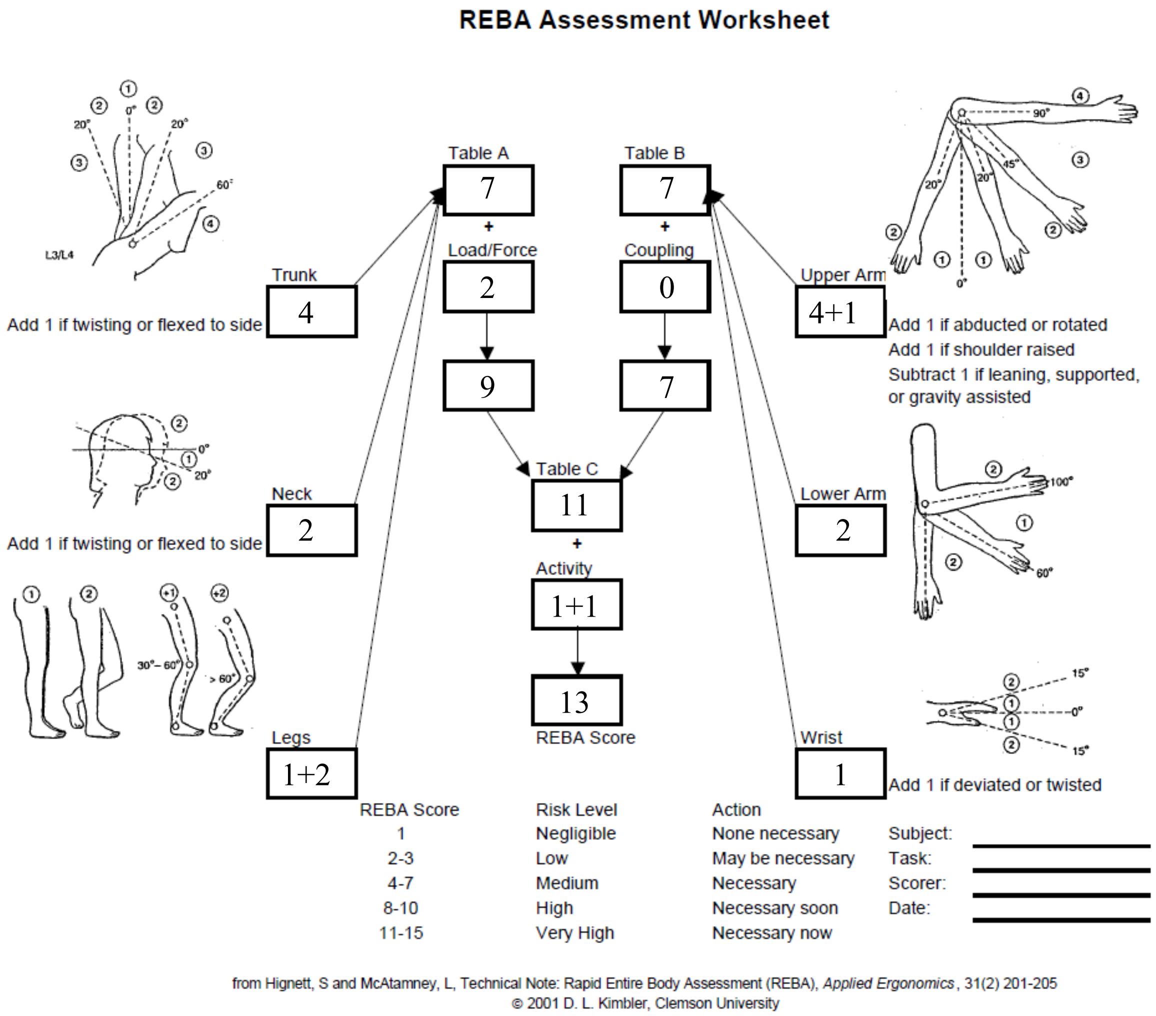


Figure 47: REBA analysis of gripping cartons on the floor.

REBA Score is 13, which mean that the work posture is risky and has to be avoided. In this work posture a lifting aid would be helpful in order to reduce the load and the risk of injuries in the lower back.

