CHALMERS

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Design of an electrical driven pallet stop

An innovative multi-way component for modular pallet handling systems

Master's Thesis in Product Development

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a coesia company

Department of Industrial and Materials Science
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, 2018

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Gothenburg, Sweden 2018

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Cover: A render of the final result, an electrical driven pallet stop.

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Abstract

A 10 million cycles lifetime was reached with a certainty of 99% for all platforms except one. This elongated the lifetime with 1000% compared to the main competitors of electrical driven pallet stops was the main finding from this report. A robust construction favourable against applied forces was applied. The product developed was designed to fit with all pallet handling systems of FlexLink AB. Making the change from pneumatic to electrical operation with the product developed in this thesis the return of investment, from a total cost of ownership perspective, was reached after one year.

Known as the fourth industrial revolution, Industry 4.0 involves rapid changes over many domains. To be at the forefront of smart factory solutions, electrical control, robotics and fully automated production lines are the way to go. Being open-minded to new and innovative ideas is important to be a market leader when shifting into Industry 4.0. Changing from pneumatic to electrical operation of products can drastically increase the effectiveness and controllability of systems.

To develop the new solution a process with several development steps was executed, from generation of concepts through prototyping to a final design. A wide range of ideas was generated and merged together into concepts that later were evaluated. This was done in iterations where the detail level was increased and the number of concepts were narrowed down for each phase until only one remained. Computer-aided tools were included to ensure that the concept was physically feasible before testing started. The final concept was refined and tested with respect to functions, performance and design.

Keywords: pallet, conveyor, production, FlexLink AB, linear, stepper motor

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Contents

List of Abbreviations

2D	Two Dimensional
3D	Three Dimensional
B2B	Business to Business
BESO	Bi-directional Evolutionary Structural Optimisation
BESO2D	Topology Optimisation of 2D structures using BESO algorithms
BOM	Bill Of Materials
CAD	Computer Aided Design
CNC	Computer Numerical Control
CPS	Cyber-Physical Systems
DFA	Design for Assembly
DFA-index	Design for Assembly Index
DFM	Design for Manufacturing
DFR	Design for Reliability
DoE	Design of Experiments
EN AC-46000	A type of Aluminium Alloy
EPS	Environmental Priority Strategies
FEA	Finite Element Analysis
FMEA	Failure Mode and Effects Analysis
FoS	Factor of safety
FOV	Field Of View
IIoT	Industrial Internet of things
ISO	International Organization for Standardization
LED	Light Emitting Diode
MoS	Margin of Safety
PA	Polyamide
PA6 GV30	Polyamide 6 + 30% glass fibre
Pd	Probability of detection
PEST-analysis	Political, Economic, Social and Technological analysis
Po	Probability of Occurrence
POM	Polyoxymethylene
PRIMA	Manufacturing Process Information Maps
RD&T	A Robust Design and Tolerancing
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RoHS	Restriction of Hazardous Substances
RPN	Risk Priority Number
S	Severity
SKF	Svenska Kullager Fabriken
TCO	Total cost of ownership
TO	Topology Optimisation

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Chapter 1

Introduction

At Chalmers University of Technology during the fall semester of 2017, a master's thesis project within product development was conducted and which is described in the following report. This master's thesis project has been carried out in cooperation with FlexLink AB to develop an electrical driven pallet stop to fit with existing product platforms. This chapter begins with a description of FlexLink, followed by the background to the project and project definition containing aim, purpose and limitations. Thereafter, the research questions and a description of the report structure.

1.1 Company Background

Originated from Svenska Kullager Fabriken, SKF in 1980 FlexLink launched their first conveyor system, the XL conveyor platform, which is still their biggest selling product. Only two years later, in 1982 the first pallet handling system was launched [1]. Since then, FlexLink has grown into a large company with almost 1000 employees and more than 8000 installations all over the world [2]. In 2011, the Italian based Coesia Group acquired FlexLink [3]. The Coesia Group is mainly focused on advanced materials, automated machinery, industrial process solutions and precision gears. It is a multinational corporation operating in over 30 countries. They have over 6 000 employees and a global revenue of 1.475 million EUR in 2016 [4].

FlexLink is a factory automation expert and has launched conveyor systems and pallet handling systems in both aluminium and stainless steel to allow presence in many types of factories. Some of the larges industries that systems are delivered to are healthcare, automotive, food, electronics and personal care [2]. FlexLink is a business to business company, B2B, and has a wide range of customers globally, from international corporations to local companies. There are operating units all over the world and the headquarter is located in Gothenburg, Sweden which host the Product and Supply Division.

FlexLink's values are; respect, responsibility, knowledge and passion [5]. The company has a sustainability program that permeates the daily work and it is called "Making tomorrow today" [6].

1.2 Project Definition

A conveyor system is handling equipment which moves goods from one location to another. It allows efficient and quick transportation of material. FlexLink's conveyor systems uses chains or belts to transport goods. In Figure 1.1, a conveyor system with chain and pallets is displayed. The systems have different routes that are used to stock up on goods and a control station that keeps track of what pallet is containing exactly what piece of material.

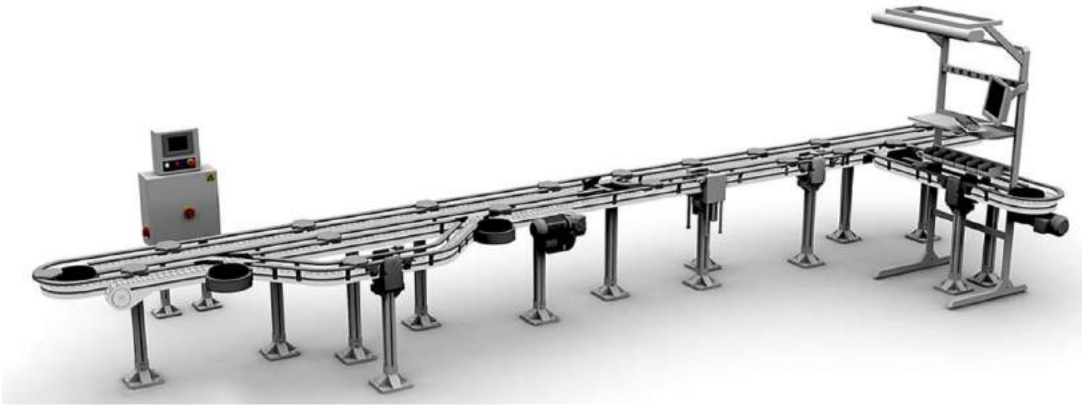


Figure 1.1: A pallet handling system with a chain conveyor.

The pallets are built of mainly two parts, see Figure 1.2. The top part can be customised depending on what material it is to transport. The bottom, narrower, plastic part which by means of friction in the contact with the chain is transported on the belt. In the front of the bottom part is a shock-cushion to not make impact on other pallets when queued. The hollow sections to the right and left on the lower end of the front part is where the pallet-stop is acting. The component between the chain and the beam in figure 1.2 is called slide rail. The supporting rails are running along the track and fastened with brackets, see figure 1.2.

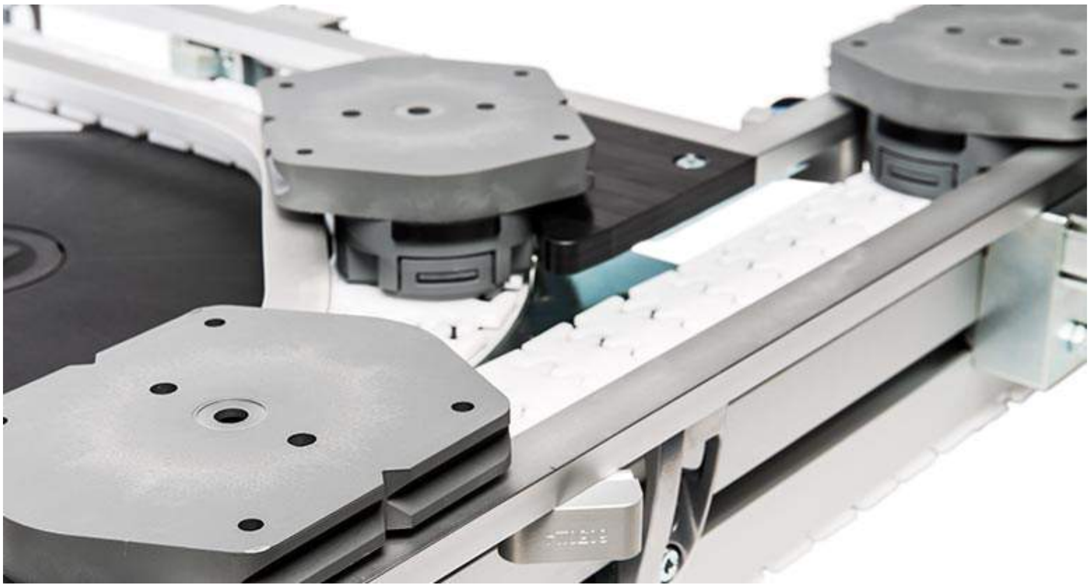


Figure 1.2: A pallet that consists of a bottom part which is in contact with the chain and a top part carrying the goods.

The project defined together with FlexLink is to introduce an electrically driven pallet stop into existing product platforms. In the latest product catalogue from 2016, there are no electrical driven pallet stops, only pneumatic [7]. Most newly built factories today do not have a pneumatic system within the premises, and thus need to purchase a generator for compressing air. Pneumatic motors are loud compared to the electrical ones and lower the quality of the working environment for the employees on the site. In addition to that, the pneumatic motor have a higher energy loss than its electrical equivalent. Using an electrical actuator eliminates the need for the pneumatic components and their extra connections.

Electric actuators can be networked and reprogrammed quickly and also provide complete control to configure velocity, position, torque, and applied force depending on what application they are to be used for. Today, FlexLink have a non-standardised electrical product that suffers from quality issues and has a failure rate of 10%. The product, shown in Figure 1.3 and 1.4, consists of one electrical actuator with one piston rod and one house with a hole lined with a mechanical bushing. The bushing is shown in Figure 1.5 and has four rows of roller balls to distribute the force and reduce friction. To obtain the correct direction of movement of the piston rod, a keyway in the rod is held in place by a set screw in the outer part shown in Figure 1.6. The screw has been fixed with Loctite to better be held in place.

Figure 1.3: One existing geometrical variant of electrical product.

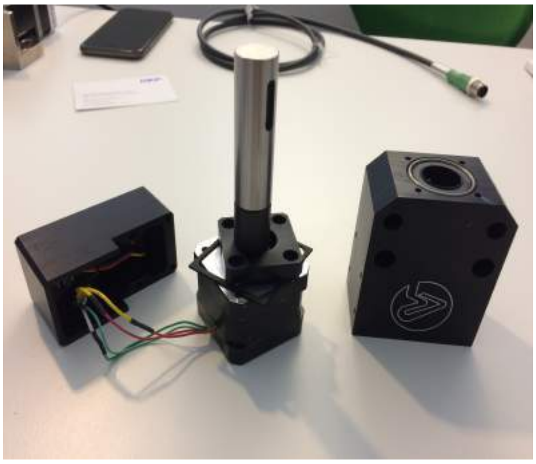


Figure 1.4: The components of the existing electrical product.

Figure 1.5: Roller ball bushing used in the existing product

Figure 1.6: Intermediate component with set-screw hole.

The main issues with the existing product are leakage of lubrication to the motor, damaged bushing due to inaccurate guiding of the rod and the set-screw is often loose due to incorrect usage of Loctite. In addition to that, the housing holding the bushing is a single massive piece of aluminium. That is unnecessary from a material and manufacturing point of view and making it a necessity to have extra connectors between the product and rails.

At FlexLink, there have been two earlier development project with the goal of producing an electric pallet stop between year 2012 and 2015. None of them have succeeded mainly because of misinterpretations of the customers need and too tight demands. That together with the projects being constantly de-prioritised and change of the responsible engineer. The aim of this project is to create a product that is electrically driven, fits with multiple product platforms and resolves the quality issues presented. The solution should fit with FlexLink's design guidelines and be more efficient in material usage.

1.2.1 Research Questions

The purpose is to identify and demonstrate a concept that is sufficiently robust at handling the speed and forces. Also, to present the concept with possibility of implementation in the near future in the FlexLink pallet handling systems. Adding the potential for cost reduction that follows by the developed product. With the purpose and aim defined, a number of questions that this master´s thesis attempts to answer are formed;

– What type of construction is most favourable for gaining a satisfactory robustness against the applied forces?

– Is is possible to create one modular concept that can fit with all the pallet handling product platforms?

– How much cost reduction is possible with the concept compared to the pneumatic product?

1.2.2 Deliverables

The expected outcome of the project is to create a number of concepts and review them to evaluate their potential. Based on their capability, judgements will be made to choose one final concept. When a final concept is chosen, further development with regards to design and efficiency will result in;

– A working prototype of the concept

– Specification of the selected design

– Detailed CAD-models and visualisations of the final design

– Detailed CAD-models and visualisations of the connected modules.

1.2.3 Delimitations

This master's thesis project is carried out during one semester by one person meaning a total of 800 working hours and time span of just over four months. Regarding the product, the following delimitations will exist;

– The project will be based on electrical actuators from the company STEGIA

– There will be no development of electrical circuits or the actuator itself

– Using only Dassault Systems CAD software SolidWorks

– No profound commercial assessment will be made

– Benchmarking and patent analysis will be limited to Europe and North America

1.3 Report Structure

Chapter one will give a broad introduction to the project and put the problem in a context. The second chapter will cover the methods used in the project divided into what phase of the product development process they were used.

The report is built up in a chronological order, with the exception of chapter nine, to ease the understanding of the product development process and what steps were taken during the project. Because of that, each of chapter three to chapter eight, contains both results and discussion points. Therefore there is no chapter that contains discussion only, however the main points will be summarised in the final chapter of the report.

The third chapter will present a pre-study that describes the findings from the market-, technology- and competitor assessment. It contains a problem exploration together with identified customer needs. Chapter four will explain how the customer needs together with other inputs were translated into the product's requirement specification.

In chapter five the iterative process of create, combine and eliminate concept will be presented together with the final concept. Chapter six will describe the next step of the development process with determining interfaces and constituent parts. Chapter seven will describe the process of the detailed design and the different aspects considered. The eight chapter will present the final design of all the developed components.

The ninth chapter will describe the use of prototypes in all phases of the development process. Chapter ten will cover the implementation of the product and present cost calculations and ethical considerations. Chapter eleven will conclude the project and describes recommendations for further work with the developed product together with a design improvements, risks and consequences

Chapter 2

Method

In this chapter, the methods that were be used during all phases of the master's thesis project are presented. Knowledge about the methods used were gained through previous experience during the bachelor- and master's education as well as working experiences. The methods each have a description of how they were used and a justification of why they were selected.

2.1 Preparatory Work

To avoid unnecessary work, an inventory of the business and product environment were made. The methods that was used to map the market, identify market elements and the technologies will be further described in this section. The market, customers, users, suppliers and competitors are active elements. To understand and analyse them was important to create a product with a high customer value.

To provide a holistic view of the environment that the company operates in and to get an idea of what is going on externally, a PEST-analysis investigating political, economic, social and technological factors, was conducted [8]. It was used to identify possible threats, constraints and opportunities and get an understanding if the market will grow or fall in the future [9]. The analysis was carried out by first defining the objectives and the limitations of the analysis, which was similar to the project delimitations, and identify information sources. Thereafter, factors of relevance was stated during the sorting of the gathered information to get a concise analysis summary. This provided an understanding about what opportunities, threats and constraints there are from the macro environment.

To map the existing technology, a patent analysis was made. Two kinds of patent searches were performed, a first screening and a landscape search. The first screening was used to show existence of leading actors and pattern in how the solutions were designed. The searched were performed using the search engine Espacenet [10], with keywords and boolean operators. Patents relevant for the project was extracted and further investigated [11]. The landscape search was used to get an understanding for how the number of filed patents have changed over time and to get an indication of how "hot" or mature the product is at the moment.

A field study was done to collect information that could not be found in the office setting. It was useful to see the components in reality to get a deeper understanding of them. The field study was performed using direct observation and hands-on mounting. The components interesting for the project were the existing pneumatic product range and the existing electrical. Since FlexLink had multiple platforms which the electrical stop was wanted in, an investigation of each and one of them was done. The design-space, conveyor speed, maximum load and other constraints were identified. It was a prerequisite for to work of finding synergies and differences between the platforms. The design-space was identified after assembling a section of a conveyor system with pallets in SolidWorks [12]. The FlexLink product catalogue [7] was used as a knowledgebase of technical data.

To further explore the problem areas, tests and studies on the electrical stop was made in a lab environment. A test rig with load cell was built and used together with LabVIEW software [13] to convert the signals into numerical values. An accelerometer application called SensorLog [14] was used on an iPhone 5s to validate the information from the load cell. The MATLAB software [15] was then used to process the data and create graphical illustrations of the displacements, forces and torques.

By searching externally, information about other companies products and ideas on how they have solved a specific problems can be found [8]. This is called competitive benchmarking and was made to understand where FlexLink's existing product are now in relations to others and what characteristics are important for creating a new, successful product. This was done using mainly Internet to find the competitors and the search was limited to Europe and North America.

Another key element was to understand the existing products and what the concerns truly are. This was made by interviewing customers and different functions within the company, to get different levels of information and a cross-functional view of the product. A study visit was made where a semi-structured interview [16] was held with a production engineer at SKF in direct connection to the production lines. Within FlexLink, semi-structured interviews were held with one product quality engineer, one project manager, one workshop technician and the product manager of pallet handling systems. The notes were re-written in a more structured manner and supplemented immediately after the interview to not miss any significant impressions. A survey was sent out to customers in Germany where numerous production sites with pallet handling systems are located. The survey was made to get quantitative data while the interviews were made to get qualitative data.

Affinity diagrams were used to reduce and arrange the qualitative data. Relevant quotations and statements were extracted from the interviews and the survey. One by one, the quotations and statements were read and interpreted and thereafter placed in categories. The categories were not predefined, they emerged as the citations about the same topic were grouped. The categorisation process went on until all quotations and statements were placed in a category or removed if considered irrelevant to the project [17]. From each category, customer requirements were distinguished.

All of the summarised information from the preparatory work then served as input to the requirements of the product.

2.2 Requirements

From the pre-study requirements originated from FlexLink, customers and current legislation. Requirements were a prerequisite to evaluate concepts. All the collected requirements was summarised in a requirement specification and depending on their importance divided into demands and wishes. The wishes were ranked using a prioritisation matrix to establish the relative importance of the needs [8].

The requirement specification was created to specify all criteria on the solution which were driven by the needs of the stakeholders. It contains engineering characteristics placed in categories to provide a good overview. All the characteristics contains a description, what measuring method to be used and what target value to reach, and how to verify the criterion. The requirement specification served as the cornerstone of the development process because a comparison of a generated concept against the requirement specification indicated if the project was close to a solution and on the right track.

In the beginning of the project, a target specification was be made and as the project moved on, it was subject to change as new knowledge occur. When closing in to detailed design, the final requirement specification was set since some specifications were depending on the solution.

2.3 Concept Development

In the concept development, the work was carried out in iterative cycles with the generation and evaluation phases [8]. The concept development was done in three stages which are visualised in Figure 2.1. Each expansion in the figure represents a stage meaning that the number of concepts increased. Each neck represents an elimination which meant that the number of concepts decreased.

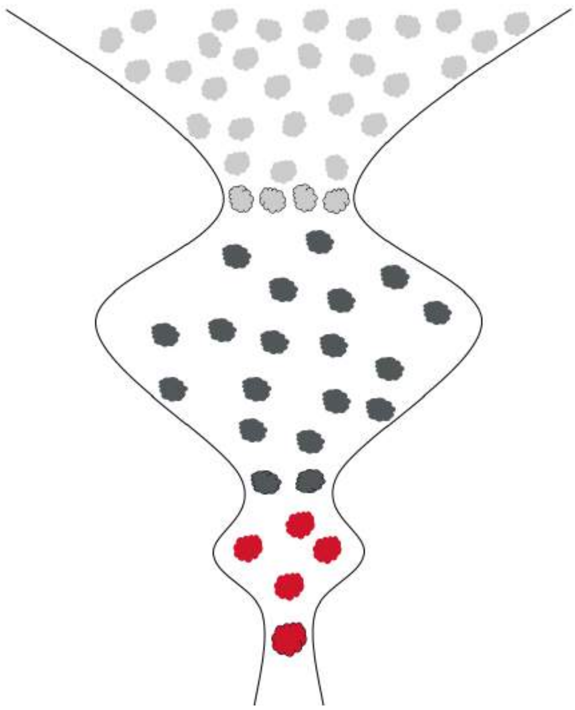


Figure 2.1: An illustration of the concept development process with the clouds representing ideas or concepts.

As a start, a Function-Means modelling [18] was used to get an overview and an understanding of what the product should do. The functions and the means of the product were listed in a hierarchical order to visualise the structure and relations between the functional requirements. This was used as a reference for what the new solution should be able to do.

Two different methods were used for concept generation in the early concept generation stage. Free brainstorming sessions was used in exploring the design space in an open manner. This was to let personal ideas flow freely to access more radical ideas and innovative solutions [19]. All possible supporting tools such as coloured pencils, photocopier, geometry map, ruler and charcoal were allowed to bring forward the creativity. Five sessions of two hours each were allocated for this purpose with a maximum of one session per day. Sessions of external searches using the Internet was added to find parts of a product or products where similar functions existed and get inspiration from the solutions. Four sessions of three hours each were allocated along with many shorter sessions to look up sudden ideas.

Since an early concept generation phase generated numerous concepts, the amount was needed to be reduced into a more manageable amount. An elimination matrix [18] was used to eliminate the concepts that did not fulfil the demands in the list of requirements. By eliminating concepts, project resources could be addressed to the concepts that had higher potential of fulfilling the project mission. The concepts that remained from the elimination matrix were ranked with a scoring matrix, in this case a Pugh matrix [8]. It helped in comparing the different concepts against a reference based on a number of critera. Wishes from the requirement specification were set as criteria. The criteria were not weighted to allow for a quicker selection process. The first Pugh matrix used FlexLink's current solution as the reference. A 1-3 scale was used, if it was better, it got "+", the same gave "0" and if it was worse it got "-". For each concept, the total score was calculated by summing the number of "+" and "−". The score was then used to determine if a concept was weak or strong.

A Morphological matrix [18] was a used to systematically generate a larger number of concepts in the further concept development stage. It was carried out by breaking the system down into smaller problems and and find solutions to them. Then a random stimulation was used to put one solution for each problem together into a combination representing the whole product. When feasible combinations were identified, it resulted in concepts. The result from the Pugh matrices was used to combine strengths from different concepts and creating new and better concepts.

The second Pugh matrix used the strongest concept from the first Pugh matrix as reference. Simpler models were created using Mecchano and cardboard of the top concepts from the third Pugh matrix to easier understand the concepts [20]. In the end of the evaluation in the further concept development stage, a Kesselring Matrix or concept scoring matrix [8] was used. The matrix ranked each concept based on how well they fulfilled the criteria which were ranked based on their importance. All concepts were compared with an optimal solution. The matrix gave clear indications of which concepts had the highest potential to satisfy the stakeholders.

In the detailed concept development stage, further development of the remaining concepts were made. Simulations of the concept were performed to evaluate the movement patterns and integration of the concepts with other parts of the system. For the decision on which of the remaining concepts to choose for further development, a pros and cons list was used. It listed the strengths and weaknesses of each concepts starting from the requirements specification. This served as the basis for the final decision [8].

The final concept development stage contained generation of sub-solutions for different features of the product. The main method for this development phase was first searching for solutions. Both internal searches with brainstorming sessions and external searches with screening the Internet for solutions solving similar problems were performed. Then they were evaluated on how well they satisfied the desired feature. The evaluation was made using weighted Pugh matrices.

2.4 System-Level Design

When the concept was fully selected, the project entered the phase of defining the product architecture. Meaning interfaces, connection points, standard components and a first layout of the geometry [8]. A close co-operation with STEGIA was essential because they delivered the circuit board and motor. All electrical components took a certain physical space and had be fitted into the product. Both phone meetings and face to face meetings were held with their mechanical engineers and electrical engineers. Compromises between design, robustness and function was made.

With modularity of the design, the aim was to subdivide a system into smaller parts that could be independently designed and then used in different configurations. Besides cost reductions and increased flexibility of the design, modularity offered benefits such as augmentation and exclusion. A decision of the modularity was taken based on in what extent the product was generic and what parts needed replacements to suit all platforms. To identify which connection points that should be used, the existing attachment functions on FlexLink's products were studied with the intent of reusing them.

Different components required different characteristics of the materials. These characteristics were described and used as the starting point in the selection. Topical tribologic factors and theories were investigated to understand how motion influenced the selection. To create an understanding of what material was interesting for further use in the process, a first screening was made. Environmental Priority Strategies, EPS, was used to assess which of several design options was preferable from an environmental standpoint. The idea of the EPS-analysis was to make a list of environmental damage costs available in the same way as a list of ordinary costs such as materials, processes and parts. The calculation was made by means of a price list on the environmental damage costs for different materials and processes [21]. The results of the method was a damage costs for emissions and use of natural resources expressed in Environmental Load Units, EUL. The ELU is corresponding to one Euro of environmental damage cost [22].

2.5 Detailed Design

Entering the detailed design phase, design for reliability, DFR, was the first thing focused on. Reliability is the probability that a product, under specified conditions and a time interval, performs its intended function. The principle states that a product fails when the stress experienced by the product exceeds its strength [23]. Decreasing the probability of failure would increase the probability of success. This was done by first identifying and assessing relevant unreliability occurrences such as harmful conditions, human errors, failure modes and mechanisms [24].
A Failure Mode and Effects Analysis, FMEA, was made to identify weaker parts of the design [25]. The risks identified were graded on a scale from one to 10 in three categories; probability of occurrence, Po, probability of detection, Pd, and severity, S. Multiplying the three digits generated a Risk Priority Number, RPN, from one to 1000. The FMEA accordingly helped in anticipating risks with the concept and what the effects of a specific failure would be and the severity of it. The analysis for the product was made on a level investigating only the main components. Not all the components were treated separately. The robustness of the system was evaluated by studying the most sensitive connections and parts of the concept design. A Robust Design and Tolerancing, RD&T, software was used to ensure that the size of the gaps, the flushes and parallelism between different parts were consistent [26]. This was depending on

the individual parts and their variation. The tool was used to simulate the effect of geometry decisions and manufacturing methods on all the parts in the concept.

The design optimisation process was carried out in five steps. First the system and the available design space was defined. Then the optimisation problem was formulated thereafter an analytic model was created depending on the nature of the problem. Using the analytic model, the problem space was explored to ultimately find an optimal solution.

The analytic model was created as a rough geometry layout of the housing using topology optimisation, TO. Bi-directional evolutionary structural optimisation, BESO, algorithms was used. The topology optimisation of 2D structures, BESO2D, software helped determining the areas of where strength and support was needed [27]. Since the software only dealt with two-dimensional optimisation, simulations were made in all three planes and then joined together in a computer aided design, CAD, model. The framework of design of experiments, DoE, [8] was used in the development of further defining the structure of the main component. It was used to actively improve the design by finding the best combination of the parameters. A full-factorial with three factors on two levels was conducted. A Finite Element Analysis, FEA, was the used for analysing stress, strain and strength of the mechanical structures defined in the DoE. The simulations were made using ANSYS [28]. Combining these two methods gave a deeper understanding of what parameters had large effects and where reinforcements were needed. The main effects and the interaction factors were calculated and plotted in a normal probability plot. The result from this was to give a clue of the answer to research question one described in section 1.2.1.

Design for Manufacturing, DFM, describes the process of designing a product to facilitate the manufacturing processes and reduce the manufacturing costs. DFM allowed potential problems to be fixed in the design phase where it was less expensive than to address them later on in the process. The DFM was investigating possible reductions in the costs of components as well as reductions in the costs of the methods used.

Material and manufacturing methods were carefully analysed based on the components' design and needed properties. The software CES EduPack 2016 [29] was used together with manufacturing process information maps, PRIMAs, in the shape of selection matrices [30].

Design for assembly, DFA, describes the process where products are designed with ease of assembly in mind. It involved minimising the cost of assembling which for most products contributed to a small fraction of the total cost [30]. The expression of time equals money can be applied here. The $\text{DFA}_{\text{index}}$ describes the ratio of the theoretical minimum assembly time to an estimate of the actual assembly time for the product [8]. This concept helped in developing an intuition for what drove the cost of the assembly.

To determine the theoretical minimum number of parts, the same three questions were asked for each part in the proposed assembly. Parts satisfying one or more of these conditions was considered having a need to be separate. The questions were; 1) Was the part needing to move relative to the rest of the assembly? 2) Did the part need to be made of a different material from the rest of the assembly for fundamental physical reasons? 3) Did the part have to be separated from the assembly of maintenance reasons? [8].

The goal of an interaction between the human and a machine is to allow effective operation. A human controls the machine while the machine gives feedback simultaneously that confirms or denies the operators' control which aids the decision-making process. A user interface that is self-explanatory, efficient, and user-friendly to operate is ideal [31]. Making potentially wrong actions difficult or even impossible. There are mainly two elements that communicates with a user, information elements and control elements. By finding the answer to the following two questions, these elements could be found [8]. 1) Which functions does users need to perform the tasks and by which accuracy does the users need to control the functions? 2) What information does the user need to perform tasks and by which accuracy does the users need to get the information? Minimising the semantic distance between what the interface communicated and mental models existing was beneficial.

