Development of a new lifting device for Tetra Pak R1

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Abstract

This report describes the development and design of a new concept for a lifting device in Tetra Pak's R1 filling line. It is important that the problems and challenges with the current design, the Tetra Pak R1 Elevator, is fathomed to get a better understanding of what was aimed to achieve in this thesis and why.

The purpose of the Tetra Pak R1 filling line is to automatically fold, fill and seal cartons of food with the package type Tetra Recart® Midi. The packages are moved through the different production steps inside specially designed carriers, before the final folding the packages must be removed from said carriers; it's the Elevators job to separate them and place the packages on the following part of the production line.

The current Elevator, although working properly, suffers from several faults and annoyances. It does its job and it does it well; the major issues are not in regard towards its functions, the problems are related towards reconfigurations between volumes, manufacturing costs, weight of the machine and complex assemblies to mention a few. It is these problems the new concept will have to address.

In this thesis, all the important steps in the development process from mission brief to final concept is described. As a framework, *Ulrich and Eppinger's Product Design and Development* was used.

Information was gathered internally through interviews, focus groups, documents, manuals and hands on experience with the machine. While inspiration for the concept generation was accomplished with both internal and external searches.

Due to the size and complexity of the project, the problems were decomposed into smaller sub-problems, the solutions for those were later combined, studied and adapted to find solutions for the overall concepts. The most promising concepts were further developed, ranked and screened until one final concept remained.

In the end, a final concept was designed that proved to be an improvement in nearly every regard compared to the current Elevator. Implementation of this concept might prove very beneficial for both Tetra Pak and their customers.

Keywords: Product Development, Machine Design, Tetra Pak, Lifting device, CAD

Sammanfattning

Den här rapporten beskriver utvecklingen och designen av ett nytt koncept för en lyftanordning i Tetra Paks Fyllningslinje R1. Det är viktigt att problemen och utmaningarna med den nuvarande lösningen, Tetra Pak R1 Elevator, är förstådda för att underlätta förståelsen av vad detta examensarbetetes syfte är och varför.

Syftet med fyllningslinjen Tetra Pak R1 är att automatiskt vika, fylla och försluta förpackningar av typen Tetra Recart® Midi. Förpackningarna transporteras runt produktionskedjan i specialdesignade hållare. Inför sista steget i produktionslinjen måste hållare och förpackning separeras, och det är Elevatorns uppgift att utföra detta och lämna över förpackningarna till nästa steg i produktionslinjen.

Den nuvarande Elevatorn, som visserligen fungerar korrekt, lider av flertalet fel och irritationsmoment. Den gör jobbet, och den gör det bra; det största problemet med den är inte relaterat till dess funktioner, problemen relaterar till omjusteringar mellan volymer, tillverkningskostnader, vikt av maskinen och komplexa sammansättningar för att nämna ett par. Det är dessa områden det nya konceptet måste adressera.

I detta examensarbete är alla relevanta steg inom utvecklingsprocessen från uppdragsbrief till och med det slutgiltiga konceptet beskrivet. Som en mall har *Ulrich and Eppinger's Product Design and Development* använts.

Informationsinsamling utfördes internt med hjälp av intervjuer, fokusgrupper, manualer, dokument och praktisk erfarenhet genom användning av maskinen. Informationssökning och inspiration till konceptgenereringen utfördes internt såväl som externt.

På grund av storleken och komplexiteten av detta projekt bröts problemen ner till mindre delproblem, lösningarna på dessa problem blev sedan kombinerade, studerade och anpassade för att finna helhetskoncept. De mest lovande av koncepten blev vidareutvecklade, rankade och sållade tills endast ett koncept återstod.

I slutändan designades ett slutgiltigt koncept som visade sig vara en förbättring i nästan varje omfattning jämfört med nuvarande Elevator. Att implementera detta koncept i framtiden kan visa sig vara väldigt värdefullt för Tetra Pak såväl som för deras kunder.

Nyckelord: Produktutveckling, Maskinkonstruktion, Tetra Pak, Lyftanordning, CAD

Preface

This Master Thesis will finalize our studies in Mechanical Engineering and has been performed at the Division of Product Development at Lund University, Faculty of Engineering, in cooperation with Tetra Pak.

The goal of this Thesis was to develop a new concept of a lifting device in the filling line Tetra Pak R1.

The project has been both challenging and instructive, and we have been able to use a lot of knowledge gained from our education, and at the same time learned a lot.

We would like to thank our supervisors at Tetra Pak, Tomas Nilén and Erland Annerfeldt, for the opportunity to work with this project, and for all the feedback and guidance during the project.

We would also like to thank all the people at Tetra Pak, who has given us a lot of advice, shared their expertise and helped us along the way. A special thanks to Richard Persson, who has given us a lot of advice regarding Mechanical Design, along with Lars Carlsson for giving us valuable hands-on experience with the machine.

Finally, we would like to thank our supervisor at Lund University, Per-Erik Andersson for supporting us with feedback on the academic part of this Master Thesis.

Lund, January 2017

Joakim Ottosson Winmalm and Staffan Thorsell

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1 Introduction

This chapter will give a short introduction to the thesis, where a short company background and a description of the problem is included.

1.1 Company background

Development of Tetra Pak’s first product was started in 1943 with the goal to make the package use a minimum amount of material while providing the maximum amount of hygiene. In 1951, the company AB Tetra Pak was started by Ruben Rausing in Lund, Sweden. Their first product was the classical tetrahedral package containing milk. The company grew very fast, and is today the world leading company in food processing and package solutions, with over 23000 employees based in 85 countries [1].

Tetra Pak’s latest packaging system, Tetra Recart®, was born in 2003. This is a revolutionary package-solution system, which offers packaging of all kinds of products that traditionally would have been packed in cans or glass jars. The technology simultaneously sterilizes both the package-material and the product, which results in longer shelf life. Some examples of packed foods are tomatoes, beans, vegetables, soups and sauces [2].

1.2 Problem description

Tetra Pak’s filling line by the name of Tetra Pak R1 was designed to automatically fold, fill and seal cartons of food with the package type Recart® Midi. This type of package is currently available in three different sizes; 340, 390 and 500 ml. The filling line has gone through a lot of changes during its time of service. Most of the entities of the production line have gone through major improvements and configurations but the part called Elevator has not been updated in a long time. This is the part Tetra Pak wishes for us to either replace or improve.

When the packages are inserted into the machine they are placed in specially designed carriers, which purpose is to hold the packages in place during the folding, filling and sealing. The carriers also simulate the shape of classical metal cans, making it possible to use standard rotary fillers in the process line. The Elevator is a machine that is part of the Tetra Pak R1 filling line, which purpose is to remove the package from the carrier (1) and place it on the next part of the production line (2), see figure Figure 1.1. Since the carriers are constantly moving it is vital that the concept will be able to remove the packages in a quick and synchronized fashion, under different circumstances such as speed and changing package- and carrier-sizes. It won't be a matter of simply moving the packages from point (1) to point (2), because of the high velocity, a crash could seriously damage the machine which would be disastrous, whereas synchronisation is a must.

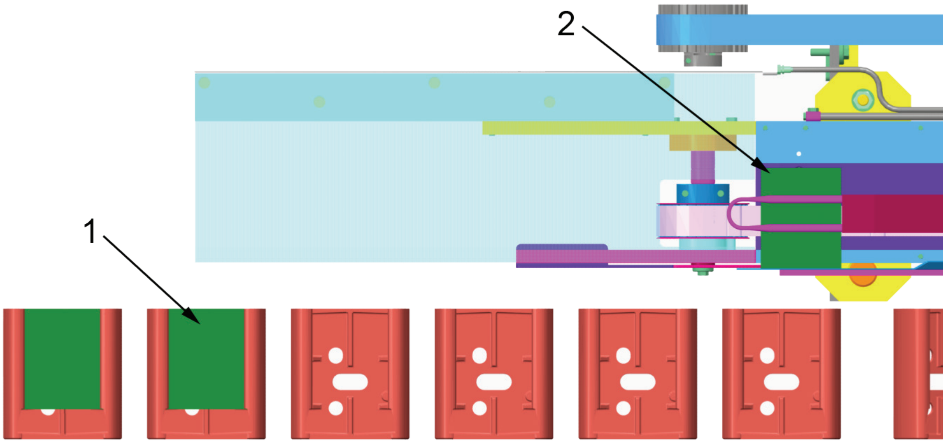

Figure 1.1. Pick-up and drop-off for the package.

1.3 Limitations

Due to the immense size of the assignment and the limited time to realize the objective, it was decided that the project would only cover as far as the final concept phase.

2 Methodology

This chapter includes a description of the methodology used throughout this thesis. The method is based on the generic product development process by Ulrich and Eppinger [3]. Since their method is generally designed for consumer-products and this project is not, the general framework will be the ordinary process with some slight adjustments to cater to the differences.

2.1 Planning

At an early stage of the thesis a project plan was created in order to allocate all the available time and resources. The project plan was visualized in a Gantt-scheme due to its simple and perspicuous view. The project was started in September 2016 and continued until the end of January 2017, and corresponded to 20 weeks of full-time studies. The Gantt-scheme can be seen in Appendix A.

2.2 Background study

In order to get an insight and complete understanding of the task the first weeks of the project was assigned to background studies. All information was collected via Tetra Pak, either from experts in our field of interest, hands-on experience with the Tetra Pak R1 Elevator or company documents and manuals. Being able to study the machine physically was an excellent way to gain a deeper understanding of the problems at hand and with the aid of the different manuals the more technical specifications were gathered and understood.

2.3 Concept development process

Ulrich and Eppinger's [3] development process was used as an approach for this thesis. Due to the size of the project and the limited time, it was considered unreasonable to go further than the concept development phase.

The concept development process used in this thesis was divided into 5 steps; *identifying customer needs, establish target specifications, generate product concepts, select product concepts and test product concepts*

The process was iterative, which means that it was not a straight process line. The workflow would jump back and forth between the different stages as new ideas or new information arose during the process [3, p. 16]

2.3.1 Identifying costumer needs

This method was performed to get a better understanding of the problem and to get information of what improvements the consumer wanted of the product. The goals of this method were to [3, p. 54]:

- Ensure that the product is focused on customer needs
- Identify latent-, hidden- as well as explicit-needs
- Provide a fact base for justifying the product specifications
- Create an archival record of the needs activity of the development process.
- Ensure that no critical customer need is overlooked or forgotten.
- Develop a common understanding of customer needs among members of the development team

The process of identifying the customer needs follows the following 5 steps:

gathering raw data from customers, interpret raw data from customers, organize the needs into a hierarchy, establish the relative importance of the needs and reflect on the results and the process

2.3.1.1 Gather raw data from customers

To collect the useful information to identify the customer needs, different types of methods were used. Ulrich and Eppinger suggest that the three methods *interviews, focus groups* and *observing the product in use* should be used in order to create a high-quality information channel directly from the customer [3, p. 56]. Two of these three methods were applied to gather the raw data from customers; *interviews* and *observing the product in use. Focus groups* were not used since the number of customers of the Tetra Pak R1 Elevator was very limited. The only primary customers are the machine operators and the technical service staff, and they were just a few people at each factory. This method typically includes 8 to 12 customers [3, p. 56], and the resources to organize such a focus group was thus, not possible.

2.3.1.2 Interpret raw data in terms of customer needs

The gathered data was studied, discerned and interpreted in order to befit all possible needs the consumer might desire. The needs were categorized and ranked on merit and importance and later used as benchmarks for the new solutions. These needs were kept unspecific to avoid being inhibitory towards the development-team's creativity.

2.3.1.3 Organize the needs into a Hierarchy

The needs gathered from the previous step was then organized into a hierarchical list to make it easier to work with. The hierarchical list sorts the customer needs in categories and reduces the total number of needs. The list resulted in primary needs that were more general, and secondary needs which were more specific.

2.3.1.4 Establish the Relative Importance of the Needs

The needs in the hierarchical list was rated after their relative importance. The needs were graded in 3 steps due to their importance. In this process, the approach was to rely on the team members experience gained from the customers.

2.3.1.5 Reflect on the Results and the Process

The final step in identifying the customer needs was to reflect on the results and the process. It was important to make sure that everything that needs to be included in the process was there, and that the results were reliable.

2.3.2 Establish target specifications

While *customer needs* were kept unspecific and left open for interpretation in order to avoid being inhibitory, target specifications were a set of boundaries telling developers what the product needs to do while avoiding addressing how it does it. These specifications spell out precise, measurable quantifications to map out a frame that the developers needed to satisfy. [3, p. 72]

2.3.3 Prepare the list of Metrics

The needs were translated into measurable metrics. This is often a difficult task, and many needs were not possible to translate into a measurable unit. The needs that were not possible to measure were still relevant, and was indicated as subjective and later evaluated by a panel of customers. [3, p 78]

2.3.4 Collect competitive Benchmarking Information

It is always important to compare the new product with competitive products, to make sure the product has the specifications the customer expects. The Elevator is not a consumer product and has no competitors since it is a very specific product for Tetra Pak. The only benchmarking that will be performed was against the current version of the Elevator.

2.3.5 Generate Product Concepts

A product concept is a rough approximation of how the final product will satisfy the needs of the consumers. It is in no way a final solution but rather an expression of an idea. It is usually compounded of sketches or rough physical models, and often accompanied by a short explanatory text.

The goal of the concept generation phase was to produce a number of product concepts that satisfies the customer needs and the target specifications. From those product concepts the development team would later choose a final concept to proceed with.

2.3.6 The Five-step method

The five-step method is a procedure where one breaks down the larger problems into smaller sub-problems. Solutions are then identified for each of the smaller problems and combined to solve the bigger picture.[3, p 99] This procedure follows five steps, which are as follows;

Clarify the problem – clarify the entire problem and break it down into smaller sub-problems.

Search externally – extract information from sources outside of the development team. Study patents, related products, literature and interview experts and lead users.

Search internally – extract knowledge and ideas from the development team.

Explore systematically – explore ideas and possible solutions by using classification trees and combination tables.

Reflect on the solutions and the process – while this is presented as a last step in is used constantly during the entire process [3, p 120]

During the concept generation phase, it was important to have a very nurturing and creative environment in order to generate as many concepts as possible. In this process, no ideas were trivial or beneath mentioning; it was crucial that every solution were considered. Even an insubstantial idea can inspire greatness.

2.3.7 Concept selection

During the previous steps several concepts was generated unhindered by logic and critical thought all to nurture the developers creative sides. During the concept selection phase, it was time to evaluate the concepts in regard towards the customer needs. During this process, each concept was evaluated regarding its strengths and weaknesses and compared to each other. The method of choice fell on *Decision matrices.*

2.3.8 Decision matrices

The development team rates each of the concepts according to the needs and specifications whereas each specification is hieratically weighted in regard to importance. This method was contrived of two separate processes; *Concept screening and Concept scoring.*

Concept screening is a quick method of narrowing down the concepts to a few better suited alternatives by deciding if each concept is either better (+), worse (-) or equal (0) to a reference concept. By doing this the developer gets a good overview of which concepts has potential, which concepts can be combined and which to discard. [3, p 130]

Concept scoring is a more precise and thorough investigation where each concept is compared to each other and evaluated in regard to weighted criteria. This is achieved by taking every criterion into consideration, evaluating them and deciding how important they are for the final product and issue a weighed score. [3, p 134]

2.3.9 Concept testing

The victorious concept that was chosen will be studied and scrutinised in order to verify the legitimacy of the solution. If all the calculations proves true, the concept can be regarded as feasible and be cleared for further development.

3 Background study

This chapter will present all information necessary for understanding the problem of this thesis. The essential parts of the filling line will be described, together with more detailed information about the current solution. All information was gathered through Tetra Pak.

3.1 Tetra Pak R1 filling line

Tetra Pak has two machines available for forming and sealing their package Recart, the Tetra Pak R1 and the R2 [2]. The Tetra Pak R1 is their fastest machine and can produce up to 24000 packages per hour, and has a continuous speed through the whole process line. The machine is designed to work with standard rotary fillers, which is the same units used for the filling of cans [4]. The whole process line can simply be divided into five main steps, seen in Figure 3.1.

1. The infeed is the first step where the unfolded packages are picked one by one and inserted into the machine.
2. Once positioned in the machine the packages are transported into the second part of the process line where the top of the packages is sealed shut.
3. In the next part of the production line the now half sealed packages enter a standard filling unit where they are filled with the product. These filling units are the same as the ones used to fill cans, and can be of different types. The filling unit is not a part of the Tetra Pak R1 filling line, it is bought separately from a different manufacturer.
4. The now full packages are transported to the next part of the line where the bottom of the containers are sealed. They are now completely sealed.
5. The last step of the process is the final folding of the packages; it is here the packages get their final rectangular shape.

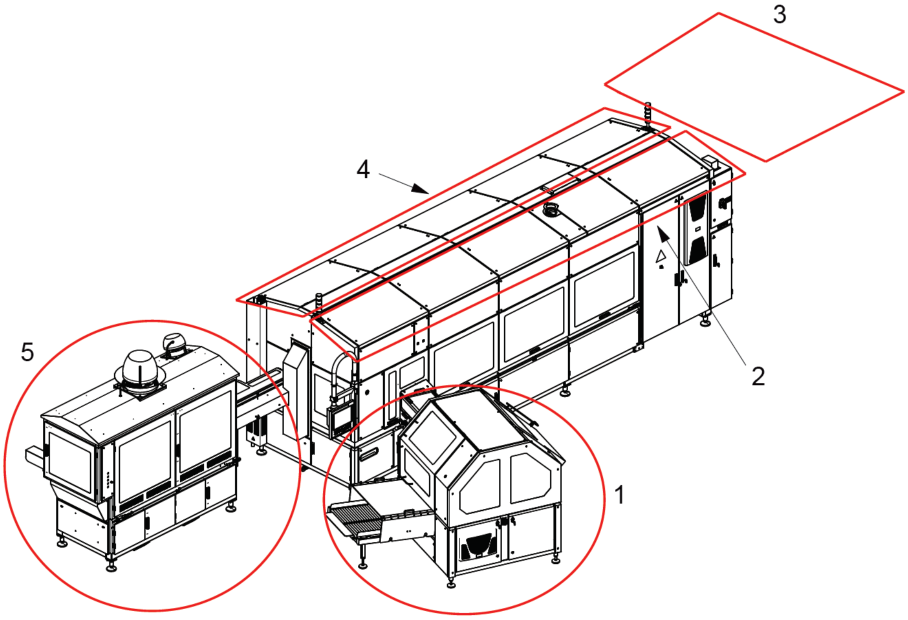

Figure 3.1. Tetra Pak R1 filling line.

3.2 Carrier transport

When the packages are inserted into the machine they are placed in a specially designed carrier, the job of these carriers is to stabilize the containers and simulate the shape of classical cans to enable the use of the standardized filler units. The carriers are following a rail that moves around in a closed path with two parallel tracks connected with circular ends. The carrier transport has a constant velocity and is the core of the filling line. The packages stay inside the carriers during the filling and sealing process, but at the last step of the production line, the packages must be separated from the carriers. In Figure 3.2, the relevant part of the carrier transport is seen. At this point, the packages have been filled and completely sealed, and are ready for the final folding. The shaded area represents the area where the packages gets separated from the carriers. This is the area where the Elevator should be placed.

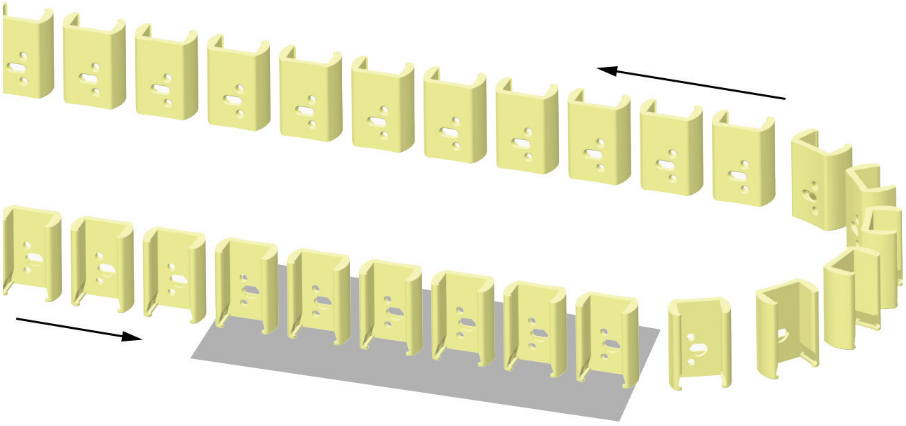

Figure 3.2. Carrier transport.

3.3 Drop-off zone

After the packages have been separated from the carriers, they need to be placed in the next part of the production line. This part starts with a zone where the packages are placed and synchronized to get into the following timing-belt. This zone is located 194 mm above the bottom of the carriers, and is seen in Figure 3.3. The packages are lowered down onto a rotating disc (1), and are then controlled by a metal guide (2), to get into the path where the following timing-belt (3) continue to push the package forward.