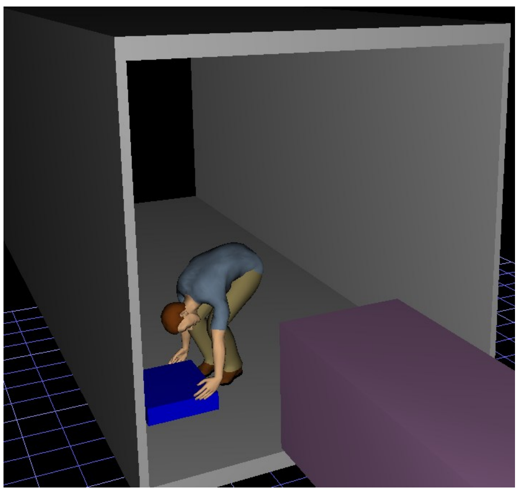


Figure 48: Illustration from Jack.

Table 5: Tables for REBA.

REBA Assessment Worksheet Tables

Table A

Trunk	Neck 1 / Legs 1	2	3	4	Neck 2 / Legs 1	2	3	4	Neck 3 / Legs 1	2	3	4
1	1	2	3	4	1	2	3	4	3	3	5	6
2	2	3	4	5	3	4	5	6	4	5	6	7
3	2	4	5	6	4	5	6	7	5	6	7	8
4	3	5	6	7	5	6	7	8	6	7	8	9
5	4	6	7	8	6	7	8	9	7	8	9	9

Load/Force

0	1	2	+1
< 5 kg	5 - 10 kg	> 10 kg	shock or rapid build up

Table B

Upper Arm	Lower Arm 1 / Wrist 1	2	3	Lower Arm 2 / Wrist 1	2	3
1	1	2	3	1	2	3
2	1	2	3	2	3	4
3	3	4	5	4	5	5
4	4	5	5	5	6	7
5	6	7	8	7	8	8
6	7	8	8	8	9	9

Coupling

0 Good	1 Fair	2 Poor	3 Unacceptable
Well-fitting handle and a mid-range power grip	Hand hold acceptable but not ideal, or coupling is acceptable via another part of the body	Hand hold not acceptable although possible	Awkward, unsafe grip, no handles; coupling is unacceptable using other parts of the body

Table C

Score A	Score B 1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Activity

+1	1 or more body parts static (held > 1 min)
+1	repeated > 4 per min in small range (not walking)
+1	rapid large changes in posture or unstable base

from Hignett, S and McAtamney, L, Technical Note: Rapid Entire Body Assessment (REBA), *Applied Ergonomics*, 31(2) 201-205

NIOSH Lifting Equation Current State

The links between the different variables are defined in NIOSH under *Theoretical Framework.*

Case 1 – Grip a carton at a height of 1,75 meters

$$RWL = LC * H_M * V_M * D_M * A_M * F_M * C_M$$

$LC = 23\ kg$

$H = 30\ cm \dashrightarrow H_M = 0{,}833333$

$V = 175\ cm \dashrightarrow V_M = 0{,}7$

$D = 80\ cm \dashrightarrow D_M = 0{,}87625$

$A = 0° \dashrightarrow A_M = 1{,}00$

$F_M = \{Table\ 1\} = 0{,}45$

$C_M = \{Table\ 2\} = 1{,}00$

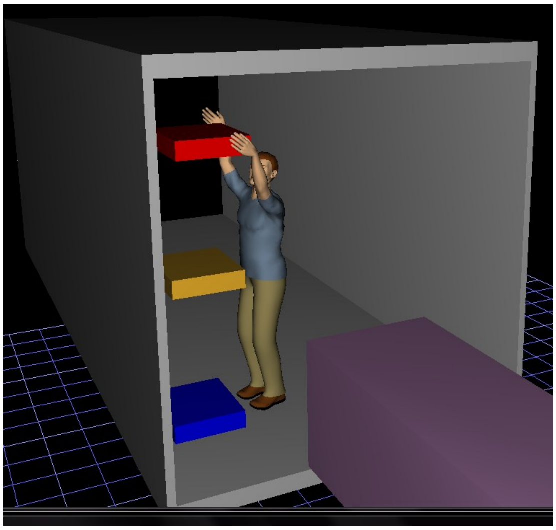


Figure 49: Illustration from Jack.

$$RWL = 23 * 0{,}8333 * 0{,}7 * 0{,}87625 * 1{,}00 * 0{,}45 * 1{,}00 = \mathbf{5{,}29\ kg}$$

The maximum weight of the cartons when managing cartons from this height is 5,29 kg. If the load is heavier than 5,29 kg there is a risk of musculoskeletal disorders.

Table 6: Frequency Table (FM)

Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤1 Hour		>1 but ≤2 Hours		>2 but ≤8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

Table 7: Coupling Multiplier (CM).