Cognitive ergonomics was concerned with perceptions, reasoning, response, and how theses parameters were affected during interactions among humans and other elements of a system [31]. The human sensory intake and perceptions were focused on finding ways to communicate with the user through the design. These parameters were taken into account when creating the final design.

2.6 Prototyping

Prototypes are draft versions of products that allowed exploration of the ideas. Prototypes were created to show the intention behind a feature and the overall design of the concept. Since it is cost effective to change a product early in the development process rather than to make changes later on in the process or even after production have started. Prototyping allowed for gathering of feedback while still planning and designing the product. High-fidelity full scale prototypes were mostly used since they allowed realistic user interaction. However, the creation of prototypes differed from creation of the final product in terms of material, process and verification [8].

Different types of prototypes were created in the phases of the development depending on what was desired to investigate or evaluate. The further into the project the design came, the higher level of the prototypes had.

Chapter 3

Preparatory Work

To put the problem in a holistic context and broaden the basis for information, the pre-study was made. A market analysis was conducted to understand what is going on around the product. By investigating the existing technology and what the competitors are doing good a benchmarking could be made. Input from different stakeholders are described. Last, a deepened investigation of the current products and the problem was conducted.

3.1 Market Analysis

The market analysis was performed to get an understanding about what is currently trending on the market related to the identified problems areas of the product. The market trends are divided into four different areas; political, economica, socio-cultural and technological. FlexLink is a business to business company and the products are mainly delivered to production sites around the world. Therefore, the socio-cultural category mainly focuses on company activities. Possible information sources was identified together with factors of relevance to sharpen the scope of what was considered important and sources of where to find information, see table 3.1. The objective was defined as "Is it profitable to develop a new type of stop for a pallet system?"

Table 3.1: The four different areas to the market trend analysis of interest and the how information was found.

	Possible sources of information	**Areas of information**
Political	Government Office of Sweden, European Commission, news agencies	Environmental directives, Current legislation, Government policies
Economica	Newspapers, economical journals	Political economy, taxation specific, customer drivers, production methods
Socio-cultural	International Organization for Standardization, journals, labor unions, social media	Marketing trends, workers attitudes and opinions
Technology	European Commission Joint Research Centre, Patent database	Maturity of technology, manufacturing maturity and capacity, and technology access, licensing and patents

Found during the analysis which spans all these areas is the Industry 4.0 [32], also known as the fourth industrial revolution. It involves rapid changes over many domains with huge risks and powerful economic and social impact [33]. The world is facing some big challenges in areas of economics, social and environmental. With an ever-increasing global competitive pressure, personalised products, shortened product life-cycles and fast evolving technologies. This requires efficient processes. So far, only tendencies and challenges can be discerned [34].

3.1.1 Political

Restriction of hazardous substances, RoHS, is an EU directive regulating the use of ten substances often occurring in both metal alloys and plastic compositions. The regulation is an effort to reduce hazardous materials in the manufacture of various types of electronic and electrical equipment [35]. This is one of initiatives to handle the global issue of consumer electronics waste. As the speed of technology evolution is increasing the consumers are discarding old products which often ends up as landfill in less privileged countries [36].

Registration, Evaluation, Authorisation and Restriction of Chemicals, REACH, is another EU regulation. It addresses the production process and the use of different chemical substances together with the potential impacts on both humans and the environment in the EU [37]. That non-naturally occurring chemical substances leak out can have consequences for the water quality among others [38].

The Machinery Directive is an EU legislation which arouse to ensure a common safety level in machinery [24]. It makes it easier for companies to adapt to a single set of standards instead of having different configurations for different countries. In Sweden, there are additional directives around low voltage, electromagnetic compatibility [39, 40] and product safety [41].

FlexLink have well established supply chains with different manufacturers in China. About half of all products in terms of money are manufactured in China. Adding to that, FlexLink has four sales units in China, two in Japan and one in South Korea [42]. With the escalation of the political situation taking place between North Korea and the United States, this development may be a major risk to the supply chain and sales volume in both North America and East Asia.

3.1.2 Economical

Automated production processes has for the last sixty years been rapidly increasing and is now the everyday life of most production heavy companies but also smaller companies [43, 44]. It provides a lot higher accuracy and effectiveness compared to human driven production lines. There are no signs that the inquiry is descending.

Total cost of ownership, TCO, is a financial estimation tool to help buyers and company owners to determine the costs, both direct and indirect, of a product or system. It is a management tool that helps in seeking to quantify the financial impact of deploying a product over its life cycle [45]. TCO can be used in full cost accounting which can add new dimensions to the analysis compared to traditional tools, even ecological economics and social costs [46].

A large urbanisation has been going on in China during the last 20 years leading to large scale migration to the manufacturing areas around the major cities [47]. With more manufacturing moving away from coast and further into China's mainland in the last years, workers are finding more opportunities closer their home region with proximity to their relatives. During the New Year holiday, workers often meet their friends who introduce them to new opportunities that offers a small raise of salary and closer to home [48]. Each year, many workers are simply not showing up again after the holidays [49]. This leads to high staff turnover and less experienced work force.

3.1.3 Socio-cultural

Another aspect of the migration and growth of China's industries is the strengthened position of the workers. Companies have started to offer better working conditions and treat their workers fairly in terms of breaks, salary and vacation possibilities. These companies often have better retention rates and tend to attract new workers more easily. This increases the life quality for the workers but on the other hand raising the costs for the companies. It is a cost - benefit situation [50].

With a more widespread and intense use of the Internet, the power of public relations is emerging. It is the main drive of the marketing communication machine. There are findings pointing out that "public relations make an organisation more effective when it identifies strategic constituencies in the environment and then develops communication programs to build long term, trusting relationships with them" [51]. To clearly communicate the company's values is important to profile itself.

Other things that often are communicated is the different certifications that companies spend significant sums on and are proud of. ISO 9001 is governing the quality processes [52] and ISO 14001 is the environmental management [53], which are two popular certifications. One study is pointing out that companies which have ISO certifications perform better than its competitors [54] while another study argues that is does not make any difference [55].

3.1.4 Technological

Additive manufacturing or 3D-printing is a manufacturing method that grows and expands to include more and more materials. One of the new trends in printing materials is to add carbon fibers which makes the tensile strength on the same level as aluminium [56], [57]. Further, it can be implemented as not only a way of conduct rapid prototyping, but also a production method.

Cyber-Physical Systems, CPS, are integration of physical processes, algorithms, computation and networking. The systems contains complex loops with feedback where the physical processes and computations are affecting each other [58]. "CPSs are expected to play a major role in the design and development of future systems" [59]. The potential in both economic and societal of CPS is a lot greater than what has been earlier realised. By adding functionality to the product it will be possible to use it in the CPS.

The market for development of new sensor types is strong [60]. There are sensor systems requiring almost no power at all, called zero-power sensors. These sensors are capable of detecting physical signals from 5 Hz to 1.5 kHz, with sourcing load capacitance as high as 200 pF [61], which classifies as super capacitor while maintaining a broad bandwidth. This is a technique that might be possible to include in the next generation of products.

Industrial Internet of things, IIoT, is a part of the broader Internet of things, IoT. It is used primarily in the manufacturing industry to for example create an intelligent maintenance systems [62]. In the future, companies will be successful in capturing new growth opportunities through three approaches using IIoT: "boost revenues by increasing production and creating new hybrid business models, exploit intelligent technologies to fuel innovation, and transform their workforce" [63].

3.2 Technology and Competitor Analysis

To further investigate the technology, patents were examined for trends and smart solutions, and to understand the state of the current technology used in the product. Two kinds of patent searches was conducted, a first screening and a landscape search, to get both depth and width. The competitors was identified and analysed through an Internet-based benchmarking to give an idea of how FlexLink and the current product portfolio stands up relative to its competitors.

3.2.1 Patents

By answering the questions in the left column of table 3.2, keywords and synonyms were generated that served as input to the patent searches. They keywords were used in different combinations not to miss relevant patents. Starting with broad searches with only one or two keywords and then narrowing the search by adding keywords until a satisfactory amount of patents remained. With satisfactory meant that the amount of patents was so few that they could be read through the timeframe of the allocated time for the patent analysis.

Table 3.2: The strategy to generate keywords

Question	Answer	Keywords	Synonyms
What problems does the invention solve?	Pallets must stop at an exact position	pallet, stop, position	fix, location, fasten, break
What is the invention?	A housing for a lead screw nut to a stepper motor	housing, lead screw, nut, stepper motor	assembly, case, fasten, element, block, console, cabinet
What does the invention do?	Keeps the pallet in place to create a queue and let go of the pallets at regular intervals	in place, interval, queue	fix, holding, distance, separation, delay, lag, break, phase, halt

No dominating actor was found during the screening but it can be noted that a majority of the patents were only concerning China. This made them impossible to read and thus only figures in the patent applications was studied. There were no dominant patent classes to use in the further screenings. Both of these two results complicated the further analysis, which could mean that important patents were missing from the summary made.

Since the product, that were to be developed, consisted of multiple functions the screening was divided. One concerned the coupling between the motor shaft and the piston rod. Findings related to this area was different ways to handle angular, parallel and axial displacements. A further developed Oldham coupling [23] can be seen in figure 3.1 which is very good at handling axial misalignment [64].

Another coupling found handling both axial and angular displacements is shown in figure 3.2 and made with elastic wires [65].

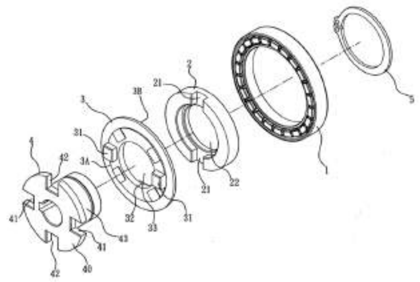


Figure 3.1: Patent TWM540941 which is a cross-type of an Oldham coupling [64].

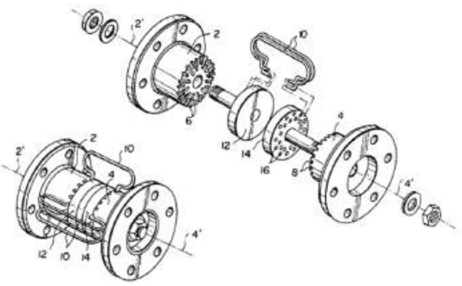


Figure 3.2: Patent JPH02271111 that uses electrical wires to create flexibility [65].

Figure 3.3 shows a "structure of a universal transmission shaft and a flexible coupling which has not only traditional universal transmission system but also an additional flexible coupling to guarantee angle and displacement compensations for vibrations" [66]. A linear electric push rod is displayed in figure 3.4 which consist of a "flexible push rod connected to a motor shaft. A bearing assembly comprises a bearing base fixed on the screw, a pair of conical roller bearings is arranged oppositely" [67] which gives good axial bearing capability and thrust.

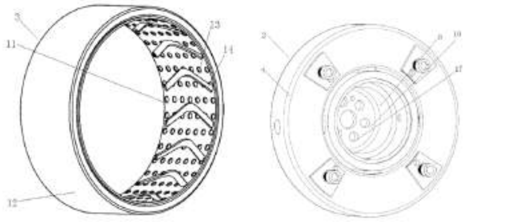


Figure 3.3: The CN102628479 patent is a solution to handle displacements and vibrations [66].

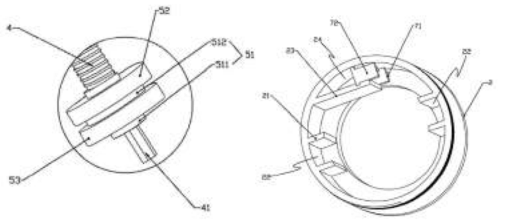


Figure 3.4: Patent CN105529866 presents a way of create good axial bearing [67].

Another screening concerned the construction of the piston rod and the structure of the motor shaft. Figure 3.5 displays a telescopic shaft solution used within milling [68]. It is another way of creating linear motion. There are different ways to fasten the motor shaft, in figure 3.6 a conical connection is shown which "provide linear actuator function" [69]. The benefit of this solution is that the shaft could be attached after the stepper motor has been completely assembled.

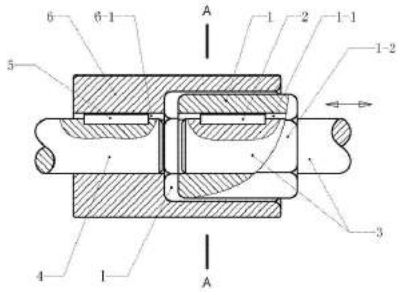


Figure 3.5: A telescopic shaft-mechanism is one way to create large linear motion and is explained patent CN205841542 [68].

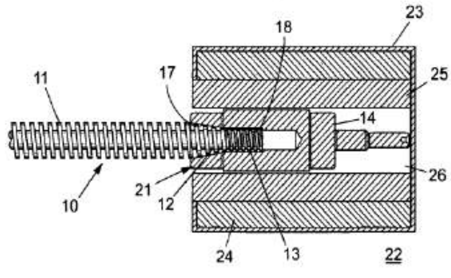


Figure 3.6: The patent US2012146439, describes a way of using conical connection between the shaft and the rotor i an actuator [69].

A landscape search is presented with a graph of how the number of patents have changed over time. Three different screenings were made which each used different keywords to get a better depth of the analysis, it is displayed in figure 3.7. As seen from the three lines in the graph, the area where the lines intersected are located in the time span of 2007-2012. This indicated on one hand that the product is in the maturity phase of the S-curve [70]. On the other hand, the red line and the grey line and figure 3.7, indicated that it is still in the expansion phase and that there are merits to retrieve.

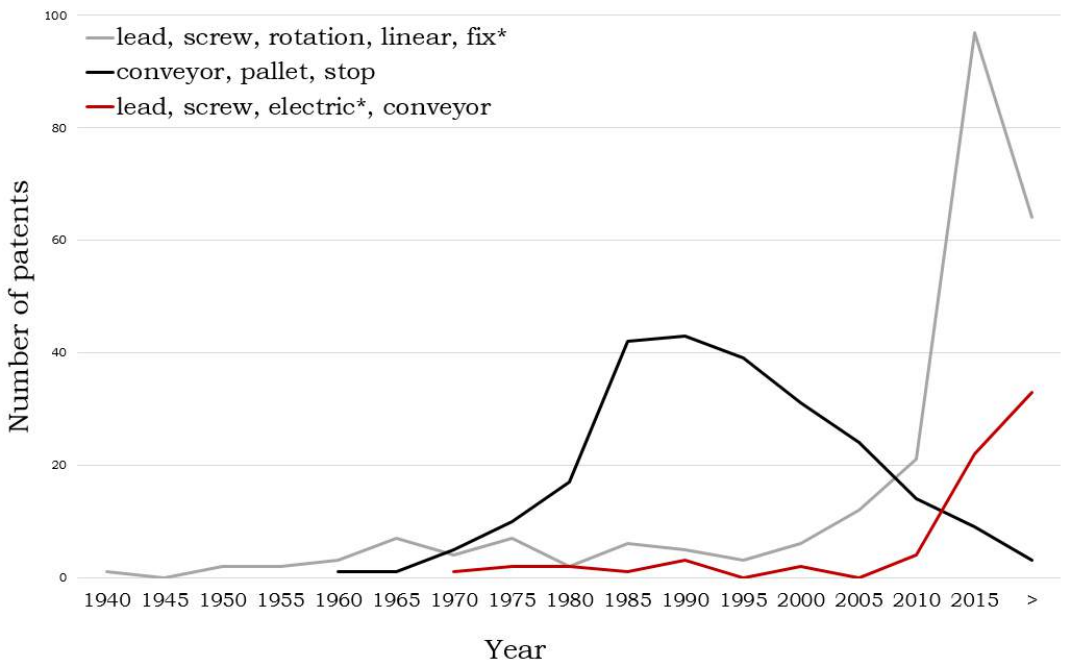


Figure 3.7: The three lines are each showing one patent search with different keywords that are displayed in the graph legend.

3.2.2 Benchmarking

To identify possible competitors to FlexLink's electrical pallet stops, the market was first scanned for companies developing conveyors and then if they offered electrical pallet stops. Two competitors were found, both of them located in Germany, ASUTEC and WörneR. They have stepping motors as actuators and a geometric locking of the rod rotation to create linear motion. Both are mounted by means of screws and nuts through holes in the housing holding the actuator and rod. The housing is located alongside the conveyor beam on a twin track conveyor. This means that the pallet is transported forward by two parallel chains and also has two contact points to the chain instead of one contact point that the product to be developed in this project has. It gives an advantage of being able to stop the palettes from below, closer to the centre of gravity than the side that is further away from the centre of gravity.

WörneR's stops are shown in figure 3.8 and have rectangular shapes with flat surfaces on the tip that collides with the pallet. It is cut around the top which is functioning as space for a damping function [71]. In figure 3.9, ASUTEC's electrical stop is shown. It has a different geometric cross section of the tip and material all the way up to the edge of the housing.

It has no damping [72]. Both of the tips are made out of stainless steel and have a housing of press-cast aluminium.

Figure 3.8: The electrical pallet stop, ELD-190 from WörneR Automatisierungstechnik GmbH [71].

Figure 3.9: ASUTEC GmbH's electrical pallet stop, ASUTEL-150 [72].

When investigating the technical characteristics of the three stops, some differences are noticed. As all of stops are using i stepper actuator, it is known that the relation of torque and speed is similar to a ski slope. It makes it been impossible to achieve maximum torque at maximum speed. It is therefore desirable to have as good trade-off as possible between these two characteristics. The technical data from the three stops are presented in table 3.3. After stopping a palette, the shaft must be pulled back to release past the palette and then move out to stop the next palette before it passes. The cycle time is therefore in close relation to the time window between two palettes transported on the conveyor.

Table 3.3: Technical data for the three electrical pallet stops investigated in the benchmarking.

Product		**ASUTEC ASUTEL-150 [72]**	**WörneR ELD-150 [71]**	**WörneR ELD-65 [71]**
Pallet weight at conveying speed	6 m/min	150 kg	190 kg	65 kg
	9 m/min	105 kg	170 kg	45 kg
	12 m/min	75 kg	150 kg	40 kg
	15 m/min	60 kg	N/A	N/A
	18 m/min	50 kg	80 kg	29 kg
	24 m/min	30 kg	50 kg	15 kg
	30 m/min	N/A	35 kg	10 kg
	36 m/min	N/A	25 kg	7 kg
Time to rise	8 mm	N/A	300 ms	300 ms
	9 mm	160 ms	N/A	N/A
	15 mm	250 ms	N/A	N/A
	25 mm	420 ms	N/A	N/A
Time to lower	8 mm	N/A	250 ms	250 ms
	9 mm	300 ms	N/A	N/A
	15 mm	420 ms	N/A	N/A
	25 mm	650 ms	N/A	N/A
Cycle time		3,5 s	3 s	3 s
Initialisation time		N/A	6 s	6 s

3.3 Problem Exploration

To get a clearer picture of the problem and understand what was needed to be done, the problem was further explored. The different platforms where the stop was desired to fit was assembled to get measures of the available design space. What pallet types to stop and existing geometrical constraints on the contact surfaces was identified. Then the stop was tested to understand the acting forces.

3.3.1 Product Platforms

There were five different product platforms which the pallet stop was desired to be compatible with. They all carry different pallet types and have its own characteristic cross section, see appendix A.1 for illustrations. To create a stop that suited all the platforms it was important to identify geometrical synergies. Each of the platforms have different pallets, to get an understanding of how fast the stop needs to act the entry window for each platform was investigated. The pallets needed to be stopped even if they were in a queue with no spacing between. The minimum entry window was defined as distance between the end of the first stop pocket to the start of the second stop pocket, figure 3.10.

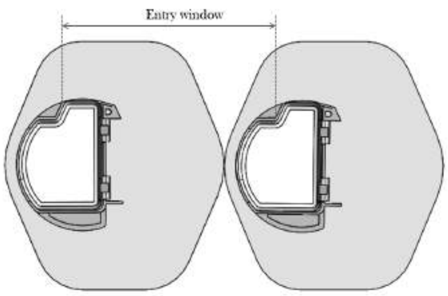


Figure 3.10: The distance between two pallets where the stop is acting.

The entry window was calculated for each platform and this gave a time for how fast a cycle had to go since the pallets are travelling in the maximum speed of 20 m/min. The distance that the stopper had to travel to stop the pallets was also measured. The maximum load each platform's pallet could handle was found using the product catalogue [7]. All that information is shown in table 3.4. Since the Optical system are using different types of plastic trays instead of pallets, they were not used in the analysis.

Table 3.4: The different platforms with the total times of the entry windows.

Platform	Length	Weight	Time
X65	10 mm	40 kg	359 ms
X85	10 mm	40 kg	471 ms
XT	10 mm	200 kg	758 ms
Optical	15 mm	50 kg	N/A

To understand the space between the chain and the guide rail, a 50 mm cube was inserted into each platform and pressing it towards the long side of the chain and removing the areas that intersected, see figure 3.11, 3.12 and 3.13. Since the XT and Optical tracks did not have a guide rail to consider, these were left out from this analysis. The red area in figures 3.11, 3.12 and 3.13 is in the same plane as the side of the guide rail and facing the pallet. Thereafter, the three profiled cubes were merged into one common design space, see appendix A.2.

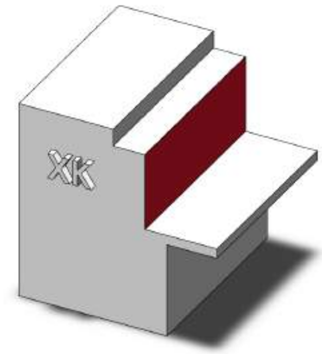


Figure 3.11: A graphical illustration of the available space between the guide rail and the beam in the XK-platform.

Figure 3.12: A graphical illustration of the available space between the guide rail and the beam in the X65-platform.

Figure 3.13: A graphical illustration of the available space between the guide rail and the beam in the X85-platform.

The last thing investigated in relation to the product platform was the shape of the contact surface between the pallet and the stopper. X65 and X85 had an angle of 115°, XH and XK had flat surfaces and the Optical platform used a cylinder. Figure 3.14 illustrates the stoppers geometry where the pallet collided with the top edge.

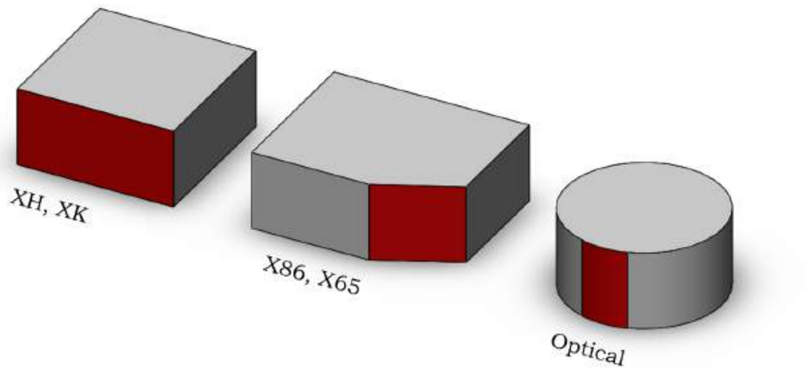


Figure 3.14: The geometry of the stoppers

3.3.2 Hypothesis

The predefined issues described in section 1.2 provided parts of the problem image with the current product but there still existing questions. Other clues were given from the two earlier projects at FlexLink, three main things were identified. The surface treatment in the contact area plays a major part in the product lifetime. The geometric relationship between the length and width on the stopper proved to be problematic because of the "sticky drawer"-effect [73]. At the beginning of the projects, the conclusion was drawn that there was no axial force going into the stop, this was a miscalculation and affecting the actuator to failure after few cycles when testing.

The first thing wanted to test was the magnitude of the axial force. The natural movement of the pallet in the X65 platform and X85 platform is illustrated in figure 3.15. A system of the acting forces was set up in the moment of impact, see figure 3.16.

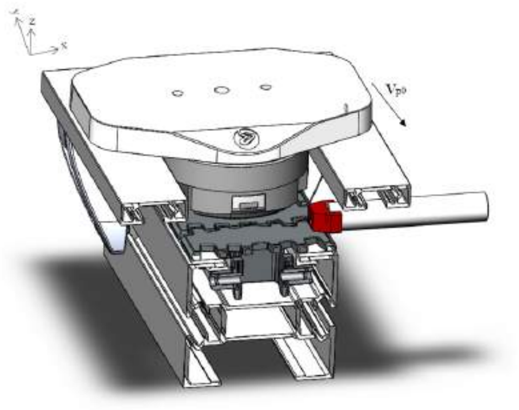


Figure 3.15: The natural movement of a pallet along the chain.

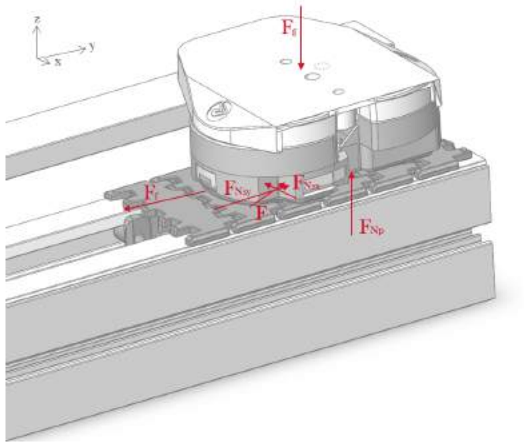


Figure 3.16: All acting forces on the pallet when colliding with the stopper.

There are additional forces to take into account. The contact surface had an angle to the speed direction, see figure 3.17. This meant that force could be divided into two components where the ratio between them was determined by the angle, see figure 3.18.

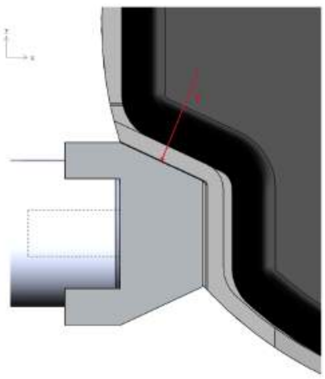


Figure 3.17: The moment of impact between the stopper and the pallet.

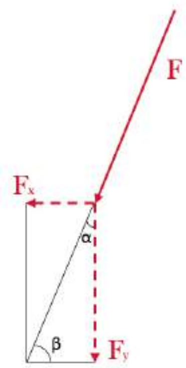


Figure 3.18: The impact force is divided into two force components, one in negative y-direction and one in negative x-direction.

The angle, α, was used for determining the ratio between the force components as presented in equation 3.1. The forces F_x and F_y are the impact forces from the stopper.

$$\begin{aligned} F_x &= F\sin(\alpha) \\ F_y &= F\cos(\alpha) \end{aligned} \tag{3.1}$$

In the steady state, as seen in figure 3.16, an equilibrium of the forces affecting the pallet can be written as

$$x : F\sin(\alpha) - F_{Nx} = 0 \tag{3.2}$$

$$y : -F_f + F\cos(\alpha) - F_{Ny} = 0 \tag{3.3}$$

$$z : F_{Np} - F_g = 0 \tag{3.4}$$

With the equations 3.2, 3.3, 3.4 and the conditions $F_f = \mu F_{Np}$, and $F_{Nx} + F_{Ny} = F$ it gives a size of the force F.

$$-\mu F_g + F\cos(\alpha) = 0 \implies F = \frac{\mu F_g}{\cos(\alpha)} \tag{3.5}$$

The values sought were those that affected the stop. Those are as large as F_x and F_y but opposite so they cancel each other out. Labelling the forces on the stop as F_{Nx} and F_{Ny} gives

$$\begin{cases} F_{Nx} = F\sin(\alpha) = \frac{\mu F_g}{\cos(\alpha)}\sin(\alpha) \\ F_{Ny} = F\cos(\alpha) = \mu F_g \end{cases} \tag{3.6}$$

In the collision between the palette and the stopper, the stopper was affected by an equal opposing force as the pallet. The impulse of this force stopped the movement of the palette while the stopper received an impulse downwards and sideways. It was an elastic collision under the assumption that all momentum was preserved in the shock [74]. The principle of conservation of the total momentum is displayed in equation 3.7.

$$m_p v_{p1} + m_p v_{p2} = m_s v_{s1} + m_s v_{s2} \tag{3.7}$$

Right before the collision, the pallet is moving and the stopper is still. After the collision, the pallet is still and the stopper is moving slightly. This means that the speed $v_{p2} = 0$ and the speed $v_{s1} = 0$, which gives the expression in equation 3.8.

$$m_p v_{p1} = m_s v_{s2} \implies v_{s2} = \frac{m_p}{m_s} v_{p1} \tag{3.8}$$

An impact means a change of momentum, that a force is applied to a particle for a time interval [74]. The rate of change of the momentum of a particle is proportional to the force F acting on it. The impact force therefore depends on time and when integrated results in the momentum as described in equation 3.9.

$$\Delta p = \int_{t_1}^{t_0} F dt = p(t_1) - p(t_0) \tag{3.9}$$

The force can be written as Newton's second law in differential form, and under the assumption that the mass is constant through the impact it wan be re-written as in equation 3.10.

$$F = \frac{dp}{dt} \implies F = m\frac{dv}{dt} \tag{3.10}$$

With the speed known and assuming the time of the impact as τ, equation 3.10 can be written as equation 3.11

$$F = m\frac{dv}{dt} \implies F = m\frac{\Delta v}{\Delta t} = m\frac{v_1 - v_0}{\tau} \tag{3.11}$$

Using a fully loaded X85-pallet weighing 40kg that is transported at the speed of $v_c = 20$ m/min = 0.33m/s. From FlexLink's Calculation Tool [75], the value of the coefficient of friction was received as $\mu = 0.25$. With the angle, $\alpha = 25°$ and assuming $\tau = 2$ ms.

$$F_{static} = \frac{\mu F_g}{\cos(\alpha)} = \frac{0.25 \cdot 9.81 \cdot 40}{0.906} = 108N \tag{3.12}$$

$$F_{Nx_{static}} = \frac{\mu F_g}{\cos(\alpha)}\sin(\alpha) = \frac{0.25 \cdot 9.81 \cdot 40}{0.906}0.432 = 46N \tag{3.13}$$

$$F_{Ny_{static}} = \mu F_g = 0.25 \cdot 9.81 \cdot 40 = 98N \tag{3.14}$$

In the moment of impact, the friction force is zero and therefore not affecting the force distribution.

$$F_{impact} = m\frac{v_1 - v_0}{\tau} = 40 \cdot \frac{0.33}{0.002} = 6600N \tag{3.15}$$

$$F_{Nx_{impact}} = \sin(\alpha)\frac{m_p v_1}{\tau} = 0.423\frac{40 \cdot 0.33}{0.002} = 2792N \tag{3.16}$$

$$F_{Ny_{impact}} = \cos(\alpha)\frac{m_p v_1}{\tau} = 0.906\frac{40 \cdot 0.33}{0.002} = 5980N \tag{3.17}$$

The coefficient of restitution, C_R, was used to compare the difference in kinetic energy immediately before impact with immediately after impact thus, the loss of kinetic energy could be estimated [76].

$$C_R = \frac{\sqrt{E_{k_{after}}}}{\sqrt{E_{k_{before}}}} = \frac{\sqrt{\frac{1}{2}m_s v_{s2}^2}}{\sqrt{\frac{1}{2}m_p v_{p1}^2}} = \frac{\sqrt{m_s(\frac{m_p}{m_s}v_{p1})^2}}{\sqrt{m_p v_{p1}^2}} = \frac{\sqrt{m_s\frac{m_p^2}{m_s^2}v_{p1}^2}}{\sqrt{m_p v_{p1}^2}} = \sqrt{\frac{m_p}{m_s}} \tag{3.18}$$

The m_s is significantly lighter than m_p which resulted in a $0 < C_R < 1$ showing that it was a real-world inelastic collision where some kinetic energy was dissipated.