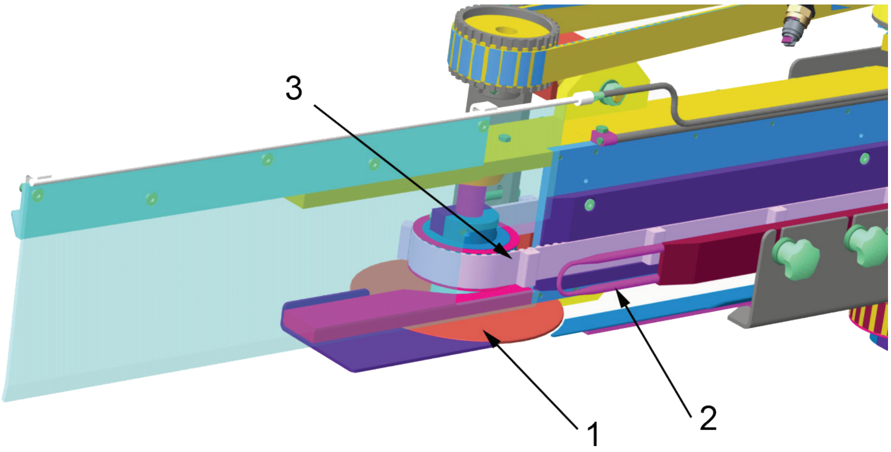

Figure 3.3. Drop-off zone for the package.

3.4 Tetra Pak R1 Elevator

The Elevator is a unit that is the link between the carrier transport and the following drop-off zone. It operates by lifting the package out of the carrier and moves it into the drop-off zone. The package is gripped by two jaws, one on the bottom of the package and one on the top. At the same time as the package moves forward together with the carrier, it is gripped by the Elevator and raised towards the drop-off zone. The current design of the Elevator is seen in Figure 3.4.

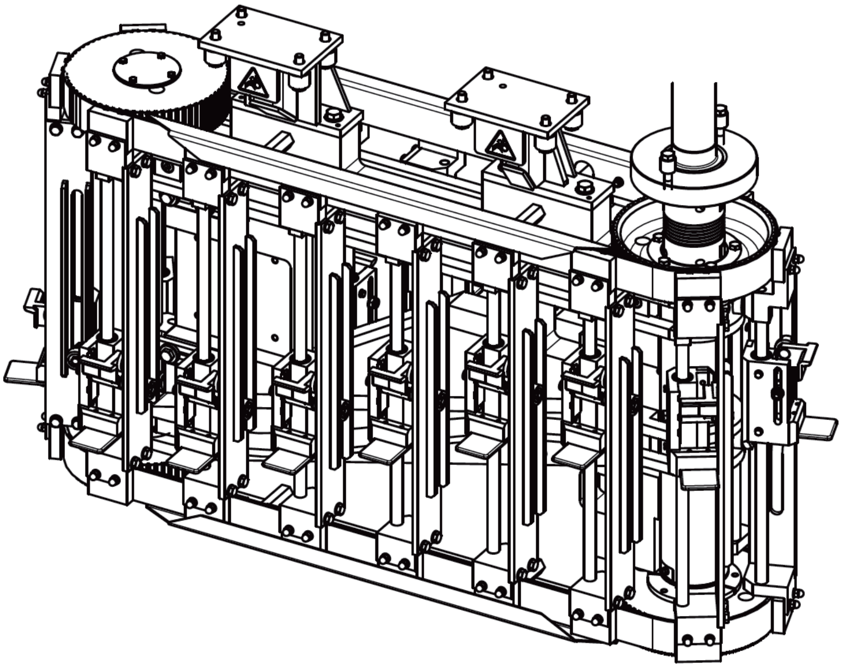

Figure 3.4. Tetra Pak R1 Elevator

3.4.1 Lifting mechanism

The Elevator is driven by a shaft, which is connected to another shaft by timing-belts and gears. The Elevator will have the same rotary speed as the driving shaft of the entire filling line. There are 16 lifting arms placed around the timing-belt at equal distances from each other. The lifting arms are connected to the belts, which will create a linear movement of the lifting arms parallel to the carrier transport. The lifting arms are placed at the same distance from each other as the carriers, and will therefore be synchronized with each other. When the lifting arms goes inside the carriers, they will follow a cam-curve as they move forward, which will lift the packages inside the carriers vertically, and create the movement needed to separate the packages from the carriers. An illustration of the movement of the package is seen in Figure 3.5.

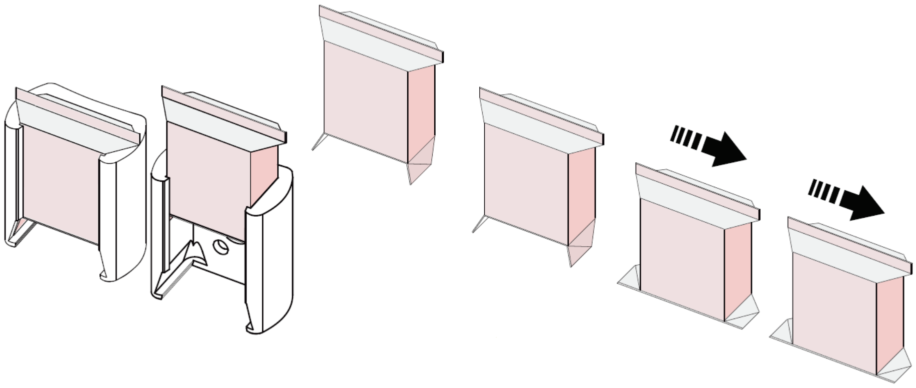

Figure 3.5. Illustration of the lift

3.4.2 Upper jaw closing

How the upper jaw is closed is seen in Figure 3.6. When the packages are raised, the lower jaw (1) is inserted beneath the package in order to thrust it vertically out of the carrier. The upper jaw helps the lower jaw by pinning the package between each other both to stabilize the package and to stop it from launching upwards due to the fast acceleration conveyed by the lower jaw. At first the upper jaw is open (2) and starts to close only after the package have risen above a certain height (3). This is achieved by giving the upper jaw a curve in the frame to follow (4).

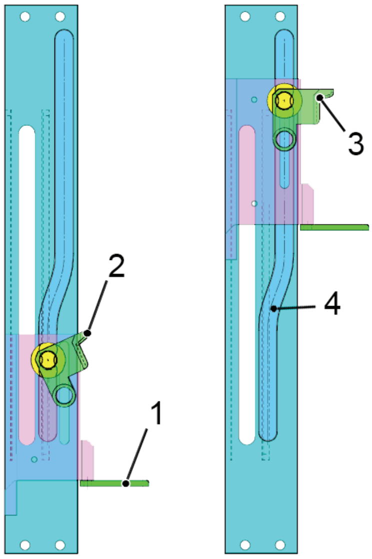

Figure 3.6. Upper jaw closing.

3.4.3 Volume adjustment

The Tetra Recart Midi packages are currently available in three different sizes; 340, 390 and 500 ml, see Figure 3.7. The bottom area of the packages is standardized among the different volumes; it is only the height of the packages that differ. In the future, a few new sizes might be introduced as well. It is therefore desired that the new concept will cater to both the old and new standards. The new design should be compatible with sizes lower than 340 ml and bigger than 500 ml [5]. To operate with these different sizes, the Elevator should be adjustable.

The Elevator is comprised of a total of sixteen different holders that, when working together, achieves a fast-paced lifting device where every holder is in a different position in the lifting process. Because there are sixteen separate holders whom all must be reconfigured separately when a volume change occurs, it is both a time consuming and a fiddling task. Since this is a manually performed occurrence it is not uncommon that mistakes are made, mistakes which causes alarms to go off and production to be halted.

Figure 3.7. Current sizes of the Tetra Recart Midi packages.

3.4.3.1 Procedure

In Figure 3.8, the package holder and a template is seen. The current procedure to modify the Elevator for different volumes is to adjust the distance between the two jaws (3,4) that are holding the package in place. To achieve this, the upper jaw (3) is fastened in the correct position with the aid of a template (5). The Elevator consists of a total of 16 separate lifting arms that must be adjusted separately.

The procedure of the height adjustment is completed in three steps:

- Loosen the screws (1 and 2).
- Adjust the upper jaw (3), which is configured into the correct position by placing the template (5) between the upper and lower jaw.
- Tighten the screws (1 and 2).

Before doing this, the template must be adjusted after the correct height depending on the package size.

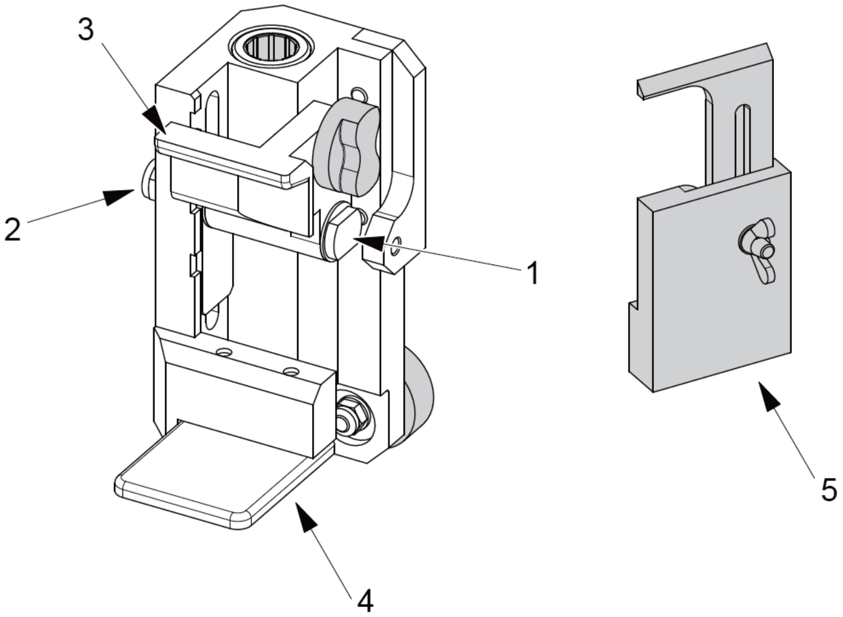

Figure 3.8. Package holder and template.

3.4.4 Carrier interface

The carriers have a specified interface that will limit the size of the jaws, which is seen in Figure 3.9. The jaws (2) must both be inside the carrier-interface (1) and synchronized with the movement of said carrier in order to perform the lift of the package. The interface is a rectangular shaped area, which are almost identical to the bottom area of the packages. Due to the height difference of the packages the carriers have to change when a volume change occurs as well, like the packages it is only the height that differ between them.

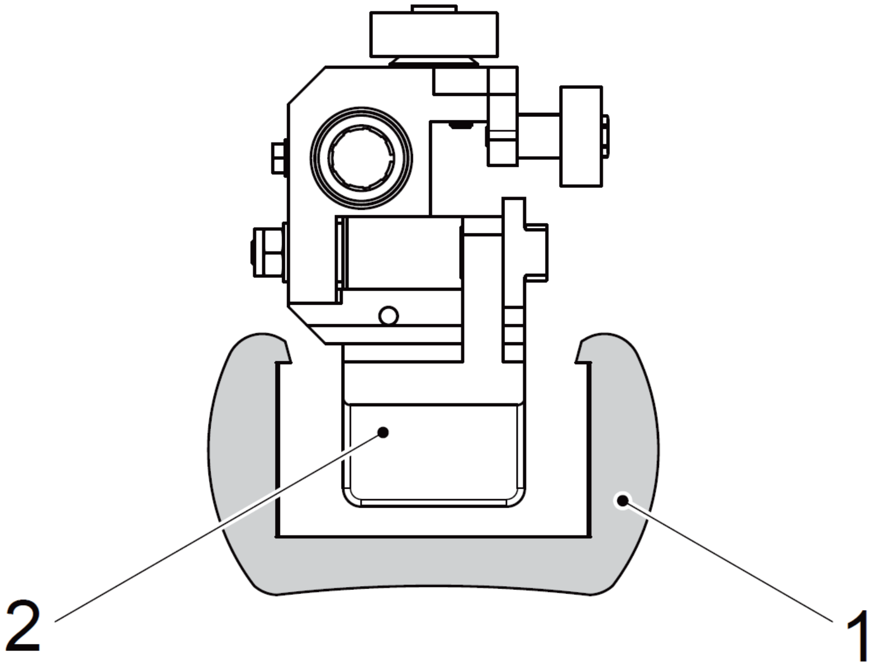

Figure 3.9. Lifting jaw inside the carrier.

3.4.5 Package shape

When the package is inside the carrier, it has not yet been folded into its final shape. The final folding of the package occurs in the next part of the production line; this means that the package will have flaps that stands out from the package both on the top and the bottom. In Figure 3.10, a package is seen with the shape which it has when it is removed from the carriers by the Elevator.

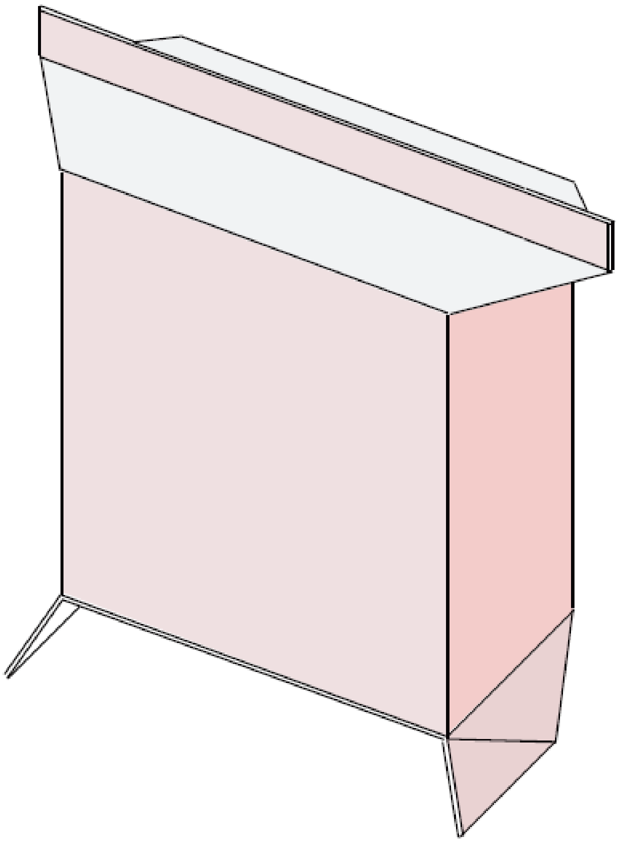

Figure 3.10. Shape of the package when lifted by the Elevator.

3.4.6 Package support

When the package is inside the carrier, it is very stable and impeded from moving in any direction except for the lifting direction. At a specific height, depending on the package size, the package will have been completely lifted out of the carrier and is only supported by the lifting jaws. To keep the package from falling, there is a guide placed at the back of the package, see Figure 3.11. This guide (1) is made of plexiglass and will support the package and keep it in the correct position until it reaches the drop-off zone, where a metal guide (2) and the following timing-belt (3) takes over.

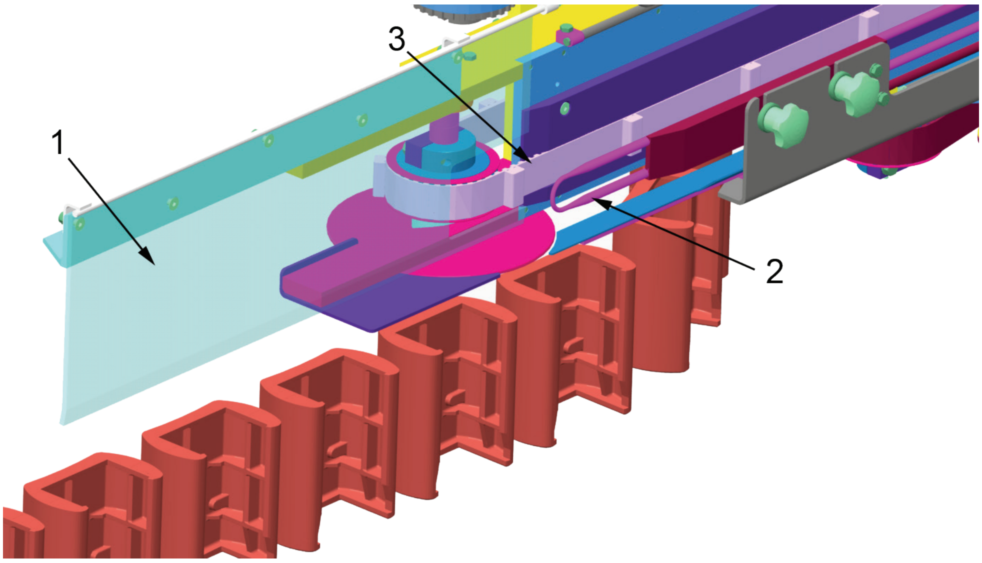

Figure 3.11. Current machine interface.

3.4.7 Elevator exit

When the packages have been raised to the desired height, they will be released and pushed towards the following conveyor-belt. Before that occurs the presently unfolded tabs on the bottom of the package must be placed in the right position. To achieve this, the package is lowered down on a rotating disc that will guide the tabs in the right direction. After this, the packages are moved to a guide which will keep the packages in the right direction and ready to be pushed further forward by the following conveyor-belt. When the packages have reached the conveyor-belt the Elevator arms starts rotating outwards and with the aid of the guide, the package is removed from the holder and is free to continue down the production line.

3.4.8 Return movement

When the Elevator has completed the lift of the packages, it has to move back into the starting position to make another lift. Since the Elevator is designed of gears and belts, it is a closed motion which will take the lifting arms back to the position where the lift began. The return movement is very similar to the lifting movement; the lifting arms are moved down and around by following the cam-curve to the height and position where the lift started. Figure 3.12 shows the cam-curve (1) that the package holder moves along during the lift and return movement, and the horizontal movement (2) of the belt.

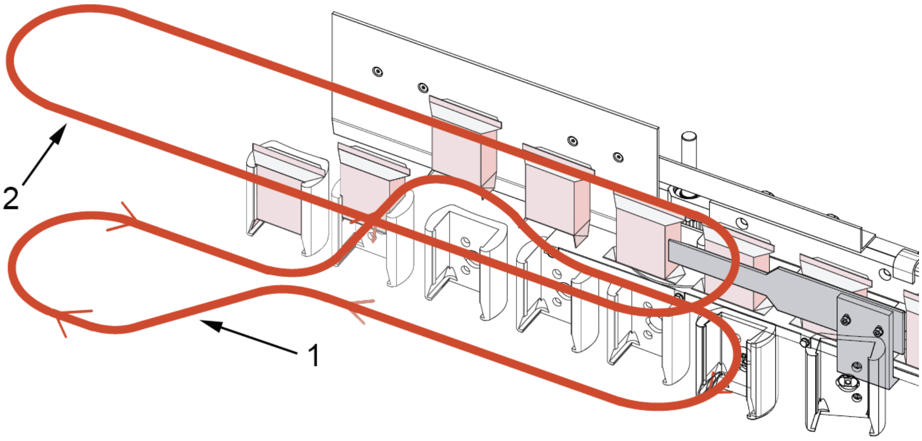

Figure 3.12. Movement of the Elevator

3.4.9 Space limitation

The Elevator has a limited space where it can be placed in the process line. The space is not limited to the volume that the current Elevator inhabits though, there is more space available for the new concept if needed. There is primarily a lot of room in front of the Elevator, but also a noticeable amount behind it.

3.5 Tetra Pak R1 Pusher

In the Tetra Pak R1 filling line there is another component that has a similar task as the Elevator, but in another part of the machine. This component is called Pusher and its function is to raise the packages around 30 mm vertically in the carriers. This is a similar movement as the Elevator needs, but the difference is that the Pusher only raises the packages a short distance while the Elevator need to raise the package all the way out of the carrier. The Pusher has a lot of functions that are possible to use as inspiration when developing the new concept of the Elevator. The design of the Pusher is seen in figure Figure 3.13.

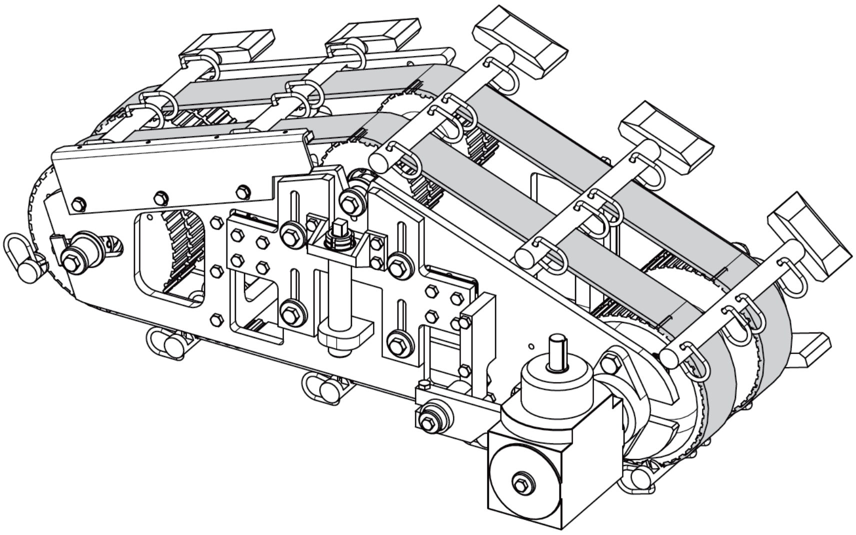

Figure 3.13. Tetra Pak R1 Pusher.