Coupling Multiplier

Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Case 2 – Grip a carton at a height of 0,9 meters

$$RWL = LC * H_M * V_M * D_M * A_M * F_M * C_M$$

$LC = 23\ kg$

$H = 30\ cm \longrightarrow H_M = 0{,}833333$

$V = 90\ cm \longrightarrow V_M = 0{,}955$

$D = 5\ cm \longrightarrow D_M = 1{,}72$

$A = 0° \longrightarrow A_M = 1{,}00$

$F_M = \{Table\ 1\} = 0{,}45$

$C_M = \{Table\ 2\} = 1{,}00$

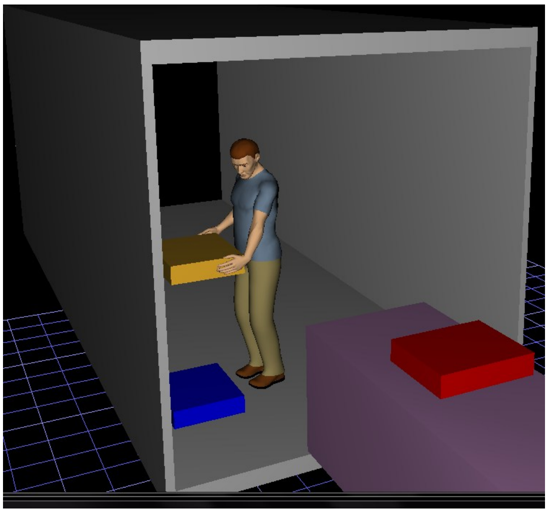


Figure 50: Illustration from Jack.

$$RWL = 23 * 0{,}8333 * 0{,}955 * 1{,}72 * 1{,}00 * 0{,}45 * 1{,}00 = \mathbf{14{,}17\ kg}$$

To secure that no risk of musculoskeletal disorders when gripping cartons at a height of 0,9 meters the maximum weight is 14,17 kg.

Table 8: Frequency Table (FM)

Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤ 1 Hour		>1 but ≤ 2 Hours		>2 but ≤ 8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

Table 9: Coupling Multiplier (CM).

Coupling Multiplier

Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Case 3 – Grip a carton on the floor

$$RWL = LC * H_M * V_M * D_M * A_M * F_M * C_M$$

$LC = 23\ kg$

$H = 30\ cm \dashrightarrow H_M = 0{,}833333$

$V = 10\ cm \dashrightarrow V_M = 0{,}805$

$D = 85\ cm \dashrightarrow D_M = 0{,}872941$

$A = 90° \dashrightarrow A_M = 0{,}712$

$F_M = \{Table\ 1\} = 0{,}45$

$C_M = \{Table\ 2\} = 1{,}00$

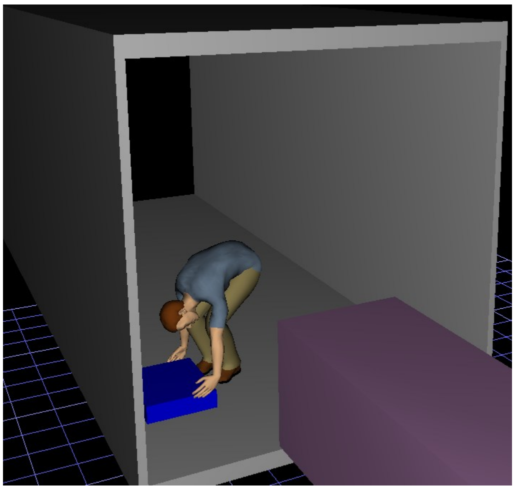


Figure 51: Illustration from Jack.

$$RWL = 23 * 0{,}8333 * 0{,}805 * 0{,}872941 * 0{,}712 * 0{,}45 * 1{,}00 = \mathbf{4{,}32\ kg}$$

In the third case, grip a carton at the floor, the maximum weight of the cartons is 4,32 kg when securing no risk of musculoskeletal disorders.

Table 10: Frequency Table (FM)

Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤1 Hour		>1 but ≤2 Hours		>2 but ≤8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

Table 11: Coupling Multiplier (CM).