For the X85 H, XK, XT and Optical, the stopping functions have other geometries, see figure 3.19. That means that the angle of attack and force components of the applied force, F, differs. Performing the same calculations for the other platforms gave an overall picture of the loads, see table 3.5.

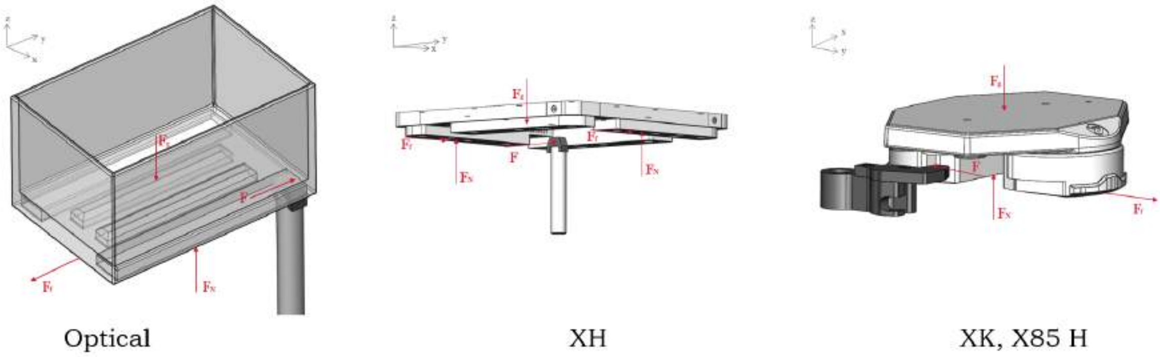


Figure 3.19: The static equilibrium for the X85 H, XK, XT and Optical platforms.

Table 3.5: The different platforms with the acting forces on the stopper

Platform	**Weight**	$\mathbf{F}_{Nx_{static}}$	$\mathbf{F}_{Ny_{static}}$	$\mathbf{F}_{Nx_{impact}}$	$\mathbf{F}_{Ny_{impact}}$
X65	40 kg	46 N	98 N	2792 N	5980 N
X85	40 kg	46 N	98 N	2792 N	5980 N
XT	200 kg	0 N	491 N	0 N	8300 N
Optical	50 kg	0 N	123 N	0 N	8250 N

Since there was no possibility of using a complete pallet system, a test environment was developed where the pallet was dropped using gravitational force. Mechanical theory was applied to the problem by dividing it into three stages;

1. The pallet performs a free fall, see figure 3.20.
2. There is an impact between the pallet and the stopper where re-distribution of momentum occurs. The stopper is pushed inwards, see figure 3.21.
3. The pallet reach a steady state equilibrium, see figure 3.22.

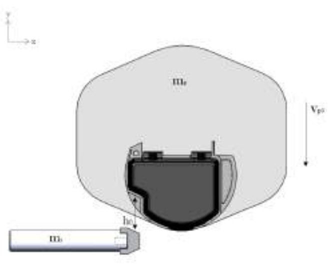


Figure 3.20: The state of the system when the pallet is released from its initial position.

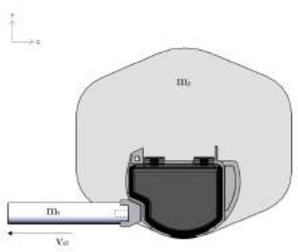


Figure 3.21: When the pallet hits the stopper it wants to move in negative x-direction.

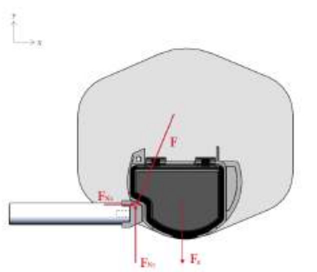


Figure 3.22: After the impact, the pallet reach a steady state with the forces shown in red.

The first stage was calculated using the principle of conservation of energy [74], which is displayed in equation 3.19.

$$\frac{1}{2}m_p v_{p0}^2 + m_p g h_0 = \frac{1}{2}m_p v_{p1}^2 + m_p g h_1 \tag{3.19}$$

In this problem, the speed $v_{p0} = 0$ and the height $h_1 = 0$, which gives the expression in equation 3.20.

$$m_p g h_0 = \frac{1}{2}m_p v_{p1}^2 \implies v_{p1} = \sqrt{2gh_0} \tag{3.20}$$

To imitate a horizontal travelling, hitting the stopper at a speed of 0.33 m/s, the pallet is dropped from a distance, $h_0 = 5.56$ mm.

$$v_{p1} = \sqrt{2gh_0} \implies 0.33 = \sqrt{2 \cdot 9.81 \cdot h_0} \implies h_0 = 0.00556m \tag{3.21}$$

Using the expression from equation 3.20 in equation 3.8 gave equation 3.22.

$$v_{s2} = \frac{m_p}{m_s}\sqrt{2gh_0} \tag{3.22}$$

It can be shown that the force was equal opposing, for both the pallet and the stopper using first equation 3.20 in 3.11 and then equation 3.22 in 3.11, by comparing the results in equation 3.23 and 3.24

$$F_p = \frac{m_p}{\tau}v_{p1} = \frac{m_p}{\tau}\sqrt{2gh_0} \tag{3.23}$$

$$F_s = \frac{m_s}{\tau}v_{s2} = \frac{m_s}{\tau}\frac{m_p}{m_s}\sqrt{2gh_0} = \frac{m_p}{\tau}\sqrt{2gh_0} \tag{3.24}$$

With the angle, $\alpha = 25°$ and assuming $\tau = 2$ ms, a numerical answer can be calculated, see equation 3.25.

$$F_x = 0.423 \cdot 40 \frac{\sqrt{2 \cdot 0.0056 \cdot 9.81}}{0.002} = 2804N \tag{3.25}$$

$$F_y = 0.906 \cdot 40 \frac{\sqrt{2 \cdot 0.0056 \cdot 9.81}}{0.002} = 6008N \tag{3.26}$$

A comparison with the horizontal case, as described in figure 3.16 was made to verify the vertical calculations. The result thus has a reliability of 99.6% and the test-method can therefore be considered sufficiently accurate to be used.

In the steady state equilibrium

$$\begin{cases} x : F\sin(\alpha) = 0 \\ y : F_g - F\cos(\alpha) = 0 \end{cases}$$

Which in the same way as in equation 3.6 gives

$$F_{Nx} = \frac{F_g}{\cos(\alpha)}\sin(\alpha) = \frac{m_p g}{\cos(25^\circ)}\sin(25^\circ) = \frac{9.81 \cdot 40 \cdot 0.423}{0.906} = 183N \tag{3.27}$$

$$F_{Ny} = F_g = m_p g = 9.81 \cdot 40 = 392N \tag{3.28}$$

that resulted in a scaling factor of 4 : 1. Meaning that theoretically the difference between the horizontal reality and the vertical case can be translated using the scaling factor. If a pallet with a weight of 5 kg is used in the vertical case, it could represent the horizontally travelling pallet of 20 kg.

3.3.3 Testing

A test rig with a vertical drop using a load cell to measure F_x was built up by existing rigs and aluminium profiles. The stop was mounted in the rig, see figure 3.23 and 3.24. The pallet with a load of 5,455 kg was mounted on a profile with wheels running along the rear profile in figure 3.26 and 3.25.

In the first set of runs, the rod was firmly threaded into the load cell which resulted in difficult-to-understand values with undesirable behaviour. The rig was then reconstructed so that the rod was only in contact with the edge of the load cell. An accelerometer was added onto the pallet to verify the movement of the pallet. The data was sampled with a mean sampling rate of 5 ms. The test-runs was executed by lifting the pallet to a pre-calculated height and then drop it by hand down onto the stop. No additional load was applied to the pallet, the gravitational force was the only big actor.

Figure 3.23: The test rig shown from the front with the stop mounted on the front profile to fit with the load cell.

Figure 3.24: The test rig shown from the behind showing the connection between the load cell and stop.

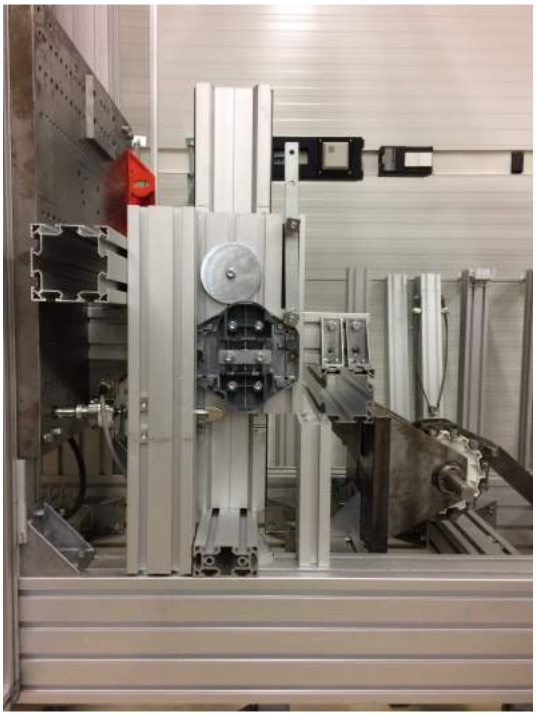


Figure 3.25: The pallet running downwards along the rear profile due to gravitational force.

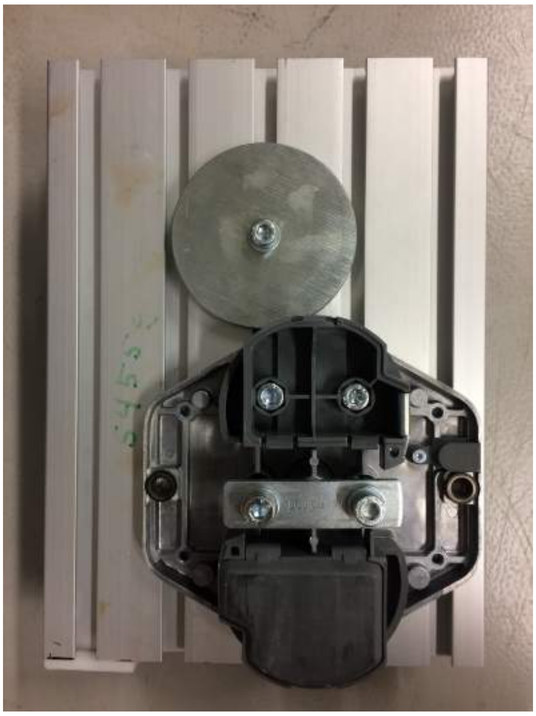


Figure 3.26: The pallet mounted onto an aluminium profile with an additional weight.

100 drops were performed in the second round and a part of the result is illustrated in figure 3.27. As seen, the peaks each have a ramp profile and only one showed the spike that was coming from the impact. There were quite big fluctuations when the pallet was supposed to be still, this was because the pallet was held and dropped by hand. That the peaks were not equally large were assumed to be due to the fact that it was not possible to keep the pallet exactly in the same place each time.

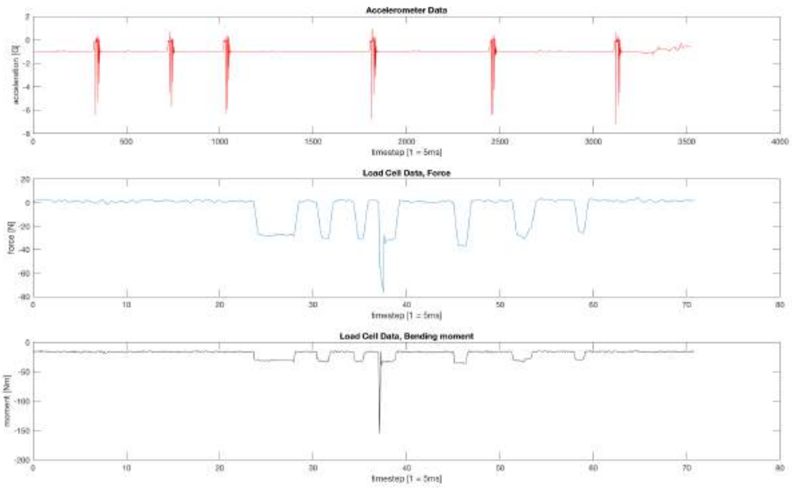


Figure 3.27: Results from the second round of tests, dropping the pallet by hand.

To eliminate the height problem, a beam was placed beneath the pallet and this was then retracted to release the pallet, see figure 3.25. In the third round of tests, 100 drops were made and a sample of 11 drops is shown in figure 3.28. In this round, the spikes are clearly visible in several of the drops, although the peaks were still not equally large. It was then assumed that a better drop function was needed and that the sampling time needed to be lower.

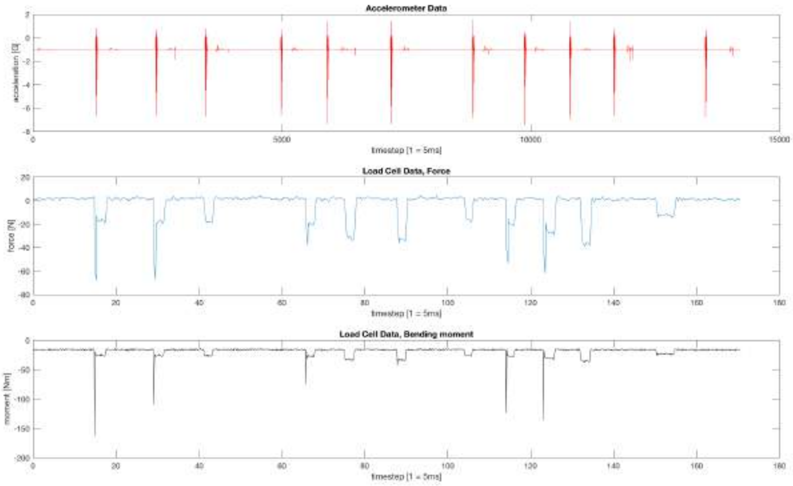


Figure 3.28: Results from the third round of tests using a beam when dropping the pallet.

A pneumatic stop was installed to drop the pallet from the pre-calculated height to get the same time that the release took every time. The sampling time was lowered from 5 ms to 1 ms and another set of 100 drops were performed. This gave an expected appearance on the results graphs but it was still odd that the spike did not show on all the peaks.

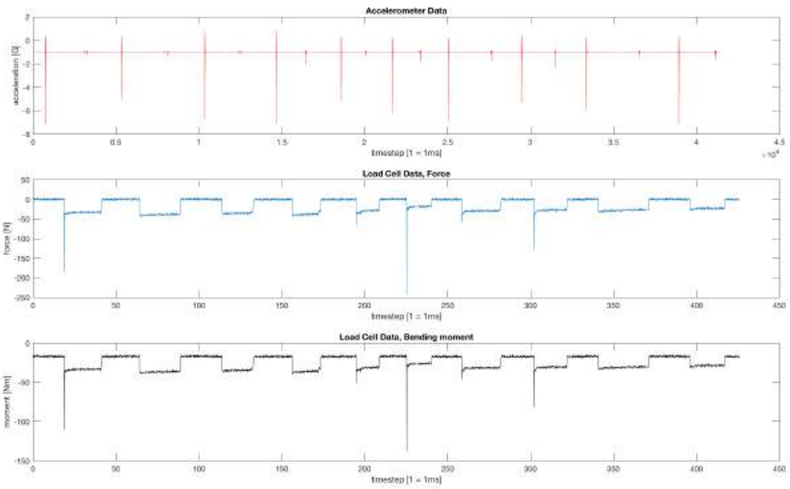


Figure 3.29: Results from the fourth round of tests where a pneumatic stop was used for when dropping the pallet.

The accelerometer had a sampling frequency of 1000 Hz which corresponds to a sampling time of 1 ms meaning that both the load cell and the accelerometer had the same resolution.

When comparing the accelerometer data displayed in figures 3.27, 3.28, 3.29 it could be seen that the acceleration was almost equally large each drop while the load varied significantly. A conclusion was drawn that the sampling rate was still too low to display what happens with enough clarity. It is the phenomenon of temporal aliasing meaning that the sampling rate needs to be doubled to avoid aliasing. Since 1 ms is the maximum sampling rate of the LABview program used, a more accurate mapping of the impact force could not be performed. This also showed that the previously assumed time of impact $\tau = 2$ms was too large. It was also realised that the pallet used had a scaling factor of 1 : 3.6 and not the calculated 1 : 4

When it hit the stop, the palette bounced back slightly before it settled on the stop. In reality, the pallet is transported horizontally due to friction between the pallet and the chain. When the pallet hit the stop, it is not bouncing back onto the stop as fast. From those two findings it was found that the results could not be read with high reliability but rather seen as guiding values.

3.4 Stakeholder Analysis

The stakeholders were identified to find out who have an interest in, and expectations of, the product. This laid the foundation for the data collection in terms of who to approach. Both a survey and interviews was used to collect data. Based on the result from the data collection stakeholders opinions were identified.

3.4.1 Stakeholders

The stakeholders in this Master's Thesis project have been defined as the ones who interact with the product during its lifetime. Starting in development with Coesia management, FlexLink managers, FlexLink Units and its employees. Then adding manufacturers and suppliers in production, the production companies which are the customers of the product. The primary users such as technicians and installers, and the secondary users which are maintenance- and disassembling staff. All of the stakeholders would have different perspectives of what were important features or functions of the product.

3.4.2 Data Collection

Four interviews were held with Björn Tibblin - Product Quality Engineer, Rickard Ekström - Workshop Technician, Fredrik Sannehed - Project Manager and Dick Axelsson - Product Manager of the pallet handling systems. A study visit with observations and one interview with Susanne Börjesson - Production Engineer was conducted at SKF in Gamlestaden, Gothenburg. They had a XK production line transporting larger roller bearings. A survey was sent out to customers in Germany through the German Sales Unit.

A wide range of interviewees were used which also reflected in the aggregate material. Aspects throughout the entire development process, from design to maintenance, emerged. Quotations from the interviews reflect that electricity is desirable, but that electronics in this type of application is a new and topical thing. It also showed a number of things important for the whole chain of people handling the product.

"Maybe to include the sensors in the stop itself if it is quick enough, the sensors tend to be dislocated after a short period of time"

"Today there are no feedback systems at all in the pneumatic stops"

"The environmental requirements in the SKF policy says that we can no longer buy pneumatic equipment"

"Has a higher purchase price but in TCO-perspective is much cheaper"

"The environment will be different from our test area, need for an encapsulation from dust, water, moist and rust"

"It is a challenge to create a product with the same capability, its new technology compared to pneumatic"

"I want space enough to efficiently use my tools"

"A risk factor when having a common start, as the case is in almost all of the production sites"

"Don't want to interfere with the side rail because that leads to special installation"

"Want an interface that are well functioning with our own platforms with a clear indication of how to place the stop"

"Steel against steel in the contact point or surfaces sliding onto each other is bad"

"Having a battery or accumulator to make sure that enough power is provided to the actuator"

Chapter 4

Requirements

All the insights, opinions and information from the interviews together with the test results from the pre-study was summarised and evaluated together. This to see if any of the requirements were contradictory or needed to be corrected. A narrowing of the times for the stopper to perform one cycle, as described in section 3.3.1, was made. That to achieve a Margin of Safety, MoS, meaning how much higher capacity the system has beyond what needs for the intended use [23]. After discussions with the engine supplier, it was decided to have a MoS of at least 30%. The new cycle times are listed in table 4.1.

Table 4.1: The different platforms with updated time conditions

Platform	Prev. time	Total time	Time to rise	Time to lower
X65	359 ms	260 ms	100 ms	160 ms
X85	471 ms	260 ms	100 ms	160 ms
X85 H	471 ms	260 ms	100 ms	160 ms
XK	579 ms	260 ms	100 ms	160 ms
XT	758 ms	520 ms	200 ms	320 ms
Optical	N/A	260 ms	100 ms	160 ms

After the summation, evaluation and corrections all the requirements were compiled into a list. The requirements were sorted into engineering categories; function, performance, material, communication, dimensions and non-functional. A set of requirements from the requirement specification, found during the preparatory work can be seen in the table 4.2. The complete requirement specification can be found in Appendix B.1.

Table 4.2: A selection of requirements, translated from the stakeholder's comments and findings during the problem exploration.

Criteria	Specification	Measuring	Target	Unit
Provide position feedback	Connected to a smart system	Signal transmission	Yes	Yes/No
Pallets can pass with ease	No obstructing parts	Testing	Yes	Yes/No
Single functioning	Not interfering conveyor functions	Simulations	Yes	Yes/No
Time travelling inwards	Preferably as fast as possible	Timekeepin2g	100	ms
Time travelling outwards	Preferably as fast as possible	Timekeeping	160	ms
24V DC actuator	STEGIA	Visual	Yes	Yes/No
Environmentally friendly	Environmental burden	Calculations	0	EUL
Encapsulation	Protect from dust/moisture	External company	65	IP-Class
Wear resistance	Impact on contact surfaces	Surface gauge	0	nr
Clear indication of placements	In the conveying direction	Subjective	Yes	Yes/No
Feel reliable	Design language	Subjective	Yes	Yes/No
Show its origin	Distinct FlexLink design	Subjective	Yes	Yes/No
Fit between two tracks	Length	Measure	160	mm
Fit between two lines	Height	Measure	170	mm
Price	Total	Cost calculation	100	EUR

The requirements were sorted as either demands or wishes. All the demands together were set to be the minimum condition of that the new solution should fulfil. The wishes on the other hand were something wanted from the product but not a reason for concept elimination if not fulfilled.

To help the process of ranking the concepts further on in the project, the wishes were ranked. The matrix of the relative importance can be seen in Appendix B.2 and the result of the ranking is displayed as a column in the requirement specification in Appendix B.1. The ranking helped when a trade-off was identified. Compromises had to be made in the choice of material since the material needs to be strong and stiff while being strainable with a high fatigue limit. The product was needed to have flexibility in the placement of the solution, and clear indications of placement. The electric actuator needed to have as high speed and torque as possible however the solution needed to be as light and small as possible.

The specification was used as a frame throughout the rest of the project to ensure that the requirements were fulfilled in the final product. The list of requirements included target values and target groups and was divided into the different categories. The main part of the specification was set early before the concept generation phase, but was updated throughout the course of the project due to changing demands and newly gained knowledge.

Chapter 5

Concept Development

First a function-means model of the system was used as a base from which the concepts were generated. In the early concept generation stage, general ideas were sketched. The generated concepts were analysed and evaluated based on criteria from the requirement specification. In the further development phase, the concepts were combined and further developed. In this phase, simple prototypes were made and the concepts were developed with more details, and thereafter evaluated. In the next concept phase of the development, the concepts were made more detailed and more computer simulated prototypes were created. The remaining concepts were evaluated and sifted down until only one concept remained. Then, a final concept development was performed with focus on sub-solutions for different features of the chosen concepts. Ideas were evaluated with models, tests and matrices.

5.1 Function-Means Model

A functional description of FlexLink's existing product was made to understand what the product actually does, expressed in functions and means. Both the functions and the means of the product were listed in a hierarchical order to visualise the structure of the product and the relations between the functional requirements. The model describes the functions and gives examples of organs that could solve a specific function. It is displayed in figure 5.1 with the functions in grey and the means in red.

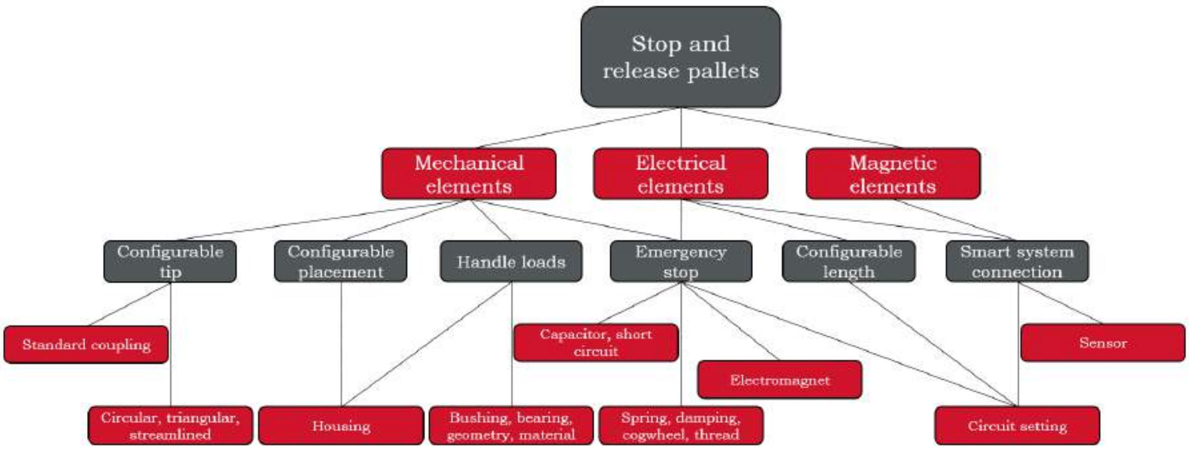


Figure 5.1: A function means three of the electrical pallet stop.

The model used three classes of solutions in the first level of means by division of the solution space into mechanical, electrical and magnetic. The second level of means served as direct inspiration to the first round of concept generation.

5.2 Early Concept Development

To generate concepts, both internal and external activities were performed. Internally brainstorming and discussions with experienced Design Engineers were to get inspiration from previous ideas and have the possibility to build onto them. The external searches were made by browsing the Internet for products which solved similar problems or sub-problems. In this stage, no strict framework were set up since a wide spectra of concepts was desirable.

Over 30 ideas, concepts and sub-concepts were generated however not all of them were unique. Some of the concepts shared the movement pattern, had the same features or were derivatives of each other. After sorting these out, the different concepts were refined and sub-concepts were combined into complete concepts, until twelve concepts remained.

5.2.1 Developed Concepts

The twelve concepts were divided into four groups depending on how movement pattern to stop the pallets. It was mostly focused on mechanical solutions with an electric drive. The red arrows in figures 5.2-5.13 of the concepts represents movement and their direction.

The first three concepts developed have in common that they stretched across the width of the conveyor. They are mounted either on the side of the conveyor or in the beam structure underneath. The friction belt shown in figure 5.2 consists of a oblong, tense circle of flexible material with one wider area covered with a high friction material that stops the pallet. It has a circular movement pattern with the motor underneath the conveyor chain. The second concept in the group can be resembled as a clock clip similar to the block brakes on bicycles and is displayed in figure 5.3. This concept has a crescentic pattern of movement with the motor underneath the conveyor chain. The tripwire concept in figure 5.4 has a translating movement pattern with the motor on the side of the conveyor. It is tensed and is powerfully pushed out, then rolled in as on a vacuum cleaner.