4 Identifying customer needs

This chapter will present the result of identifying the customer needs. Since the Elevator is a very specific product of Tetra Pak, the number of customers of the product were strictly limited. All raw data was procured within Tetra Pak.

4.1 Gather raw data

The first step of this process was to locate individuals with vast knowledge of the machine, these individuals were found by asking around at the company. The main method used to gather data was by holding interviews with those individuals. Questions for the interviews were prepared beforehand and was tailor-made in regard to the interviewees field of expertise. The interviews were held one at a time to ensure that the interviewees were unaffected by each other. Each meeting was recorded in order to ensure that no information was overlooked or forgotten and later written down for easier access. A total of five people were interviewed during this process, all of whom had great knowledge of and experience with the Elevator. A list of the interviewees can be seen in Appendix B.

Raw data was also collected through different documents and digital systems within Tetra Pak, such as manuals, performance measurements, and maintenance recommendations.

A walkthrough of the production line was also held to get a better understanding of the process and hands-on experience with the machine.

4.2 Interpret raw data

The raw data gathered from the interviews were analysed and interpreted into customer needs. A total of 35 needs was obtained, and are seen in Table 4.1.

Table 4.1 Customer needs interpreted from raw data.

	Customer needs
No.	***Need***
1	The machine is easily assembled
2	The machine is easily synchronized
3	The machine has an adjustable speed
4	The machine has an adjustable volume capacity
5	The machine has a protecting fail-safe
6	The machine is able to withstand high temperatures
7	The machine is non-corrosive in a very corrosive environment
8	The machine is water resistant
9	The machine doesn’t take damage by the filling products
10	The machine doesn’t take damage by the chemicals used for the cleaning
11	The machine is comprised of as little aluminium as possible
12	The components of the machine are easily changed
13	The machine can handle packages with different shapes
14	The machine can lift faulty packages
15	The machine is easily understood
16	The machine consists of few parts
17	The machine has few moving parts
18	The machine doesn’t obscure the view of the production line
19	The machine is easily cleaned
20	The machine can withstand the different detergents
21	It´s easy to get an overview over the machine
22	The volume change is easy to understand
23	The volume change is easy to perform
24	The volume change is quick
25	The volume change can be performed by one person
26	The machine doesn’t take damage during the volume change
27	The machine is easy to start
28	The machine is easy to turn off
29	The machine is fast to reset after a breakdown
30	The machine doesn’t deform or otherwise damage the packages
31	The machine is quiet
32	The machine is temperature resistant
33	The machine is safe to handle
34	The machine is lightweight
35	The machine consist of standard parts

4.3 Organize the needs into a Hierarchy list

The needs seen in Table 4.1 are unorganized and difficult to get an overview of. To make the list of the needs easier to work with, they were categorized in primary and secondary needs. The primary needs were the more general needs and the secondary were more specific. The organized needs are seen in Table 4.2. The importance of the needs was also assigned, based on the experience the team members gained through the interviews of different experts. The primary needs were also assigned two different labels, **N** for necessary needs and **D** for desirable needs. The necessary needs simply must be met to make the design trustworthy. The desirable needs doesn’t need to be fulfilled, but if they do it would be beneficial.

Table 4.2 Customer needs organized into a Hierarchy list.

D	***The machine is easily assembled***	
	*	The machine has fewer moving parts than the current solution
	*	The machine consists of fewer parts than the current solution
	**	The machine is lightweight
	**	The machine consists of standard parts
D/N	***The machine is resilient in an aggressive environment***	
	***	The machine is water resistant
	***	The machine is non-corrosive
	***	The machine doesn’t take damage by the filling products
	***	The machine is temperature resistant
	***	The machine can withstand the different detergents
N	***The machine has an adjustable volume capacity***	
	***	The volume change is easy to perform
	**	The volume change is quick
	**	The volume change can be performed by one person
	**	The volume change is easy to understand
	***	The machine doesn’t take damage during the volume change
D	***The machine is easy to use***	
	**	The machine is easily understood
	**	The machine is easy to start
	**	The machine is easy to turn off
	***	The machine is fast to reset after a breakdown
	**	It´s easy to get an overview over the machine
	*	The machine is easily synchronized
	*	The components of the machine are easily changed
	*	The components are quick to replace
	**	The machine is easily cleaned
	*	The machine doesn’t obscure the view of the production line
N	***The machine is safe to use***	
	***	The machine has a protecting fail-safe
	***	The machine is safe to assemble
	***	The machine is safe to operate
	***	The machine doesn’t burn users
	***	The machine doesn’t cut users
	*	The machine is quiet
N	***Package handling***	
	***	The machine can handle packages with different shapes
	***	The machine can lift faulty packages
	***	The machine doesn’t deform or otherwise damage the packages
	***	The machine can handle different heights on the packages
	***	The machine has an adjustable speed
	***	The machine won’t break

* = Less important ** = Important ***= Very important

Most of the needs were stated as necessary needs, since those needs were critical to the needed function of the machine. The two needs stated as desired was *The machine is easily assembled* and *The machine is easy to use.* Those needs won't limit the machine from operating correctly. The machine will only be assembled once and if it is difficult to do it won't be crucial. It would also operate correctly even if it's not easy to use, which make this statement desired.

4.4 Reflect on the result and the process

All the customer needs were collected through interviews, which is a method that provides a lot of information. Even though there are methods that might provide more information, such as focus groups [3, p. 57], it was considered unfitting to perform focus groups on this product since the number of people with experience of the machine was strictly limited. The interviews afforded a lot of needs, a total of 35 was identified. To consider every one of these needs will take a lot of time and resources; therefore, they may be reduced further in the development process.

5 Establish target specifications

The identified customer needs need to be translated into measurable units to be able to be set up as target specifications of the product. This chapter will explain that process.

5.1 Benchmarking

The target specifications were basically set up by benchmarking against the current design of the Elevator. The new concept has to perform the exact same task and therefore, this was enough to get the target specifications. The metrics were identified through different sources such as 3D-drawings, manual measurements, manuals and interviews.

5.2 Target specifications

Many of the identified customer needs were hard or impossible to translate into a measurable unit. The specifications that were possible to measure are seen in Table 5.1 together with some subjective metrics that were too important to neglect.

Table 5.1 Target specifications

Target specifications					
No.	**Need no.**	**Metric**	**Importance**	**Unit**	**Value**
1	1,13,18,22	Number of moving parts	*	quantity	<84
2	1,13,17,22	Number of parts	*	quantity	<1201
3	1,17,18,35	Machine mass	*	kg	<219
4	5,23,24,25, 26	Time to perform volume setting	**	min	<30
5	17,18,35,36	Manufacturing cost	**	Sek	<240000
6	2,16,19,28, 29,30	Time to reset machine after breakdown	**	min	<16
7	1,13,16,17, 18,19,22	Time to replace components	*	% of production hours	<0,6
8	32	Noise level of machine	*	dB	-
9	11,19,20,21	Time to clean machine	**	min	-
10	5,14	Height of compatible packages	***	mm	92-134,5
11	3,4	Operating speed	***	packages/h	0-24000
12	7, 33	Heat resistant	***	°C	0-95
13	-	Horizontal distance between lifters	***	mm	150
14	-	Lifting height	***	mm	232
15	8,9,12	Machine is water resistant	***	material specification	-
16	10	Product resistant	***	material specification	-
17	14,15	Machine can handle faulty packages	***	subjective	-
18	7,8,9,10,11, 21,27,31,33	The machine is robust	***	subjective	-
19	6,34	The machine is safe to use	***	subjective	-

Since a lot of the needs were combined or was otherwise involved in the different target specifications, the weighted importance may have varied between different needs. To accentuate the correct importance a mean-value was devised between the needs involved. Some of the specifications were not set, since there was no data found for them, and it was not possible to measure these units.

6 Concept generation

In this chapter, the concept generation phase is described. In here, all necessary steps and choices made by the development team is described in their effort to produce different solutions to the problem.

6.1 Clarifying the problem

The first step in the concept generation process was to get a better understanding of the problem. A lot of knowledge was already gained in the information gathering phase, but more technical understanding was needed during this process. The main problem of this thesis is to lift packages out of a carrier at the same time as they move along the process line. This problem was shown to consist of a lot of simpler sub-problems.

6.2 Decompose the problem into sub-problems

Two main problems were identified in this process, the designed trajectory of the movement of the machine, and the design of the package holder. The two main problems were dissected and simpler sub-problems were attained.

6.2.1 Movement

This main problem was determined to be very complex. There are a lot of speeds and angels that has to fit into the interface of the rest of the filling line. All movement directions need to be synchronized with the carrier transport in order for the machine to operate correctly. The solutions of the sub-problems also depend on each other, a solution of one sub-problem may reject a solution of another sub-problem. The sub-problems need to be combined in a specific way in order to function properly. It was also possible that one solution may solve a number of these sub-problems alone. In total, 4 sub-problems were identified; *Overall movement, movement in x-direction, movement in y-direction and synchronize into and out of movement.*

6.2.1.1 Overall movement

The overall movement describes how the lift of the packages should be performed overall. The lift can be performed in one continuous movement or in two or more steps.

6.2.1.2 Movement in x-direction

The X-direction was defined as the direction of which the packages moves along the process line; i.e., the same direction as the carrier transport. This sub-problem will find solutions that makes the machine move in this direction.

6.2.1.3 Movement in y-direction

The Y-direction was defined as the lifting direction; i.e., perpendicular to the carrier transport direction. This is the movement that makes the packages go out of the carrier.

6.2.1.4 Synchronize into and out of movement

The machine need to be synchronized with the carrier in a specific way in order to perform the lift correctly. This sub-problem will focus on solutions for the machine to synchronize the in and out movement.

6.2.2 Package holder

This main problem focuses on the unit that is in physical contact with the package during the lift, and is also responsible for stabilizing the packages during the movement to make sure the packages are raised safely.

6.2.2.1 Grab the package

This sub-problem focuses on the method of holding the package in place during the lift, it will describe how the machine grabs the package and how it is stabilized during the process. Sometimes errors in the previous machines can lead to faulty packages with unusual shapes. Failures in previous steps in the production line can lead to packages that are not completely sealed, folded in the wrong way, deformed or empty. Packages that has some kind of deformation are sorted out from the production line in the step that follows after the Elevator; due to this fact, the machine must be designed to handle faulty packages as well. Some examples of faulty packages that the Elevator need to be able to handle are seen in Figure 6.1.

Figure 6.1. Examples of faulty packages.

6.2.2.2 Volume adjustment

The machine needs to be compatible with packages of different volumes. This sub-problem will describe how the machine is set up for different volumes of the packages.

6.3 Idea generation

With these different sub-problems in mind, the team started to generate ideas for solutions. Ideas were generated in different ways. The team started with internal brainstorming sessions, where the creativity of the group members was used. The ideas were shared with each other, which in turn created more ideas. External searches were also used a lot during the idea generation. Internet was a great source for finding patents and inspiration from solutions of similar problems. Discussions with Tetra Pak's developers were held to find current solutions within Tetra Pak. First crude solutions for each sub-problem was generated, and later combined and further investigated to find possible ways to get overall concepts.

What follows is a simplified presentation of the different sub-problems described only in text. The team had several ideas in each category, if a more detailed sketch of every single one were to be presented, it would prove both time-consuming and unnecessary in the long run. Since most of the solutions would be screened out in an early stage anyway, wasting time presenting faulty ideas was not a compelling move.

6.3.1 Overall movement

The solutions of this sub-problem explain how the lift is going to be performed rather than a technical description of the solution. The movement can be continuous or divided into a number of steps. The team decided to just consider one or two steps, since three or more steps would be too complex. A summary is seen in Table 6.1.

Table 6.1. Solutions of sub-problem overall movement

Overall movement	
One continuous movement	The lift is performed by one movement
Movement in two steps	The lift is divided into two separate movements

6.3.2 Movement in the x-direction

Different crude solutions of moving the lifting device in the same direction as the carrier transport are seen in Table 6.2. Some solutions require a rotation motor, which is available in the machine.

Table 6.2. Possible solutions of the sub-problem movement in the x-direction

Movement x-direction	
Timing-belt and pulleys	Timing-belt and pulleys create the linear movement
Chain and gears	Chain and gears create the linear movement
Linear motor	A linear motor creates the linear movement
Translation screws	A translation screw is used to translate rotation to linear movement
CAM mechanism	A cam mechanism is used to create the movement
Hydraulics	The machine is moved with hydraulics
Pneumatics	The machine is moved with pneumatics
Rail	A rail is used to guide the movement. Must be combined with a solution that creates the movement
Wire and pulleys	A wire is used together with pulleys to get the linear movement

6.3.3 Movement in the y-direction

This is the movement that lifts the package vertically out of the carrier. Solutions for solving this problem are seen in Table 6.3. Note that it is the same solutions as for the x-direction since both sub-problems regards to linear motion.

Table 6.3. Possible solutions for the sub-problem movement in the y-direction.

Movement y-direction	
Timing-belt and pulleys	Timing-belt and pulleys creates the linear movement
Chain and gears	Chain and gears creates the linear movement
Linear motor	A linear motor creates the linear movement
Translation screws	A translation screw is used to translate rotation to linear movement
CAM mechanism	A cam mechanism is used to create the movement
Hydraulics	The machine is moved with hydraulics
Pneumatics	The machine is moved with pneumatics
Rail	A rail is used to guide the movement. Must be combined with a solution that creates the movement
Wire and pulleys	A wire is used together with pulleys to get the linear movement

6.3.4 Synchronize into and out of movement

Solutions of this sub-problem are more general formulations of how the mechanism will work rather than the technical solution. Some overall solutions may not need this function since it is a solution that depends on the selections of other sub-problems. The crude solutions are seen in Table 6.4.

Table 6.4. Solutions of the sub-problem synchronize into and out of movement

Synchronize into and out of movement	
The holder is rotating into/out of position	Only the holder of the packages is rotating in position
The holder is pushed in/out	Only the holder of the packages is pushed in position
The whole lifting arm is rotating into/out of position	The whole lifting device is rotated into position

6.3.5 Grab the package

When the package is inside the carrier, both the back of the package and the sides are blocked by the carrier and is not available for grabbing onto during the lift. This will limit the solutions to grabbing the packages from the top and bottom during the lift. If the package is pushed up and out of the carrier first, the blocked sides of the package will be visible and available for grabbing onto. This creates more options, which is one huge advantage of using a two-step solution. Solutions of this sub-problem are seen in Table 6.5.

Table 6.5. Solutions for grabbing the package

Grab the package	
Jaw under	A jaw is used to push the package from the bottom
Jaw over	A jaw on the top is used to support the package
Vacuum from the side	Vacuum is used to grab the package from the vertical surface on the side of the package
Suction cup from the side	A suction cup is used to grab the package from the vertical surface on the side of the package
Gripping arm	A gripping arm is used to grab the package from the sides
Clamping	Two belts are used to clamp the package from the sides and push it forward
Push from back	A jaw is used to push the package from the back to support the package

6.3.6 Volume adjustment

To make the machine compatible with different sizes of the package, some adjusting possibilities towards the holder may be needed. This problem depends on the chosen grabbing method. Crude solutions are seen in Table 6.6.

Table 6.6. Solutions for volume adjustment.

Volume adjustment	
Move jaws	The jaws are moved to adjust for different volumes
Replace holder	A special holder is designed for each volume, and the entire holder is replaced to adjust volume
Machine is moved	The entire machine is moved to make the adjustment

6.4 Sub-concept screening

To make the process of generating overall concepts more straightforward, some of the concepts of the sub-problems was discarded at an early stage. After research and discussions with experts at Tetra Pak, some of the solutions were found to be unsuitable for the application.

For the overall movement, the team decided to go further with both ideas *One continuous movement* and *Movement in two steps.*

The two sub-problems *movement in the x-direction* and *movement in the y-direction* had a lot of solutions that could be eliminated after further investigation. Table 6.7 shows the screening of these sub-problems.

Table 6.7. Shows the screening of the sub-concepts movement in the x- and y-direction.

Movement x-direction and y-direction	*Continue*
Timing-belt and pulleys	Yes
Chain and gears	No
Linear motor	No
Translation screws	Yes
CAM mechanism	Yes
Hydraulics	No
Pneumatics	No
Rail	Yes
Wire and pulleys	No

Five of the nine ideas were eliminated, and the motivations for that are seen below.

Chain and gears

This solution is similar to timing-belts and pulleys, but chains and gears does not provide the same accuracy and speed [6]. They are also more expensive and not as flexible as timing-belts and pulleys.

Linear motor, hydraulics and pneumatics

These three solutions were eliminated for the same reason. To use any of these components, extra complexity need to be added to the concept. The components need to be added to each of the lifting arms, which would result in a lot of extra parts in the machine. Linear motors need electricity added to each of the moving lifting devices, and hydraulics and pneumatics need houses. These components would be difficult to add to the moving parts. Electricity would also be vulnerable in the moist environment in the machine. Another problem was that linear motors are not inherently suitable for use in a vertical axis, if the motor is shut down the motor cannot hold the load, and will fall [7, p. 15]

Wire and pulleys

This solution provides a flexible driving path; but, since wires can slip, it is not a suitable solution [8, chapter 11-10]. The moving path must be synchronized with the carrier transport, and slipping may result in an unsynchronized movement which will cause the machine to crash.

Minor removals

For the sub-problem *Synchronize into and out of movement,* all solutions were kept for further investigation.

For the sub-problem *grab the package,* only one solution was screened out. The idea of using vacuum to grab the package from the side seemed to be to complex and requires a lot of additional parts in the machine.

One solution on the last sub-problem *volume adjustment* was screened out. Moving the whole machine for adjusting the volume seems unnecessarily complex.

6.5 Overall concepts

The different concepts for every sub-problem was combined and inspected. The team had been thorough and conceived an immense number of concepts during their brainstorming activities, some of them can be seen in Appendix C. When the time for combining these solutions arrived, some worked better than others; this is a more detailed description of the more promising cases.

6.5.1 One continuous movement-solutions

There are many steps to consider during this entire process; below, the concepts that fulfil these in a continuous movement are described.

6.5.1.1 Concept A

Each holder moves along an oval rail with the same speed as the carriers. The vertical movement of each holder is controlled by a CAM-curve. The trajectory of the rail moves beneath the carriers at which point the holders start to rise, grabbing the packages and raising them towards the awaiting conveyor-belt at the next area in the production line. The concept is seen in Figure 6.2.

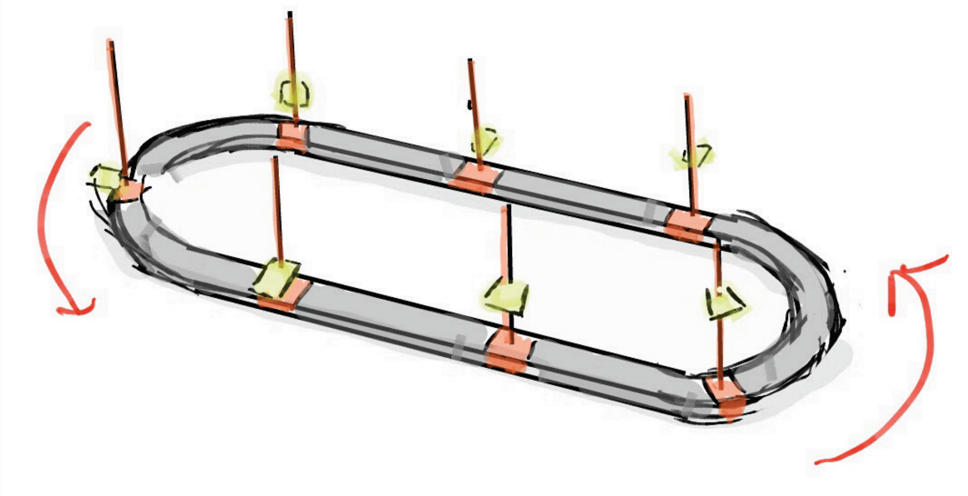

Figure 6.2 Concept A

6.5.1.2 Concept B

The packages are gripped from below by a retractable jaw. By making the jaw retract before it collides with the conveyor-belt at the top, the movement of the machine will remain in only two planes instead of the current three. This decreases the complexity of the movement and the machine itself. The concept is seen in Figure 6.3.