Coupling Multiplier

Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

REBA Analysis Future State

Case 1 – Grip a carton at a height of 1,75 meters

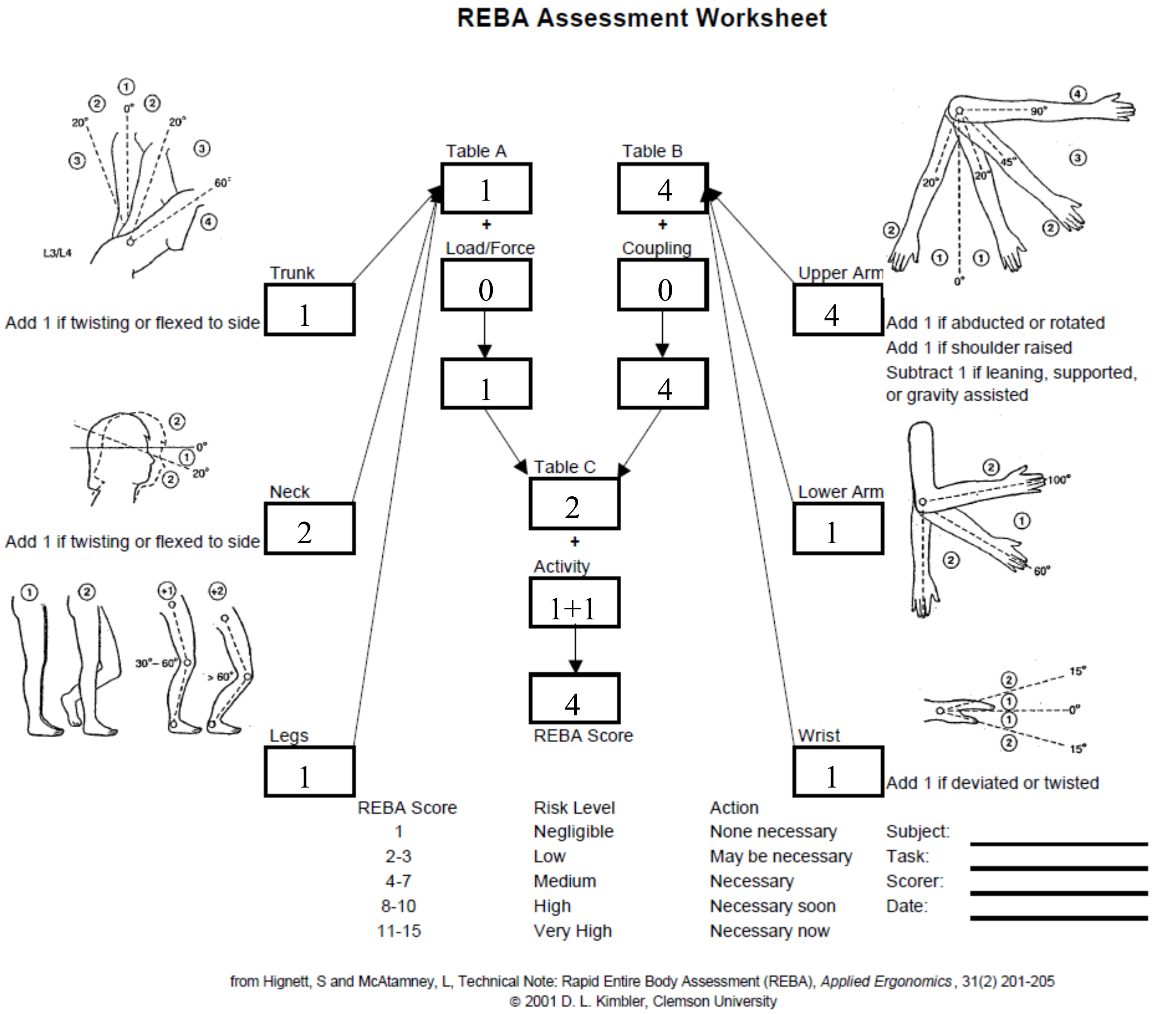


Figure 53: REBA analysis of reaching for cartons at a height of 1,75 cm.

The analysis of the Future State included the same three cases as the Current State; *Case 1– Grip a carton at a height of 1,75 meters, Case 2 – Grip a carton at a height of 0,9 meters and Case 3 – Grip a carton on the floor*. By using ParceLift in Stage One the REBA score of *Case 1* is 4, which mean that risk level is dramatically lowered to a medium level. Redesign of the workstation is necessary, but close to may be necessary.

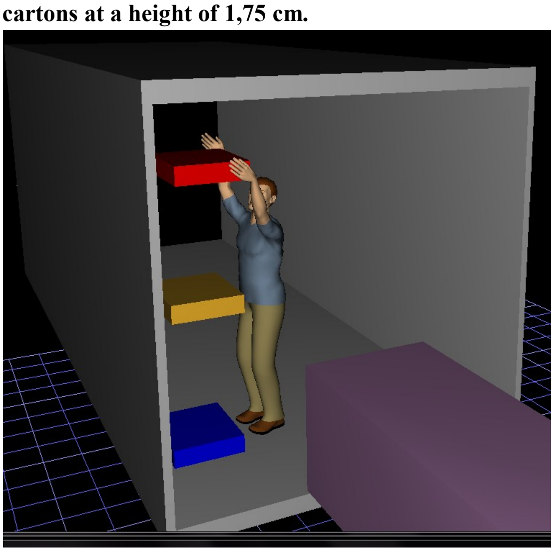


Figure 52: Illustration from Jack.