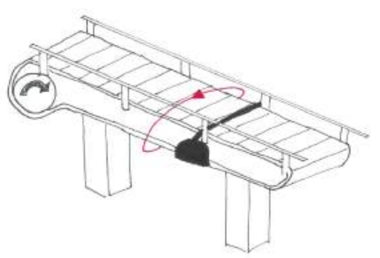


Figure 5.2: The friction belt concept

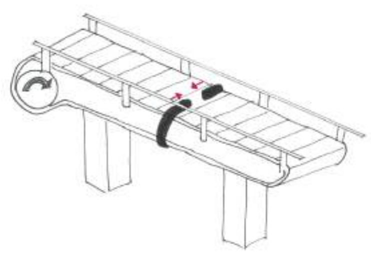


Figure 5.3: A concept with inspiration from a bicycle break

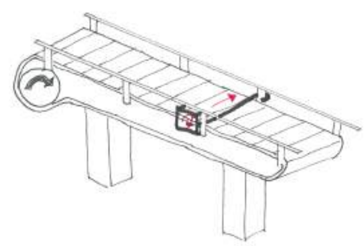


Figure 5.4: The tripwire concept

The next group of three concepts have in common that they have a surging motion to stop the pallets. The windmill concept, in figure 5.5, uses gravitational force to drop down and the motor to be pulled up again. The same type of movement is used for the butterfly wings concept where a part of the guide rail is used for folding down onto the conveyor. It is visualised in figure 5.6. This concept can be properly integrated and almost masked in the existing structure. However, there is a problem with handling the minimum entry window described in section 3.3.1. The wave concept displayed in figure 5.7 uses a horizontal surging movement where the stopper is folded out by means of a pre-stressed spring. The spring is tensioned using the motor as it withdraws the stopper. It is helped by the weight and movement of the pallet that wants to move with the conveyor chain.

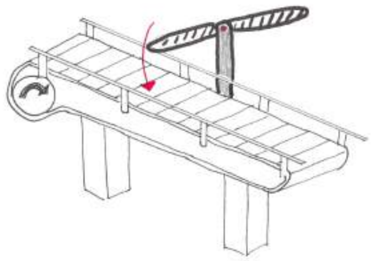


Figure 5.5: A concept with inspiration from a windmill

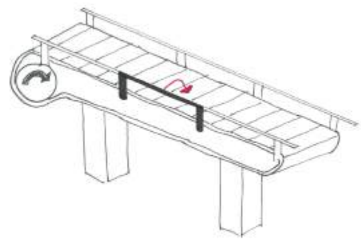


Figure 5.6: The butterfly wings concept

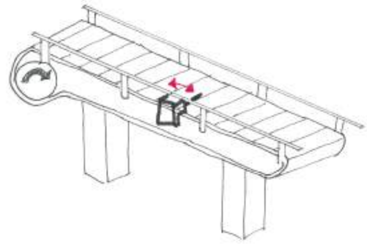


Figure 5.7: A concept with inspiration from wave movements

In the third group, all concepts uses vertical movement or force to stop the pallets. The mountain concept, described in figure 5.8, raises and creates a hill in the path of the pallets. It has a major challenge in that the chain has a constant length and must be tense all the time. The guillotine uses gravitational force to drop down quickly and is retracted to its starting position by the motor. This concepts is displayed in figure 5.9 and has the strength of stopping the pallet in its centre. A more innovative mechanism is shown in figure 5.10 and uses a strong electromagnet for stopping pallets. However, the impact of magnetism on different types of goods needs to be investigated further.

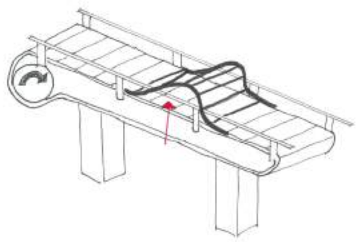


Figure 5.8: The mountain concept

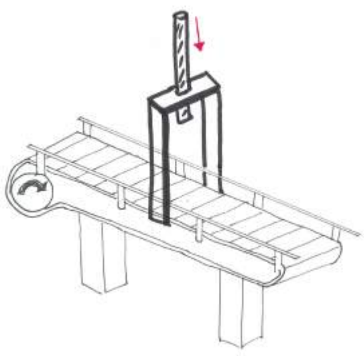


Figure 5.9: A concept with inspiration from a guillotine

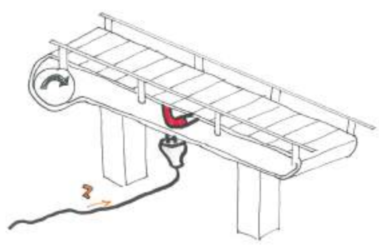


Figure 5.10: The electromagnet concept

The fourth group of concepts is approaching the pallet from the side of the conveyor, entering between the track and the guide rail. The poking finger concept, in figure 5.11, has a piston that translates linearly back and forth to stop and release the pallets. This is one of the solutions that most resemble the original product. The next concept is inspired by a scissor lifts movement and is illustrated in figure 5.12. It can move back and forth quickly, however it is not compatible with larger loads from the side, which made exploring different mounting options for this concept necessary. The last concept in this group was developed with inspiration from number XV of Polhem's mechanical alphabet [77]. A rotating motion of a wheel in the centre. It is only provided with teeth on half of the wheel, is transmitted to a translating motion of the arm. The concept shown in figure 5.13 moves back and forth while the rotation occurs only in one direction.

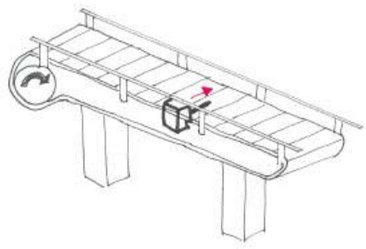


Figure 5.11: A concept with inspiration from poking someone with a finger

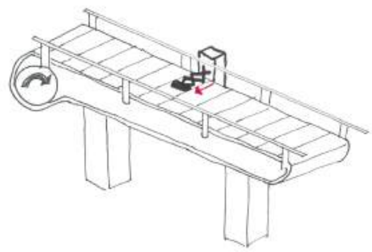


Figure 5.12: The scissor lift concept

Figure 5.13: A concept with inspiration from Polhem's mechanical alphabet

5.2.2 Elimination

To winnow down the number of concepts, an elimination of concepts which did not fulfil the demands was made. In the elimination matrix in table 5.1, the concepts were evaluated by their fulfilment of specific criterion. These where based on the demands from the requirement specification with the intent of including all the demands. However, the concepts' level of details was quite low in this early stage which resulted in that the concepts could not answer whether or not they fulfilled some of the demands. The criterion in the elimination matrix were therefore to some extent based on the level of detail of the concepts.

Table 5.1: All twelve concepts in relation to how well they supported the wanted functions of the new product and the decision of further development or not.

	Friction Belt	**Bicycle**	**Tripwire**	**Windmill**	**Wings**	**Wave**	**Mountain**	**Guillotine**	**Electromag.**	**Finger**	**Scissor**	**Polhem**
Fit between two tracks	+	+	+	+	+	+	+	+	+	+	+	+
Fit between two lines	+	+	+	+	+	+	-	-	+	+	+	+
Pallets pass with ease	-	+	-	+	+	+	+	+	+	+	+	+
Single functioning	+	+	-	+	+	+	-	-	+	+	+	+
$\sum$ +	3	4	2	4	4	4	2	2	4	4	4	4
$\sum$ -	1	0	2	0	0	0	2	2	0	0	0	0
Further Development	No	Yes	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes

The friction belt and the tripwire concepts were eliminated because they were in the way of the pallets in their passive position. To get over the strip of the friction belt, albeit small, meant an increasing risk of stopping the pallets when it was not wanted. Creating a reliable release mechanism for the tripwire was spotted as a risk factor.

Both the mountain and the guillotine was eliminated due to the height of the construction. The space between the conveyor lanes was often made as low as possible to be space effective. Since the space between the lanes was determined by the size of the goods there was a risk that the concepts would not fit into all constructions. They were therefore eliminated.

The concepts that was still remaining after the elimination were evaluated using a Pugh matrix. It helped when comparing and ranking the concepts based on both demands and wishes. Because the level of detail of the concepts was quite primitive, the most concrete criteria were used in the Pugh matrix in table 5.2. The original product was used as the reference.

Table 5.2: The concepts remaining after the first elimination are here evaluated based on additional criterion.

	Reference	**Bicycle**	**Windmill**	**Wings**	**Wave**	**Electromag.**	**Finger**	**Scissor**	**Polhem**
Fit between two tracks	0	0	0	0	0	0	0	0	-
Fit between two lines	0	0	0	0	0	0	0	0	0
Pallets pass with ease	0	0	0	0	0	0	0	0	0
Power generation	0	+	+	+	+	+	+	+	+
Without effects on the goods	0	0	0	0	0	-	0	0	0
Strong against impact forces	0	+	0	0	0	-	0	-	-
Single functioning	0	0	0	-	0	0	0	0	0
$\sum$ +	0	2	1	1	1	1	1	1	1
$\sum$ 0	7	5	6	5	6	4	6	5	4
$\sum$ -	0	0	0	1	0	2	0	1	2
Net Value	0	2	1	0	1	-1	1	0	-1
Ranking	5	1	2	5	2	8	2	5	8
Further Development	No	Yes	Yes	No	Yes	No	Yes	No	No

The reference is the one to be redesigned and therefore it was not used for further development in its present form but components of it and its functionality were further implemented in other concepts. The wings concept was eliminated because it has a jointed movement in the same direction as the force impact which would create a need for excessive over-dimensioning which was not desirable. The concept of an electromagnet was not realised because a large part of the goods transported on the conveyors contained sensitive electronics.

If used so that the pallet hit straight against the flat front of the scissor lift, it would be possible to fend the loads in a good way. That was not possible when mounted, as seen in figure 5.12, thus it would have been weak in the impact direction and it was therefore eliminated. As for the Polhem concept, the rotation takes place inside the engine housing and therefore it can not only go one way. It came up during conversations with the supplier that the motor needs to go back and forth to use the existing counter.

5.3 Further Concept Development

This stage was about developing and refining the existing concept and combining ideas. All concepts in this phase had a higher level of detail compared to the concepts in the earlier phase. The concepts generated in this phase of the process were evaluated starting from their strengths, weaknesses and intended usage.

A morphological matrix was used to come up with sub-solutions which resulted in a very large number of ideas. The most promising partial solutions were chosen to get a manageable amount to work with, these are displayed in figure 5.14. The partial ideas were sorted after which function they had. A total of 75 combinations were possible. Feasible combinations were then identified and translated into concepts.

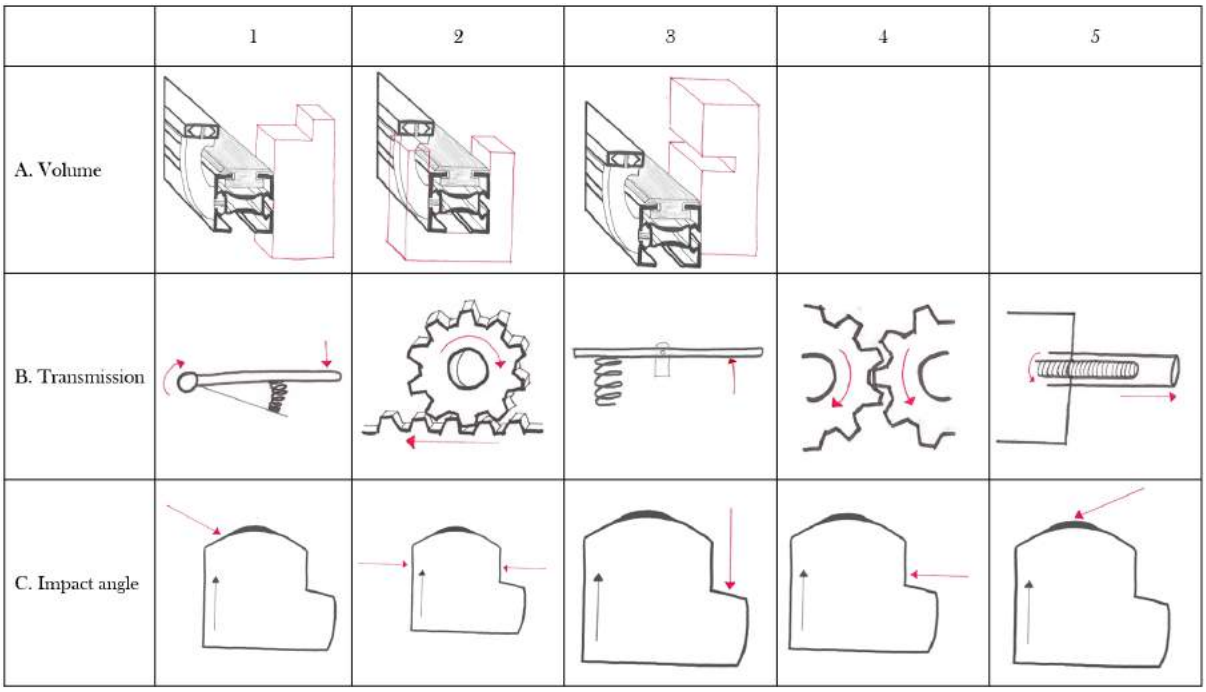


Figure 5.14: A matrix representation of the generated sub-solutions.

From all the combinations, two concepts turned out to be more interesting than the others and that was the combinations A1-B2-C3 and A1-B3-C4. These were developed further to achieve the same level of detail as the other concepts which was a prerequisite for being able to compare all fairly.

5.3.1 Developed Concepts

Both the bicycle and the A1-B2-C3 concept, which was called the bowl concept, use the same gear principle with translating rods and rotating gears. As for the bicycle in figure 5.15, it was possible to either move both arms simultaneously or one arm at a time. Using them simultaneously would have divided the impact force between the arms and therefore each arm did not necessarily have to hold the whole load. While using them one at a time would speed up the movement since when one arm is reversing, the other is moving onward and each arm takes every other pallet.

The bowl concept use only one arm with a two thirds cogwheel in the end as shown in figure 5.16. There the cogs could be made different sized depending on the speed and stability needed for each phase of the movement. The advantage is that a small angle change around the centre of rotation gives a relatively large movement at the top farthest away from the centre thus a quick movement can be implemented.

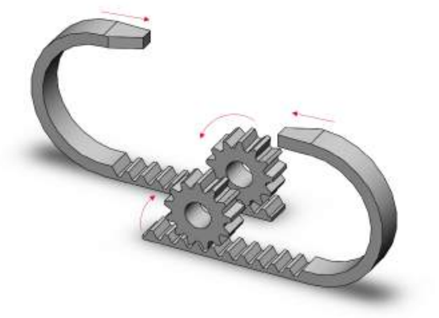


Figure 5.15: A further development of the bicycle-concept stopping the pallet at two points.

Figure 5.16: The bowl-concept originated through the morphological matrix (A1-B2-C3).

Just like in the bowl concept, a rotation is used to come out and stop the palette as shown in figure 5.17. In this way, the load directed towards the engine would be considerably lower. The disadvantage is that most of the load is taken up by the rotation centre, which can create wear at a critical point. The finger concept, displayed in figure 5.18, has a simple translating motion. It is sensitive to impact directly against the motor, therefore it uses a bearing to handle most of the load. Through a correct dimensioning of the bearing and the shaft, a long life time can be achieved.

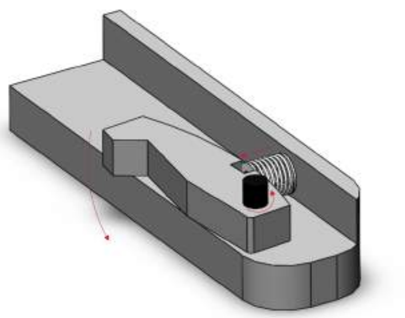


Figure 5.17: A further development of the wave-concept with a stressed spring.

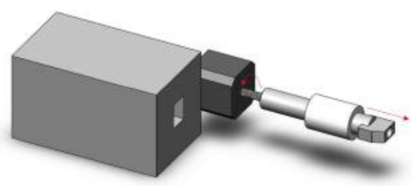


Figure 5.18: A further development of the finger-concept.

The windmill concept was modified to only have one wing which made it more compact, see figure 5.19. The height was a matter of concern as well as if the wing could cause damage on the goods transported on the pallets since it was entering sideways from above. In contrast to the windmill, the pendulum concept shown in figure 5.20 is entering sideways from below.

The pendulum originated from the morphological matrix combination A1-B3-C4. In the back end of the pendulum, a spring is attached which serves as a help to raise the pendulum upwards quickly enough.

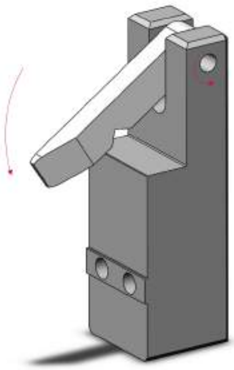


Figure 5.19: A further development of the windmill-concept with cavity to fit with the guide rail.

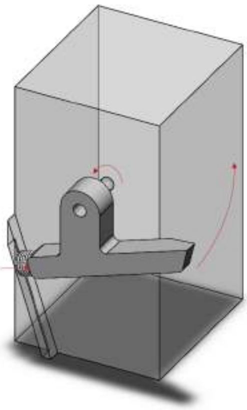


Figure 5.20: The pendulum-concept originated through the morphological matrix (A1-B3-C4).

5.3.2 Elimination

To evaluate the concepts, simple models were constructed to help the evaluation process. The models are shown in appendix C.1. A Pugh matrix was then used to evaluate the concepts, see table 5.3.

Table 5.3: An evaluation matrix with the remaining concepts.

	Bicycle	**Bicycle**	**Windmill**	**Pendulum**	**Wave**	**Bowl**	**Finger**
Fit between tracks and lines	0	0	-	-	+	0	+
Estimated lifetime	0	0	-	-	+	0	0
Need of maintenance	0	0	-	-	0	0	+
Speed	0	0	-	-	+	+	+
Strong against impact forces	0	+	0	0	+	0	0
$\sum +$	0	1	0	0	4	1	3
$\sum 0$	5	4	2	2	1	4	2
$\sum -$	0	0	4	4	0	0	0
Net Value	0	1	-4	-4	4	1	3
Ranking	5	3	7	7	1	3	2
Further Development	No	Yes	No	No	Yes	Yes	Yes

The bicycle which was the concept with the highest score from the previous ranking in matrix 5.2 was used as reference. The new and refined concepts were compared with the reference. The criterion were updated due to the increased level of details of the concepts, some criterion were removed and new ones were added.

The windmill and the pendulum had significantly lower score than the others, it was due to three different things. The windmill concept builds a lot it height and gives a limitation about how much vertical distance there at least must be between two lanes. The same applies to the pendulum concept, it builds a lot from the side of the track and then limits how close the lanes can stand relative each other. Both of them a have a retraction movement that demands a direction opposite to the force of gravity which creates additional load on the motor. In the long run, this extra load gives a shorter life time and more need of maintenance.

A weighted Pugh matrix was used to help further reduce the number of concepts. The weighted Pugh matrix included elements from the ranking of the wishes and compared the concepts based on the optimal solution. The ranking was partly based on the ranking in the requirement specification as described in section 4. The criterion were refined further as the concepts were more even in terms of features and performance. The weighted Pugh matrix is displayed in table 5.4 and uses a scale of 1-10 where 10 is the best score a concept can get. The score was multiplied with the weight and then summarised into a net value from which a ranking was made.

Table 5.4: A weighted ranking of the remaining concepts.

	Weight	**Reference**	**Bicycle**	**Wave**	**Bowl**	**Finger**
Possible to add an emergency stop	10	10	5	5	5	5
Wear resistance	7	10	5	7	4	7
Allowing multiple placement	5	10	3	9	9	9
Weight	3	10	5	7	6	7
Estimated lifetime	8	10	7	5	7	8
Need of maintenance	6	10	5	8	6	7
Speed	4	10	6	7	6	7
Net Value		430	225	273	257	299
Ranking			4	2	3	1

From the weighted ranking, it was revealed that a gear mechanism was not preferable compared to the other alternatives. Rotating an arm from one of the ends required a large moment thus set higher requirements on the motor capacity. Because the motor was predetermined, there were no modifications to do with it to ensure a margin. The ability to place the concepts onto multiple platforms was the main issue with the bicycle concept. In the cases were it was required to stop the pallets straight from the front, all the moment was generated around a single axis which made it prone to break after fewer cycles than the concepts. It was determined that the wave concept and the finger concept should be used for further development.

5.4 Detailed Concept Development

Detailed CAD models of the two remaining concepts, the wave concept and the finger concept, were made in SolidWorks. The movement patterns were included and the concepts were mounted onto a platform. This was to clearly understand how they interacted with the pallets and communicate the advantages and disadvantages of each concept. This made it possible for the managers and engineers at FlexLink to give feedback on the two proposed concepts.

5.4.1 Developed Concepts

The components of the finger concept is shown in figure 5.21. It consists of a shaft with a magnetic ring around it to be independent of the direction of mounting. The stopper is mounted onto the shaft and a bearing is located around the shaft. It is all enclosed by the housing which connects the stop to the conveyor. The main elements of the wave concept are the motor with the associated screw that drives the rotation of the stopper. A circuit board with a processor reading the magnet which is mounted onto the stopper. The magnet is connected to the stopper and lies 2 mm from the processor. A spring is helping the movement of the stopper. The components are enclosed by the housing connecting the concept to the conveyor. All components are shown in figure 5.22.

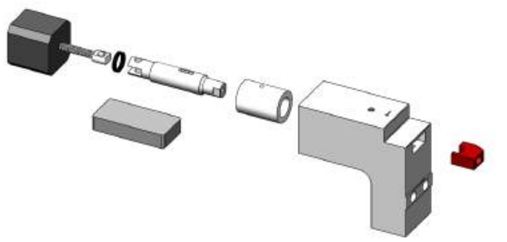


Figure 5.21: An exploded view of the finger concept with the stopper shown in red.

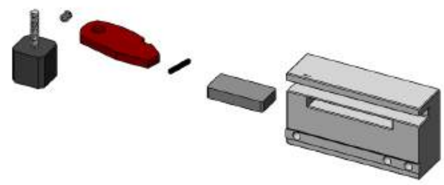


Figure 5.22: An exploded view of the finger concept with the large stopper shown in red.

The motor drives the movement of the stop with control from a circuit board using a built-in counter to keep track of the stopper's position. The finger concept has a straight translational movement as seen in figure 5.23, while the wave concept has a slight arcuate movement which is shown in figure 5.24. It is thus only the stopper moving outside of the housing, as desired, in both concepts.

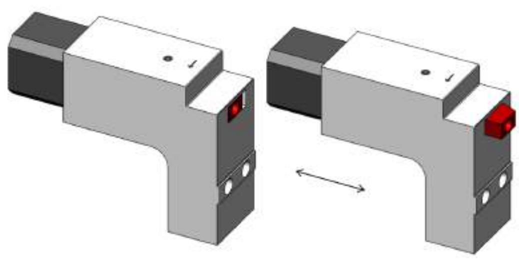


Figure 5.23: The translating motion of the finger concept.

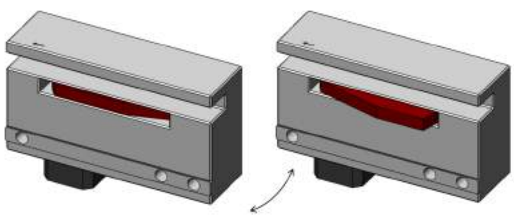


Figure 5.24: The arced motion of the wave concept.

Both concepts were mounted onto the X65 platform which has the smallest gap between the chain and the guide rail, see figure 5.25 and 5.26. Thereafter, the movements of the stoppers were evaluated in relation to the pallets and the other parts also attached along the side of the beam.

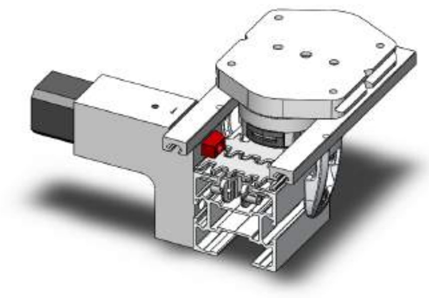


Figure 5.25: The finger concept mounted onto a conveyor and shown in relation to a pallet.

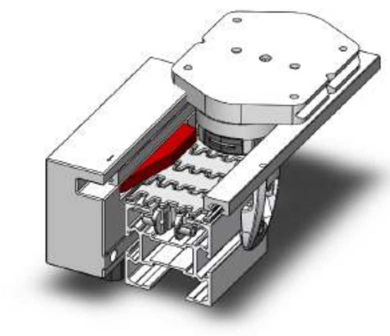


Figure 5.26: The wave concept mounted onto a conveyor and shown in relation to a pallet.

5.4.2 Elimination

The evaluation was made using a pros and cons list which can be seen in table 5.5. Expertise from FlexLink's PSD department was used to obtain feedback on the two concepts. It was then understood that it is often crowded on the side of the beam on which the stop would be attached.

Table 5.5: Comparison between the two remaining concepts

Criterion	**Finger**	**Wave**
Allowing multiple placement	+ Rotation in the centre entail direction independency	- Rotation at one end entail direction dependency
Robust	+ Large area inside the housing to handle the load	+ Avoid most of the force directed against the motor
Weight	+ Same amount of material as used today	- 50 % more material
Estimated lifetime	+ No rotation outside of the housing	- Most of the load taken in the rotation centre
Design	+ Clean design with an impression of power	- Square design with an impression of weight
Dimensions	≈ 92 x 42 x 95 mm	≈ 82 x 150 x 44 mm

The table showed strengths and weaknesses of both concepts. The finger concept had the most strengths and therefore served as the basis for further development. What determined the final decision was the area of the side of the beam that each concept required. This was a strong limiting factor for future merchantability. The function of using a spring from the wave concept was kept in mind. This concept was called the Fingertip.

5.5 Final Concept Development

The overall structure of the concept was now set and the major features of the solution determined. The project entered a phase of iterating sub-solutions for particular parts which carried critical features. These functions of the concept were developed separately and at this stage, it was important to not sub-optimise the product. Three critical factors were found; the bearing element, the coupling between the shaft and the motor and the exact position of the stop. This section will describe the detailed development of each function.

5.5.1 Bearing Elements

The function that the bearing carried was the ability to handle load over preferably ten million cycles. Five different bearings were found, displayed in figure 5.27, and evaluated. The first bearing type studied was a linear ball bearing with five trajectories of balls. These are good at handling dynamic loads and usually have a very long lifetime.

The second bearing was a plain bearing combined of steel and copper. It has an outer layer of steel and an inner layer of copper. It has embossed lubrication pockets that gradually releases lubricants during operation after the first lubrication. It has advantages in terms of long maintenance intervals and it can withstand shocks, vibration, high loads and corrosive environments.

The third bearing alternative was polyoxymethylene, POM, an acetal plastic sliding surface on copper-plated steel body. Is requires only initial lubrication and then minimal maintenance. It can handle shocks and strokes as well as alignment errors to a certain extent. The needle bearing was a compact alternative with the main advantage of having a larger surface area in contact with the shaft meaning that they can support a higher load.

The fifth bearing studied was a newer version of the regular linear ball bushing with an increased level of performance, improved lifetime and reliability. It has a tilting feature that compensates for misalignment which may be caused by bending of the shaft. Also, it can be used in clean environments.

Figure 5.27: From the left; Plain bearing, bronze bushing, acetal plastic and copper bushing, needle axial bearing, linear ball bearing

Price, load capacity and maintenance were the main parameters used in the evaluation where the improved linear ball bearing from SKF was selected [78]. The full evaluation matrix can be found in appendix C.2.

5.5.2 Shaft Couplings

A table listing of all main types of couplings was used to identify which ones would be suitable for this concept [23]. The main function of the coupling was to compensate for angular misalignment and reduce the load directed towards the motor. Four coupling types were found and studied, and they are displayed in figure 5.28. The first coupling can be associated with teeth that overlap and create the possibility of movement in one plane. It has a high robustness and longevity in level with a gearshift.

The second coupling is a type of hinge joint that is stiffer than a tooth coupling with the torque around a pin. It can also, to some extent, compensate for the load directed towards the motor through the fit of the pin. A coupling type that has an even better damping against the load towards the motor is the third coupling that contains a part of elastomer. The use of an elastomer in the coupling adds a damping function into the system. The elastomer allows the coupling four degrees of freedom, although not so generous.

The fourth coupling is a ball and socket joint which has four degrees of freedom. It can perform larger movements than the elastomeric coupling but do not have the ability to act as a damper. Depending on the design, it can handle relatively large axial displacements.

Figure 5.28: From the left; Tooth coupling, hinge joint coupling, elastomeric coupling, ball joint coupling.

Ability to handle displacements, simplicity of the design and lifetime were the main parameters used in the evaluation where the hinge joint coupling was selected. It had fewer degrees of freedom than both the elastomeric coupling and the ball and socket joint coupling but it was not considered necessary to have more than two. The full evaluation matrix can be found in appendix C.2.

5.5.3 Placements

The pallet for the X65 and X85 conveyor has a built-in angle in its design, as described in section 3.3.2, which should be possible neutralise. The angle in the pallet is 25°. From the calculations made in the hypothesis, the axial load has a sinusoidal relation to the applied force. Therefore it was assumed that an angling of 20°should neutralise the axial force. A 20°angling is illustrated in figure 5.29.

To theoretically find the point in which the axial force is zero, simulations were made. In figure 5.30, the result of the simulations in both the impact moment and steady state is displayed.