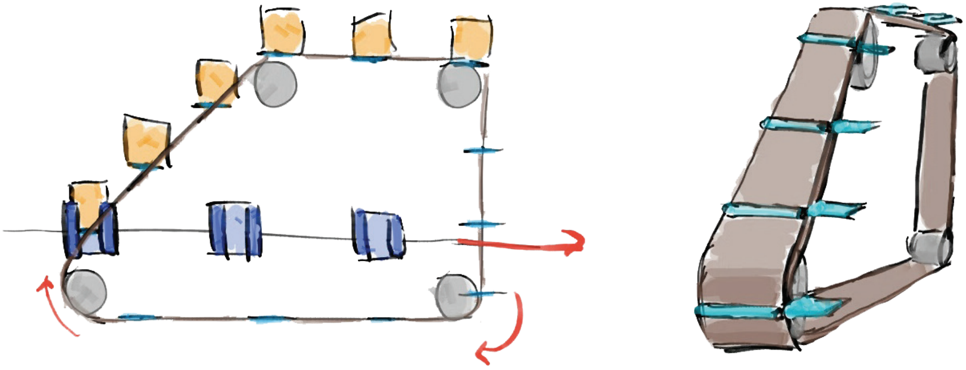

Figure 6.3. Concept B

6.5.1.3 Concept C

Similar to concept B, in this concept the timing-belt in the next part of the production line is prolonged in order to stabilize and enfold the package during the lift. The concept is seen in Figure 6.4.

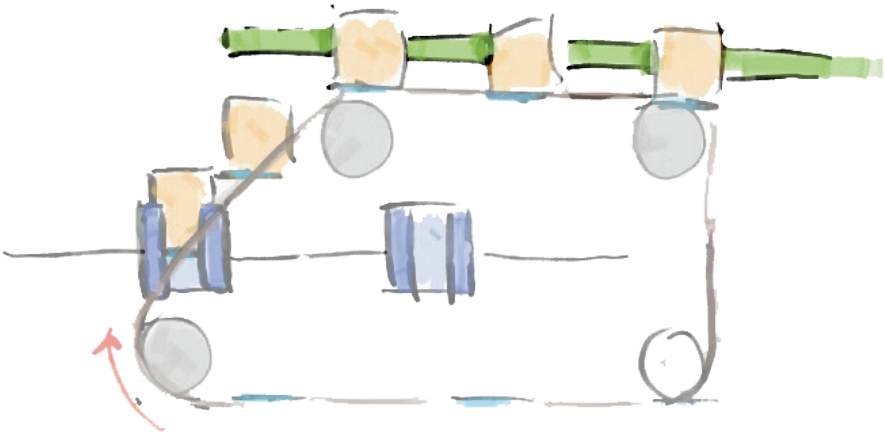

Figure 6.4. Concept C

6.5.2 Two step movement-solutions

Due to the fact that the task is quite a complex one, it is sometimes beneficial to break the problem down into two; below, a description of the concepts that accomplish the desired outcome in two steps instead of one are shown.

6.5.2.1 Concept D

With the aid of a redesigned Pusher, the package is removed from the carrier and raised vertically. Released from the carrier the package is ensnared by two side-gripping conveyor-belts. These conveyor-belts transport the package to the correct position, where it is dropped off at the next part in the production line. The concept is seen in Figure 6.5.

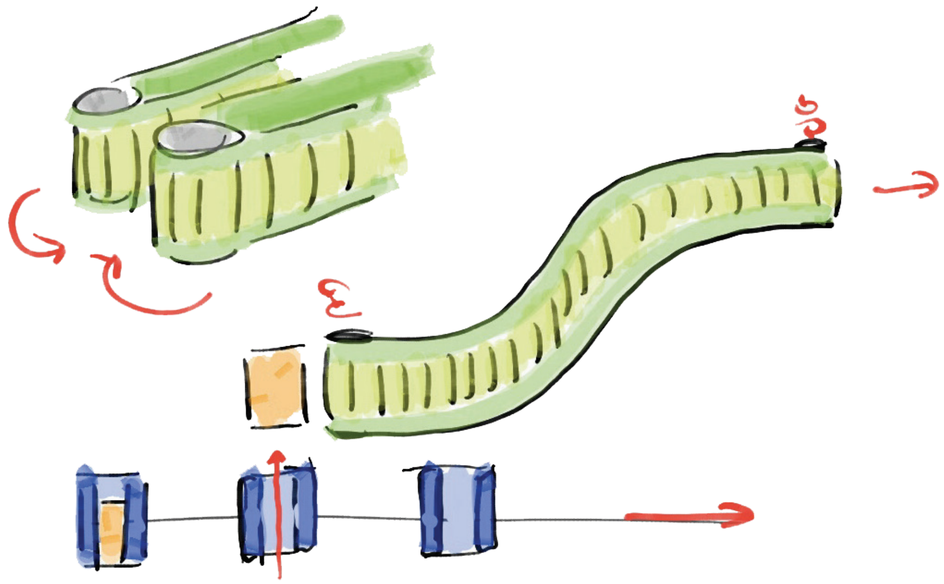

Figure 6.5. Concept D

6.5.2.2 Concept E

The package is raised above the carrier from below by the aid of a Pusher. Once clear of the carrier it is gripped by a spring-loaded mechanism around the sides. The gripping-mechanisms is located along a belt-driven course that will transport the package from above the carrier towards the next conveyor-belt and then back again. The grip of the arms is tightened by guides along the track that directs the arms closer together and increasing their pressure on the package. At the top of the movement the guides edges of and the spring drives the arms apart effectively dropping the package. The concept is seen in Figure 6.6.

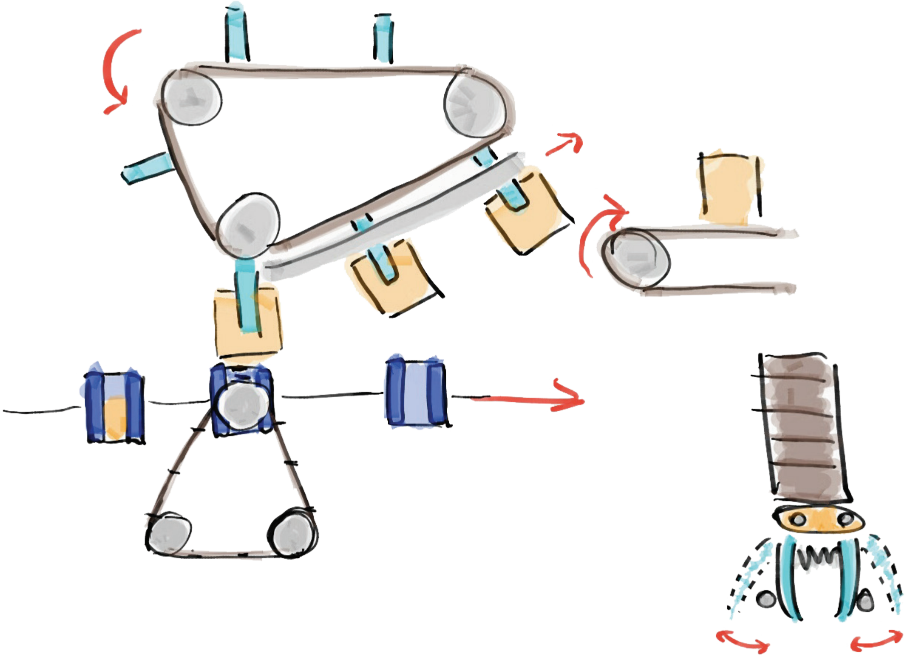

Figure 6.6 Concept E

6.5.2.3 Concept F

The package is removed from the carrier with the aid of a Pusher, a guide above the carriers nudges the package forward where it falls flat on its front-side atop a conveyor-belt. This conveyor-belt transports the package up towards the awaiting conveyor-belt in the next part of the production line. Along its track there is a guide that slowly inclines the package to the correct standing position. The concept is seen in Figure 6.7.

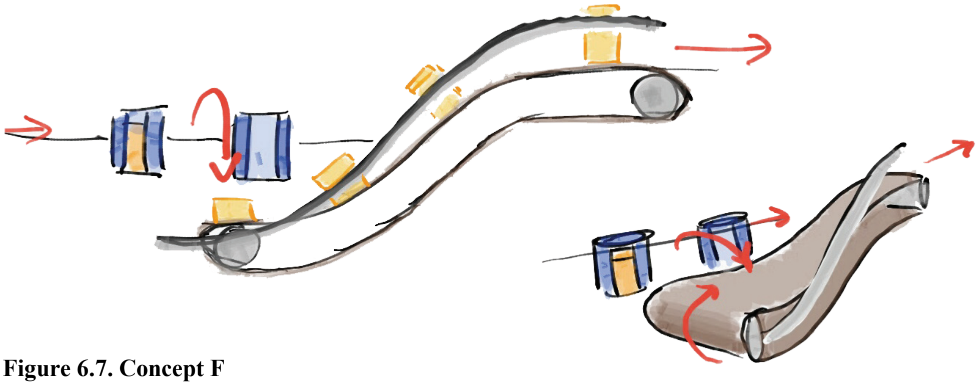

Figure 6.7. Concept F

6.6 Focus group

A focus group was held with developers at Tetra Pak, were the six different concepts were presented and discussed to get more ideas and comments on how the concepts should be further developed. From this focus group, the team got a lot of feedback from experienced developers which gave an indication of what direction the concepts should be taken. Participants of the focus group can be seen in Appendix D.

6.7 Concept Screening

During the development process up until this point, the different concepts have not been scrutinized to any sizeable extent. In order to thin out the herd and avoid putting more time and effort into unpromising concepts, a *Concept Screening* was performed. This first screening was rather rough where every concept was ranked against a reference concept (the current solution). If a concept was better, similar or worse than the reference in a specific category it was awarded with either a “+”, “0” or “-“. The development was continued with the more promising concepts while those lacking will be left behind. Table 6.8 describes the *Concept screening*.

Table 6.8. Overall concept screening

	Concept						
Selection Criteria	**A**	**B**	**C**	**D**	**E**	**F**	**Current Elevator (reference)**
Ease of assembling	+	+	+	0	+	+	0
Resilient of environment	-	+	+	+	+	+	0
Ease of volume adjustment	0	0	+	+	+	+	0
Ease of use	0	0	0	0	0	0	0
Safety	0	0	0	0	0	0	0
Package safety	0	-	-	-	-	-	0
Stability during lift	0	-	-	0	-	-	0
Durability	-	+	+	+	+	+	0
Ease of cleaning	+	+	+	+	+	+	0
Sum +'s	2	4	5	4	5	5	0
Sum 0's	5	3	2	4	2	2	8
Sum -'s	2	2	2	1	2	2	0
Net score	0	2	3	3	3	3	0
Rank	3	2	1	1	1	1	3
Continue	**No**	**No**	**Yes**	**Yes**	**Yes**	**Yes**	**No**

The result of the Concept screening was analysed and it was decided that four concepts would move on towards the next phase of the development-process. This was the four concepts that received a “Yes” in Table 6.8.

6.7.1 Discarded concepts

In the concept screening, there were two concepts that performed worse than their counterparts.

Concept A had the worst performance among all the concepts. It was clear that it was lacking severely in several categories and for this reason alone, it would be discarded. During a focus group with leading Engineers at Tetra Recart it came to the development teams attention that a similar concept had already been used in the machine only to later be replaced by the current solution. This was confirmation that while the concept would work, it would not be equal to the task and it was a correct decision to discard the concept.

Concept B performed a lot better in the screening and due to its many similarities with Concept C it will be improved upon in a way. The concept was discarded only because it performed a bit worse than concept C and there was no point continuing two fairly similar concepts. The difference between the two was that Concept C utilized the timing-belt from the next part of the production line to stabilize the package, while Concept B did not.

6.7.2 Promising concepts

Via the screening process it was recognized that four different concepts seemed promising enough to further develop. One concept from the one-part solutions and three from the two-part solutions. Since every concept used a similar technique to remove the package form the carrier, and where only the way they transported the package the final distance differed; it was reasonable for the concepts to have performed so similarly in the screening.

7 Concept selection

This chapter describes the concept selection. The concepts that passed the screening process were further developed with a more detailed description of the functions and overall dimensions. After this the final selection was made.

7.1 Further development of concepts

The concepts that passed through the previous screening was closer to ideas that conveyed what the concept did rather than a detailed look at how it does it. In this step, the different concepts were scrutinized and further developed in order to solve those questions. Ideas that had previously been generated was used and combined to match the concepts. Some new ideas also came up during this process. Each of the redeveloped concepts are presented with a more detailed description in the following section. The concepts were also given dimensions to match the real interface in the machine, by synchronizing and assembling the concepts together with the carrier transport.

7.1.1 Development of concept C

When it comes to belt-driven apparatuses, the angle of the belt affects the performance and speed. By making the overall shape of the concept include three instead of four gears, the design will be less complex and the synchronisation with the rest of the production line will be easier to maintain.

At the top of the movement the lifting plate slips in between two rails. The distance between the rails are large enough for the plate to pass through but not large enough for the package, which slides along the rails into the next part of the production line instead. With this design, the lifting plate wont risk colliding with the awaiting timing-belt on its way down and its movement can remain two-dimensional. By adjusting the angle of the belt during its decline the lifting plate can avoid the carriers.

The idea of using the following timing-belt to stabilize the package during the lift was discarded, but it did inspire the replacing solution; instead, two timing-belts with protruding guides was placed around the package parallel to the driving-belt. With these, the packages will be stable and safe. To be able to operate with different package and carrier sizes, these stabilizing-belts can be readjusted length wise. Concept C is seen in Figure 7.1.

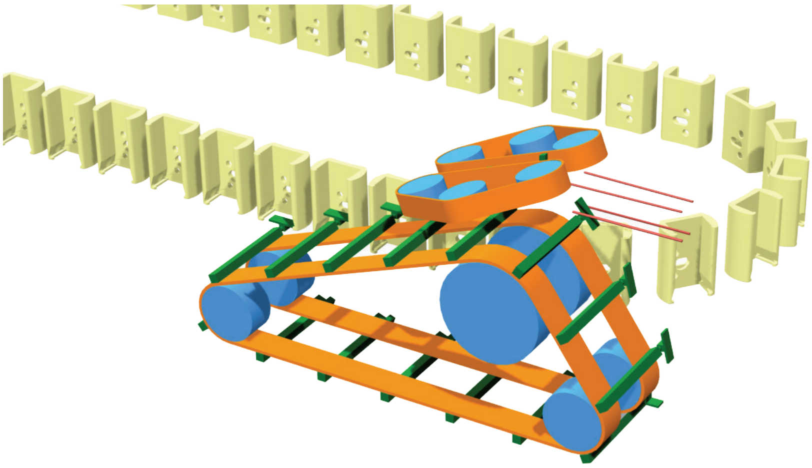

Figure 7.1. Concept C.

7.1.2 Development of concept D

The package is removed from the carrier by being raised upwards with the aid of a redesigned Pusher. The Pusher lifts the package just above the upper limit of the carrier; whereas, the package is gripped by two side-gripping conveyor-belts. These conveyor-belts transport the package to the correct position, where it is dropped off.

Two rails reach in between the conveyor-belts at the top, when the belts begin parting at their upper limit the package begins to drop, the two rails are there to catch it. Since the package still have a horizontal velocity it begins to slide on the rails, which steers it into the next part of the production line. The overall shape of the concept is seen in Figure 7.2.

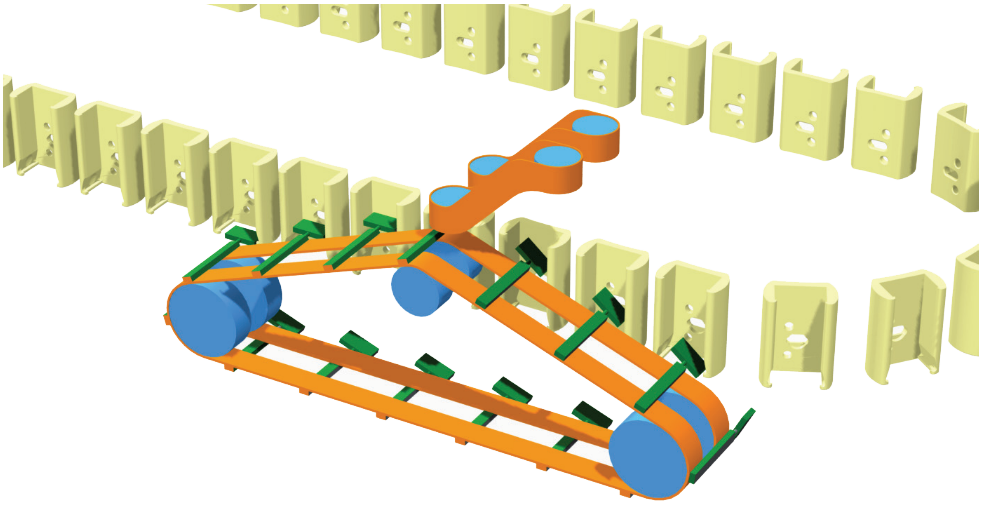

Figure 7.2. Concept D.

7.1.3 Development of concept E

The removal of the package from the carrier follows the same principle as concept D, with a redesigned Pusher; however, in this concept the package is gripped by a spring-loaded mechanism from above instead of the side-gripping conveyor-belts.

Above the carriers, the spring-loaded gripping-mechanisms travers a belt-driven coarse; designed to pick up the packages right above the carriers; move them up and drop them off at the next part of the production line. The track is designed in a quadrangular shape with a low tilt at the drop-off to ensure a smoother landing for the packages. Two metal guides follow the path of the gripping-mechanisms; when the mechanism is supposed to grip a package, they move closer together to force the arms together; and when it is time for the drop-off, they slowly edge away and the gripping-arms are pushed apart by the spring; and the package is dropped.

The machine is supposed to be able to handle every package, even damaged ones. While studying malformed packages a pattern emerged, while the damage on the package was irregular and random, the lower half of the package was always solid. Considering this fact, it was decided that the mechanism had to grip the lower half of the package. Due to the different sizes of the containers the gripping-arms must be of a significant length. Because of the different heights of the carriers both the Pusher and the belt-driven coarse must be adjustable. Concept E is seen in Figure 7.3.

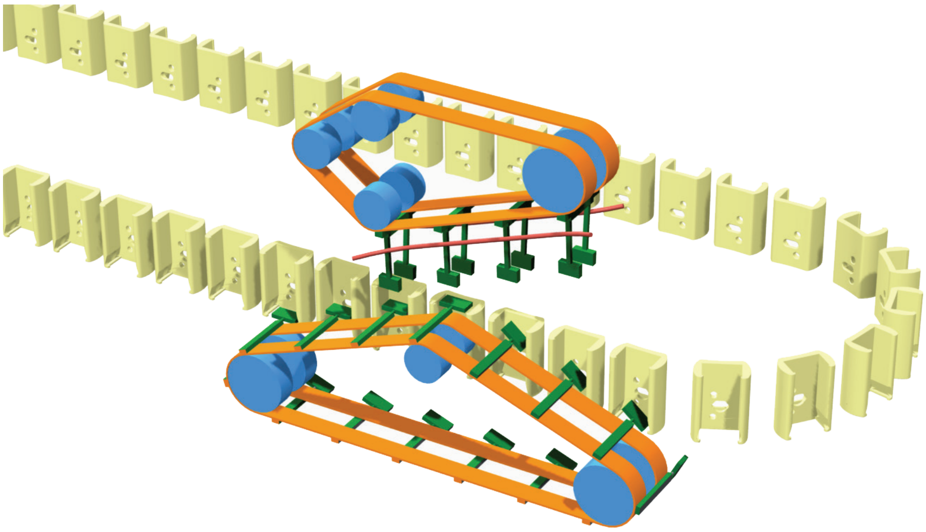

Figure 7.3. Concept E.

7.1.4 Development of concept F

In this concept the same Pusher as in previous concepts is being used. This time however, the holders that are in contact with the packages are modified to be taller. In this concept, it is vital that the Pusher won't be in the way; by making the lifting plates into more of an "L" shape, the Pusher will be able to remain a lot further from the carrier-track than previously.

When the package is raised above the carrier, it is nudged by a guide which in turn makes it fall forward on an angled conveyor-belt. This belt, which can be seen in Figure 7.4, is equipped with plates that will ensure that the packages remain synchronised during this movement. The conveyor-belt will transport the packages to the drop-off height; along the path, a guide follows which slowly slides underneath the package and lifts it to an upright position. The conveyor-belts starting position is right below the top of the carrier to minimize the falling height of the packages.

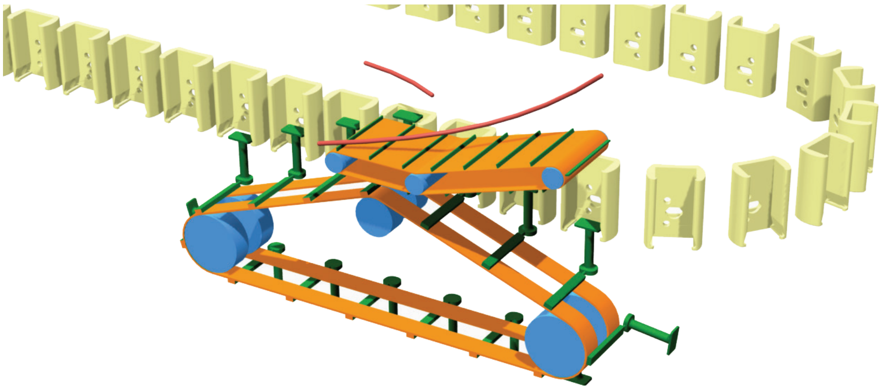

Figure 7.4. Concept F.