Case 2 – Grip a carton at a height of 0,9 meters

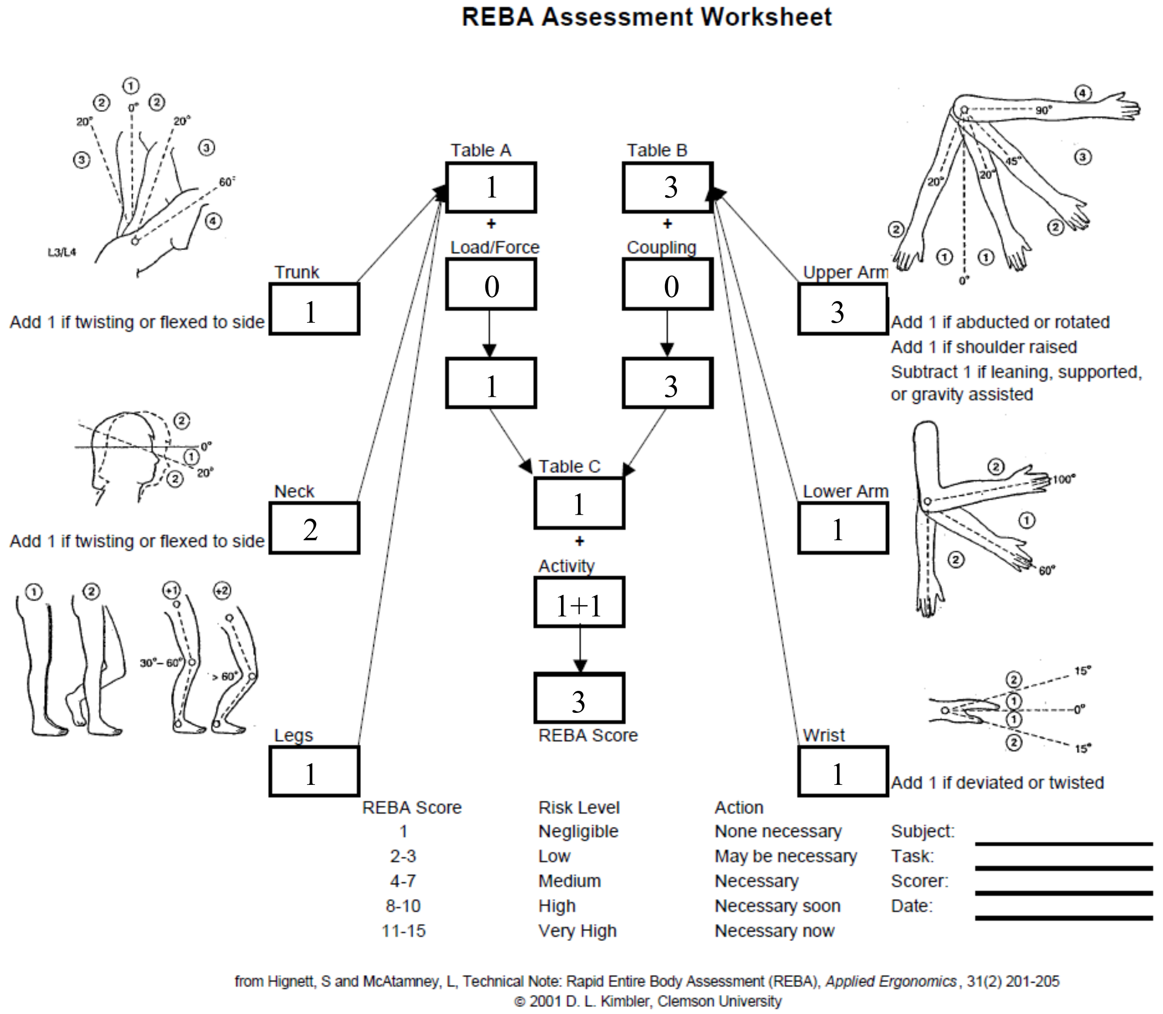


Figure 54: REBA analysis of gripping cartons at a height of 0,9 meters.

For *Case* 2 is the REBA Score 3, which mean a redesign of the workstation may be necessary because the risk level is low.