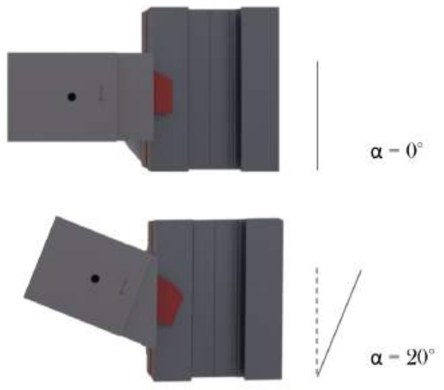


Figure 5.29: Angling of the pallet stop at 0 and 20 °.

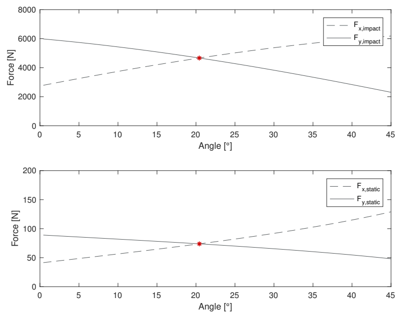


Figure 5.30: Simulation of angling from 0 to 45 °during the impact and the subsequent steady state. The zero-point is displayed with a red star in both simulations.

The results from the simulations showed that the optimal angling was 20.43 °. A verification of the theoretical calculations was made using the same test rig as for the test in section 3.3.3. The test rig was modified to achieve the angling, see figure 5.31 and 5.32. If the test was proven successful it would have been beneficial to implement this angling in the design.

Figure 5.31: The test rig shown from the front with the angle present.

Figure 5.32: The test rig shown from behind.

The result of the testing is shown in figure 5.33. There were still both forces and moments present in the test runs. When the magnitude of them were compared to the loads in figure 3.29, no big difference existed. In the case of 0°, the minimum force was -198 N and minimum bending moment was -116 Nm.

When angling the stop 20.43°, the minimum force was -145 N and minimum bending moment was -83 Nm which is lower but not close to zero as expected. This meant a reduction of the force and torque of less than 30 %.

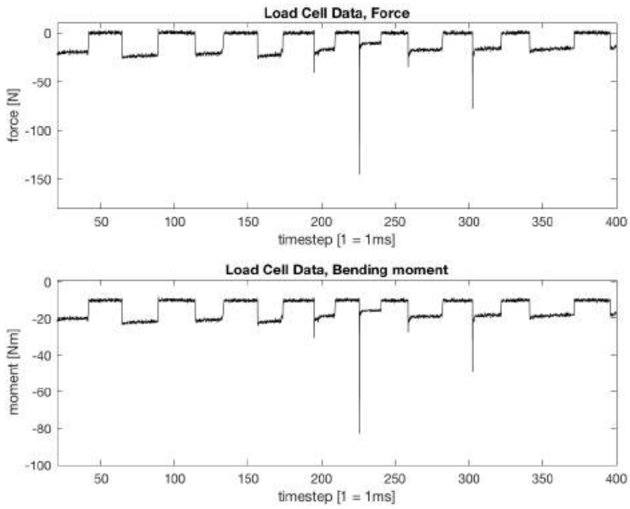


Figure 5.33: The loads and bending moments measured from tests with an angling.

Based on this tests, the profit was not considered to be large enough to implement this change. It would cause the design to be completely direction-dependent and thus a doubling of the number of stops that needed to be produced. As it needed to be both a right pallet stop and a left pallet stop to cover the whole conveyor range.

Chapter 6

System-Level Design

In the prior stage the focus was on the core idea of the product. The next phase of the development process was to identify the subsystems and define their functions. In this phase, the degree of modularity was determined together with the interfaces and separation of function among the subsystems [8]. Other decisions made in this phase was which components should be designed and which should be purchased, and what materials and manufacturing methods should be used. The environmental impact was also evaluated.

6.1 Variants

There were demands from some users that there should be an emergency stop so that if there was a power failure or accident the stop would go out and stay in its outer position to keep the queue of pallets in position. At the same time, this was not a requirement for all users.

The function of providing position feedback on the exact position of the stopper was highly wanted for those users who had a high degree of automation on site. While those who not used this feature would not want pay for a functionality they neither needed nor used. Based on this, it was possible to separate the product offer into two variants. Those who wanted an emergency stop also wanted the smart features while those who wanted a simpler product did not want any of the two features.

A simple stop became the base product and from this a premium was also created. The premium stop included all smart connectivity such as controlling interconnected stops and providing position feedback. It had the feature of an accumulator that is recharged and used as a spare in case of power failure.

6.2 Product Architecture

The architecture of the product determined the commonality of specific components and how easily a module could be replaced without impacting the rest of the system. Implementing the decisions from section 5.5 into the finger concept described in section 5.4.1 was the base for the product architecture. The product architecture with the parts developed so far is displayed in figure 6.1.

The motor, the circuit board that controls the motor and the screw connecting the motor with the shaft was outsourced components. The supplier, STEGIA, contributed with the associated design and engineering to these components. The motor screw is fastened into the shaft where a hinge joint coupling was implemented in the shaft. Around the shaft, the improved linear ball bearing is located. The bearing is encased in the housing, the circuit board is also placed in the housing but enclosed using a lid.

The fact of using no angling made it possible to attach the platforms from two sides of the stop. The X65 and X85 platforms used the same side, while the Optical and XT platforms used the other side. The stop is mounted onto the X65 and X85 platforms with the help of a connector placed on the front side. The connector at the left side of the housing in figure 6.1 is used for mounting the stop onto the XH and Optical platforms. This design decision meant that the concept came one step closer to answer research question two, described in section 1.2.1.

The connectors were designed so that they fit with all fasteners already in use. Through borrowing design from another products within the company's product line, savings on development and manufacturing costs was made.

The five house-shaped modules are platform dependent guides. The X65, X85 and Optical platforms have one guide each while the XH platform have two since it needs to be even more flexible in its placement. The guides are steering the stoppers which are illustrated in red in figure 6.1. The X65 and X86 platforms uses the same stopper, while the XH and Optical have one each. The standardisation of components and the modularity gave opportunities to easily make changes later on.

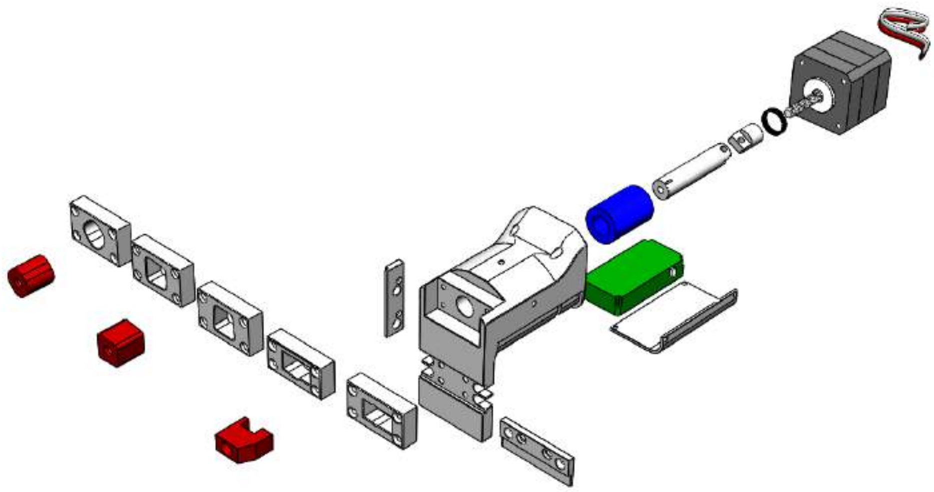


Figure 6.1: All the parts developed so far that together represents the products architecture.

The modular design was an attempt to combine the advantages of standardisation with those of customisation. That allowed for local optimisation of each module and reduced the risk of sub-optimising the product.

6.2.1 Generic Parts

The generic parts are the ones used all the time and are platform independent. This meant that each component was not optimal for each individual platform but the best option overall for the platforms together. Using generic parts reduced the costs as fewer tools need to be produced and controlled. It is the housing, lid and two parts that together makes the shaft that constitutes the generic parts. The parts are showed in figure 6.2 and will all be designed in-house. The manufacturing will be made by an external company.

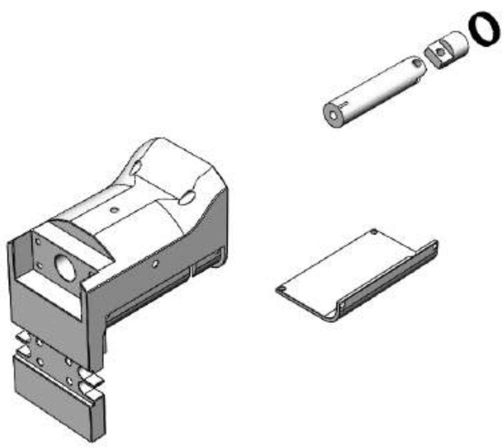


Figure 6.2: The generic parts that are to be present in all configurations

6.2.2 STEGIA's Parts

The motor, motor screw and circuit board together with associated parts were outsourced components. The parts are showed in figure 6.3 and would be purchased completely. These parts are also generic and therefore platform independent. For the platforms carrying the lightest loads, the engine was slightly oversized. However, by using one single motor as a generic component cost savings were made through quantity procurement. This is called economies of scale, and gave the possibility of purchasing at a lower per-unit cost when components are purchased in large quantities [50].

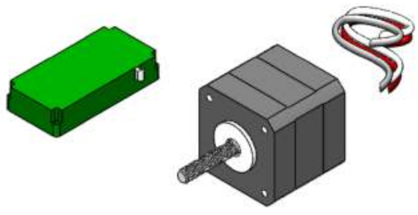


Figure 6.3: The components from STEGIA that is generic but not in-house developed

6.2.3 Modular Parts

The modular parts would configure the stop depending on what platform it was intended to be mounted on. It is the connectors, guides and stoppers that constitutes the modular parts. The parts are showed in figure 6.4 and all would be designed in-house while the manufacturing were to be made by an external company.

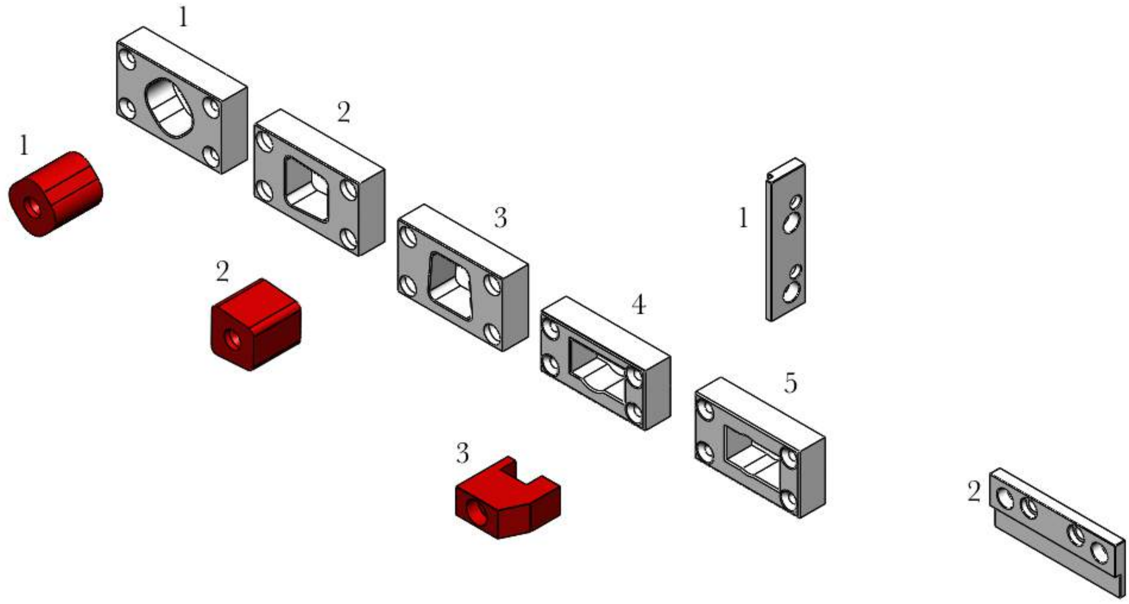


Figure 6.4: The modular parts that will change depending on what configuration is wanted

Table 6.1 was made to define what modules that together with the generic parts were to configure each platform's stop. A complete stop needed one connector, one guide and one stopper outside of the generic parts. By using the same component such as the stopper in both the X65 and the X85 platforms, more savings were made.

Table 6.1: The different parts needed for each platform

Platform	**Connector**	**Guide**	**Stopper**
X65	2	4	3
X85	2	5	3
XT	1	2, 3	2
Optical	1	1	1

6.2.4 Standard Parts

The ISO metric screw threads measured in millimetre are the world-wide most commonly used set of standard screws [79]. These are parts that conforms to a published specification from the International Organisation for Standardisation, ISO.

By using standard parts, advantages are won. It speeds up manufacturing and reduces manufacturing costs and the same parts can be purchased and used all around the world. FlexLink uses some of the most common dimensions of the metric screws with different lengths and other ISO specified machine elements. By using these, no orders for machine elements were needed since there was in numerous stock and could be used directly.

6.3 Interfaces

Depending on the function of each module, interfaces were created to match the function. Applied loads, load direction and design freedom were parameters taken into consideration when developed the interfaces. The interfaces between the modular and generic parts were designed using hole patterns and screws. The interfaces between the externally delivered parts and the in-house produced, generic parts were positioned and held in place in different ways by means of screws. Each of the interfaces between chunks in a slot-modular architecture are of different types from each other, so that the various chunks in the product cannot be interchanged [8].

6.3.1 Generic - Modular

The function of the connectors were to guide and secure the exact position of the stop in relation to the platform. The first connector, displayed in figure 6.4, can be placed in two ways, as seen in figure 6.5. If mounted with the holes to the right it fits with the XH platform, with the holes to the left, it fits with the XT platform. The same structure applies for the second connector, as seen in figure 6.6. If mounted with the holes upwards it fits with the X65 platform, with the holes downwards it fits with the X85 platform. The guide was used for guiding the stopper and prevent it from rotating. Each platform had its own guide which was mounted onto the housing using four screws.

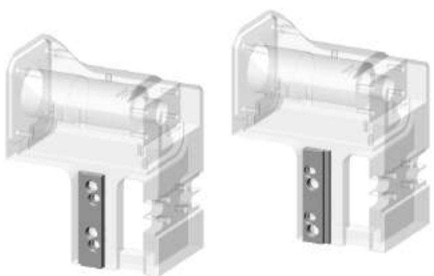


Figure 6.5: The interface between the connector and the housing of the stop for the XH and XT platforms.

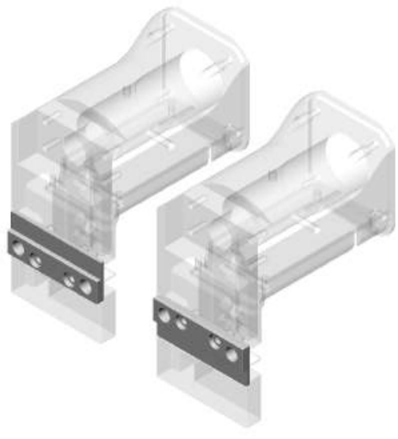


Figure 6.6: The interface between the connector and the housing of the stop for the X65 and X85 platforms.

6.3.2 Generic - External

The linear ball bearing had the function of guiding the shaft and counteract the applied loads. It was mounted from the backside of the housing into a cylindrical hole, see figure 6.7. The bearing have four holes used for positioning depending on the direction of the load. The circuit board is located on the underside of the housing. Its function is to control the motor and track the position of the shaft. It is mounted, as shown in figure 6.8, using four screws. The circuit board is protected from dust, moist and nudges using a lid. The motor is mounted on the backside of the housing using four screws, as displayed in figure 6.9. Two entering from the front and going into the motor, and two from the back and going through the motor.

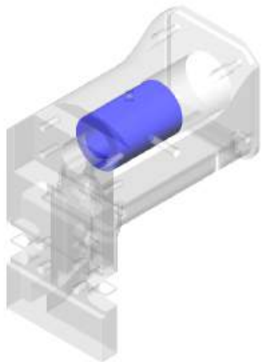


Figure 6.7: The cylindrical interface between the linear ball bearing and the motor.

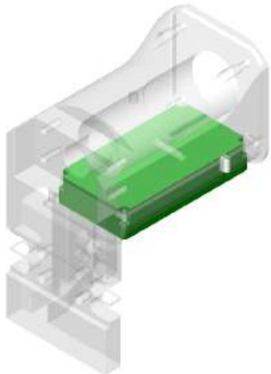


Figure 6.8: The position of the circuit board in the housing.

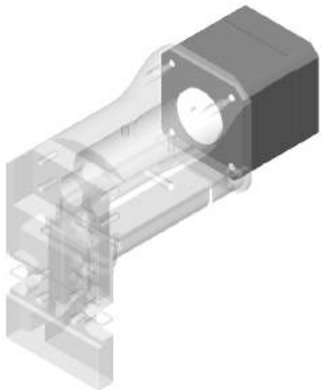


Figure 6.9: The interface between the motor and the housing secured by four screws.

6.4 Materials

Choosing the right material combination was an important thing learned from the previous projects, as described in section 3.3.2, there were a lot of problems in the material combination of the stopper and the guide. Documentation from tests of the surface treatments in the earlier projects were found and examined. The difficulties that arose in connection to the material choices were mainly due to the fact that two materials slide on each other.

When two surfaces slide against each other, abrasion occurs inevitably and it is based on the theory of asperity contact. Aspirations are very small elevations in the surface of the materials since not a single material is truly smooth on an atomic scale. Sliding wear is characterised as relative motion between two smooth solid surfaces in contact under load [23]. In the sliding contact, wear can occur because of adhesion, abrasion surface fatigue or chemical reactions. Abrasive abrasion occurs when aspirations in one surface dig into the other and loosen parts from there. It can be described as they are grinding against each other. This occurs when the materials have different hardness.

Adhesive abrasion essentially means that atomic or molecular forces in one surface after some time remove parts from the other surface. Surface fatigue occurs from maximum shear stresses at contacts lines beneath the surface. Peak values can be high in small areas of contact. Cracks can be initiated from surface flaws and particles. Contact shear stresses enables the crack growth which leads to material loss.

Chemical reactions occur when materials react with each other and atomic exchanges happens [80]. Tangential traction on the surface, the size of the contact area and material properties such as the yield strength each play a role in whether and how abrasion occurs.

6.4.1 Tribology

To understand what happened between two interacting surfaces in relative motion, two tribology theories was studied. Bowden and Tabor developed a theory of adhesive friction. When two surfaces touches, initial contact at the higher asperity tips occurs. Due to high stress at this points, those asperities suffer plastic deformation which permits strong adhesive bonds. In other words, the shear strength and hardness of soft material decides the value of friction. This meant that whatever properties of the pairing, harder material, the value of friction would not change [80]. Archard's theory is a simple model used to describe sliding wear with the result defining that the volume of the removed dross due to wear is proportional to the work done by friction forces [23]. Meaning that minimising the total normal load and the sliding distance while maximising the hardness of the softest contact surfaces, the best result is reached. This knowledge was later used when selecting materials.

6.4.2 Characteristics

The material on the shaft through the linear ball bearing required a certain hardness and surface fineness. These properties was specified by SKF and therefore, it was not investigated more closely [78].

The surface contact between the guide and the stopper however needed more attention. Various sliding bearings manufacturers were examined to identify what materials they used between in the contact between the shafts and bearings. This was done to get a starting point from which material combinations worked in that type mechanical applications. Screenings were then conducted using the CES EduPack software [29]. One segment of plastics and one segment of metals were found.

For the other in-house designed components, the main goal was to minimise the weight and the price. These parts will contain most of the design and therefore needed to be flexible in possible manufacturing methods. The material together with the manufacturing technique needed to handle complex shapes, thin goods thicknesses and relatively high stresses. The material for the housing needed to fit well with the existing product range and established supply chains. It was desired to have a light weight and cost effective material. Screenings were then conducted using the CES EduPack software [29].

6.5 Environmental Priority Strategies

A list of the environmental damage costs for the different materials and processes used was compiled using a template [22]. The calculation was made on the existing product to be used for comparison against the new product created. Influential factors were disassembling mechanisms, the product structure, detection of disassembling points, the use of toxic materials and joining methods.

If a stop were to perform five million cycles and stopping pallets in average 10 times a minute would result in a lifetime of 84000 operating hours. For a production plant with eight operating hours of the pallet system per day, it is expected that the stop would last approximately between two and three years. The analysis gave an influence of approximately 158 EUL. How much each material and the energy consumption contributed to the results can be seen in table 6.2. The full result is presented in appendix D.1.

Table 6.2: Relation of how much each material and the energy consumption impacts the environment.

Material	**Impact [ELU]**
Aluminium	0.7109
Steel	0.0593
Zinc coated steel	0.1202
Stainless steel	2.7839
Cast steel	0.5381
Silicon rubber	0.0143
Polyamide	0.0088
Polypropylene	0.0014
Electricity, EU average	153.5200
Σ	157,757

Chapter 7

Detailed Design

Construction of the detailed concept was carried out to ensure feasibility of the product and to establish the concept design. The reliability analysis was first carried out to identify deficiencies and risks in the current state of the design. The concept's robustness was evaluated and the durability assessed. Once identified, the detailed design was commenced handling these risks by design optimisation, selection of materials and manufacturing techniques and selection of assembling methods. Then, the concept was adapted to be used by a user and improving the aesthetics and visual design.

7.1 Design for Reliability

Reliability is described as the probability of success, meaning having no failures. A failure is depending of the loading conditions, system geometry and material properties [8]. A FMEA was made to systematically predicting possible errors and evaluating the consequences of these errors. Corrective measures by re-designing were made to the concept which led to that the risks were lowered and controlled. Then, the quality of the concept was assessed by RD&T simulations. Some physics of failure was used for calculating the predicted lifetime of the concept.

7.1.1 Failure Mode and Effects Analysis

The outcome of the FMEA was detection of a few critical components and risks that needed correction. The risks were categorised into three categories. The red category with a RPN>200 meant that actions were needed. A RPN between 100 and 200 generated the grey category indicating that it was second priority but still important, and with a RPN<100 the risks belonged to the white category meaning that no specific actions were needed. In appendix E.1, the complete FMEA is presented. Although the RPN was only 100 on two risks regarding electrocution, factors scoring 10 indicated possibility of serious consequences. They were therefore categorised as red anyway. Four significant risks that needed actions were identified.

The first risk was regarding sharp edges on the housing and connector because they were easy to get cuts from when handling. This could be remedied by reviewing the drawings and specifying to the supplier of the details that all sharp edges should be broken. The second risk was entanglement in the stopper, loose cords and possible electrocution from the housing and motor connection. By making a safety audit and having sufficient safety around the product and the connecting conveyor, this risks can be counteracted and reduced significantly.

The third risk that needed action was the obviousness of the mounting on the conveyor beam, if not installed correctly, this will quickly lead to failure. Through a self-explanatory design and clear assembly manual, this risk could be reduced. The fourth risk observed was the dimensioning of the bushing. Since this is the largest load carrier, it should have a life span that exceeds the desired number of cycles. By calculating the life expectancy, the correct dimensioning could be found.

7.1.2 Robustness

The robustness was found to be design-sensitive and slight changes to the design of a component caused profound changes in the results. To simulate the statistical variation of the assembly, the RD&T software was used. It was a help to understand the effect of manufacturing and assembling methods.

The main issue found was the inaccuracy of the position of the parts when using counterbored screws, as seen to the right in figure 7.1. When changing to countersunk screws, as seen to the left in figure 7.1, the result was drastically improved. This since the countersunk always sits in the middle of the hole, in contrast to the counterbored that could move within the tolerance range and create variation. Only small, acceptable variations remained.

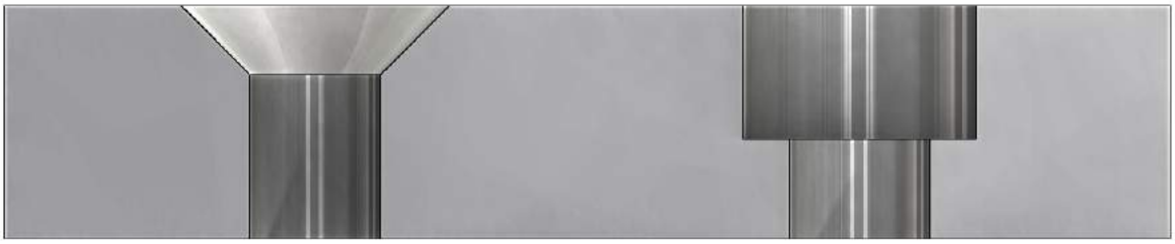


Figure 7.1: A countersunk screw to the left and a counterbored screw to the right

7.1.3 Lifetime Calculations

Failures are be distributed over time where the highest failure rates correspond to premature failure and to end-of-life wear [76]. Products that fails or do not live up to the lifetime they promise lower the customer satisfaction. Field failures are very costly and to avoid them with a margin, a safety factor is needed. It was calculated using equation 7.1. The LBCD 12 D-2LS bearing from SKF was evaluated by calculating its lifetime with a reliability from 95-99%.

$$s_0 = \frac{C_0}{P_0} \tag{7.1}$$

Where s_0 is the static safety factor, P_0 the maximum static load [N] and C_0 is the basic static load rating [N]. When having operating conditions with shock loads, the s_0 needed to be between 3-5. Factors of safety, FoS, is the load carrying capacity of the system beyond the actual applied loads. The modified basic rating life L_{ns} [km], displayed in equation 7.2, describes how long total distance the axis pass through the bearing with load before failure. The n corresponds to the reliability, $L_{10s} = 90\%$, $L_{5s} = 95\%$ and $L_{1s} = 99\%$,

$$L_{ns} = 100 \cdot c_1 \cdot c_2 \cdot f_s \cdot (\frac{C}{P})^3 \tag{7.2}$$

where P is the equivalent dynamic load [N], and C is the dynamic load rating [N]. c_1 is a factor for reliability and c_2 a factor for the operating conditions.

The f_S is a factor for stroke length, depending on the ratio between the raceway length l_t of the linear ball bearing and the stroke length l_s used during operation with the relation in equation 7.3.

$$f_s = \frac{l_s}{l_t} \tag{7.3}$$

From SKF, technical and calculation data was received [78].

$C_0 \in [570, 930]$ N

$C \in [800, 1220]$ N

$l_t = 18.4$ mm

$c_2 = 1$

c_1 for 90% $= 1$

c_1 for 95% $= 0.62$

c_1 for 99% $= 0.21$

Theoretically calculated data can be found in section 3.3.2 and was used in the calculations.

$l_s = [10, 15]$ mm

$P_0 = [98.2, 123, 491]$ N

$P = [98.2, 123, 491]$ N

P_0 and P is the same since when the pallet hit the stopper, the stopper was not moving and when retracting, the same load was still present. The impulses present in the moment of the impact were handled by the safety factor, s_0. Using the values, from table 3.4 and 3.5 in section 3.3, to find the loads and values l_s. With l_t known, the f_s were calculated.

$$f_{s10} = \frac{10}{18.4} = 0.543$$
$$f_{s12} = \frac{12}{18.4} = 0.652$$
$$f_{s15} = \frac{15}{18.4} = 0.815$$

The minimum of s_0 and L_{ns} were calculated using equation 7.1 and 7.2. The results are displayed in table 7.1.

Table 7.1: The different platforms with the minimum calculated reliability and safety factor.

Platform	f_s	**P**	**min**(L_1s)	**min**(L_5s)	**min**(L_10s)	**min**(s_0)
X65	0.543	98.2 N	6165 km	18202 km	29359 km	5.8
X85	0.543	98.2 N	6165 km	18202 km	29359 km	5.8
XT	0.543	491 N	49 km	146 km	235 km	1.2
Optical	0.815	123 N	4709 km	13903 km	22434 km	4.6

In terms of the safety factor, all platforms except the XT platform reached above the upper limit. The s_0 was needed to be between 3-5 according to SKF [78]. What should be noted here is that, it is the minimum values used in the calculations meaning the worst case possible. If using a mean value of the load ratings, C_0 and C, the result were significantly improved.

As stated in the requirement specification, presented in section 4, the expected lifetime was demanded to be at least 5 million cycles and desired to be 10 million cycles. One cycle means one time with load and one time without load of 10 mm or 15 mm.

$$\text{5 million cycles of a 10 mm stroke length} = 5 \cdot 10^6 \cdot 10 \cdot 10^{-6} = 50 \text{ km}$$
$$\text{10 million cycles of a 10 mm stroke length} = 10 \cdot 10^6 \cdot 10 \cdot 10^{-6} = 100 \text{ km}$$
$$\text{5 million cycles of a 15 mm stroke length} = 5 \cdot 10^6 \cdot 15 \cdot 10^{-6} = 75 \text{ km}$$
$$\text{10 million cycles of a 15 mm stroke length} = 10 \cdot 10^6 \cdot 15 \cdot 10^{-6} = 150 \text{ km}$$

When comparing these results with table 7.1, all platforms except the XT platform met the lifetime expectation of 10 million cycles with 99%. The XT platform only reached that requirement with 90%.