7.2 Concept scoring

To evaluate the remaining redeveloped concepts a concept-scoring-matrix was used, see Table 7.1. Contrary to the previous concept-screening, this matrix was a lot more complex and detailed. In this, each of the customer needs gathered from interviews and other research was translated into weighted specifications where each needs importance was considered and ranked. For instance, safety needs were ranked a lot higher than accessibility since safety always comes first; i.e., a high score in safety will affect the final score more than the accessibility. Each of the concepts was individually ranked on every single need and given a score between one and five; rank one was given if the concept performed horrible in that category; rank three was used as the reference-number, meaning that if a concept was equal to the current solution it would also be given an average score; rank five was given if a concept performed a lot better than the reference in a particular category; finally, the in-between numbers two and four was given if a concept was a little worse or a little better than the reference. Each need was evaluated by the team, where their knowledge and experience gained during this thesis was utilized.

Table 7.1. Concept scoring.

		Concept									
		C		D		E		F		Current elevator (Ref)	
Selection Criteria	***Weight(%)***	***Rating***	***Weighted Score***	***Rating***	***Weighted Score***	***Rating***	***Weighted Score***	***Rating***	***Weighted Score***	***Rating***	***Weighted Score***
Ease of assembly	11										
Consist of few parts	2	5	0,10	4	0,08	4	0,08	4	0,08	3	0,06
Consist of few moving parts	2	4	0,08	2	0,04	3	0,06	4	0,08	3	0,06
Components are easy to replace	4	4	0,16	3	0,12	4	0,16	4	0,16	3	0,12
Low mass	3	5	0,15	4	0,12	4	0,12	4	0,12	3	0,09
Resilent of environment	5	4	0,20	3	0,15	2	0,10	4	0,20	3	0,15
Volume adjustment	13										
Is easy to perform	4	3	0,12	1	0,04	2	0,08	4	0,16	3	0,12
Is quick to perform	9	5	0,45	1	0,09	4	0,36	4	0,36	3	0,27
Ease of useage	16										
Easy to understand	2	3	0,06	3	0,06	3	0,06	3	0,06	3	0,06
Fast to reset after breakdown	3	3	0,09	4	0,12	2	0,06	2	0,06	3	0,09
Easy to syncronize	3	2	0,06	3	0,09	3	0,09	2	0,06	3	0,09
Easy to clean	5	5	0,25	3	0,15	4	0,20	4	0,20	3	0,15
Good accessibility	3	4	0,12	4	0,12	4	0,12	4	0,12	3	0,09
Safety	16										
Safe to operate	12	3	0,36	3	0,36	3	0,36	3	0,36	3	0,36
Safe to assemble	4	3	0,12	3	0,12	3	0,12	3	0,12	3	0,12
Package handling	33										
Handle deformed packages	8	3	0,24	2	0,16	2	0,16	4	0,32	3	0,24
Handle empty packages	7	3	0,21	2	0,14	2	0,14	4	0,28	3	0,21
Doesnt deform packages	10	3	0,30	2	0,20	2	0,20	1	0,10	3	0,30
Handle different speeds	8	3	0,24	3	0,24	3	0,24	3	0,24	3	0,24
Manufacturing ease	6										
Low material cost	3	4	0,12	3	0,09	4	0,12	4	0,12	3	0,09
Use of standard components	3	4	0,12	4	0,12	4	0,12	3	0,09	3	0,09
Total weighed score		**3,55**		**2,61**		**2,95**		**3,29**		**3**	
Rank		**1**		**5**		**4**		**2**		**3**	
Continue?		**Yes**		**No**		**No**		**No**		**No**	

7.2.1 The Chosen Concept

As seen in Table 7.1, concept C performed best overall with a score of 3,55; and because of that, it will be the chosen concept to be taken into the final development phase. Both concept D and E performed underwhelming and achieved a score lower than 3, they performed worse than the current solution; and it won’t be relevant to continue development of them, because of this. Concept F did quite well, it was not the best of the four but it did score 3,29 which was better than the current solution; and if the winning concept somehow fails in a later step, it will always be possible to go back and continue with this one instead.

The strengths of concept C was primarily the simplicity of the design and the quick volume change. Because of the simplicity, the concept was comprised of relatively few parts. Fewer parts correlates to a lower weight and a more open assembly, which in turn affects the cleaning in a positive way. Considering that the only step needed to modify the concept regarding different volumes was readjusting the stabilizers, the volume change was both a lot faster and easier to perform than the current solution.

8 Further development of the winning concept

In the previous chapter one concept was chosen to further develop. In this chapter a more detailed description of functions, components and calculations will be presented. The concept will move to a phase where major parts are defined and preliminary dimensions after the current circumstances are set.

8.1 Design of the Lifting device

The lifting device is the designed model that is responsible for the entire lift of the packages. This is the most important part, and has been the most time-consuming part to develop. During the further development phase, there has been a lot of new insights which has resulted in changes in the design a couple of times.

8.1.1 Impact of the initial lift

The initial contact of the package and lifting plate results in an impact between the two, it is vital that the package survives the initial impact without any deformation or otherwise gets damaged. The impact itself is a result of; a moving object, the lifting plate; colliding with a stationary object, the package; which deforms slightly during its acceleration. The chosen concept makes it impossible to avoid this and it must be investigated if the package can bear the impact load during the lift. As a reference, the current solution is investigated. Since the package survives the impact without getting deformed or damaged it is a good guideline where one could assume that if the new concept has a smaller impact than the current solution, it will be safe.

The impact on the package is related to the vertical speed of the lifting arm when it hits the package. Since the horizontal speed is the same between the holder and carrier, the interesting magnitude is the angle of the holder when it hits the package. By analysing the lifting-curve of the current Elevator, it was found that when the lower jaw hits the package, the angle of the curve is roughly 24°. This can be seen in Figure 8.1. To avoid any deformation or damage to the package the lifting-angle should be 24° or lower, where lower will result in a lower impact. As a goal, the team decided to aim for a lifting-angle of 20°. This will ensure that the impact-velocity is safer than the current solution. A lower angle will result in a longer horizontal dimension for the design. This problem was dismissed since there is a lot of extra space available before and after the current machine.

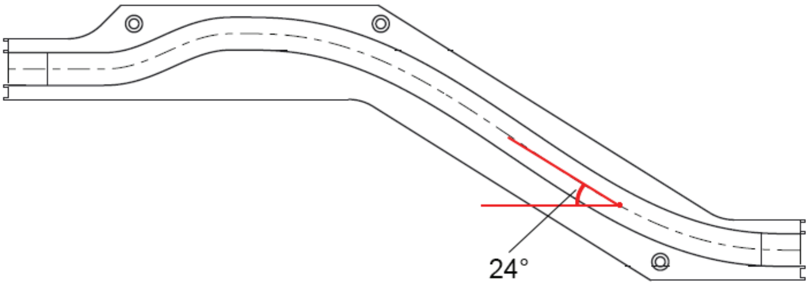

Figure 8.1. The current lifting curve showing the angle where the lifting jaw hits the package.

8.1.2 Calculation of vertical acceleration at top wheel

At the top of the upper pulley, where the belt travers around the pulleys circumference, the lifting arm will deaccelerate its vertical speed towards zero while the horizontal speed increases. Since the winning concept doesn’t have anything keeping the package down, it is vital that the package won’t leave its perches on the lifting plate. By choosing the radius of the pulley, so that the deceleration of the lifting plate will be less than the gravitational force, the package will remain seated and the problem will be bypassed. The calculations showed that the minimum diameter of the top pulley had to be at least 209 mm, to avoid accelerations above the gravitational acceleration, depending on the chosen angle of the lift. In Appendix E, all necessary calculations can be found.

8.1.3 Return movement

A vital part of this concept is the return movement; it is a necessity that the lifting plates avoid the carriers at all costs. Earlier in the development process a three-pulley design was made thinking it would be able to avoid the carrier-coarse by simply moving the back-pulley further back. That would work on the smaller carriers, the bigger carriers were a bit trickier however. Calculations showed that to avoid the bigger carriers the decline of the lifting plates had to be lower than 7,584°. With such a low decline, the available space for the machine simply wasn't enough.

To accommodate for these new discoveries a new, forth pulley was introduced. By adding the forth pulley to the design, the problem of the decline was solved, the available space would not cause an issue and the design remains fairly simple. Figure 8.2 shows how the introduction of a forth pulley changed the geometry of the set up.

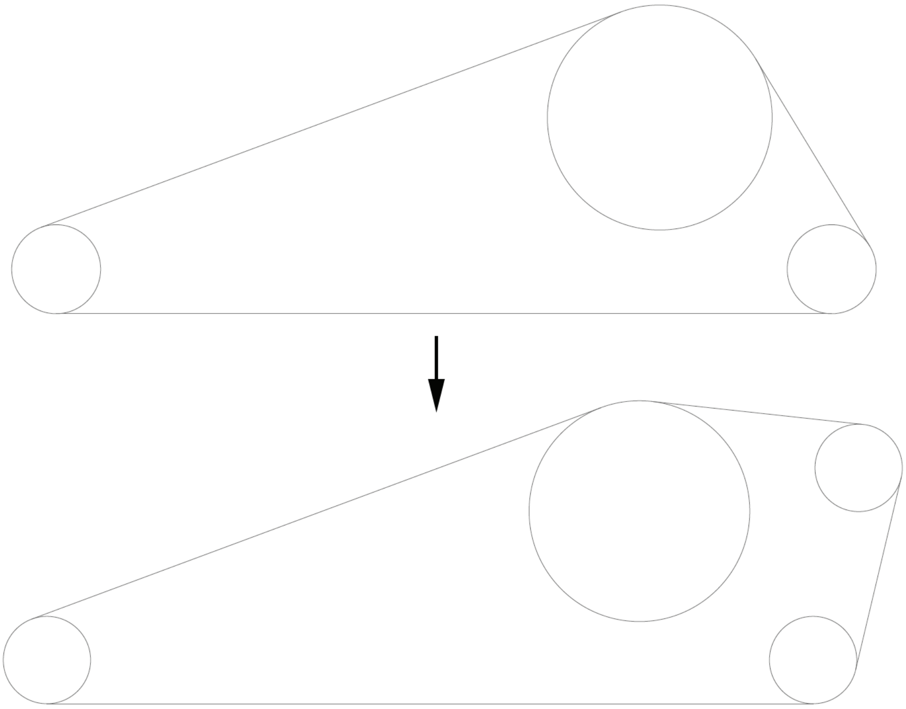

Figure 8.2. Shows how the design changed to avoid the carriers.

8.1.4 Choice and dimension of timing belt and pulleys

The choice of the different dimensions on the timing-belt and pulleys were made based on several different aspects. Aspects such as type of material, dimensions and tooth-profiles. Tetra Pak employ a company named Aratron when it comes to their needs in this category; and the supervisors at Tetra Pak forwarded their information since it was only logical for the team to employ the same company for this concept. Aratron is an application expert within this field, and are providing transmissions from different quality suppliers [9]. The first step in this process was to find a suitable type of belt, and the choice fell on the standard profile ATK10K13. This profile has been used in similar applications within Tetra Pak, and after discussions with developer at Tetra Pak [10], this belt standard seemed like a suitable choice. The profile has a self-guiding rail in the middle of the belt, which always keeps the belt in the correct position.

For the belt to always stay synchronized with the carriers during the lifting process, the angle of the lift has to be chosen in a specific way. The reason for this was because the chosen belt has a distance of 10 mm between each of its teeth, which means that the distance between mounted components on the belt must be at a multiple of 10 mm. The distance between the carriers are 150 mm. To remain synchronized with the carriers, the horizontal length between the lifting plates attached to the belt must be 150 mm; and the length of the lifting section must be dividable by 10 mm. The lifting plates on the belt must be attached at this distance between each other to ensure that there was synchronisation around the belt. The lowest possible angle of the lifting section was procured by mounting the lifting arms with a 16 teeth-distance, which was equal to 160 mm, see Figure 8.3. With this type of design, the lifting angle α becomes:

$$\cos(\alpha) = \frac{15}{16} \rightarrow \alpha = 20.364°$$

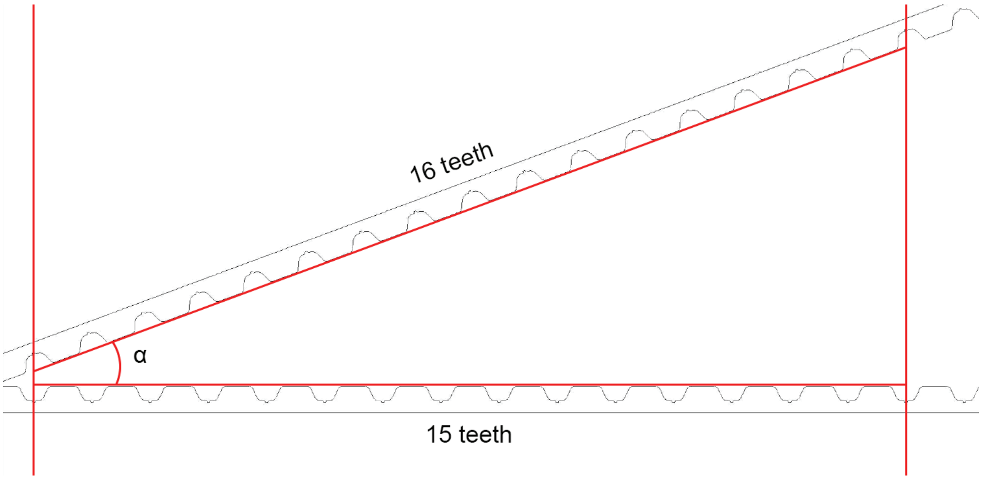

Figure 8.3. Lifting angle of the belt.

The next step was to select suitable dimensions for the pulleys and the belt length. As an aid for this, a calculation software from Mulco [11] was used. The pulleys were selected regarding special quick releases for the lifting arms in mind. This type of quick releases makes it possible to mount components on the belt without putting any screws into it. It makes the mounting and service of the machine easier. The quick releases are an invention from Tetra Pak that is used in other parts of the machine, and is therefore a standard part which is confirmed to perform well. The quick release is seen in Figure 8.4.

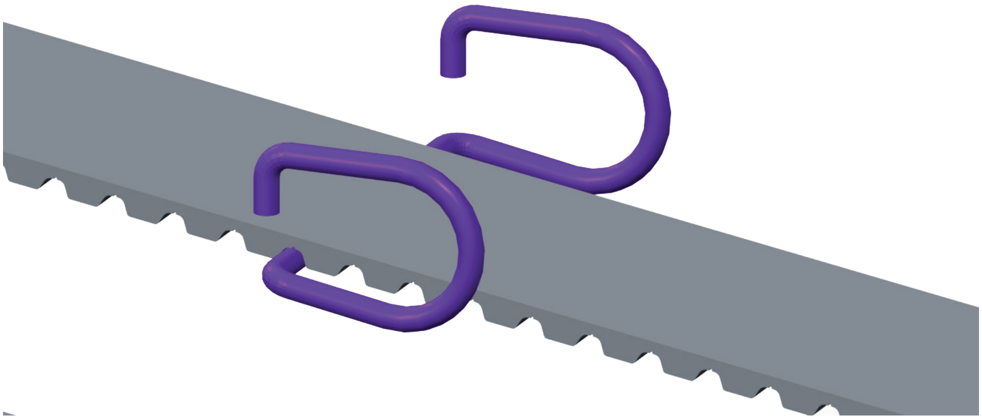

Figure 8.4. Quick release for mounting components on the belt.

One of the drawbacks of using this type of quick release was that each quick release occupies the volume where one of the teeth of the pulley will interfere with the belt. The solution to this was to remove the teeth of the pulleys that were affected by this. Since the belt was designed to have lifting arms attached at every sixteenth tooth of the belt, the pulleys needed to have a tooth-number which was dividable by 16, to keep it synchronized. Every 16th tooth must be removed from the pulleys to make them compatible with the quick releases.

The three smaller pulleys were selected with a tooth-number of 32, which gives them a diameter of 100.04 mm. As the lifting angle was selected to 20.364°, the minimum radius of the top pulley needs to be at least 113,4mm, see Appendix E. The top pulley was selected with a tooth-number of 80, giving it a diameter of 252.83 mm [12, p 25]. This size satisfies the condition of the minimum radius of the pulley. Both pulley sizes have a tooth number that was dividable by 16, and makes them compatible with the quick releases. With this selection, two teeth must be removed from the three smaller pulleys, and five teeth from the larger pulley. These pulleys are all standard sizes offered by Aratron.

These pulleys were inserted into the calculation software [10] to verify how the geometry of the pulleys in relation to each other should look like, and to adapt the dimensions after a suitable length of the belt. The length of the belt was selected to be 2400 mm, which resulted in the dimensions given in Figure 8.5. This belt length makes it possible to mount 15 lifting arms around the belt, with an equal distance of 160 mm between each other.

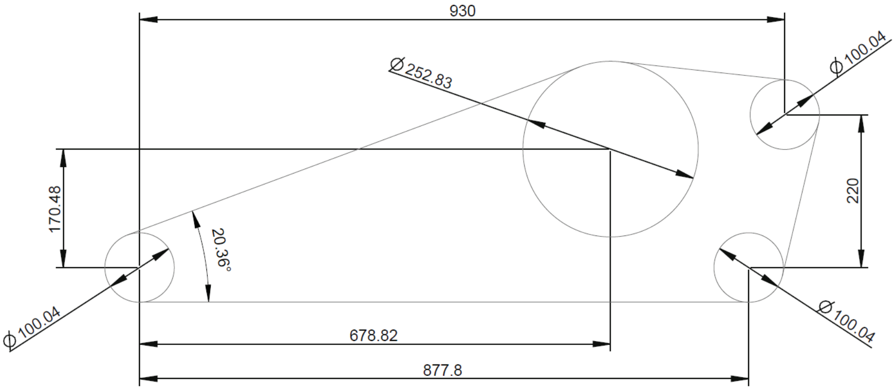

Figure 8.5. Geometry for the belt and pulley set up.

To complete the selection of the belt dimensions, the width of the belt also has to be selected. A design guideline from Aratron [12, p 18] was used to determine which belt width was needed to resist the loads acting on the design. From the guideline, it was realized that the tangential forces on the belt was not going to be crucial for the dimensioning of the belt width. Calculations on the forces resulted in a belt width of 5 mm, and the smallest available belt was 25 mm. The width of the belt was selected by considering that the loads were located outside the belts; and therefore, contributes to twisting the belt. A wider belt will have better strength against shearing. No calculations of this manner was performed since they were deemed unnecessary by the team and a prominent developer at Tetra Pak [10]. Since the Pusher can handle its loads, which are higher than for this part; one can assume that it will work here as well. The belt width was decided to be set to 50 mm after discussions with developers at Tetra Pak.

Two of these belt and pulley set ups will be mounted parallel to each other for the possibility to mount shafts between the belts. This will also make the design more stable against the shearing loads acting on the plates that are lifting the packages.

8.1.5 Lifting plate

The dimensions of the lifting plate will be chosen in regard to several different parameters, where the most relevant magnitude was the area of the plate in contact with the bottom of the package. The vertical speed of the plate was not the only parameter affecting the impact of the package, the area of the contact surface between plate and package was crucial as well since the force of the impact will be distributed over the contact area. The resulting pressure will determine whether the package will survive the lifting experience deformed or not. The dimension of the lifting plate has also been set regarding the drop-off station, the drop-off concept demands that the lifting plate only covers roughly half of the bottom area. A more detailed description of the drop-off zone will be presented later in this report.

A calculation of the impact on the packages in relation to the area of the lifting plate was made by estimating values and comparing the result with the current solution of the Elevator.

When the plate hits the bottom of the package, it was assumed that the package would be deformed by roughly 3 mm. This means that the package will accelerate from stationary to the vertical speed of the lifting plate over a distance of 3 mm. By making this assumption, the acceleration of the package could be calculated, and with the desired area of the lifting plate, the pressure on the package could be determined. The result of these calculations showed that the lifting plate needed to have a contact area with the package of at least 1550 mm^2 to exert the same pressure on the package as the current Elevator. Calculations can be found in Appendix F.

The dimensions of the lifting plate in contact with the package was selected to 65*26 mm, which results in an area of 1690 mm^2; that was above the calculated minimum area of the plate. Making the plate wider will be risky due to the interference with the carrier. With these dimensions, the tolerance towards the carrier will be enough to avoid the plate from crashing into it.

To make it possible to connect the plate to a lifting arm, the design included a part which was thicker than the contact area. A hole was placed in that area, which was to be the connection to the lifting arm. The design of the lifting plate is seen in Figure 8.6.