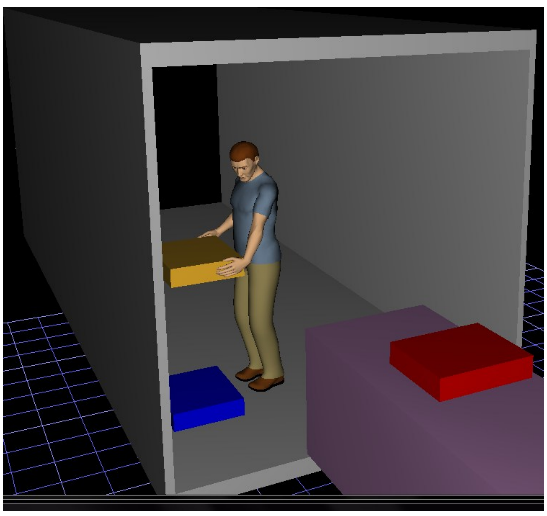


Figure 55:Illustration from Jack.

Case 3 – Grip a carton on the floor

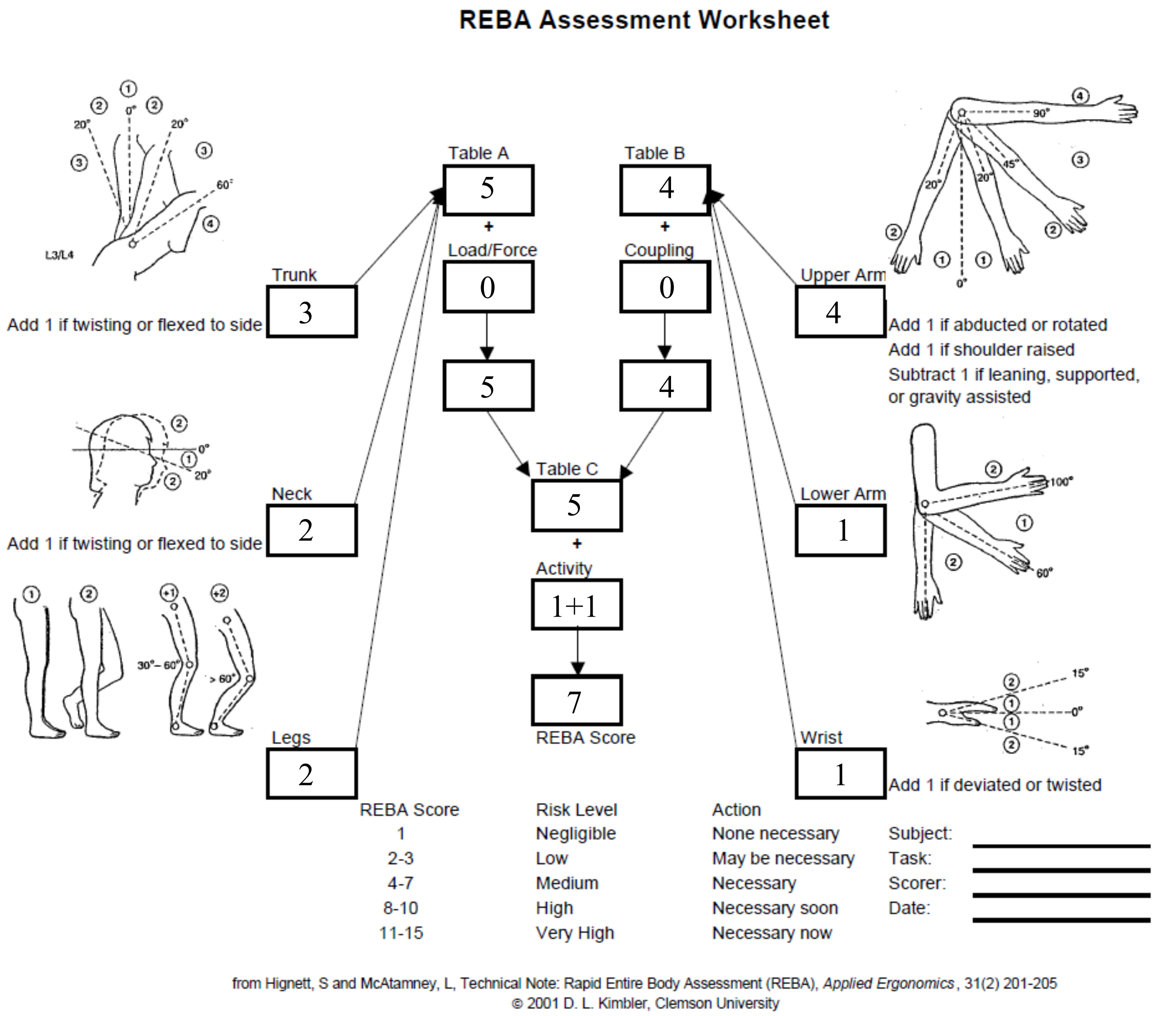


Figure 56: REBA analysis of gripping cartons on the floor.