7.2 Design Optimisation

The main component of the concept was the housing and the optimisation was therefore focused on it. The goal of the optimisation was to develop a detailed overall layout and form design for the main component ensuring compatibility with the auxiliary components. Thereafter detailed layouts and form designs for the auxiliary components were made using the same albeit slightly modified model. Optimising and completing form designs of the components completed the overall layout.

The optimisation problem was set up with respect to the embodiment. The objectives were to minimise the weight of the component while minimising the stresses. The restrictions were the outer dimensions, the applied forces and the maximum force allowed propagating into the motor. The design variables possible modify were the material, the width and the length of the housing. Parameters assumed fixed were the maximum material cost, form of the pallets, weight of the pallets and using a linear movement.

An analytic model was created using FEA simulations. First, a two-dimensional topology optimisation tool was used to generate a free form result. The results were weighed together and then interpreted into a CAD-model. The CAD-model was used to simulate the stresses, strains and strength of the mechanical structure.

7.2.1 Topology Optimisation

With the given design space and the loads, previously measured and described in section 3.3.3, the topology optimisation was set up. The BESO2D software was used which gave a result using gradient-based algorithms [27]. With the goal of maximising the performance of the system, an optimised structure of the material layout was the output. The material layout is displayed in figure 7.2. Free forms naturally occurred, as expected using this type of method. That meant that the result was not possible to export without modifications. The colours and shapes were interpreted and processed. A CAD-model was created from the results, displayed in figure 7.3.

The rounded top, from figure 7.2, is seen in the model as well as up-side-down L-shape on the side of the housing.

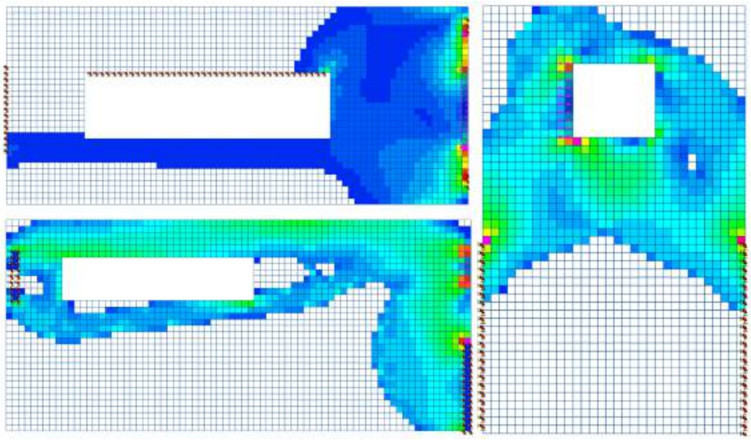


Figure 7.2: The three planes of 2D material layout, in the upper left the top view is visible and in the lower left is a side view. To the right is the front view.

Figure 7.3: A CAD-model based on the interpretations made from the BESO2D results.

7.2.2 Finite Element Simulations

The CAD-model was used as basis for the Finite Element Simulations. A two level factorial design DoE with three variables was created to investigate the influence of the length and with of the housing together with the material. The FEM was applied using the program ANSYS [28] to simulate the von Mises stress and the deformation of all the eight runs. The result of von Mises stress together width the factors and levels are summarised in figure 7.4. The stress is plotted in the same scale for all the runs, so it is possible to compare the designs with the help of the colours.

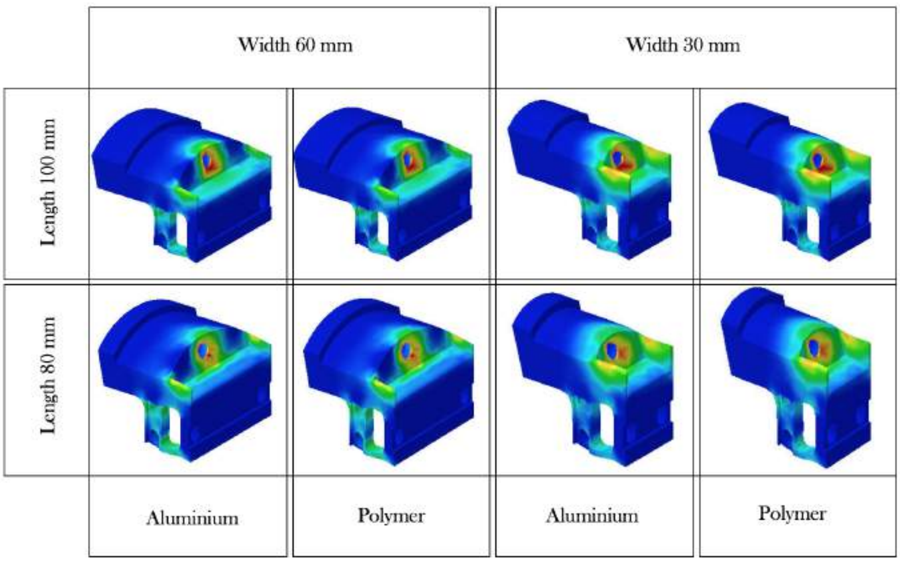


Figure 7.4: Summary of the result and the DoE factors and levels used in the eight runs.

With the result, the main effects and the interaction factors were calculated and plotted in a normal probability plot, as seen in Figure 7.5. The active factors were the length and the width while the other factors were non-active and did not play a significant role in the outcome.

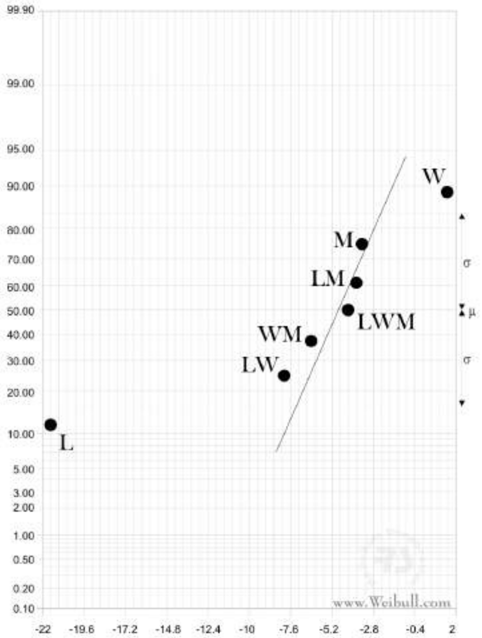


Figure 7.5: The main effects and interaction factors in a linear regression log-diagram.

When interpreting the results, the best design is given with a shorter length and a wider width. It is seen in the amount of red colour around the holes in figure 7.4. The two designs with the lowest amount of high stresses are the ones in the lower left corner of figure 7.4. However, when the deformations of the two different materials were compared, aluminium performed better.

7.3 Design for Manufacturing

To reduce the costs of components, the design was reviewed. The use of fasteners increased the cost of manufacturing a part due to handling and feeding operations. However, by minimising the variation of fasteners and keeping to standard components, the costs could still be kept low. The use of self-tapping and chamfered screws was preferred since it improved the success of placement.

Custom components designed especially for one product only, are produced using the same types of production processes as standard components. However, that adds additional costs for tooling, raw materials, processing and handling.

When the production volume increased, the unit cost decreased. Adding to that, quality and performance is normally also elevated [8]. With that knowledge, it was examined whether some components could be eliminated and thus increase the production volume of other components. The stopper for the XT platform was symmetrical and thus the guide could be redesigned to be direction independent. With this, one of the guides could be eliminated. The guide rail runs over the front top of the stop in the X65 and X85 platforms. The consequence of that was that the guide was not visible when mounted. It was therefore considered unnecessary to have two different guides when only one stopper was used for the X65 and X85 platforms. Because the X85 guide rail is placed higher than the X65 guide rail, the guide of X65 fits under both thus eliminating one more of the guides.

The principle of economies of scale also applied to of processes. Cost reductions in terms of the methods could thus be reached by choosing the same or similar processes to produce the various components. The selection of manufacturing methods depended on the materials selected.

7.3.1 Materials

Desired low weight and low price while remaining resistant to elastic deformations and a high fatigue strength was objectives used when screening the material database in CES Edupack. The result of the screenings is presented in figure 7.6.

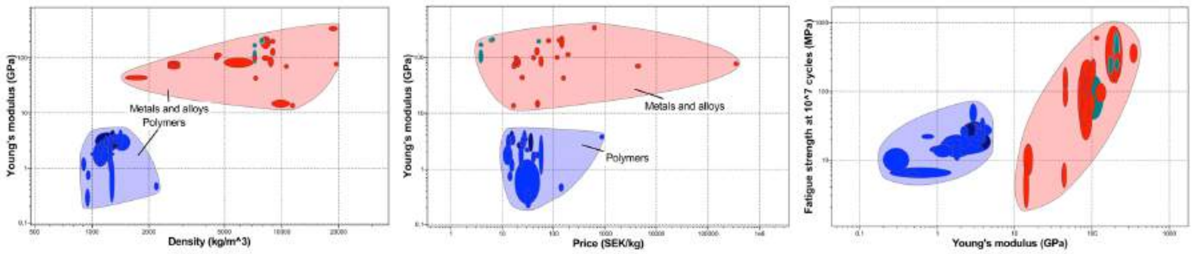


Figure 7.6: Comparison between metals and alloys, and polymers in terms of weight, price, elasticity and fatigue strength.

As described in section 6.4.2, the material for the housing needed to fit well with the existing product range and established supply chains. Therefore, a metal was the given choice which was verified screening different materials. Aluminium alloys provided the best material properties, as shown in figure 7.7. An all-round castable universal alloy called EN AC-46000 was chosen.

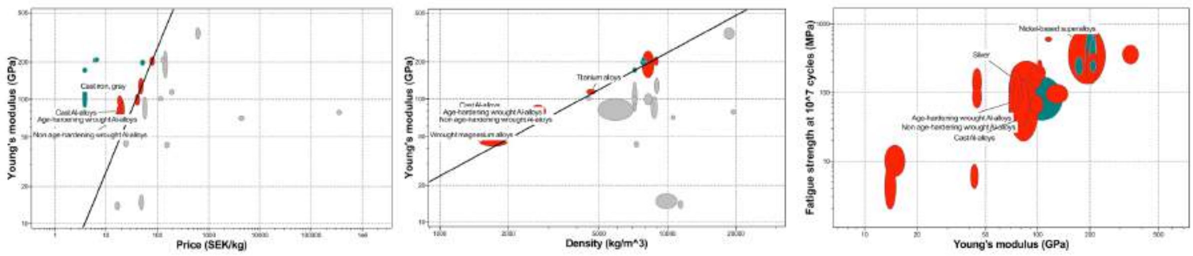


Figure 7.7: Comparison between different metals and alloys in terms of weight, price, elasticity and fatigue strength.

The material on the shaft required a certain set of properties, specified by SKF which also defined a number of suitable materials [78]. Chrome hardened Cf53 steel (1.1213) was selected as material for the shaft.

The material combination on the guide and the stopper was not straightforward. The properties of the pairing needed to handle the complexity of the movement under load. This meant that the material combination had to be resistant to elastic deformations, fatigue, strong during compression and tough against fractures. Adhesive abrasion is the dominant type of wear when stop is pulled back with an applied static force. To avoid this, low solubility in the surface of the surface, thus as different materials as possible was desired. In figure 7.8, materials with a lower price than 30 SEK/kg were evaluated based on these factors.

As described in section 6.4.1, through maximising the hardness of the softest contact surfaces the best result was theoretically reached. Metals generally have a higher hardness than polymers. In this application however, the material combination also needed a high impact resistance and low friction between the surfaces. Properties such as small thermal softening at the current service temperature, good heat conductivity and low deformation hardening were desired [80].

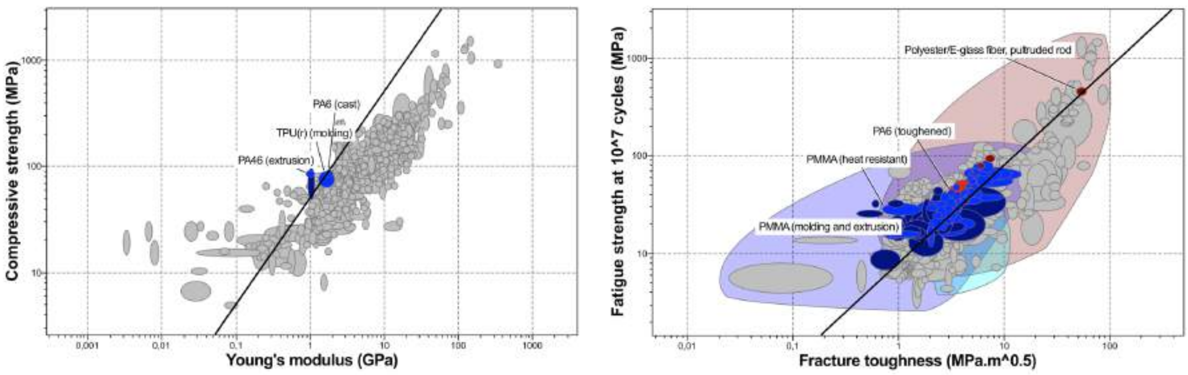


Figure 7.8: Comparison between materials in terms of elasticity, toughness and strength.

Using the same material but with surface coating on one of the contact surfaces, the lifetime could be extend, but the original problem still remained. An option was to create a low cost component that was sacrificed and exchanged on a regular basis.

To reduce adhesive abrasion, surface coating of stellites, carbides, carbides, nitrides or oxides may be relevant. However, if this coating was worn out metal metal contact occurs which leading to very heavy wear. There are circumstances that affect what kind of oxidative abrasion was happening and the sliding speed was an important factor. At high sliding speeds, the temperature between the areas in contact increased. This led to an increased rate of wear.

Polyamide 6 + 30% glass fibre, PA6 GV30, is a special type of polyamide filled with glass fibre, which is much harder and has higher elasticity modulus compared to other types of PA6 plastics. It is used primarily for the manufacturing of components that requires high strength [30]. The PA6 30GV was selected as material for the stopper.

7.3.2 Manufacturing Methods

With the design geometry and the aluminium alloy called EN AC-46000 chosen for the housing, pressure die casting was selected as manufacturing technique. The combination of technique and material has been proved successful even for complicated thin-wall castings with high stresses. This since the material had a fairly low ductility, electrical conductivity and low melting temperature [29]. This method was used for the connectors and the lid as well.

To produce the shafts with the desired surface roughness and geometry accuracy, automatic machining was selected as manufacturing method. This method had good replication accuracy and easy to control with gauges.

Manufacturing the stoppers in PA6 GV30 with injection moulding was selected. Injection moulding is a manufacturing process for producing parts in large volumes at a low cost which was desired. It had the benefit of being very repeatable and because the tolerances of this component needed be narrow, it was a clear advantage.

7.4 Environmental Priority Strategies

The calculation was made on the concept with all the components. With the same condition, as described in section 6.5, of stopping pallets 20 times a minute resulting in an expected lifetime between two and three years. The analysis gave an influence of approximately 155 EUL. How much each material and the energy consumption contributed to the results can be seen in table 7.2. The full result is presented in appendix E.2. An overall improvement of the environmental load with ≈1.5% was reached compared to the existing product.

Table 7.2: Relation of how much each material and the energy consumption impacts the environment.

Material	**Impact [ELU]**
Aluminium EN AC-46000	0.5639
Steel	0.0224
Steel 1.1213	0.2059
Cast steel	1.1151
Silicon rubber	0.0112
PA6 30GV	0.0057
Polypropylene	0.0105
Electricity, EU average	153.5200
Σ	155,455

7.5 Design for Assembly

Focusing attention on assembly costs yielded indirect benefits. As a result of the DFA, the overall parts count, manufacturing complexity, and support costs were all reduced along with the assembly cost. If a product contains fewer parts it will take less time to assemble, thereby reducing assembly costs. The expression for the DFA index is

$$\mathrm{DFA}_{\mathrm{index}} = \frac{\text{Theoretical minimum number of parts} \cdot 3s}{\text{Estimated total assembly time}}$$

The ideal DFA-index for assembling one component in one second with no assembly difficulties gave an index of 100. The existing product have 11 components, 21 fastening elements and a estimated total assembly time of 180 seconds. That gave an index of 0,53. The theoretical minimum number of parts in the concept was 12 components and 18 fastening elements. The estimated total assembly time was 150 seconds which gave an index of 0,60. If re-designing the lid to be fastened with a snap-fit, the number of parts could be reduced with four fastening elements and reduce the assembly time with ≈30 seconds which would give a new DFA-index of 0,65.

By minimising the assembly directions so that all parts could be assembled from one direction, time was saved. To add parts is from above, in a vertical direction parallel to the gravitation was the most beneficial. Therefore, the mounting arrangement was that after the guide was attached to the housing, the bearing, shaft parts and engine were mounted from the same direction. It was achieved by making the dimension of the hole between the bearing and the engine wider.

The effort it takes to grasp, orient, and mount a part is dependent of mainly two factors, the geometry of the part and the path to the insertion point [8]. Designing the part to have self aligning features would improve the assembly time. By adding conical widening at the opening of all holes possible, as precise movements were not required from the worker.

7.5.1 Assembling Methods

The two parts of the shaft was assembled with the smaller shaft part press fitted to a pin, as displayed in figure 7.9. The longer shaft part was loose fitted onto the same pin, to get the desired mobility in the joint. The magnet was fitted onto the smaller shaft part. The magnet was attached by a thin milling and secured against the edge at end of the milling.

Figure 7.9: The first step of assembling the product is to put the two parts of the shaft together and add the magnetic ring.

The next part of the assembly process is described by means of figure 7.10. The bearing was inserted into the housing with a, by SKF, pre-defined hole tolerance fitting. The already mounted shaft assembly was added. Then, the circuit board was mounted in the housing using four screws. The motor was mounted, with a specific torque to not damage it, using two screws from behind and two from the front through the housing. Thereafter, the cords from the circuit board to the motor was connected and the lid sealed over the circuit board. When those steps were finished, a basic unit was created.

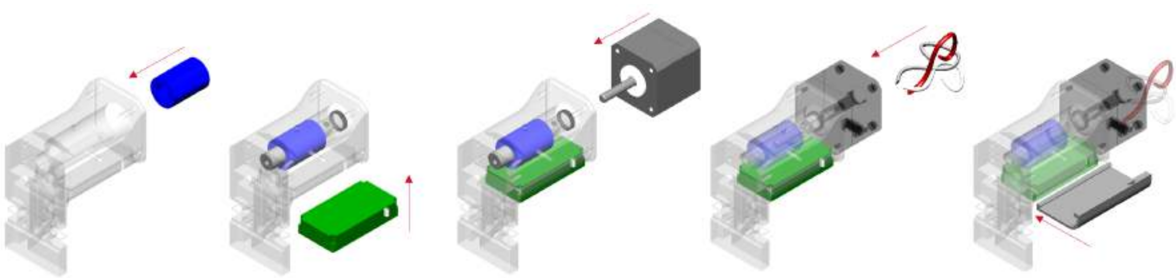


Figure 7.10: The order in which a basic unit is mounted with the generic parts and the STEGIA parts.

To add the modules and making a special configuration, as shown in figure 7.11, the stopper was first mounted onto the shaft. Then, the guide was attached using four screws. Last, the connector was added using one screw for XH and XT platforms, and two screws for X65 and X85. The bearing was rotated into position, depending on the direction of force, and fixed with a screw. The connector was mounted onto the housing using one or two screws depending on the configuration. Then, the guide was mounted using four screws. Last, the stopper was attached to the shaft.

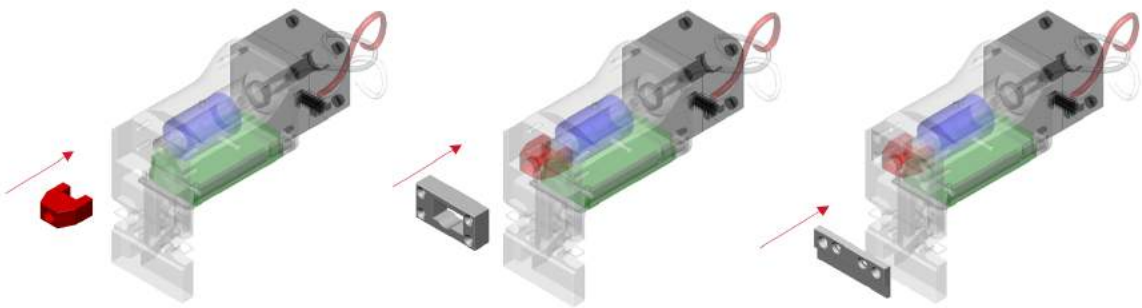


Figure 7.11: The order in which the platform specific parts are mounted to create a configuration.

7.5.2 Standard Elements

The bearing LBCD 12 D-2LS was a standard component purchased from SKF. The screws used were the standardised metric screw sizes M3, M4 and M8. The M8 screws were used to mount the stop onto the conveyor beam. The M3 screws was used to mount the circuit board and the guiding module to the housing. The M4 screws were used to assemble the connector to the housing and the stopper to the shaft.

7.6 Interaction Design

The goal of this phase was that the operator needed to provide minimal input to achieve the desired output, while the machine minimised undesired outputs to the user. The system needed to be pleasant to use so that the user was subjectively satisfied when using it. That meant she liked it and wanted to use it again, she got a positive experience from the interaction. What could be developed and refined in the concept were the haptic design parameters and the visual design parameters. By developing these parameters, the usability could be improved.

Two different variants of the stop are available, as described in section 6.1, meaning there are two levels of controlling functions. The accuracy of control the user had at its disposal to operate the stop was determined by the variant used. All that was done via the software for the control system which was not delivered or handled within the framework of this project. No physical controls was placed in the product. The user needed to know if the stop was in progress, if something was wrong but the stop was still running or if it was not running at all. To understand exactly what was wrong the control system had to be used. Visual communication was used for this purpose and was generated from the framework of cognitive ergonomics.

7.6.1 Usability

Usability measured the ability of a machine to help the user to perform a specified task [31]. By answering the question "can someone use this interface?", the usability was improved. When introducing a new product, the guessability of it was important. Meaning with what effectiveness, efficiency and satisfaction which a user can complete the assembling of the particular product for the first time. To enhance that, a few improvements were made to the concept design.

To communicate to the user what was up and down on the product, the upper side was designed with a curvature while the underside was made flat. This was to be perceived by the user as a human who has a rounded shape on her head and flat surface under the shoes. When designing the product to fit most platforms, the possibility of placing the product wrong increased. To reduce this error, the sides of the stop were designed differently to help the user to mount it onto the right platform.

Mounting the stop correctly onto the platform was the fundamental step towards having a well functioning product. Since the pallets on a conveyor came from the same direction all the time, the stop had to communicate in what direction it should be in relation to the conveyor direction. Depending on the placement of the stop, the bearing had to be rotated to work optimally. A hole was made on the side, not used for mounting the stop onto the platform, large enough to insert a screwdriver. With the help of a screwdriver the bearing could be rotated. Adding marking on the stoppers and the guides gave the opportunity to either deliver a kit containing a base unit and all the modules, or delivering ready-made configurations.

A prototype was used for usability testing to identify the guessability of the concept. Four persons from customer support and the finance department were tasked to put the connector in position and then hold it in the right position against the conveyor beam, without any instructions or drawings. Those who had a technical background managed this easily in just a few seconds, while those without technical background took over a minute to get it together. The feedback was to deliver it with a manual image without text, similar to IKEA manual thus having seen the final result before made it easier to place the parts correctly.

7.6.2 Cognitive Dimensions

The sensory intake through vision represents 80% of the total information intake [31]. That made the field of view, FOV, important to consider. How should elements be placed to make it possible to see the logo and symbols used for communication was studied.

The marking on the stoppers and the guides was made using a combination of index, arrows, and signs, characters. The size was determined by how large the component was and how far from the user it is at the moment of interaction. The conveying direction was marked with an arrow as most of FlexLink's product range were. The visibility when mounted onto the conveyor was considered and the logo was placed on the stop thereafter. The characters were positioned above or to the side of the index elements.

The user must have sufficient knowledge to interpret the information presented, the interface therefore had to match the skills and experience of the user. People are different and have different interaction preferences which made it a subjective area. The perception was depending on both internal and external factors. The internal was represented by mostly experiences and expectations. The external factors were mainly contrast, intensity and frequency of the stimuli.

It was therefore beneficial to study how other products in FlexLink's product range looked and indicated interaction.

It was decided to communicate that sides that were to be connected to each other were marked with opposing arrows, as seen in figure 7.12. To label what module belonged to what platform, characters were placed on the side of the components, as seen in figure 7.13.

Figure 7.12: Two opposite arrows indicating connecting surfaces.

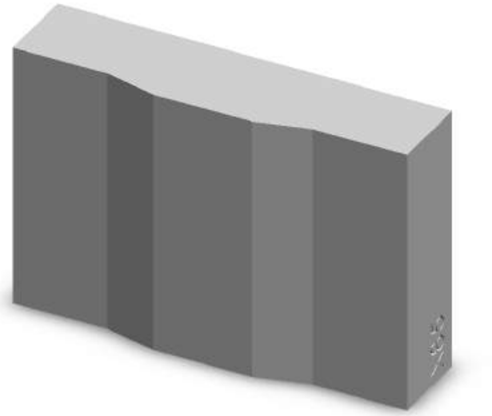


Figure 7.13: Characters in the side of the part letting the user know what platform it belongs to.

A Light Emitting Diode, LED, was used to communicate to the user if the stop was in progress, if something was wrong but the stop was still running or if the stop was not running at all. In the western society there are stereotypes of colours which affected the selection of the LED-colour. Green was associated with; fine, on, continue while blue was associated with; cold, water, calm. Blue was chosen because of its more natural colour than green. If a steady light, the stop worked as intended. If the LED was flashing, something was wrong but the stop still functioned. If no light, the stop was not running at all.

7.7 Form Design

Aesthetics is a measure of the ability of the machine to bring positive emotions through direct sensory input. The look and feel of the product was considered. By eliminating sharp edges, curves and disturbing lines the product communicated stability and elegance. The parameters considered were size, shape, orientation, colour, brightness and surface structure.

As stated in the requirement specification in appendix B, the design should be stylistically pure and show its origin with a distinct FlexLink design. FlexLink wanted to communicate that it is a company with passion for innovation, developing high-quality products with respect for people and the environment. Products from FlexLink are premium products made with confidence, precision and efficiency [5]. A trade off originated between keeping it simple and including all the possible brand profile.

7.7.1 Streamlines and Kinked Silhouettes

To communicate efficiency and speed to the user, a streamlined shape on the top of the housing was implemented to reduce the perceived size. The shape is displayed in figure 7.14. Directly after the peak of the curvature, the line was cut obtain possibility to mount the motor, however the streamlined shape was maintained. It gave a sense of motion to the expression of the housing and improved the cleanliness of the design.

To gain stability in the look of the housing, a kinked silhouette, as seen in figure 7.15, was implemented looking at the design from the front. By using a sharper bend instead of the conventional soft curve, an aesthetic effect was generated. It generated a feeling of confidence and strength.

Figure 7.14: A streamlined shape indicating clear direction and speed.

Figure 7.15: A kinked shape communicating stability and strength.

7.7.2 Chamfers and Rounds

To achieve a dimension of confidence and precision in the design, chamfers were used to smooth edges which can be seen in figure 7.16. It gave a feeling of possibility of fitting into smaller areas that were space-limited. It communicated a stronger and more technical design compared to the expression from rounded edges.

Rounds was also used, as in figure 7.17, since it was beneficial in terms of the amount of dust and dirt that settles on the product's surfaces. Larger radii created a softer look while sharper radii gave an expression of high precision, quality products.

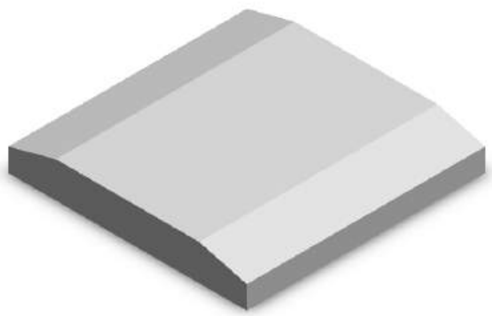


Figure 7.16: An example of two edges with chamfers

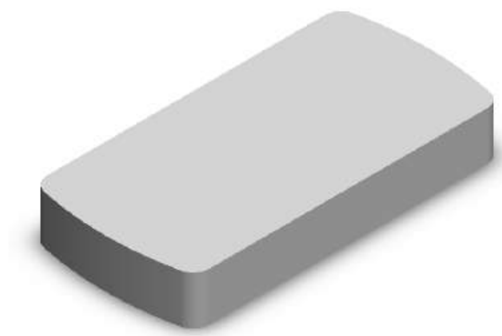


Figure 7.17: A rectangle with small radii in the corners which is a characteristic in most FlexLink designs.

7.7.3 Graphical Elements and Colouring

Using logos and other graphical elements gave a brand recognition and showed the product's affiliation, see example in figure 7.18. The logo was placed on the side of the stop to be visible when mounted onto a platform.

The two colours were constantly used in FlexLink's product design. White aluminium on the beams and all metal details, and dark grey on all plastics communicating interaction. The two colours are displayed in figure 7.19. The dark grey colour were used to enhance the usability of FlexLink's products since it was consistently used on parts that the users could interact with. By continued on using that colour coding, it became easier for those previously working with FlexLink's products. It also gave a clue to new users as well, because a different colour on a detail communicated where on a product something could be moved or opened.

Figure 7.18: An example of the FlexLink logo.