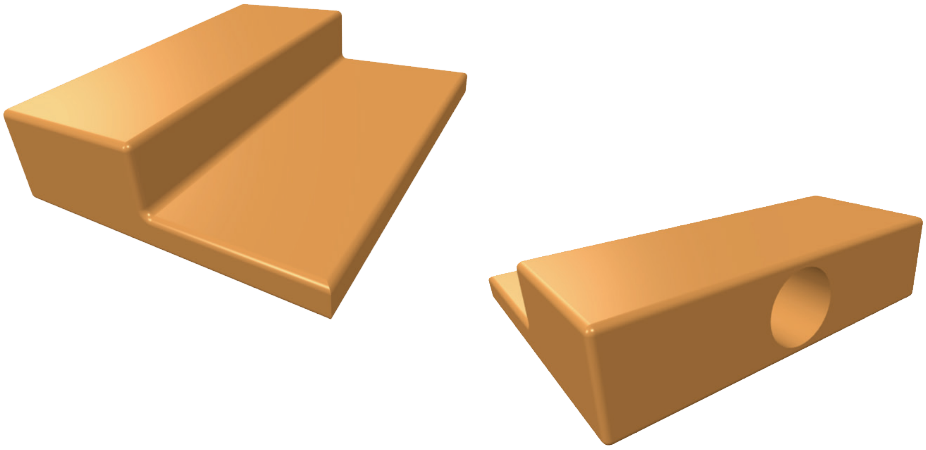

Figure 8.6. Lifting plate.

8.1.6 Lifting plate – rotation

To ensure that the package would be safe and stable during the entire lift, it was advantageous to keep the package in a horizontal position. Since the angle of the belt was changing during the top of the lift, the lifting plates will also have to change its angle. By making the lifting plates able to rotate around the axis of the lifting arms, they can be kept in a horizontal position during the entire lift. It was preferable that the lifting plate was able to only rotate in a limited range. If the lifting plate were able to rotate around the entire revolution, it would increase the risk of failure since the lifting plate might hit the package at an awkward angle. Figure 8.7 shows the angles that are affecting the lifting plates during the lift. To keep the lifting plates in a horizontal position during the entire lift, they must be able to rotate 20.36+6.21= 26.57° around the axis of the lifting arms.

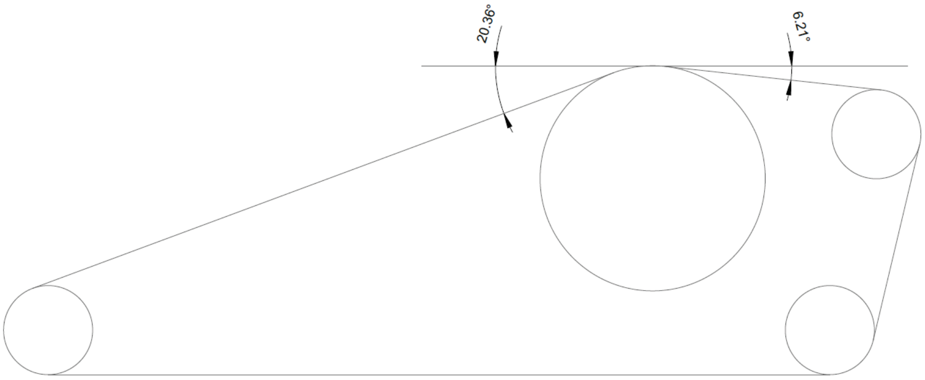

Figure 8.7. Show the angles of the incline and decline.

To adapt the design after this, a new solution was introduced. An exploded view of the design is seen in Figure 8.8. In the lifting arm, there is a threaded hole where a screw is mounted; and in the lifting plate, there is an oval hole where the screw goes in. The design makes the lifting plate able to rotate around the axis of the lifting arm but is limited to the desired angles. When the lifting plate rotates, the screw rotates with it. When the screw head collides with the oval hole, the rotation stops. The dimensions of the oval hole determine which angles the plate can rotate.

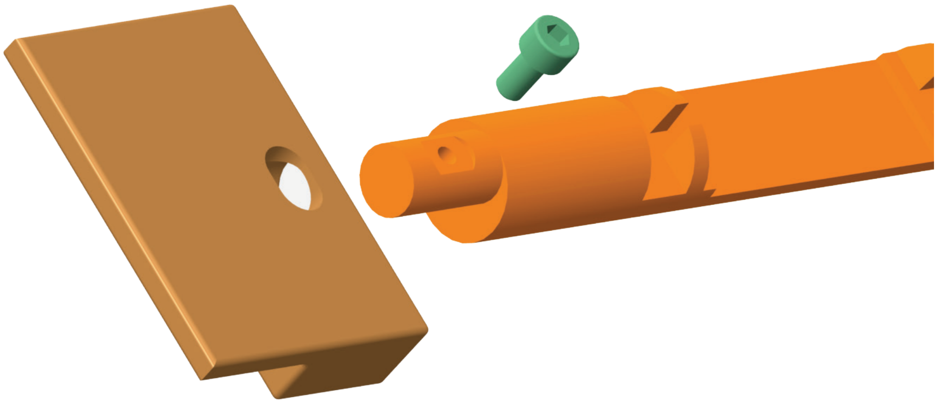

Figure 8.8. Explored view of the lifting plate mounted to the lifting arm.

8.1.7 Lifting arm

As mentioned earlier, a specially designed quick release will be used to mount components on the belt. To connect the lifting plate to the belts, a lifting arm was used. The lifting arms were connected to the belts with the quick releases, and the lifting plates were connected to the lifting arms. Together, these components create the design which translates the motion of the belts to the lifting plates. Just as the quick-releases, the lifting arms are also standard components which has been developed within Tetra Pak. The use of standard components is a big advantage, since it saves a lot of costs developing new parts. This was one of several reasons the team decided to use this type of lifting arm, the others being mentioned in a previous chapter. The arm has been slightly adjusted to match the design of the lifting plate. In Figure 8.9 the lifting arm is seen, mounted to the belt together with the lifting plate.

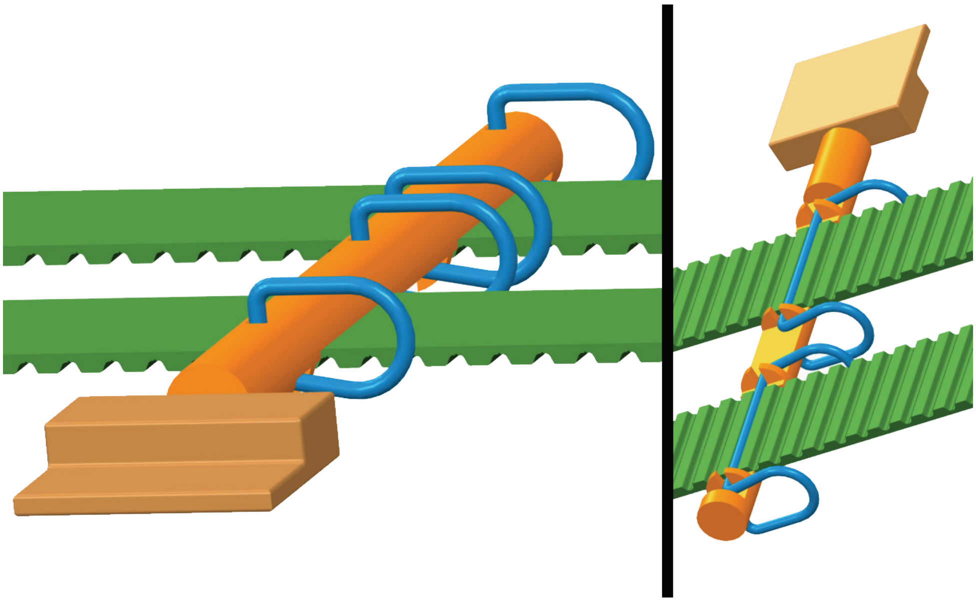

Figure 8.9. Lifting arm mounted on the belt.

8.1.8 Driving pulley and belt tension

The idea of the entire design was to have one pulley in charge of driving the belt while all others were fastened on bearings and able to rotate freely. At the same time, one pulley needed to be adjustable in order for the belt tension to be modifiable. Of the four pulleys, only one can be moved without it affecting the performance of the design; that was the pulley furthest to the right (4) in Figure 8.10. It was important that both the incline and decline of the belt trajectory before passing the carriers remained the same, which only freed up pulley number four (4). The choice of the driving pulley fell on the third one from the left (3). The driving pulley must remain fixed in the same position, and since it will be pulling the belt, the belt tension will be at its highest right before the pulley. On the other side of the pulley, the belt tension will be lower since the pulley will push the belt rather than pull. Another aspect to consider during the choice of the driving pulley was the wrap angle of the belt. It was preferable to have as large of a wrap angle as possible to ensure minimal wear on both pulley and belt. Pulley number one (1) has the largest wrap angle, and was the best choice to be the driver pulley in this particular regard; but since it was vital that the belt was tensed during the lifting section, the third pulley (3) was considered to be the best choice for the driver pulley, anyway. This pulley has a wrap angle of 97.1°, which was enough to be considered safe [13, p 654].

In short, the timing-belt is driven by the third pulley (3) while the rest is freely rotating around their individual bearings. The forth pulley (4) is adjustable so that the belt can be tensed, it will also make it easier for the belt to be removed and changed for a new one when the tension can be decreased by simply moving one of the pulleys. The respective pulley numbers can be seen in Figure 8.10.

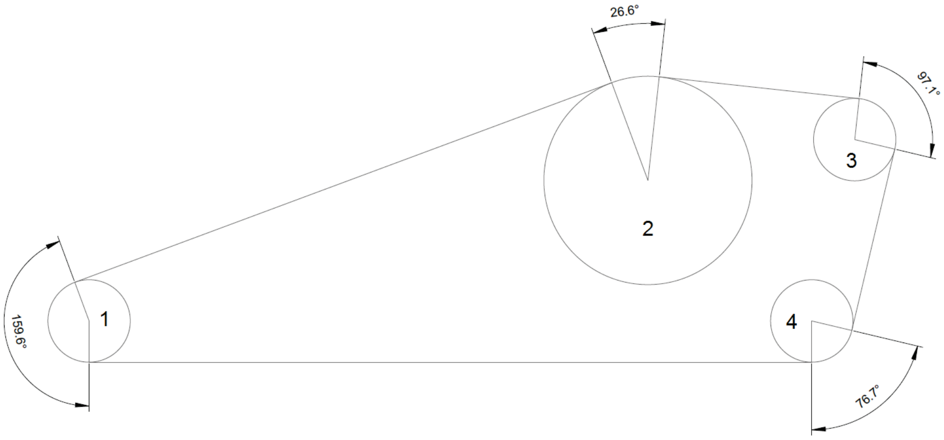

Figure 8.10. Pulley and belt set-up with wrap angles.

8.1.9 Final design – lifting device

All the different aspects of the design were put together and a final design was created. A housing was added to the design, to show how the pulleys would be mounted together in the correct positions. The design is seen in Figure 8.11.

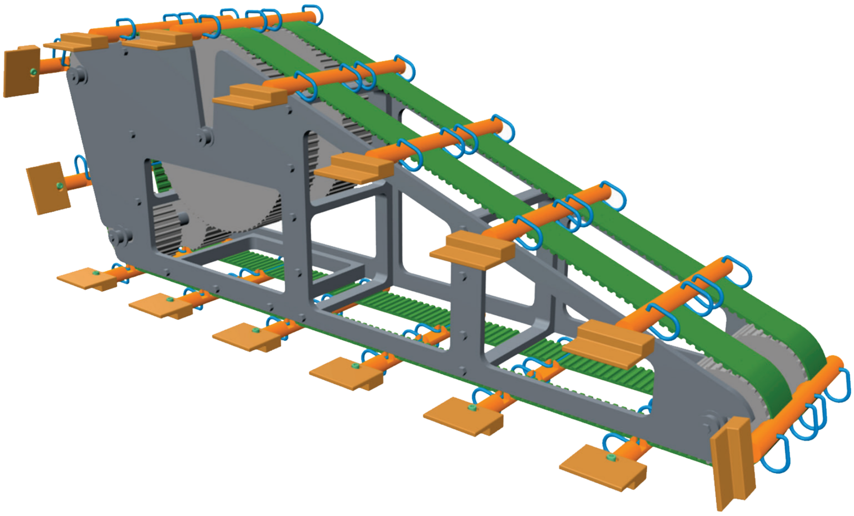

Figure 8.11. Final design of the lifting device.

8.2 Stabilizers

When the package is removed from the safe embrace of the carrier, it is only held from below by the lifting plate. If the package is left alone there is a risk of falling. By letting the package be surrounded by a guide and a timing-belt, this problem will be eluded.

8.2.1 Timing-belt

The timing-belt will travers besides the package and are equipped with support bars which purpose is to catch and steady the package when or if it starts to fall in either direction. The trajectory and speed of the timing-belt will match the package to avoid any needless friction and rough contact. Both the timing-belt and its support bars won’t be in contact with the package at all times, their purpose is not to hold the package, rather support it when the need arises. The support bars are cylindrical objects fixed at the timing-belt with enough spacing between each other for the package to fit in-between. The timing-belt is equipped with threaded holes along its length. The support bars, which are equipped with a threaded part as well, are fastened onto the timing-belt by being screwed onto it. It is important that the length of the belt is dividable by 160 mm, since the support bars must be synchronised, the distance between the support bars must be the same. The timing-belt with support bars is seen in Figure 8.12.

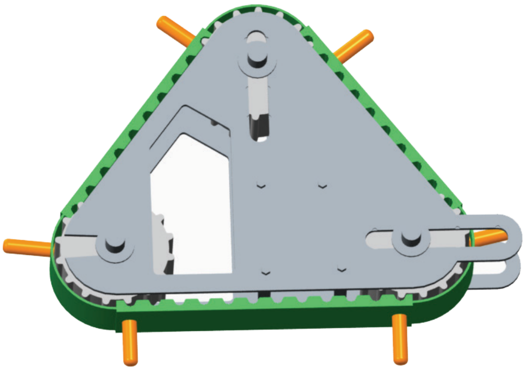

Figure 8.12. Supporting timing-belt.

8.2.2 Guide

While a timing-belt moves with the package on one side, a panel made of plexiglass works as a stabilizer on the other side. This is a solid surface designed to work as a support providing as little friction as possible between package and surface. The bottom of the plexiglass is bevelled to ensure a safe and smooth initial contact with the package.

In earlier steps of the concept the stabilizer involved two timing-belts, one on each side. Due to the lack of space and unnecessary extra parts that an extra timing-belt would result in, it was removed and replaced with the plexiglass since it’s already a part of the current machine interface. In Figure 8.13, the stabilizing timing-belt (1) is seen assembled in the machine together with the plexiglass guide (2). In the figure, a package (3) is seen right when it's leaving the carrier; it can be seen how the supporting bars are stabilizing the package on its sides, preventing it from falling.

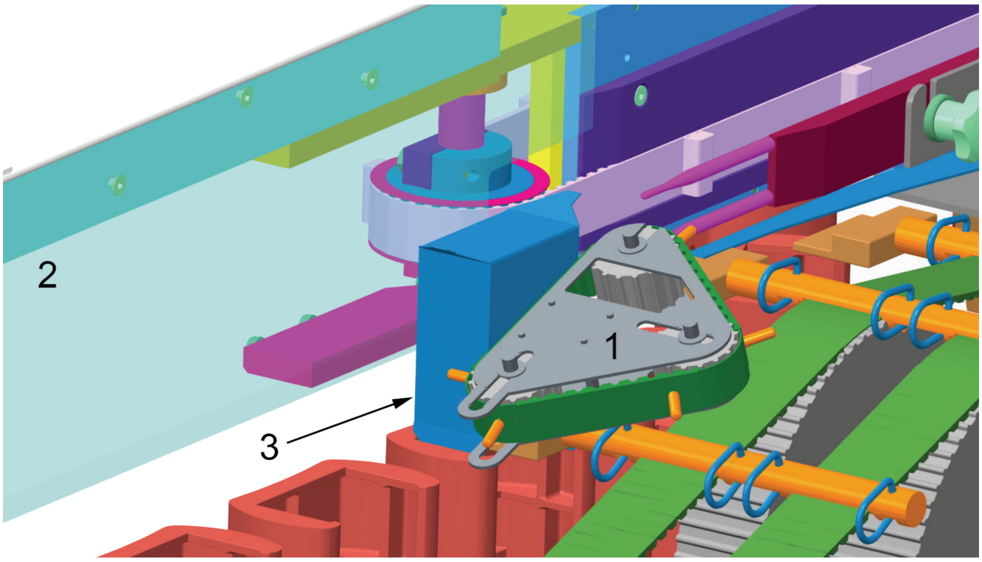

Figure 8.13. Supporting timing belt mounted in the machine.

8.2.3 Volume adjustment

Since the timing-belt travers with the package, and the carrier- and package-height differ between volumes, it stands to reason that the timing-belt must adapt as well. By designing the timing-belt with three pulleys and making the middle and lower one moveable, the total length of the contraption will be adjustable. This is seen in Figure 8.14. In the length of the frame where the two moveable gears are fastened,

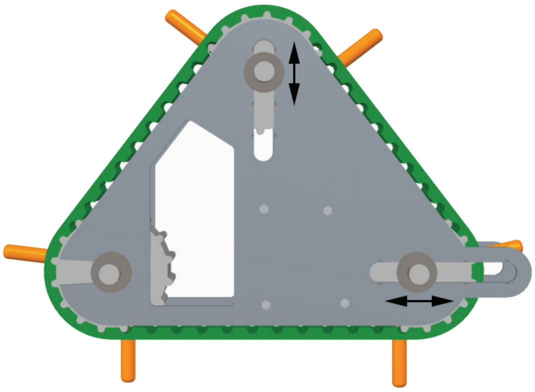

Figure 8.14. Volume adjustment procedure.

there are tracks designed to make the length fast adjustable after the different volumes.

The plexiglass is a fixed mass so it won't be adaptable; however, that won't be necessary since it will only need to support the package when it has left the carrier entirely. The height-difference of the smallest and largest package is roughly 42,5 mm, the height of the smallest package is 92 mm; the package, if it is dimensioned after the largest carrier, will in other words reach the plexiglass before it leaves the carrier.

Since both the bottom of the packages and the drop-off plate will always be at the same height, there won't be any need for modifications regarding the volume change. The only component of the concept needing adjustments will be the stabilizer-belt; and with this solution, that will be a smooth process, as well.

8.3 Delivery

Right below the top-peak of the upper pulley, the delivery-station is situated. It is here the package will be removed from the lifting plate and placed at the following conveyor-belt at the next part of the production line.

8.3.1 Drop-off plane

The drop-off plane was redesigned to match the solution of the new lifting concept. In the current design, there is a rotating disc located at the drop-off zone. This disc was removed and replaced by a new solution that fulfils the same task. In Figure 8.15, the new design is seen. By designing the lifting plate (1) to only envelop roughly half of the package bottom; an opportunity occurred where the package could be left at a shelf (2), which only covers the second half of the package bottom, simply by letting the lifting plate pass through that plane during its decent. When the lifting plate has passed through (3), the width of the shelf starts to increase, to ensure the package stays stable on the plane.

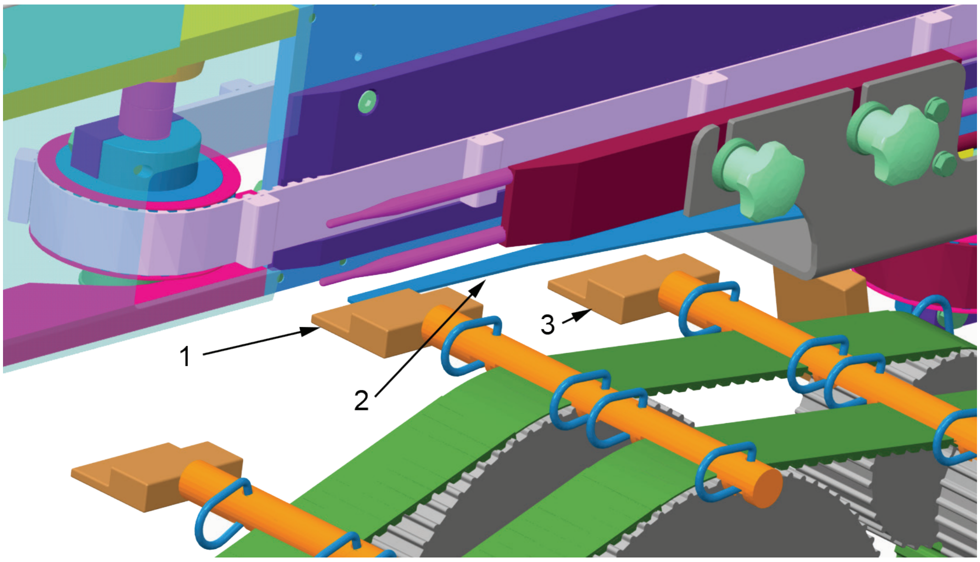

Figure 8.15. Design of the drop-off plane.

In order to avoid a collision between the lifting plate and the framework, which the metal guide is fastened onto, a small geometry was removed. The new design of the framework can be seen in Figure 8.16.

Figure 8.16. Adapted framework.

8.3.2 Timing-belt and Guide

The delivery station is seen in Figure 8.17, which shows the timing belt (1), the metal guide (2) and the redesigned drop-off plane (3). It is important that the machine remain in control over the package at all times; by using the timing-belt from the waste-handling in the next part of the production line, it will be able to catch the package right when it leaves the grip of the stabilizing timing-belt. On the other side; a metal guide, also from the following waste-handling, is designed to steer the package inside the drop-off. Since the shelf is designed to only support the package on a part of the bottom, it falls upon the guide and timing-belt to keep it upright and steady.