REBA Score is 7, which mean that the work posture is at a medium risk level.

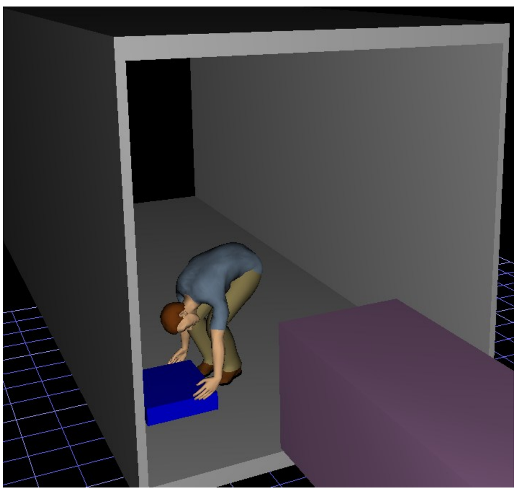


Figure 57: Illustration from Jack.

NIOSH Lifting Equation Future State

The links between the different variables are defined in NIOSH under *Theoretical Framework.*

Case 1 – Grip a carton at a height of 1,75 meters

$$RWL = LC * H_M * V_M * D_M * A_M * F_M * C_M$$

$LC = 23\ kg$

$H = 25\ cm \longrightarrow H_M = 1$

$V = 175\ cm \longrightarrow V_M = 0{,}7$

$D = 80\ cm \longrightarrow D_M = 0{,}87625$

$A = 0° \longrightarrow A_M = 1{,}00$

$F_M = \{Table\ 1\} = 0{,}45$

$C_M = \{Table\ 2\} = 1{,}00$

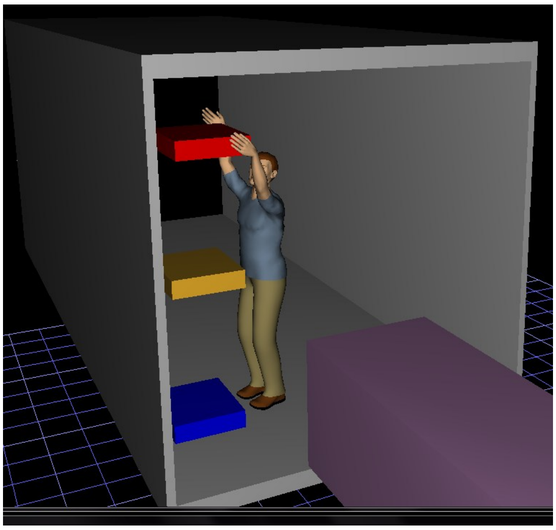


Figure 58: Illustration from Jack.

$$RWL = 23 * 1{,}00 * 0{,}7 * 0{,}87625 * 1{,}00 * 0{,}45 * 1{,}00 = \mathbf{6{,}35\ kg}$$

The maximum weight of the cartons when managing cartons from this height is 6,35 kg. If the load is heavier than 6,35 kg there is a risk of musculoskeletal disorders, which will not occur when implementing ParceLift.

Table 12: Frequency Table (FM)

Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration ≤1 Hour		>1 but ≤2 Hours		>2 but ≤8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

Table 13: Coupling Multiplier (CM).

Coupling Multiplier

Coupling Type	Coupling Multiplier V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Case 2 – Grip a carton at a height of 0,9 meters

$$RWL = LC * H_M * V_M * D_M * A_M * F_M * C_M$$

$LC = 23\ kg$

$H = 25\ cm \dashrightarrow H_M = 1{,}00$

$V = 90\ cm \dashrightarrow V_M = 0{,}955$

$D = 5\ cm \dashrightarrow D_M = 1{,}72$

$A = 0° \dashrightarrow A_M = 1{,}00$

$F_M = \{Table\ 1\} = 0{,}45$

$C_M = \{Table\ 2\} = 1{,}00$

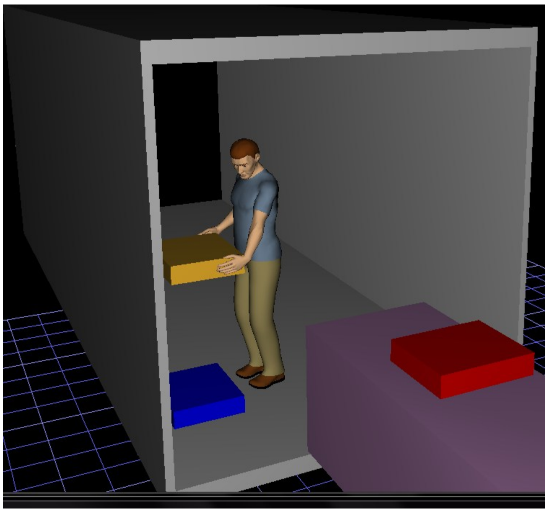


Figure 59: Illustration from Jack.