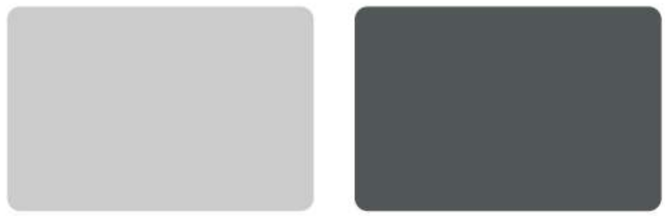
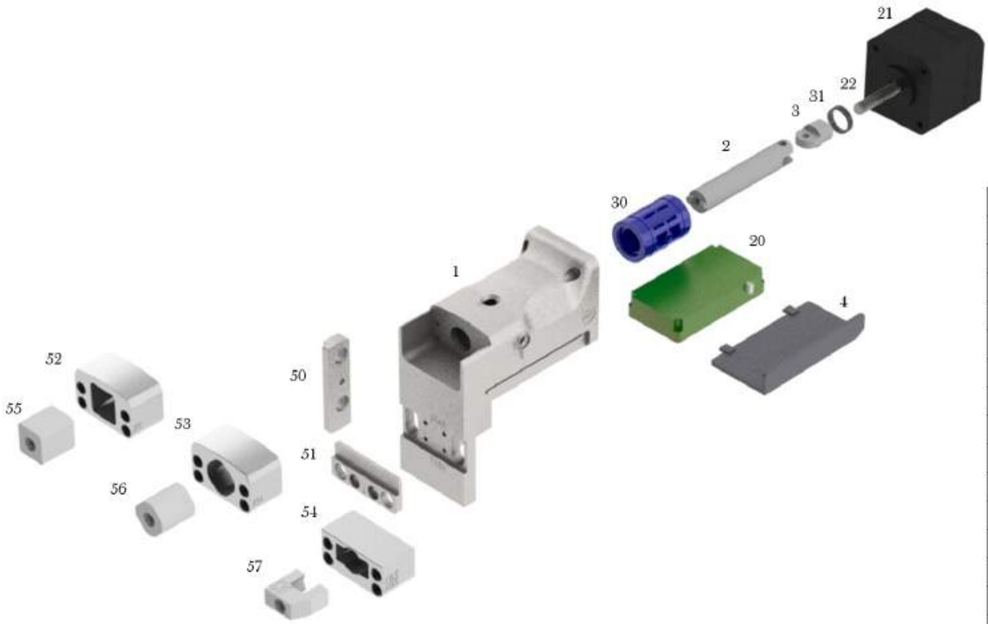


Figure 7.19: The two colours used in FlexLink's product design are white aluminium and dark grey.

Chapter 8

Final Design

The detailed design combined with knowledge gained through prototyping and modelling, resulted in the final design. The final design of the concept and its components are illustrated in Figure 8.1. The following chapter will describe the final design of the product and its modules with illustrations and Bill Of Materials, BOM.



Nr.	Component
1	Housing
2	Shaft A
3	Shaft B
4	Cover
20	Circuitboard
21	Motor
22	Motor Screw
30	Linear Ball Bearing
31	Magnetic Ring
50	Connector XHXT
51	Connector X65X85
52	Guide XT
53	Guide XH
54	Guide X65X85
55	Stopper XT
56	Stopper XH
57	Stopper X65X85

Figure 8.1: An exploded view of the final design with all the components included

8.1 Generic Parts

The housing, the cover for the circuit board and the shaft were the generic parts developed. They are platform common and where the logo was placed and most of the distinguishing design were visible. Each of the components will be further described.

8.1.1 Housing

The housing are shown from all planes in figure 8.2 to illustrate the design and its features. The arrows in the front and left view are there to help the user place the connector in the right way depending on what platforms to be mounted on. There are corresponding arrows on the connectors, so that when two arrows point with the tips against each other, the parts are correctly mounted. The lollipop shaped elevation, in the right view of figure 8.2, are there to help the user understand what is up and what is down in the concept. It also has the functionality of hindering mounting attempts on that side.

Figure 8.2: The housing shown from different planes.

The circuit board are to be placed in the cavity in the bottom of the housing. The slit that runs along the bottom of the cavity is used to read the magnet's position. The form design features, described in section 7.7, were implemented into the design.

Silhouettes are highlighted with red lines in figure 8.3. The two lines to the left of the figure shows rounds, the view next to the far right shows a kinked silhouette and the view to the far right are pointing out a two level streamline.

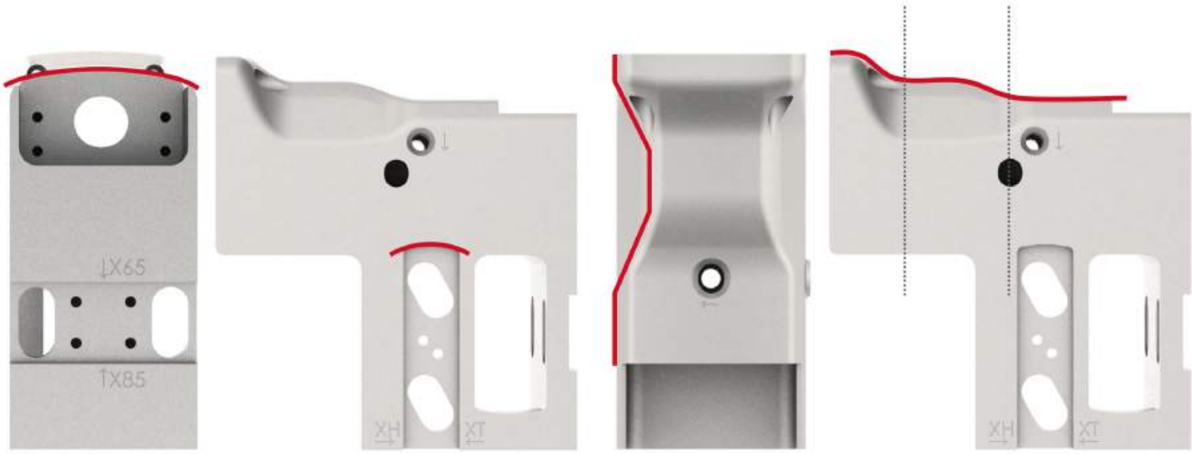


Figure 8.3: Different silhouettes in the design of the housing that are found in many other FlexLink products.

By implementing these design features made it possible to recognise the concept as a FlexLink designed product. There are four holes around the centre of the body, as seen in the top, bottom, left and right view of figure 8.4, are holes in which the ball bearing is positioned and held in place by means of a screw. The hole visible as a black circle in the middle of figure 8.4 was made to allow rotation of the bearing, which depends on the direction from which the pallets comes from. The bearing should be turned 90 degrees counter clockwise from the pallet's impact direction.

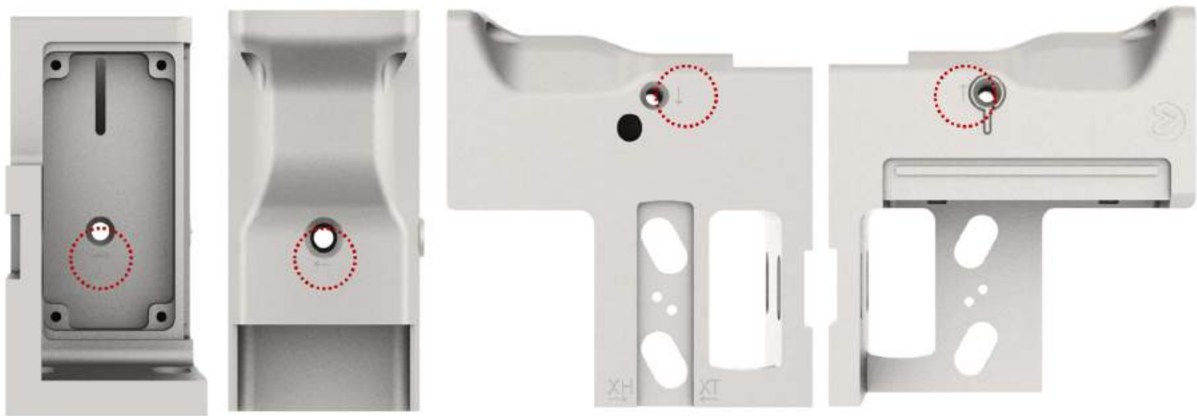


Figure 8.4: The indicators for the conveying direction.

8.1.2 Cover

The cover, or lid, shown in figure 8.5 is made out of dark grey plastic and is mounted with a built-in snap-fit. It has a cut corner to match the shape of the motor. A relatively large logo are placed on the surface facing the side if used with the XH or XT platform.

Figure 8.5: The cover protecting the circuit board, contacts and cords.

8.1.3 Shaft

The shaft are designed and manufactured in two parts to enhance the hinge joint coupling. It is displayed in figure 8.6 and attach to each other using a metal pin. A magnetic ring is mounted onto the smaller part of the two shaft components. The longer shaft has a very fine surface finish to not damage the linear ball bearing. The stopper is mounted on top of the longer shaft part using a screw.

Figure 8.6: The two shaft components when mounted together functions as a hinge joint.

8.2 Modular Parts

The modular parts are the connectors, the guides and the stoppers. The guides and stoppers were marked with the platform name while the connectors were left without. This is because the corresponding text is located on the housing, and it is not possible to place the connectors in the wrong cavity as they have different geometry.

8.2.1 Stopper

The stoppers are made out of white plastic and are shown in figure 8.7. They all have the same interface towards the shaft. One stopper only fits with one guide. The stoppers have different geometry depending on that they are stopping different kind of pallets as described in section 3.3.2.

Figure 8.7: The three different stoppers labelled with the platform name on one side.

8.2.2 Guide

The stoppers are made out of hard steel and are shown in figure 8.8. They all have the same interface towards the housing and are attached with four screws. The guide is the part that will take the first major impact load upon collision between the stop and palette. One guide has one corresponding stopper.

Figure 8.8: The three different guides labelled with the platform name on the right side.

8.2.3 Connector

The two different connectors are made out of aluminium and shown in figure 8.9. The XH and XT compatible connector are shown vertically in the figure and is mounted to the housing using one screw. The X65 and X85 compatible connector are shown horizontally in the figure and is mounted to the housing using two screws.

Figure 8.9: The two connectors with arrows to indicate placement.

8.3 External Parts

STEGIA supplied the motor, motor screw and circuit board along with cords. The fastening elements were of the shelf components in FlexLink's distribution centre where the products are to be assembled. Since standard sized screws of M3 were used no special orders had to be made. Other FlexLink fastening elements were also of the shelf components in FlexLink's distribution centre. The linear ball bearing was supplied by SKF though a well established supply chain.

8.4 Freedom to Operate

Existing patents was investigated to confirm that there is freedom to operate. A patent search was performed. The focus of the search was the shaft coupling in combination with the motor, which was considered to be the most distinctive characteristic. The search methodology was similar to the one that was used in the pre-study 3.2.1. None of the findings indicated that the concept was dominated by any other patent. Most of the patents that were found involved the motor function itself or was about the sliding surface. A conclusion could therefore be drawn that FlexLink is free to operate with the concept developed in this report.

Chapter 9

Prototyping

The following chapter will describe each of the prototypes and the purpose of it. Depending on the objective of the prototype, they had different functionality and detail level. A scheme for which kind of prototype was produced during what phase of the development, see table 9.1, was created.

Table 9.1: The relation between the different design phases and prototypes.

Design Phase	**Type of prototype**
Concept development	
Early concept development	Sketches and software mock-ups
Further concept development	Paper prototypes
Detailed concept development	Software simulated prototypes
Final concept development	Software based proof-of-concept prototypes
System-level design	Proof-of-principle prototype and working prototype
Detailed design	Functional prototype
Final design	Visual prototype

All the sketches, CAD-based simulations and prototypes from the concept development are displayed and discusses in section 5. The rest of the prototypes will be further discussed in the following sections. The prototypes were created alongside the development to validate or investigate something.

9.1 Proof of Principle Prototype

The first physical high-fidelity prototype was created through CAD-modelling in SolidWorks and use of an in-house 3D-printer, as displayed in figure 9.1. It was made full scale and served to verify key functional aspects of the intended design.

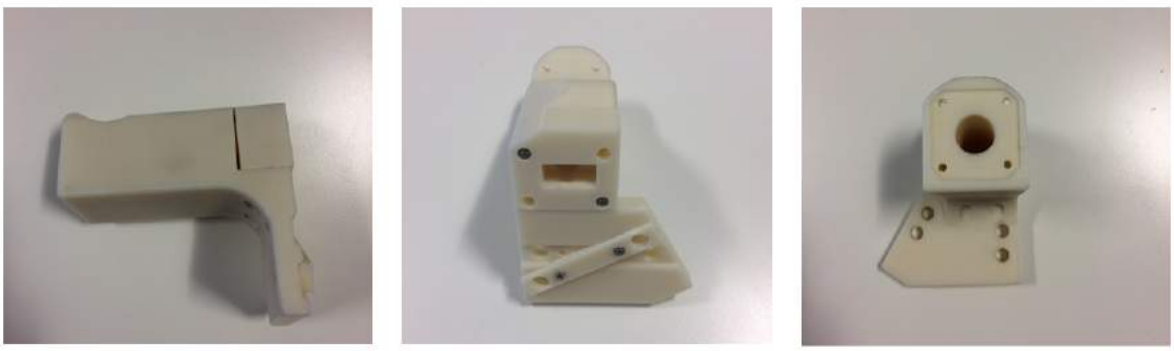


Figure 9.1: The first prototype made to verify the key functions of the concept.

The intent of the prototype was to investigate if the house could be mounted onto more than one platform and that the linear motion was possible through the guide module. However, no details of the shaft design, manufacturing methods or assembling methods was regarded. The mounting onto different platforms was made by moving the connector between the two different slots and thereby rotate it 30 °. Its length, width and height was 120 x 50 x 90 mm. It did not have close to all the functionality wanted in the final product.

9.2 Working Prototype

A more serviceable prototype was made to evaluate the mounting of the motor and mounting onto a conveyor beam, see figure 9.2. A normal linear ball bearing was used in this prototype that had nearly all of the functionality as wanted of the final product. When this prototype had been evaluated, another one was made with improvements.

Figure 9.2: The first working prototype made to investigate the movement of the stopper.

The hole pattern was changed, as seen when comparing the left frame of figure 9.2 and 9.3. The silhouette were change into being used as a basis for ordering a computer numerical controlled, CNC, machine-generated test series that were be tested in the vertical rigs. The main objective with the prototypes in this stage was to learn how the different functions of the concepts worked individually and in relation to each other. The prototypes were created with free form production and in full scale.

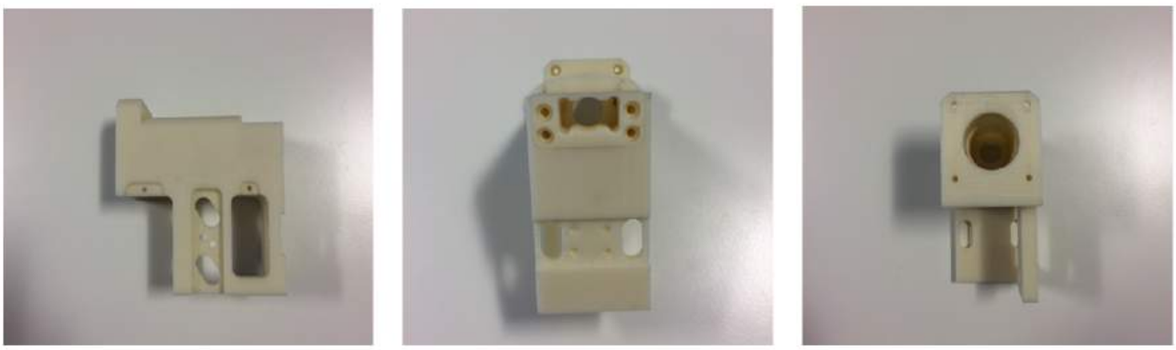


Figure 9.3: The second working prototype made to validate the design for CNC-machining.

9.3 Functional Prototype

The functional prototype was rapid prototypes and made out of carbon fibre reinforced plastic. It has the same strength as aluminium but only in one direction, therefore it suited to begin testing on that prototype while waiting for the real CNC-machined aluminium prototypes. The prototype is displayed in figure 9.4 and captured both the function and to some extent appearance of the intended design, though it was created with different techniques and out of different material.

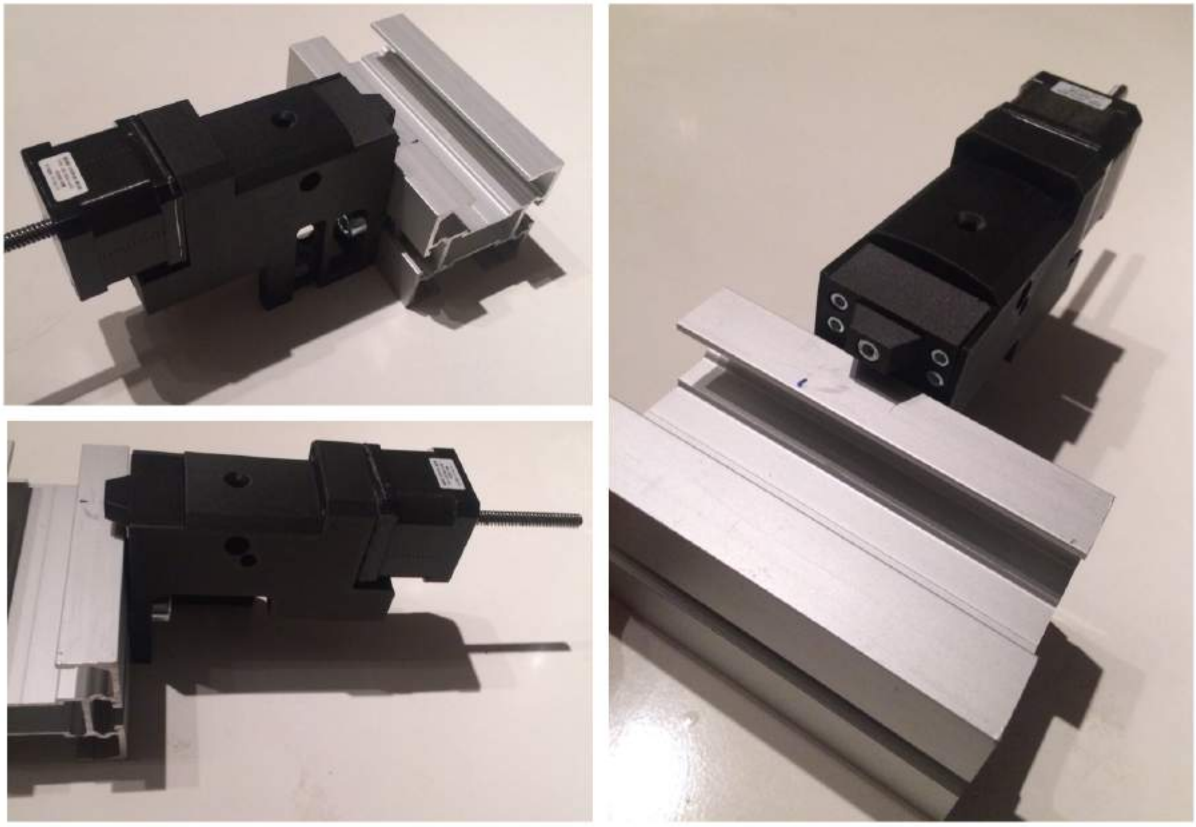


Figure 9.4: A working prototype with more alike properties to the final product.

9.4 Visual Prototype

A visual prototype was created and used for presenting the final concept to the product owner at FlexLink and the opponents at Chalmers, the prototype can be seen in figure 9.5. It represented the size and the appearance of the final design however not constructed out of the right material. It was attempted to colour the materials to closely simulate the intended final exterior look. As it was a visual prototype it did not have all the functionality.

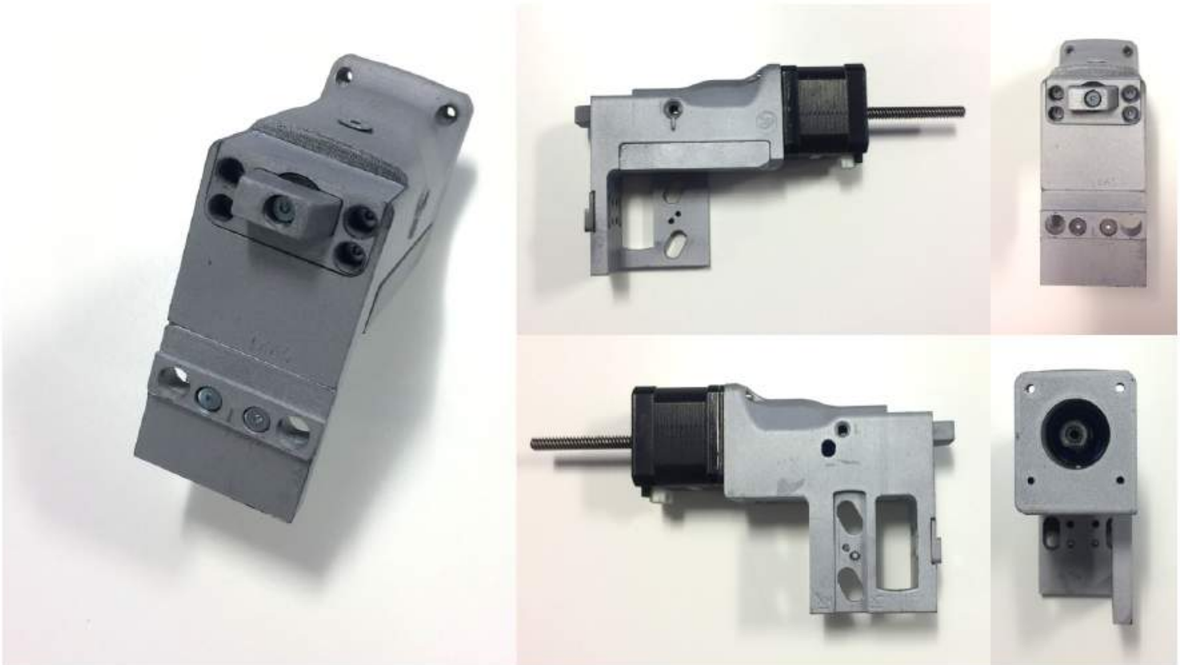


Figure 9.5: A visual prototype illustrating the exterior look of the final design.

Chapter 10

Implementation

This chapter will present an assessment which evaluated the concept in terms of market prerequisites. An economic analysis provided the basis for if the price requirement was reached and to confirm that the product will be profitable for the company to launch. Then, the different product variations will be presented and through what channels they are to be sold. Finally, if there are any ethical dilemmas will be investigated and if so, how they should be handled.

10.1 Cost Calculations

The cost of a product to the company was more than just purchase of raw materials. The manufacturing methods and additional cost were important parameters adding up to the total cost of the product. To ensure that the product was still a good purchase for the customer, the cost of the product over its life cycle was examined.

10.1.1 Manufacturing Cost

The manufacturing cost for each in-house designed part in the product was calculated with the software CES Edupack [29]. The estimated manufacturing cost in total and for each part can be found in Table 10.1.

Table 10.1: Manufacturing cost for each part in the concept.

Part	**Cost [SEK]**
Housing	33.29
Cover	0.29
Shafts	12.47
Connector	0.83-0.97
Connector X65X85	*0.83*
Connector XHXT	*0.97*
Guide	12.31-14.29
Guide X65X85	*14.29*
Guide XH	*12.76*
Guide XT	*12.31*
Stopper	0.51-0.58
Stopper X65X85	*0.51*
Stopper XH	*0.58*
Stopper XT	*0.55*
Sum:	$\approx$ **59-62**

The mass was calculated based on the part's volume and the material's density. The cost was calculated based partly on properties such as material, manufacturing method, mass, length and complexity of the part. The other parameters adding to the prize was the batch size, load factor, overhead rate and the capital write-off time. The manufacturing plant was assumed to be running 12 hours a day, which resulted in a load factor of 50%. The production facilities FlexLink used were spread all over the world, the overhead rate was based on the average rate in Europe, 1290 SEK/h [29]. In fact, that number might be lower as it is generally cheaper to produce volumes of parts in for example Asian countries. The manufacturing tools were estimated to last for at least five years. The batch size was estimated to be 100.000 units over 10 years.

10.1.2 Total Cost

To create a more holistic perspective about what the actually cost of the product was, the costs for the external parts and fastening elements were added. Moreover, costs for assembling, distribution and administration were thereafter added to get the total cost. A profit margin of the same percent size as for the pneumatic stops was applied. By adding these numbers, the cost for the new product was 1.9 times the price for the current equivalent pneumatic product. The exact numbers cannot be published due to confidentiality. This was what it costed the customer to buy the product and thus the price for a one-time investment.

10.1.3 Total Cost of Ownership

When investigating the cost for the product life cycle, the result differed. There are, as described in section 1.2, benefits with changing from a pneumatic to an electrical system in more than one aspect. Most newly built factories today do not have a pneumatic system within the premises, and thus need to purchase a generator for compressing air. The setting of a pneumatic system, as seen to the right in figure 10.1, have four connected stops with one air compressor and a control unit. These hoses were filled with pressurised air and were usually about 20 m long. It was therefore a volume of approximately 9 litres of air never used and a long distance on where leakage could occur. A pneumatic system have an efficiency of $\eta \approx 20\%$. The electrical system, as described to the left in figure 10.1, instead had cords which transported electrical impulses and had an efficiency of $\eta \approx 80\%$.

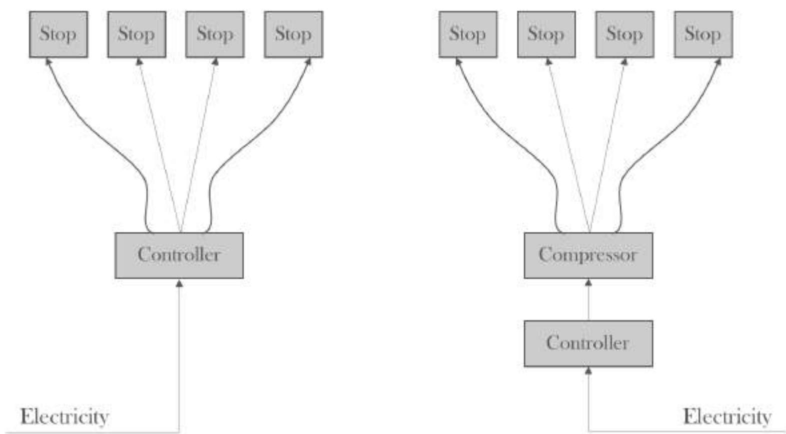


Figure 10.1: A system layout of the electrical stops to the left and the pneumatic stops to the right.

All pneumatic systems experience leaks, and these leaks contribute to the lower efficiency of pneumatic systems. In the interview with Susanne Börjesson at SKF, she described that leak were problematic and sometimes hard to identify. As a result, resources to maintain the pneumatic system were required as the performance varied over time as the seals were worn.

If ignoring the TCO perspective, short-term equipment cost savings would be made since the price of an electrical stop is 1.9 times the cost of a pneumatic. However, when investigating the cost of pressurising air to drive the stop compared to having electricity driving the stop it was found that savings where made after a little more than a year. In figure 10.2, a pneumatic and electrical system is compared with the price only calculated based on the purchase price and the number of kWh consumed. When added costs for maintenance and purchasing a generator for compressing air, the difference was striking and can be seen in figure 10.3.

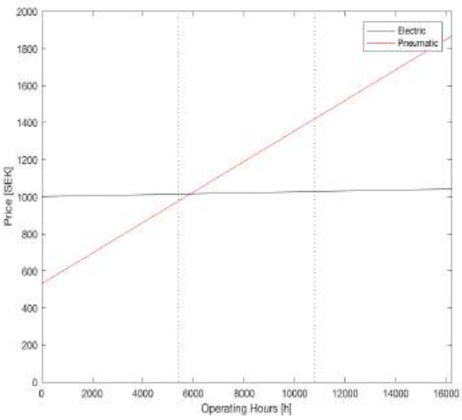


Figure 10.2: The relation between a pneumatic and electric system calculated from consumption of electricity and purchasing cost, the dotted lines indicates years.

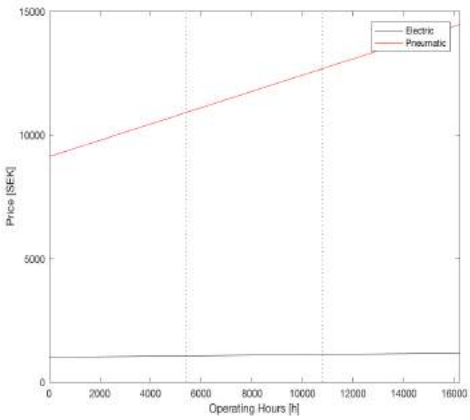


Figure 10.3: The relation between a pneumatic and electric system with additional costs, the dotted lines indicates years.

Comparing the two solutions over a product's lifetime, the electric solution was a more economical option than a pneumatic one.

10.2 Ethical Considerations

Looking on the concept from an ethical perspective, one could argue that technology replace people at work. Considering the tough competition, to have high efficiency and drive lowering of the prices are important to companies. To stay ahead by innovating is immense. Smart and innovative products provide large opportunities to shape a production plant as desired. By controlling flows and problems at the plant, people can also be monitored. Even if this is done with a good initiative, workplace monitoring is common and could be critical as the integrity of the employees are eliminated.