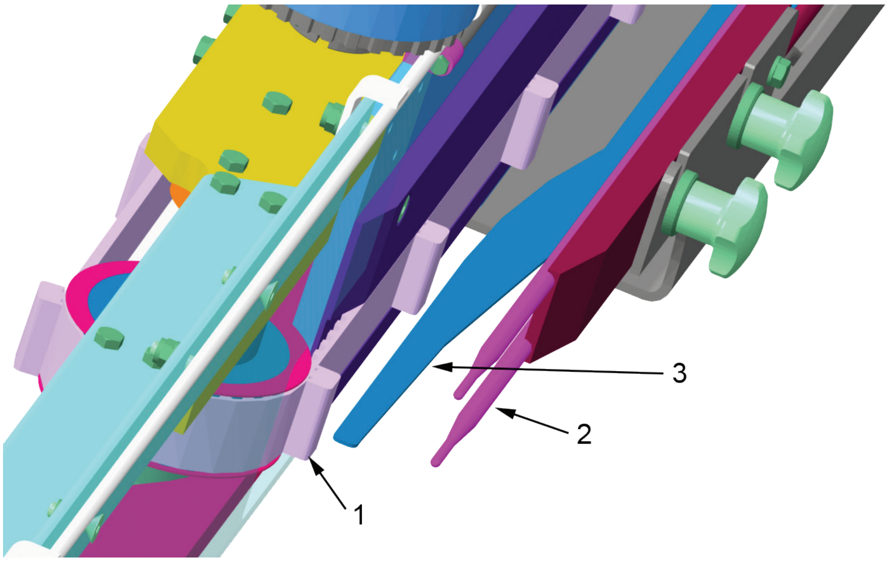

Figure 8.17. Delivery station.

The current metal guide was redesigned to match with the stabilizing timing-belt. Right when the package is leaving the stabilizing timing-belt, it needs to be supported from the side by the metal guide. To make the transition from the timing-belt to the guide smooth, it is preferable if the metal guide is almost touching the timing-belt without interfering with the support bars. This will ensure that there is no gap from where the package leaves the stabilizing timing-belt and enters the metal guide. By designing the end of the metal guide as two parallel bars, the supporting bars on the timing-belt can slip in between the two bars and the guide can be designed closer to the timing-belt. This will ensure that the package is stable at all times, and the transition will be smooth. In Figure 8.18 the metal guide (1) is seen, when a supporting bar (2) is slipping in between.

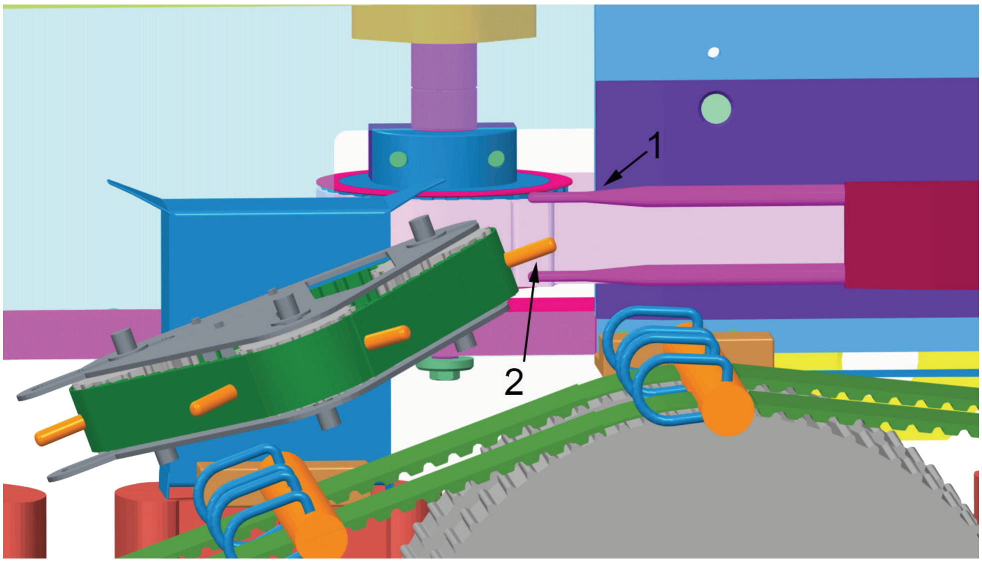

Figure 8.18. Stabilizing belt assembled in the machine

8.3.3 Flap orientation

When the package is left at the shelf, the lifting plates velocity will be higher than the package. This occurs since the belt-velocity was configured to move at 1 m/s in the horizontal direction at the lifting-section of the design. This results in a slightly higher belt-velocity, when the angle of the belt decreases, the horizontal velocity increases.

Figure 8.19 shows the lifting plate starting to surpass the package. When the package is left at the shelf (3), the timing-belt from the waste-handling station takes over and moves the package forward. The lifting plate (1) will overtake the package (2), effectively nudging the front flap (4) forward. The hind flap will move into the correct orientation naturally. While it is not necessary for both flaps to be bent outwards, it does improve stability of the package and is preferred.

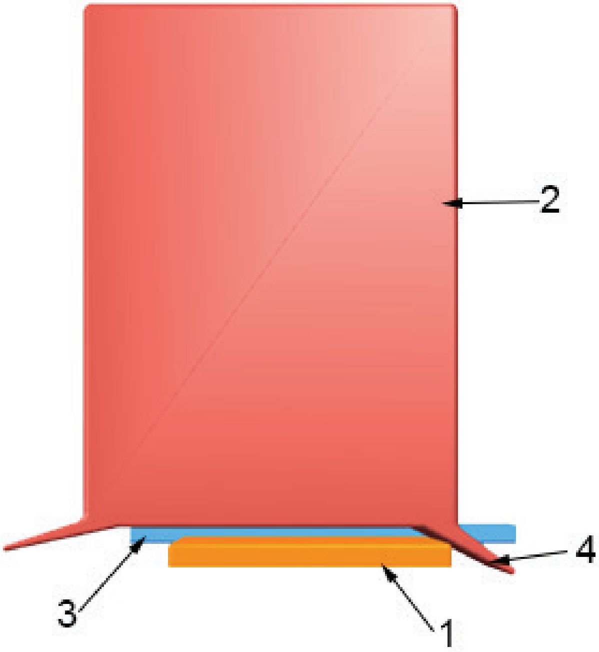

Figure 8.19. Lifting plate starting to surpass the package.

8.4 Materials

The environment that the machine will work in is quite aggressive and hostile so it stands to reason that the materials must be able to work under those conditions. As stated in the target specifications; the machine will be exposed to a high degree of moisture, high temperatures, spilled product and cleaning-agents. Since the packages are completely sealed during the interference with the Elevator, it is not necessary that the different materials are FDA approved for direct contact with food.

8.4.1 Pulleys

Since the risk of corrosion is very high in this environment, the pulleys and other metal components will be manufactured out of stainless steel. The choice fell on an austenitic stainless steel with the steel grade 1.4305. It has a great resistance against corrosion and both organic and inorganic chemicals [14]. This is the same steel that is used in many other parts of Tetra Pak, belt driving pulleys for instance.

8.4.2 Timing-belts

The timing-belts will be made of a special type of thermoplastic polyurethane called TPUAU2, which can handle the temperature span, both wet and dry food and have a decent resistance towards cleaning-agents [15, p 7]. Since the timing-belts will be exposed to skewed loads during the lift of the packages, they will be bestowed with cords made of stainless steel grade 316E. The cords will improve the stiffness and stability of the belts, the stainless steel is chosen in regard to the aggressive environmental factors in the machine [16, p. 249]. The material is from the supplier Breco, and was selected together with an application expert [17].

8.4.3 Guide

The guide that will be used during the delivery phase is the same which is already in use by the current solution. This one is made of plexiglass and since it's already in use, it's reasonable to think that it will work on this new concepts as well.

8.4.4 Lifting plate and lifting arm

The material used for the lifting plate and the lifting arm is an austenitic stainless steel with the steel grade 1.4301. It has great corrosion resistance and is able to withstand high temperatures [18]. Since the plate will have direct contact with the packages, it is this plate that will be exposed to the highest temperatures.

9 The final concept

Earlier in the development process, several target specifications were set; in this chapter, the new concept is investigated to see how well it actually performs towards said specifications. While not every particular specification is possible to study as of now, those that are, will be discussed.

9.1 Final concept proposal

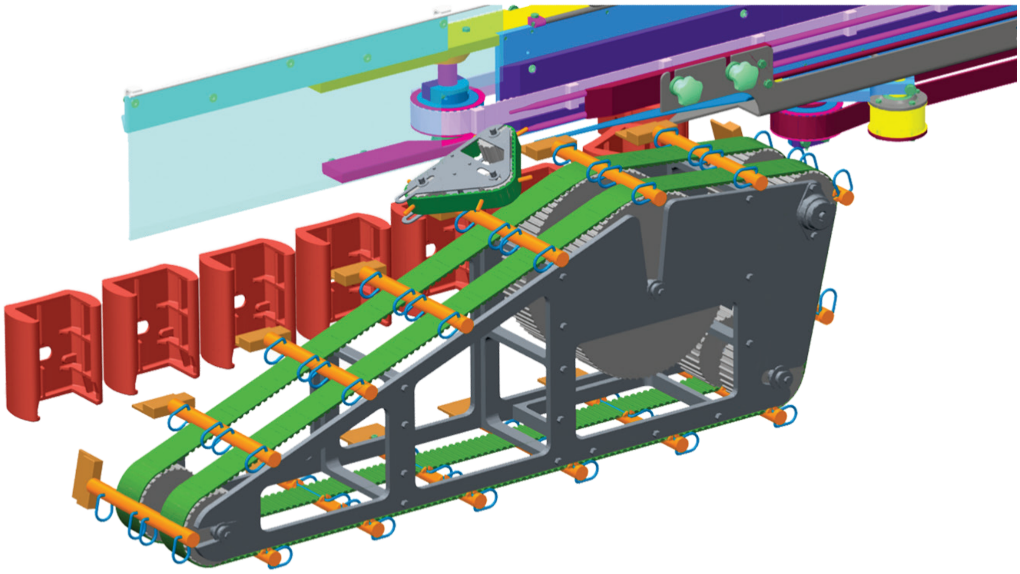

Figure 9.1. Final design of the concept.

The final concept design is seen in Figure 9.1, mounted in a synchronized position in the production line.

9.2 Fulfilment of target specifications

In chapter 5, the target specifications were set. There were three types of specifications; numerical specifications that had to be achieved, the concept could either do it or not; subjective specifications, which were hard to measure; and specifications that could be improved upon, by making the concept better than the current solution; it is the latter specifications that will be reflected over below.

9.2.1 Number of parts

The exact number of parts is unknown, it is too early to map out such detailed schematics. An approximation based on similar machines [19] can be made, however. After discussions and comparisons, the team decided that it would be roughly 400 parts in the design; compared to the 1201 parts of the Elevator, one could consider it as a slight improvement. Fewer parts will most likely result in an easier assembly, quicker component replacement and so forth.

The moving parts are calculated based on components that moves relative to each other. A shaft and a pulley, which rotates together, counts as one moving part for example. In the new concept, a total of 29 moving parts were located.

9.2.2 Mass properties

The mass properties of the final design were calculated by analysing the model in Creo Parametric. Since the materials had already been chosen, the density of the different parts where known, and the mass could be determined. The result of the analysis is seen in Table 9.1.

Table 9.1. Mass properties for the final concept.

Lifting part					
Part	Quantity	Material	Density [kg/m^3]	Mass [kg]	Total mass [kg]
Lifting arm	15	SS EN 1.4301	7900	0,38	5,71
Lifting plate	15	SS EN 1.4301	7900	0,24	3,54
Pulleys Z32	6	SS EN 1.4305	7900	3,09	18,57
Pulleys Z80	2	SS EN 1.4305	7900	20,75	41,50
Belt	2	TPUAU1	0,331 (kg/m)	0,79	1,59
Housing	1	SS EN 1.4301	7900	22,58	22,58
Quick release	30	SS EN 1.4310	7900	0,02	0,75
Additional parts	-	-	-	20,00	20,00
				Tot:	108,52
Stabilizing belt					
Part	Quantity	Material	Density [kg/m^3]	Mass [kg]	Total mass [kg]
Pulleys Z16	3	SS EN 1.4305	7900	0,37	1,12
Housing	1	SS EN 1.4301	7900	0,41	0,41
Support bars	6	SS EN 1.4301	7900	0,00	0,03
Belt	1	TPUAU1	0,158 (kg/m)	0,08	0,08
Additional parts	-	-	-	5,00	5,00
				Tot:	6,64
				Total mass	115,16

As seen in the table, the total mass of the design ended up at 115 kg, where the lifting part is responsible for the major share of the mass. In addition to the specified parts, additional mass has been added to the approximation. In the concept, there is no specified framework to assemble the machine into the ground body. The mass of these parts has been approximated to get an equivalent comparison to the current Elevator. Compared to the weight of the Elevator, which is roughly 219 kg, a weight-reduction of ~48% was achieved.

9.2.3 Volume adjustment

The time it takes to reconfigure the current Elevator to different package volumes differs between different operators, a more skilled one will do it quicker than someone with less experience. An average time of 30 minutes were set, based on the interviews.

Since no prototype is built and there is no way to actually test the new concept, an approximation has been set. Since there are only two pulleys in need of adjustment instead of the 16 different arms on the current Elevator, one could assume that it will be much faster. Roughly five minutes were approximated.

9.2.4 Manufacturing cost

Since a lot of the components in the design is made up of standard components, a rough estimation of the cost can be made. While it won't be able to be an exact calculation at an early stage like this, it can be a decent approximation and an indication of if it will be cheaper than the current solution or not. As a reference, similar parts used in different sections of the filling line are used. Their manufacturing costs are already known, whether it's the same component or components with similar manufacturing intricacy, a rough approximation of the cost could be calculated. In the end, the total cost landed on roughly 160 000 SEK. Compared to the manufacturing cost of the Elevator, which is roughly 240 000 SEK, a cost reduction of ~33% was achieved.

9.2.5 Time to reset machine after breakdown

This specification is supposed to have the same value as the current Elevator. There was no new solution developed for this function, and the new concept can use the same solution as the current Elevator. The current solution is a safety clutch at the origin of the driving shaft, which is located in the drive unit of the filling line. Since this part is outside the limitations of this project, there was no new solution to investigate. The new concept is supposed to use the same safety clutch, and will have the same time to reset the machine, as well.

9.2.6 Time to replace components

While the replacement time of the different components are hard to approximate on the new concept, assumptions can be made. Since the new concept consists of fewer parts and is of a less complex assembly, one could assume that the replacement time of different components will be quicker. Overall, the design is very open, there are not many components situated in hard to reach places. The introduction of the quick releases for the lifting arms will also reduce the time to change those components remarkably. If one compares it to the current Elevator, where nearly the entire assembly must be disassembled for some components to be replaced, one could see some advantages of the new concept.

9.2.7 Noise level of machine

The noise level of the current solution was not possible to get a measurement of, and no value of the specification were set. Like the current solution, the new concept use gears and belts to translate the rotational movement to the linear movement of the machine. Due to this fact, it is reasonable that the noise level of the new concept is similar to the current solution. Since the current Elevator have a higher number of moving parts compared to the new concept, it might even be louder.

9.2.8 Cleaning time

There is a standard automatic cleaning program that is used for the entire filling line, there wouldn’t really be any difference in time when that is concerned. The difference would be found when there is a crash and packages gets stuck, ripped open or when similar accidents occur. The operator would then have to remove the package manually, and it is here a slight advantage for the new concept since it is a more open design with fewer hidden or hard to reach places where things could get stuck.

9.2.9 Concept specifications

Table 9.2 shows how the final concept meets the target specifications. The specification marked with values are the measurable specifications which could be improved. Specifications marked with “✓” means that the concept fulfils the requirement. “=” means that the concept is assumed to have the same specification as the current solution, but the value was not able to be measured. “+” means that the concept is assumed to have a better specification than the current solution, but the specification was not able to be measured.

Table 9.2. Final concept specifications.

Final concept specifications						
No.	**Need no.**	**Metric**	**Importance**	**Unit**	**Target Value**	**Concept value**
1	1,13,18,22	Number of moving parts	*	quantity	<84	29
2	1,13,17,22	Number of parts	*	quantity	<1201	400
3	1,17,18,35	Machine mass	*	kg	<219	115
4	5,23,24,25, 26	Time to perform volume setting	**	min	<30	5
5	17,18,35,36	Manufacturing cost	**	Sek	<240000	160000
6	2,16,19,28, 29,30	Time to reset machine after breakdown	**	min	<16	=
7	1,13,16,17, 18,19,22	Time to replace components	*	% of production hours	<0,6	+
8	32	Noise level of machine	*	dB	-	=
9	11,19,20,21	Time to clean machine	**	min	-	+
10	5,14	Height of compatible packages	***	mm	92-134,5	✓
11	3,4	Operating speed	***	packages/h	0-24000	✓
12	7, 33	Heat resistant	***	°C	0-95	✓
13	-	Horizontal distance between lifters	***	mm	150	✓
14	-	Lifting height	***	mm	232	✓
15	8,9,12	Machine is water resistant	***	material specification	-	✓
16	10	Product resistant	***	material specification	-	✓
17	14,15	Machine can handle faulty packages	***	subjective	-	✓
18	7,8,9,10,11, 21,27,31,33	The machine is robust	***	subjective	-	✓
19	6,34	The machine is safe to use	***	subjective	-	✓

The table shows that all the specifications were met, and almost all of them was improved.

10 Discussion and Conclusion

In this chapter the team holds a discussion where reflections on the thesis is examined and reflected over. Some minor discussions have occurred in previous chapters; this is a more complete run-through of the thesis.

10.1 Discussion

10.1.1 Briefing

During the briefing of the mission statement the supervisors at Tetra Pak were very clear about how big of a project this was; they told us that if we would wish it, a much smaller task could be received where we would only work on a small part of the Elevator instead of working on a replacement for it. We decided to tackle the bigger assignment since it wouldn't feel as fulfilling if our solution would just be replaced once they finally took their time and developed a replacement of their own.

Going into this thesis we knew how big of a task it was; during discussions with supervisors at Tetra Pak and LTH an agreement was reached, an agreement where the thesis would only be taken as far as the final concept phase. While it saddened us not being able to finish the entire project, we realized that it wouldn't be realistic to be able to do the entire project in this short period of a time; and if it were, the quality of the final solution would most likely be substandard and nothing we could be proud of. It was very important for us to be able to take pride in our work; if we are to put our names on it, it should be something we could stand behind.

10.1.2 Customer needs

As was discussed in a previous chapter; by being a product that is not used by a lot of people, one could argue that it's not a consumer product. To use the exact same methods of gathering intel as if it were just that might not be the best of ideas. Because of this, some minor changes to Ullrich and Eppingers methods were made.

While they argued that you needed considerably more interviews to discern all of the hidden needs of a product; we argue that since our interviewees have a tremendous amount of knowledge and experience with the machine, they can be counted as expert-users and our lack of quantity is more than made up for with quality. We interviewed; an operator of the machine, who works with it daily; developers of the machine; an instructor of the machine, who educates operators of the machine; and service personnel, whose job is to repair and maintain it. Trying to hold focus groups would not be realistic since that would mean having to fly people in from all over the world for something that might result in some minor discovery. While we might have missed some minor detail from our interviews; we agreed that the result was satisfactory enough and since it wasn't our only source of intel, it would probably be discovered later.

The biggest problem, or cause of concern in our gathering of raw data, was the fact that the machine we had access to, along with all the personnel, was working within a perfect factory under mint conditions. Everything was clean, well maintained and operated by skilled engineers. That won't be the case in a factory located in Brazil, for instance. It would probably have been valuable for the project to actually visit a real factory to study the interactions with real people; however, we are still confident that we discerned most of the needs and first and foremost, the most vital ones. One cannot overlook the fact that we might have missed something because of this, however.

10.1.3 Development process

The development process was a lot more iterative than previously thought, while we had allocated a lot of time and resources for this in the planning, we could never have imagined how often we had to go back or begin generating new ideas because of some minor occurrence that happened in a later phase of the development process. From day one of the concept generation to the last day of calculations; we adapted, improved and changed our concepts to prevail over whatever came our way.

It is a well-known fact that every development process is iterative; somehow its always surprising by how much it actually is, even so.

10.1.4 Target specifications

During the composing of the target specifications, we put up a few values which would be hard to measure, and even harder for us to measure on our own concept. One of those were the noise level. It is possible to measure it on the current machine; we have been told however, that the Elevator doesn't make more noise than the rest of the machine. Our solution, which is belt driven, will probably make even less sound. Allocating both time and resources into measuring a unit that in the end won't affect the result seemed only unnecessary. Another value which was not included in the target specifications was the time it took to clean the machine. This time depends on many aspects, such as cleaning interval, type of filled product and the current production quantity. Different factories all over the world have different water quality which affects the cleaning time as well. All these aspects makes the cleaning time fluctuate a lot, and therefore it was difficult to get a reasonable measurable unit. These different specifications were instead compared between each other, we do not know how loud the concept is, for instance, but is it louder than the current Elevator?