$$RWL = 23 * 1{,}00 * 0{,}955 * 1{,}72 * 1{,}00 * 0{,}45 * 1{,}00 = \mathbf{17{,}00\ kg}$$

To secure that no risk of musculoskeletal disorders when gripping cartons at a height of 0,9 meters the maximum weight is 17 kg. When using ParceLift any loads higher than 17 kg will be handled.

Table 14: Frequency Table (FM)

Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤1 Hour		>1 but ≤2 Hours		>2 but ≤8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

Table 15: Coupling Multiplier (CM).

Coupling Multiplier

Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90

Case 3 – Grip a carton on the floor

$$RWL = LC * H_M * V_M * D_M * A_M * F_M * C_M$$

$$LC = 23\ kg$$

$$H = 25\ cm \dashrightarrow H_M = 1{,}00$$

$$V = 20\ cm \dashrightarrow V_M = 0{,}835$$

$$D = 75\ cm \dashrightarrow D_M = 0{,}88$$

$$A = 60° \dashrightarrow A_M = 0{,}808$$

$$F_M = \{Table\ 1\} = 0{,}45$$

$$C_M = \{Table\ 2\} = 1{,}00$$

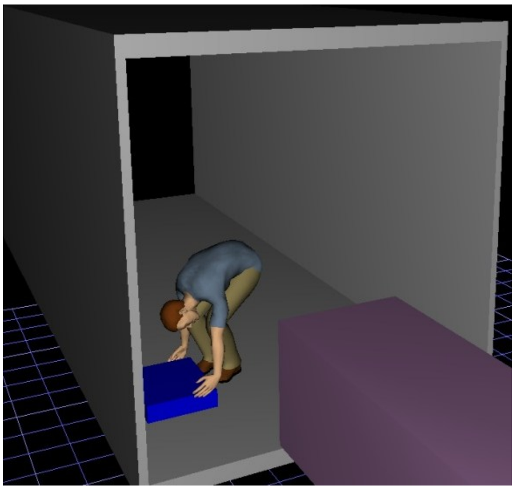


Figure 60: Illustration from Jack.

$$RWL = 23 * 1{,}00 * 0{,}835 * 0{,}88 * 0{,}808 * 0{,}45 * 1{,}00 = \mathbf{6{,}14\ kg}$$

In the third case, grip a carton at the floor, the maximum weight of the cartons is 6,14 kg when securing no risk of musculoskeletal disorders.

Table 16: Frequency Table (FM)

Frequency Multiplier Table (FM)

Frequency Lifts/min (F) ‡	Work Duration					
	≤ 1 Hour		>1 but ≤ 2 Hours		>2 but ≤ 8 Hours	
	V < 30†	V ≥ 30	V < 30	V ≥ 30	V < 30	V ≥ 30
≤0.2	1.00	1.00	.95	.95	.85	.85
0.5	.97	.97	.92	.92	.81	.81
1	.94	.94	.88	.88	.75	.75
2	.91	.91	.84	.84	.65	.65
3	.88	.88	.79	.79	.55	.55
4	.84	.84	.72	.72	.45	.45
5	.80	.80	.60	.60	.35	.35
6	.75	.75	.50	.50	.27	.27
7	.70	.70	.42	.42	.22	.22
8	.60	.60	.35	.35	.18	.18
9	.52	.52	.30	.30	.00	.15
10	.45	.45	.26	.26	.00	.13
11	.41	.41	.00	.23	.00	.00
12	.37	.37	.00	.21	.00	.00
13	.00	.34	.00	.00	.00	.00
14	.00	.31	.00	.00	.00	.00
15	.00	.28	.00	.00	.00	.00
>15	.00	.00	.00	.00	.00	.00

Table 17: Coupling Multiplier (CM).

Coupling Multiplier

Coupling Type	Coupling Multiplier	
	V< 30 inches (75 cm)	V ≥ 30 inches (75 cm)
Good	1.00	1.00
Fair	0.95	1.00
Poor	0.90	0.90