To not have enough security restrictions around the product to avoid injuries and incidents when in use can be problematic from more than one point of view. The fact that people and goods can be hurt but also that the company can be described in the media to not have reliable products, if the accident arises as a direct consequence of improper use of the product.

Another ethical discussion point is the production of aluminium which is the material most used in the concept. It is located close to the surface of the earth and in a relatively thin layers and large land areas can therefore be exploited. It is easy to recycle aluminium but since this material have not been used in large scale for more than 40 years, many of the products are still in use. Only about 20 percent of the aluminium produced comes from recycled material [81].

10.3 Product Launch

With all the knowledge gained through the report, a strategy for launching and how the product will be sold and distributed will be presented. Intangible values will be described. Presented are also the product variants could be marketed to gain as large positive outcomes as possible.

10.3.1 Intangible Values

The intent with the design of the concept was to be in line with FlexLink's values, as described in section 1.1, and design guidelines. The product differentiates a lot compared in terms of design to the two competitors studied in section 3.2.2. This results in an intangible value for FlexLink in terms of branding.

The product will help distinguish FlexLink's brand on the market of pallet handling systems. Even though the company is operating in a B2B environment, it is still a person on the other company taking the decision to buy a product or not. The sleek design and branding will attract more customers and could probably be a symbol for a new product range of electric products attracting the Industry 4.0 actors, as described in section 3.1.

10.3.2 Product Variants

An approach is to implement it into new platforms developed in the future, it could be done relatively easy due to the modularity of the product. Even though certain aspects of the concept are perceived most promising to the current platforms, parts of the design could be transferred into other products that are under development now. Changing bearing and motor could increase the load possible to handle.

It should not be overlooked that FlexLink is part of the Coesia Group. It is a strength with development projects such as this within a company group, that there is a possibility to customise the product to fit other brands portfolio. Adaptions can be made with respect to physical dimensions and design features to adapt to other brands. If the developed product is not obviously fitting with the intended purpose or brand, it could fit another company within the group.

10.3.3 Marketing

FlexLink is a well established actor on the market of factory solutions even though they have not yet reached the point where the reputation becomes its own marketing. This means that some kind of publicity is needed to attract customers. To reach potential customers, trade fairs are good arenas, but also customer visits and developing customer-specific solutions through collaborations that later can be a part of the standard assortment.

To consolidate the impression of being a strong market actor, collaboration with well known and innovative customers could be a way to reach new markets. While marketing new conveyor platforms, these collaborations could be highlighted to increase the status of the company.

10.3.4 Sales and Distribution

It would be beneficial for the product to be launched at a large trade show as Interpack in Germany. This would make it possible for the customers to touch and feel the product as well as see it in its natural environment. The sales and distributions would go through the FlexLink's sales units spread all over the world.

Chapter 11

Conclusions

The final concept is considered to be at a refined conceptual level at the end of this project and to enter initial testing. This chapter describes the different aspects of what needs to be improved and developed before manufacturing can be started. Risks and consequences with implementing the concept is also discussed.

11.1 Requirements Fulfilment

An electrical driven pallet stop was developed that was possible to mount onto four platforms which was desired. The requirement regarding encapsulation was unfortunately not treated however, there are clear standards for what the product should hold for and how to achieve that.

The emergency stop and the position feedback system were possible add-ons to the standard, basic component. Two different variants of the product are to be sold, they are described in section 6.1. The requirement regarding that a 100% of the product being possible to recycle and heavily environmentally friendly will not be achieved, it can be seen more as a goal than a demand.

The rest of the requirements, described in section 4 and displayed in appendix B.1, were fulfilled and the outcome of the project can be seen as successful. A large emphasis was put on design and communication through design in this project, which meant that other parts were not performed equally careful.

11.2 Risks and Consequences

When using methods such as DFR, DFM and DFA within the same project there will ultimately be trade-offs where one have to decide on what is most important. In terms of the wished in the requirement specification, there are a clear prioritisation order, however not for the demands. There is a risk of sub-optimising the product by one method and then performing a lot worse in other aspects.

It is always a balancing process to develop multi-way components because one size fits all often means that it fits all acceptable however no one perfect. With that thought, it may have been beneficial to split the concept into two parts and let each part fit two platforms. However, the scope of this report was trying to develop one component that fitted all four platforms.

The calculations performed within this report are all theoretical and therefore does not take into account the actual conditions prevailing on site. Therefore, it should be considered to increase shaft diameter and bearing size to have a larger MoS. The shaft then needs to be milled down to get under the guide rail, which impair the visual design. However, increases the life of the construction especially for the XT platform.

11.3 Design Improvements

Improvements of the product are needed before manufacturing and launching. The improvement proposals are based on the knowledge gained mainly from the prototypes. Using the magnetic cylinder is completely untested, and safer design would be reusing the magnet from previous the design that are known to work and create a connector between the magnet and the processor. If the choice is to use a magnet cylinder anyway, it is recommended that this is carefully tested by a lifetime test to ensure the product quality.

Creating a spectre of both damped and undamped products would be beneficial to the product repertoire. The damping feature could easily be an add-on to the original component. It could be, for example, realised by means of springs. This means that even freight goods can be transported on pallets in the system without risk of breakage

The TO-tool used, BESO2D, is a 2D optimisation tool applied to a 3D construction. There is therefore reason to believe that there are sources of error in that result and should not be relied blindly on. It is recommended to use a 3D-tool for the optimisation to get a more accurate result.

In the lifetime calculations, in section 7.1.3, the strength for the XT platform was noticed to be less than for the other platforms. It has mostly to do with the fact that those pallets transports the heaviest goods. An additional part or more powerful bearing would make the construction more robust, however the advantage of having generic parts would be lost since some parts would need re-design.

11.4 Further Recommendations

Continuing this development process in a near future would help shorten the time to market and be the first company to launch a electrical pallet stop that can handle large loads, high speed and last longer than one million cycles. A start would be to during the upcoming time make use of this report in the development activities.

The second measure should be to conduct usability tests of the visual prototype that was developed within this project. It would help in understanding the future customers' perception of the product and serve as evaluation on how well the user requirements actually were fulfilled. It serves as a great starting point for further prototyping activities and for discussions that concerns possible improvement areas of the product.

As a concluding remark and something that also serves as a long-term reminder, is that FlexLink keeps being open-minded to new and innovative ideas to continue to be market leader when shifting into Industry 4.0. To be at the forefront of smart factory solutions, electrical control, robotics and fully automated production lines are the way to go.

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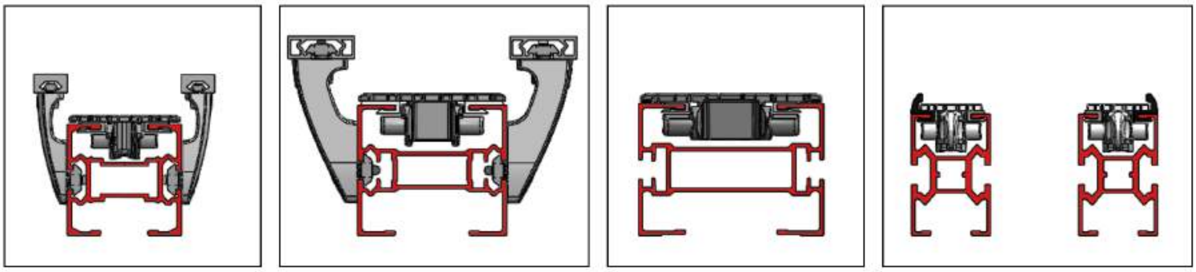
Appendix A

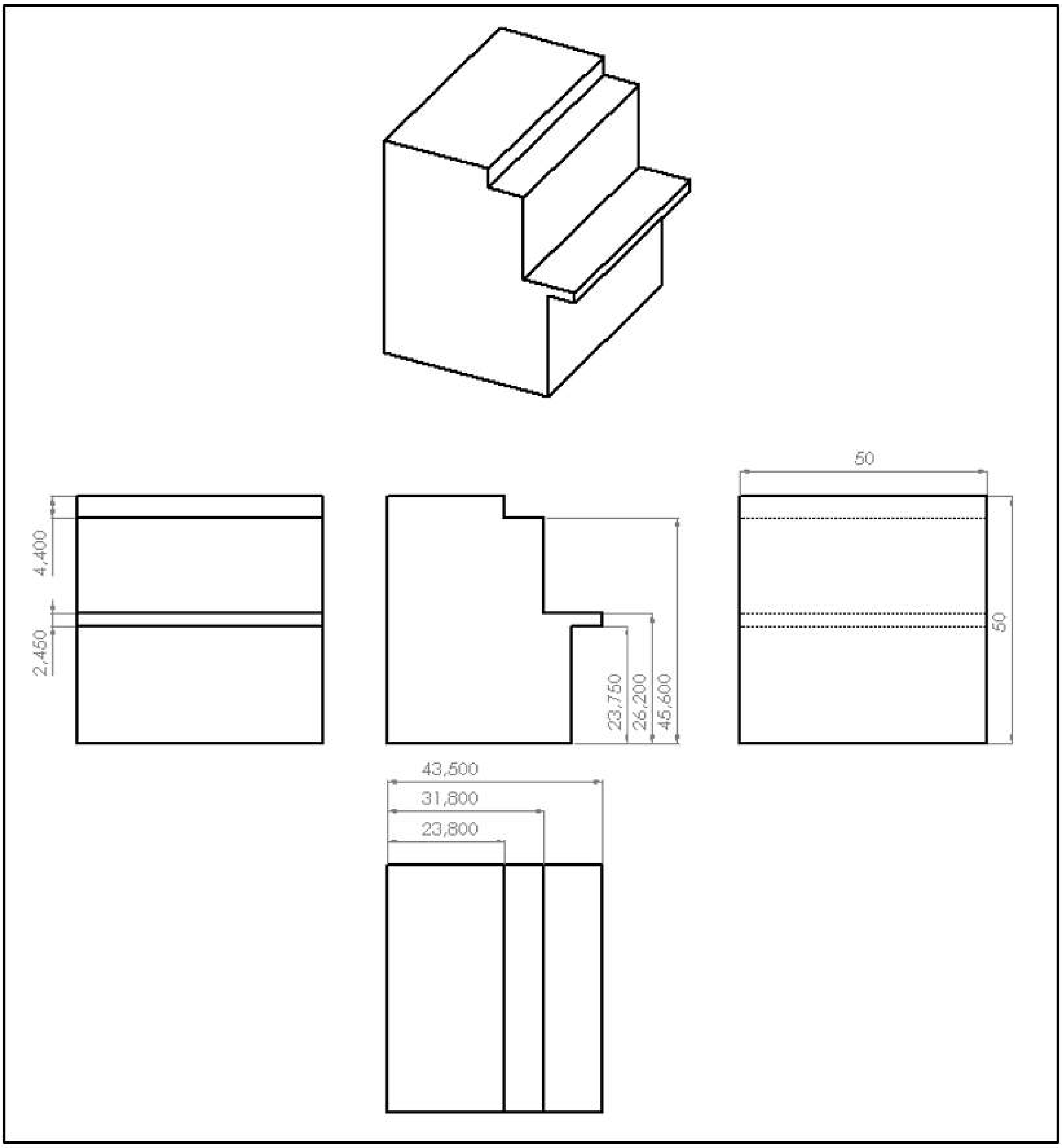
Preparatory Work

A.1 Product Platforms

The different platforms as a pallet stop was desired to fit. The X85, X65 and XK systems have guide rails while the XT and Optical systems does not. Each of the platform has its own shape of the links and pallets.



A.2 Design Space



Appendix B

Requirements

B.1 Requirement Specification

Nr.	Criteria	Specification	Measuring	Target	Unit	D/W	Standards Authority	Rank	Verification
1	**Function**								
1.1	Provide position feedbeck	Connected to a smart system	Signal transmission	Yes	Yes/No	D	User		Testing
1.2	Emergency stop	At its outer position	Short circuit	Yes	Yes/No	D	User		Testing
1.3	Allow multiple placements	Onto platform X65, X85, XH, XT		4	nr	W	FlexLink	4	CAD Sim.
1.4	Allow multiple placements	Onto platform X85, XH		2	nr	D	FlexLink		CAD Sim.
1.5	Configurable steplength	10, 12, 15mm	Measure	Yes	Yes/No	D	FlexLink		Testing
1.6	Configurable tip	Depending on platform	Subjetive	Yes	Yes/No	D	FlexLink		CAD Sim.
1.7	Pallets can pass with ease	No obstructing parts		Yes	Yes/No	D	User/FlexLink		Testing
1.9	Single functioning	Not interfering conveyor functions		Yes	Yes/No	D	FlexLink		CAD Sim.
1.10	Easy to install	Self-explaining mounting	Subjective	Yes	Yes/No	W	User	9	Usability test
2	**Performance**								
2.1	Loading capacity	Total pallet weight	Weigh	200	kg	D	FlexLink		Weigh
2.3	Time traveling inwards	Preferably as fast as possible	Timekeeping	100	ms	D	FlexLink		Timekeeping
2.4	Time travelling outwards	Preferably as fast as possible	Timekeeping	160	ms	D	FlexLink		Timekeeping
2.5	Life time	One cycle is out and in	Long time test	5	MCycles	D	User/FlexLink		Long time test
2.6	Life time	One cycle is out and in	Long time test	10	MCycles	W	User/FlexLink	1	Long time test
2.7	Encapsulation	Protect components from dust/water		65	IP-class	D	IEC		IEC 60529-test
2.8	24V DC actuator	Stegia		Yes	Yes/No	D	FlexLink		
2.9	Maintenance	No efforts needed		Yes	Yes/No	W	User	3	Long time test
3	**Material**								
3.1	Environmentally friendly	Possible to recycle	Weight	100	%	D	Project owner		CES-Edupack
3.2	Environmentally friendly	Environmental burden	Calculations	150	EUL	D	Project owner		EPS-Analysis
3.3	Wear resistance	Impact on contact surfaces	Surface gauge	0	nr	W	User/FlexLink	2	Measuring
3.4	Noise level	Peak value during a cycle	Sound meter	70	dB	D	User/FlexLink		Measuring
3.5	Contain standard elements	Percentage of all screws etc.		100	%	W	Project owner	5	Measuring
3.6	Using standard cables	Percentage of all cables		100	%	W	User/FlexLink	5	Measuring
4	**Communication**								
4.1	Clear indication of placements	In the conveying direction	Subjective	Yes	Yes/No	D	User/FlexLink		Usability test
4.2	Feel reliable	Design language	Subjective	Yes	Yes/No	W	Project owner	7	Usability test
4.3	Show its origin	Distinct FlexLink design	Subjective	Yes	Yes/No	W	FlexLink	8	Usability test
4.4	Stylistically pure	No unnecessary details	Subjective	Yes	Yes/No	W	Project owner	10	Usability test
5	**Dimensions**								
5.1	Fit between two tracks	Length	Measure	160	mm	D	FlexLink		CAD Measure
5.2	Fit between two lines	Height	Measure	170	mm	D	FlexLink		CAD Measure
5.3	Fit under the guide rails	Height	Measure	88	mm	D	FlexLink		CAD Measure
		Length	Measure	100	mm	D	FlexLink		CAD Measure
		Width	Measure	43,5	mm	D	FlexLink		CAD Measure
6	**Non-functional**								
6.1	Price	Total	Cost calculation	100	EUR	D	User/FlexLink		CES-Edupack
6.2	Weight	Total	Weigh	3kg	kg	W	FlexLink	11	CAD Calc.

B.2 Ranking

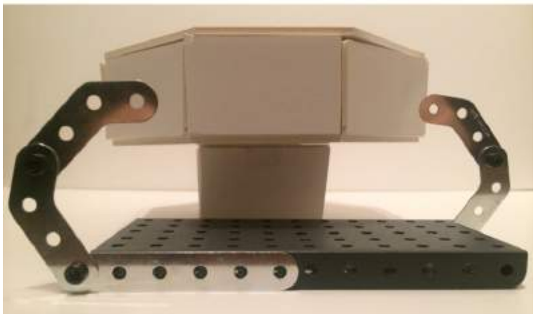
The ranking of the wishes when they were pairwise compared. 1 means that it is more important, 0 less important and 0.5 equally important. The sum was calculated and a ranking based on first the total score and then the internecine score. If they were failed to distinguish they got the same ranking.

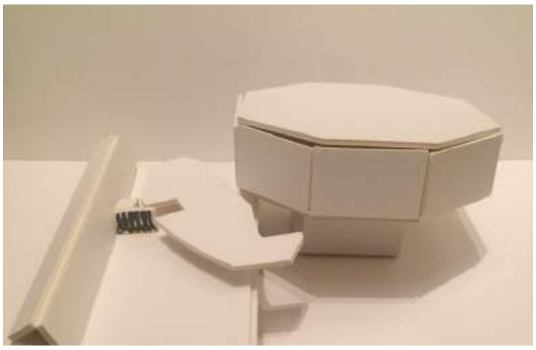
	1.3	**1.7**	**2.6**	**2.9**	**3.3**	**3.5**	**3.6**	**4.2**	**4.3**	**4.4**	**6.2**	$\sum$	**rank**
1.3	x	0	0	0	0.5	1	1	1	1	1	1	6.5	4
1.7	1	x	0	1	1	0.5	0.5	0	0	0	0	3	9
2.6	1	1	x	0.5	0.5	1	1	1	1	1	1	9	1
2.9	1	0	0.5	x	0.5	1	1	1	1	1	1	8	3
3.3	0.5	0	0.5	0.5	x	1	1	1	1	1	1	8.5	2
3.5	0	0.5	0	0	0	x	0.5	1	1	1	0.5	4.5	5
3.6	0	0.5	0	0	0	0.5	x	1	1	1	1	4.5	5
4.2	0	1	0	0	0	0	0	x	1	1	1	4	7
4.3	0	1	0	0	0	0	0	0	x	1	1	3	8
4.4	0	1	0	0	0	0	0	0	0	x	1	2	10
6.2	0	1	0	0	0	0.5	0.5	0	0	0	x	2	11

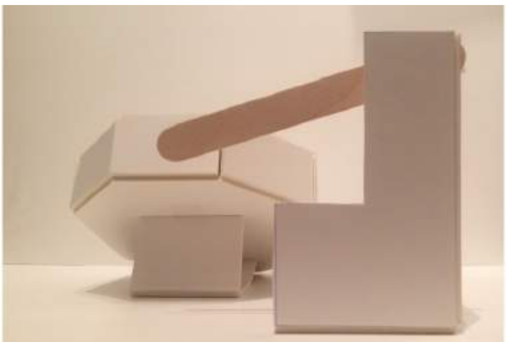
Appendix C

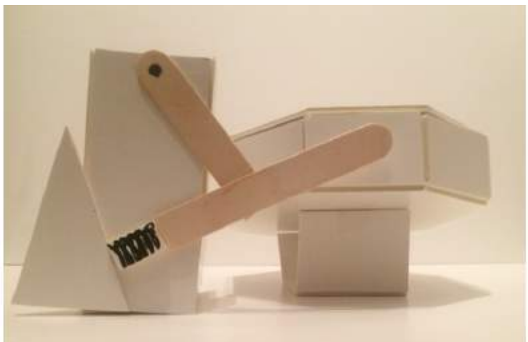
Concept Development

C.1 Further Concept Development Prototypes









C.2 Final Concept Development

Weighted ranking of bearing elements

	Weight	Reference	Linear Ball Bearing	Improved Linear Ball Bearing	Linear Needle Bearing	Plain Steel/Copper Bearing	Plain Steel/Copper/Plastic Bearing
Dynamic load capacity	8	10	9	8	10	6	6
Static load capacity	7	10	9	8	10	3	2
Diameter	3	10	6	6	7	8	8
Length	4	10	5	5	9	8	6
Number of contact points	8	10	8	10	7	2	2
Need of maintenance	9	10	9	10	9	7	7
Speed capacity	4	10	8	9	9	5	6
Price	10	10	9	9	4	5	3
Net Value		530	440	462	439	274	243
Ranking			2	1	3	4	5

Weighted ranking of couplings

	Weight	Reference	Tooth coupling	Hinge joint coupling	Elastomeric coupling	Ball joint coupling
Axial load capacity	4	10	7	7	9	7
Axial displacement	7	10	7	8	7	8
Radial displacement	5	10	2	3	4	4
Simplicity	9	10	8	9	5	8
Lifetime	9	10	7	9	6	9
Cost	10	10	9	9	7	8
Net Value		440	312	351	224	337
Ranking			3	1	4	2

Appendix D

System-Level Design

D.1 Environmental Priority Strategies

Materials & Processes		Pre-Use			Use			Post-Use																		Sum
		Production			Life			Reuse - Component			Reuse - Material			Energy recovery - combustion			Incineration - no energy recovery			Landfill			Other			
		E cost	Amount	Impact	index	Amount	Impact	index	Amount	Impact	index	Amount	Impact	index	Amount	Impact	index	Amount	Impact	index	Amount	Impact	index	Amount	Impact	Impact
	Unit	[ELU/		[ELU]	[ELU/		[ELU]	[ELU/		[ELU]	[ELU/		[ELU]	[ELU/		[ELU]	[ELU/		[ELU]	[ELU/		[ELU]	[ELU/		[ELU]	[ELU]
		unit]			unit]			unit]			unit]			unit]			unit]			unit]			unit]			
Aluminium	kg	1,991	0,357	0,710787			0			0	-0,946	0,357	-0,337722			0			0			0	0,0274	0,005	0,000137	0,710924
Steel	kg	1,21	0,049	0,05929			0			0	-1,18	0,03	-0,0354			0			0	4,21E-07	0,019	7,999E-09			0	0,059290008
Zinc coated steel	kg	3,34	0,036	0,12024			0			0			0			0			0	6,32E-07	0,036	2,2752E-08			0	0,120240023
Stainless steel	kg	33,11	0,085	2,81435			0	-30,47	0,001	-0,03047			0			0			0	6,32E-07	0,084	5,31048E-08			0	2,783880053
Cast steel	kg	2,28	0,236	0,53808			0			0			0			0			0	4,21E-07	0,236	9,9356E-08	0,0218	0,000064	1,3952E-06	0,538081495
Silicon rubber	kg	2,8	0,005	0,014			0			0			0			0			0			0	0,0658	0,005	0,000329	0,014329
Polyamide	kg	2,515	0,003	0,007545			0			0			0			0	0,336	0,003	0,001008			0	0,0658	0,003	0,0001974	0,0087504
Polypropylene	kg	0,959	0,001	0,000959			0			0			0			0	0,423	0,001	0,000423			0	0,0658	0,001	0,0000658	0,0014478
				0			0			0			0			0			0			0			0	0
Electricity, EU average	kWh			0	0,076	2020	153,52			0			0			0			0			0			0	153,52
				0			0			0			0			0			0						0	0
SUM				4,265251			153,52			-0,03047			-0,373122			0			0,001431			1,83212E-07			0,000730595	157,756943

Appendix E

Detailed Design

E.1 Failure Mode and Effects Analysis

FMEA: Electrical Pallet Stop

Part		Characteristic of failure					Rating				Actions
Component	Function	Type	Mode	Effect	Cause	Control	Po	S	Pd	RPN	Recommended Action
House	Hold components	Mechanical	Human	Injury	Sharp edges	Design/ Safety evaluation	7	10	4	280	Design review
					Prutruding parts		2	10	1	20	
				Tripping	Loose cords		2	9	2	36	
					Prutruding parts		1	8	3	24	
			Crack	Early fatigue	Crack propagations	Design calcultions	3	7	4	84	
					Stress concentrations		4	7	6	168	Design review
			Scratch	Visual defects	Impact	Material selection	8	2	2	32	
				Affect function	Deformation		3	9	6	162	Review material selection
		Electrical	Break	Eliminate function	Loose cords	Safety evaluation/ User manual	5	9	6	270	Mounting simulation
					Fire		1	9	8	72	
			Human	Injury	Electrocution		1	10	10	100	Safety audit
					Burns		1	10	8	80	
Connector	Attach stop to conveyor	Mechanical	Human	Injury	Falling down	Design/ Safety evaluation	2	10	4	80	
					Sharp edges		7	10	4	280	Design review
			Break	Early fatigue	Mounting	Testing	5	8	9	360	User Manual
			Crack		Crack propagations	Design/ Material selection	3	7	4	84	
					Stress concentrations		4	7	6	168	Design review
Bushing	Guide shaft	Mechanical	Crack	Early fatigue	Crack propagations	Design calcultions	3	7	4	84	
					Stress concentrations		4	7	6	168	Design review
			Break		Mounting	Testing	5	7	5	175	User Manual
					Dimensioning	Movement simulations	4	9	10	360	Design review
					Unaccounted impact		1	6	8	48	
Shaft	Translation of the stopper	Mechanical	Break	Early fatigue	Hardness	Design/ Material selection	3	5	9	135	Supplier contact
					Weakened coating		1	6	5	30	
					Rougness		2	5	6	60	
			Crack		Crack propagation		3	7	4	84	
					Stress concentrations		4	7	6	168	Design review
			Scratch	Affects translation	Friction	Material selection	8	2	2	32	
				Visual defects	Impact		3	9	6	162	Review material selection
Guide	Guide stopper	Mechanical	Break	Early fatigue	Hardness	Material selection	3	5	9	135	Supplier contact
					Roughness		1	6	5	30	
					Weakened coating		2	5	6	60	
			Crack		Crack propagations	Design calcultions	3	7	4	84	
					Stress concentrations		4	7	6	168	Design review
			Scratch	Visual defects	Impact	Design/ Material selection	8	2	2	32	
				Affects translation	Friction		3	9	6	162	Review material selection
Stopper	Impact point to pallet	Mechanical	Crack	Early fatigue	Weakened coating	Design/ Material selection	2	5	6	60	
					Crack propagations		3	7	4	84	
					Stress concentrations		4	7	6	168	Design review
			Scratch	Visual defects	Impact		8	2	2	32	
				Affects translation	Friction		3	9	6	162	
			Human	Noise	Impact	Testing	9	3	1	27	
				Crushing		Safety evaluation	2	10	3	60	
				Severing	Acceleration		2	10	8	160	User Manual
				Entanglement			3	10	8	240	Safety audit
Motor	Movement of the shaft	Mechanical	Vibration	Noise	Impact	Testing	9	3	1	27	
				Movements	Rotation		4	9	5	180	Long-term test
			Break	Abrasion	Friction	Design calcultions	2	9	4	72	
				Early fatigue	Mounting	User manual	3	8	8	192	User Manual
			Human	Tripping	Loose cords	Design/ Safety evaluation	2	9	2	36	
					Prutruding parts		1	8	3	24	
				Injury			2	10	1	20	
		Electrical		Injury	Electrocution	Safety evaluation/ User manual	1	10	10	100	Safety audit
					Burns		1	9	8	72	
			Break	Eliminate function	Loose cords		1	10	10	100	User Manual
					Fire		1	10	8	80	

E.2 Environmental Priority Strategies

Materials & Processes		Pre-Use			Use			Post-Use					
		Production			Life			Reuse - Component			Reuse - Material		
		E cost	Amount	Impact	index	Amount	Impact	index	Amount	Impact	index	Amount	Impact
	Unit	[ELU/unit]		[ELU]	[ELU/unit]		[ELU]	[ELU/unit]		[ELU]	[ELU/unit]		[ELU]
Aluminium EN AC-46000	kg	1,991	0,2832	0,563851			0			0	-0,946	0,28	-0,26488
Steel	kg	1,21	0,0185	0,022385			0			0			0
Steel 1.1213	kg	1,76	0,117	0,20592			0			0	-18,49	0,117	-2,16333
PA6 30GV	kg	1,84	0,0025	0,0046			0			0			0
Cast steel	kg	2,28	0,4891	1,115148			0			0	-1,18	0,24455	-0,288569
Silicon rubber	kg	2,8	0,004	0,0112			0			0			0
Polypropylene	kg	0,959	0,0072	0,006905			0			0			0
				0			0			0			0
Electricity, EU average	kWh			0	0,076	2020	153,52			0			0
				0			0			0			0
SUM				1,930009			153,52			0			-2,716779

Materials & Processes	Post-Use												Sum
	Energy recovery - combustion			Incineration - no energy recovery			Landfill			Other			
	index	Amount	Impact	index	Amount	Impact	index	Amount	Impact	index	Amount	Impact	Impact
	[ELU/unit]		[ELU]	[ELU/unit]		[ELU]	[ELU/unit]		[ELU]	[ELU/unit]		[ELU]	[ELU]
Aluminium EN AC-46000			0			0			0	0,0274	0,0032	8,768E-05	0,56393888
Steel			0			0	4,21E-07	0,0185	7,7885E-09			0	0,022385008
Steel 1.1213			0			0			0			0	0,20592
PA6 30GV			0	0,373	0,0025	0,000933			0	0,0658	0,0025	0,0001645	0,005697
Cast steel			0			0	4,21E-07	0,24455	1,02956E-07			0	1,115148103
Silicon rubber			0			0			0			0	0,0112
Polypropylene			0	0,432	0,0072	0,00311			0	0,0658	0,0072	0,00047376	0,01048896
			0			0			0			0	0
Electricity, EU average			0			0			0			0	153,52
			0			0						0	0
SUM			0			0,0040429			1,10744E-07			0,00072594	155,454778