10.1.5 Concept generation

One of the biggest challenges of this whole thesis was how big the task was. It became clear early in the process just how complex the issue could be; solve one problem and it would create two more, and this went on and on. One way for us to handle that was breaking the problem down into smaller sub-problems, by solving specific problems and later combining them proved to be a very efficient way of conducting our business. Working towards finding a solution to a smaller problem rather than a more complex and bigger one made it easier for us to be creative and open-minded, while a lot of our ideas wouldn't work in the end, it was good getting everything out on the table. Some ideas might inspire new ideas; others were possible to combine and so forth.

In the end, we created six viable concepts. At this stage our supervisors at Tetra Pak were starting to get excited with our work; according to them, they didn't expect us to manage to get this far, particularly not as quickly as we did.

10.1.6 Concept selection

Before this point, we had tried to avoid being critical towards our concepts. While it was impossible to entirely shut out our inner critical voice, we did manage to do a decent job at least. This all changed when it was time to thin out the herd with different selection-matrixes, however.

This phase begun with us arranging a focus group comprised with several different development engineers at Tetra Pak. We wanted to pick their brains out about our concepts; what did they think about them, if it inspired any ideas of their own or other general thoughts regarding them. This was a very beneficial arrangement since it gave us a clear indication on which concepts was preferred and why. It served as a great aid when we screened out two of our six concepts in the first rough screening. While we might have arrived at the same conclusions without the aid of the focus group; in the end, it proved valuable both when it confirmed our suspicions and when we learned something new.

Before the four remaining concepts would go into the final selection-matrix they would have to be more fleshed out. Before this step, the concepts were more broad ideas of how the problem would be solved and not exactly how it does solve it in detail. Going into detail; more, previously unaccounted problems came to our attention. Some of the previously more promising concepts suddenly lost their lustre, while concepts almost dismissed proved to be better than expected.

The setting up of the final selection-matrix proved to be a bit of a challenge. In our intel gathering we had managed to procure 35 different customer needs, most of which would be used in this matrix. To be able to rank and weigh all of these needs in regard to each other was an undertaking to say the least.

With the aid of our gathered knowledge and our combined intellect we set out to manage this task. One could argue that it would have been a good idea to involve people closer to the machine in this process, which would have been right. We discussed the possibility and agreed on the advantages; in the end, we decided to discard the idea primarily on the premise of the amount of time the undertaking would demand from them as well. Doing it ourselves and letting a costumer review the result seemed to be a decent substitute. This might have affected the result of the weighed needs; however, we do not think it would have flipped the scales in favour of another concept regardless.

During this concept phase, we thought that it would be impossible to create a concept where the “one-continuous” movement would be uncomplicated enough to go through with. We were certain that one of the two-part solutions would win in the end. As it turned out, it was the “one-continuous movement”-solution that won; while some of the other concepts were promising, they lacked the true simplicity of our winning concept.

10.1.7 The final concept

As said in previous chapters, we are confident in our solution and are very positive regarding its ability to perform. The only part we are not completely confident in is the drop-off station. In our eyes, that is the most likely place in the machine something might go wrong. We wish we had more time to test this part and either configure it to our liking or realising that our worry was unfounded. Due to our desire to use as many standard components as possible; we have created a concept consisting of many parts already active in other sections of the machine. This will prove valuable since it will decrease development costs while at the same time increase our confidence in the product.

In our mission statement, we received specifications on the available volume we could use for our machine; we used a bit more in the back, resulting in the need to redesign the next part in the production line. That won’t be a problem since they are planning to rebuild this part of the production line if they introduce the new package volumes, anyway.

10.2 Recommendations for future work

By now, the final concept has been chosen, dimensions and design finalized and materials researched and picked. Everything has been based on theoretical calculations, research and 3D-models. Due to the lack of time for a project of this size, it was previously decided between developers and supervisors that this was how far the project would go. The following steps is only recommendations from the development team on what they consider to be the best approach on continuing the development of this concept.

10.2.1 Prototype testing

As mentioned previously, theoretical calculation and 3D-models were used; but theory only goes so far. To truly know if this is a viable concept, a working prototype must be built and tested.

Since a lot of the concept is based on similar technology as in the Pusher, one could assume that the lifting device will work. The biggest question-mark of this concept is the drop-off station. Focusing on this part in the prototype, making sure that everything is working properly and as it should, is crucial to the continued work with this concept.

One cannot start production of a product based on assumptions, everything should be tested and verified. By directing the focus of the prototype building on a certain part of the machine is only in regard to how important that key feature is to the entire concept; if that doesn’t work, nothing will. That is why our recommendation is to begin testing the drop-off section of the concept; if that works, continue with the rest; if not, back to the drawing table and adjust the solution.

10.2.2 Set final specifications and plan downstream development

When the testing of the prototype is done, it is time to start working on more detailed schematics of the entire design and plan downstream development and production of the concept.

It is here; when the final design is set, that a closer look upon areas such as robust design, ease of manufacturing and environmental design is regarded. While these different posts have been reflected upon in previous steps, it is here that they are truly contemplated and investigated.

10.3 Conclusion

Today's Elevator is a machine that works properly, while it suffers from some minor inconveniences, the overall use of the machine is relatively carefree. This is the concept we were supposed to replace.

While everything is working as it should, there are some problems with the machine; problems like the production cost, weight of the machine, the volume change, cleaning predicaments, part replacements, overview of production line, corrosion and friction. This is just a quick recount of some of the annoyances of the Elevator, while it does its job, it's not without its faults.

When we set out to create a new solution for the Elevator, we knew that it was problems like these that we had to improve upon. It was never a question of creating something that could perform a specific task, it was an assignment where we were creating something that had to outperform an already working machine.

In the end, we designed a concept that, at least on paper, is an improvement of the Elevator in nearly every regard. We replaced large metal chunks and specially manufactured cam-curves with standardized timing-belts, time-consuming volume change with a simple configuration of two pulleys, a complex assembly with a more open one, simplified the part replacement and decreased production costs immensely. While there are still a lot of testing and building left to do before a conclusion truly can be made, in the realm of logical thinking, it truly is an improvement.

As it stands today, the Elevator and the following waste-handling station needs to be rebuilt if Tetra Pak decides to implement bigger package volumes than the current ones. That makes for a perfect opportunity to actually replace the Elevator with our concept. While there is still a long way to go before our concept is finished and ready to be produced, we do believe that its very promising and worth considering.

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Figures

Figure 3.1. Tetra Pak R1 filling line.

[19, p 1], edited by authors

Figure 3.4. Tetra Pak R1 Elevator

[19, p 1109]

Figure 3.5. Illustration of the lift

[20], edited by authors

Figure 3.7. Current sizes of the Tetra Recart Midi packages.

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Figure 3.8. Package holder and template.

[19, p 1142-1144], edited by authors

Figure 3.9. Lifting jaw inside the carrier.

[19, p 1108], edited by authors

Figure 3.10. Shape of the package when lifted by the Elevator.

[20], edited by authors

Figure 3.13. Tetra Pak R1 Pusher.

[19, p 1149]

Appendix A Work distribution and Time plan

A.1 Work distribution

The work distribution has been equally divided by the team members during this thesis. Both team members have been included in all parts of the thesis, and participated in all activities.

A.2 Comments on time plan

Some of the activities turned out to take more time than expected. The most contributing part was the concept generation, which ended up taking five weeks instead of two as planned, which pushed the time plan forward. In the end, we had less time for writing the report, but since the time plan was initial set up with margins, there was enough time anyway.

A.3 Initial project plan

Week	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**1**	**2**
Project week	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Master thesis introduction	🟩																			
Tetra Pak introduction	🟩																			
Goal defining document	🟩	🟩																		
Planning		🟩																		
Collect information		🟩	🟩																	
Gather raw data from Tetra Pak		🟩																		
Collect information from litterature			🟩																	
Identifying customer needs				🟩																
Concept generation				🟩	🟩															
Concept selection						🟩														
Evaluation of concepts						🟩	🟩													
Further concept development								🟩	🟩	🟩	🟩	🟩								
CAD modeling								🟩	🟩	🟩	🟩	🟩	🟩							
Choice of material									🟩	🟩										
Calculations									🟩	🟩	🟩									
Winter break																	🟩			
Opposition																			🟩	🟩
Prepartion for presentation																			🟩	🟩
Write report			🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩		🟩	🟩	🟩
Report to supervisors			🟩		🟩		🟩		🟩		🟩		🟩		🟩				🟩	

A.4 Performed activities

Week	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2
Project week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Master thesis introduction	■																			
Tetra Pak introduction	■																			
Goal defining document	■	■																		
Planning		■																		
Collect information		■	■																	
Gather raw data from Tetra Pak		■																		
Collect information from litterature			■																	
Identifying customer needs				■																
Concept generation				■	■	■	■	■												
Concept selection								■	■											
Evaluation of concepts									■	■										
Further concept development										■	■	■	■	■	■					
CAD modeling										■	■	■	■	■	■	■				
Choice of material													■	■						
Calculations													■	■	■					
Winter break																	■			
Opposition																			■	■
Prepartion for presentation																			■	■
Write report			■	■	■	■	■	■	■	■	■	■	■	■	■	■		■	■	■
Report to supervisors			■		■		■		■		■				■				■	

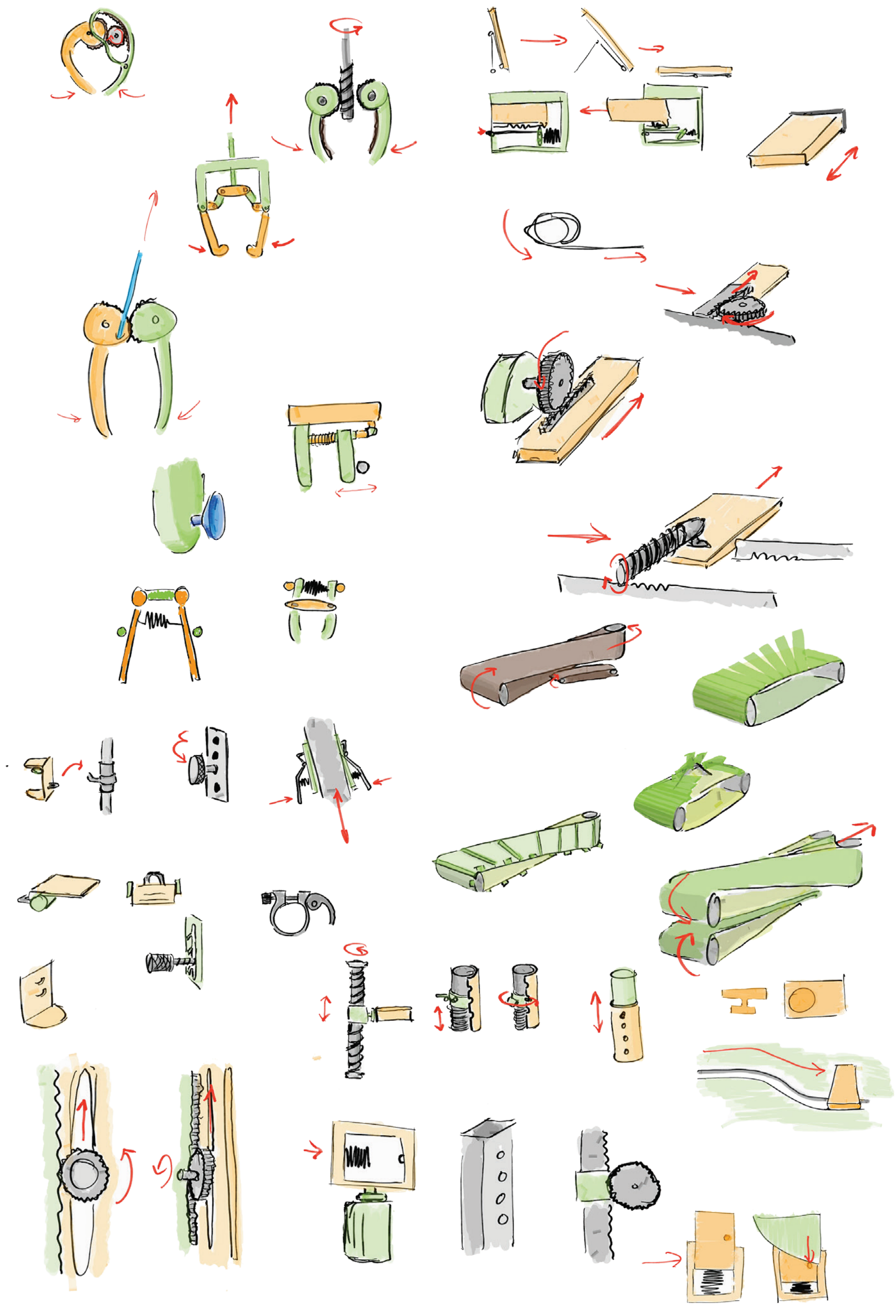
A.5 Planed and performed activities

Week	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2
Project week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Master thesis introduction	🟩x																			
Tetra Pak introduction	🟩x																			
Goal defining document	🟩x	🟩x																		
Planning		🟩x																		
Collect information		🟩x	🟩x																	
Gather raw data from Tetra Pak		🟩x																		
Collect information from litterature			🟩x																	
Identifying customer needs				🟩x																
Concept generation				🟩x	🟩x	x	x	x												
Concept selection						🟩		x	x											
Evaluation of concepts						🟩	🟩		x	x										
Further concept development								🟩	🟩	🟩x	🟩x	🟩x	x	x						
CAD modeling								🟩	🟩	🟩x	🟩x	🟩x	🟩x	x	x					
Choice of material									🟩	🟩		x	x							
Calculations									🟩	🟩	🟩	x	x	x						
Winter break																	🟩x			
Opposition																			🟩x	🟩x
Prepartion for presentation																			🟩x	🟩x
Write report			🟩x	🟩x	🟩x	🟩x	🟩x	🟩x	🟩x	🟩x	🟩x	🟩x	🟩x	🟩x	🟩x	🟩x		🟩x	🟩x	🟩x
Report to supervisors			🟩x		🟩x		🟩x		🟩x		🟩x		🟩		🟩x				🟩x	

Appendix B Interviewees

Interviewee	
Lars Carlsson	Senior Test Engineer, Tetra Recart
Christer Nilsson	Senior Test Engineer, Tetra Recart
Dan Haldeborg	Machine Operator, Tetra Recart
Jukka Tilli	Training Responsible, Tetra Recart
Jörgen Nilsson	System Specialist, Tetra Recart

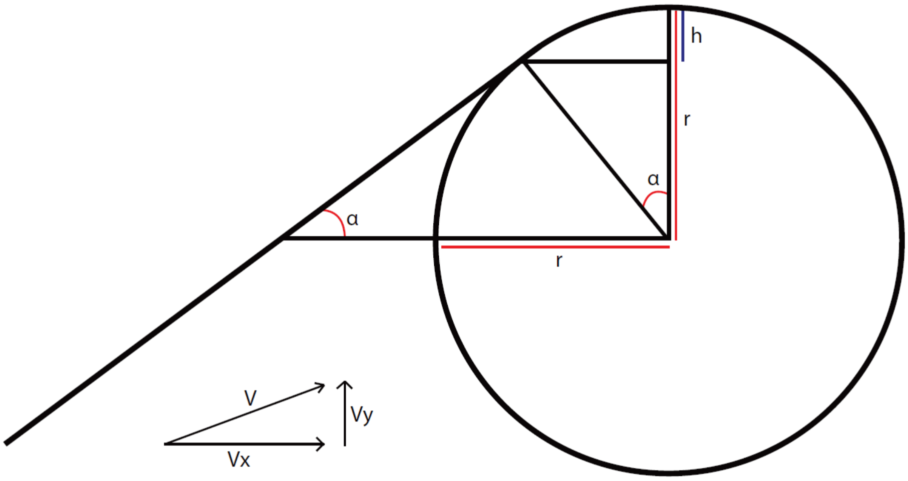
Appendix C Sub-problem concepts



Appendix D Focus group participants

Focus group participants	
Lars Carlsson	Senior Test Engineer, Tetra Recart
Rasmus Mattsson	Mechanical designer, Tetra Recart
Richard Persson	Senior development Engineer, Tetra Recart
Erland Annerfeldt	Senior Mechanical Designer, Tetra Recart
Tomas Nilén	Senior Development Engineer, Tetra Recart

Appendix E Calculations vertical acceleration



The vertical lifting height h during the path when the belt is following the top gear is calculated by the following formula:

$$h = r - r * \cos(\alpha) = r(1 - \cos(\alpha)) \tag{1}$$

The velocity in the belt direction V , is calculated by:

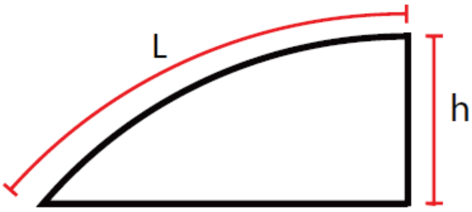
$$V = \frac{V_x}{\cos(\alpha)} \tag{2}$$

The vertical velocity is given by:

$$V_y = V * \sin(\alpha) \tag{3}$$

Where V_x is the running speed of the machine. The maximum velocity of the machine is 24000 packages/hour, which is equal to 1 m/s. The distance the belt is moving in the speed direction during the vertical height h, is calculated by:

$$L = 2 * r * \pi * \frac{\alpha}{360} \tag{4}$$



The time it takes for the belt to move this distance is calculated by:

$$t = \frac{L}{V} \tag{5}$$

The average acceleration during the lift is given by:

$$a = \frac{\Delta V_y}{t} \tag{6}$$

By combining equations (2) - (5) and inserting them into equation (6) the following relationship is obtained:

$$a = \frac{V_x^2 * \sin(\alpha) * 360}{2 * \cos(\alpha)^2 * r * \pi * \alpha} = \frac{V_x^2 * \tan(\alpha) * 360}{2 * \cos(\alpha) \ * r * \pi * \alpha} \tag{7}$$

Which gives the average acceleration for the belt during the top path where it follows the gear. Different angels of the belt elevation and radius of the gear was tested to find values where the acceleration is below the gravitational acceleration. The reason for this is to ensure that the package stays on the lower jaw during this part of the lift. Depending on the chosen elevation of the lift, different radius of the gear can be chosen. Examples of angles and radiuses that gives the inflection point of the acceleration is seen below.

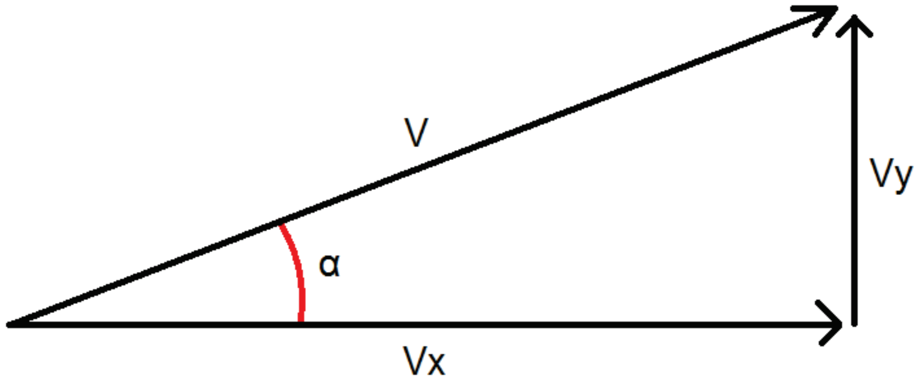
Radius r (mm)	***Lift elevation α (°)***	***Acceleration(m/s^2)***
104,5	10	9,82
107,9	15	9,82
113,0	20	9,82
120,1	25	9,82

The table shows the minimum radius of the upper gear to ensure that the acceleration does not exceed the gravitational acceleration. Depending on the chosen lifting angle, the radius of the gear differs.

Appendix F Calculations on impact of the package

A deformation of 3 mm is assumed on the package when the jaw hits the bottom of the package. It is assumed that the package will accelerate from stationary to the vertical speed of the jaw on this distance. The vertical speed, V_y of the jaw is calculated by:

$V_y = V_x * \tan(\alpha)$



The time it takes for the package to accelerate from stationary to V_y, is calculated by:

$t = \frac{s}{v_m}$, where v_m is the mean speed during the acceleration, which is:

$v_m = \frac{v_y}{2}$

The acceleration is calculated by:

$a = \frac{v_y}{t}$

The force of the impact is calculated by:

$F = m * a$, where m is the mass of the package.

The pressure on the package is then calculated by:

$P = \frac{F}{A}$, where A is the area of the jaw.

In the table below, a comparison between the current Elevator and the new solution is seen.

	Current elevator	New solution
Lifting angle α (degrees)	24,07	20,37
Deformation (mm)	3,00	3,00
Vertical speed Vy (m/s)	0,45	0,37
Mean speed Vm (m/s)	0,22	0,19
Time for acceleration (s)	0,013	0,016
Acceleration (m/s^2)	33,26	22,98
Area of lifting jaw (mm^2)	2250	1555
Force (N)	18,29	12,64
Pressure (Pa)	8129	8129

This result shows that the new solution needs an area of the lifting jaw of at least 1555 mm^2, to have a similar impact pressure on the package as the current solution.