Guiding Tracks in Overhead Sectional Doors

Kilian Gülich and Jakub Śnieżek

DIVISION OF PRODUCT DEVELOPMENT | DEPARTMENT OF DESIGN SCIENCES
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MASTER THESIS

ASSA ABLOY
Entrance Systems

Guiding Tracks in Overhead Sectional Doors

A Product Renewal Project

Kilian Gülich and Jakub Śnieżek

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Supervisor: Joze Tavcar
Co-supervisor: Anders Löfgren
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Abstract

This thesis project was done in collaboration with ASSA ABLOY Entrance Systems, and aims to increase efficiency in the design of the guiding tracks for overhead sectional doors. Withstanding wind and structural loads, while being easily installed and manufactured are some of the key aspects being considered, while maintaining the aim of reducing costs and material used. Using finite element analysis and design for assembly and manufacture, the project aims to provide a basis for ASSA ABLOY to decide on further development of the guiding tracks. The methodology used in the report is based on the Ulrich and Eppinger method for product development, and several areas of improvement on the current design are found. In summary, the results show that similar or better performance can be achieved with less material, while manufacturing costs can be significantly reduced. The report considers current manufacturing capabilities and incorporates manufacturing method and the assembly analysis formulated by Boothroyd, Dewhurst and Knight to reduce the start-up and per part cost of manufacture and assembly. Furthermore, the report suggests points of future development, and finds additional areas of the overhead sectional doors that would impact wind resistance and compliance.

Keywords: Product Development, Product Renewal, ASSA ABLOY, Overhead Sectional Door, Roller Guide Tracks.

Sammanfattning

Detta examensproject gjordes tillsammans med ASSA ABLOY Entrance Systems, och ämnar att förbättre effektiviteten i designen på rullspåren till segmenterade, lyftande dörrar. Några av nyckelaspekterna som granskas i rapporten är hållfastheten mot vindlaster och mekaniska laster av dörrens egenvikt, och att tillverkning och installation av dörrarna är enkel, med ett samtidigt mål att minska materialanvändning och kostnader. Genom att använda finita elementmetoden och design mot montering och tillverkning försöker det här projektet utgöra en grund för ASSA ABLOY att besluta kring vidareutveckling av rullspåren. Metodologin är baserad på Ulrich och Eppingers metod för produktutveckling, och flera förbättringsområden på den nuvarande designen hittas. Sammanfattningsvis visar resultaten att liknande eller bättre prestanda går att erhålla med mindre material, samtidigt som tillverkningskostnader kan reduceras avsevärt. Rapporten betraktar redan tillgängliga tillverkningsmetoder och monteringsanalysramverket författat av Boothroyd, Dewhurst och Knight för att minska både uppstartskostnad och styckvis kostnad för tillverkning och montering. Fortsättningsvis föreslår rapporten vidareutvecklingsmöjligheter och andra områden inom lyftande, segmenterade dörrar som kan bidra till ökat vindmotstånd och bättre styvhet.

Nyckelord: Produktutveckling, Produktförnyelse, ASSA ABLOY, Segmenterade Lyftande Dörrar, Rullspår.

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During this project, we have come into contact with a lot of great and helpful people, and we would like to express our gratitude to them. First, Anders Löfgren, our supervisor at ASSA ABLOY, who gave us the opportunity to learn and be a part of the team in Landskrona. Elin Elfström and Louise Bannersten, previous thesis workers and current employees, who helped us by being sounding boards and supporting us with contacts and logistics. Mikael Ström, Marcel Lightart, Arno Ruiter, György Fintor, who offered feedback and guidance. Jože Tavčar, our supervisor at Lund University, and Damien Motte, our examiner. All employees at the Landskrona office, who shared insights and offered feedback, and made us feel welcome.

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Lund, May 2023

Kilian Gülich and Jakub Śnieżek

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1 Introduction

1.1 Background

This master thesis project is a collaborative project between the Department of Design Sciences at the Faculty of Engineering LTH, Lund University and the company ASSA ABLOY Entrance Systems.

The company ASSA ABLOY Entrance Systems is one of the leading brands in industrial entrances, docking stations and automated doors, and offers an extensive portfolio of different entrance systems. Among the offerings are overhead sectional doors, which are used for a wide variety of tasks in various environments. An example of an overhead sectional door can be seen in figure 1.1. Notably, they are used as doors in docking stations for cargo trucks, which requires the doors to be large and exposed to the outside climate. Due to this, the doors experience severe wind loads dependent on the weather adjacent to the docking station, among other loads and challenges. The company is present in several countries, and development work is done across Europe. Manufacturing primarily takes place in Europe, most notably in Hungary, the Czech Republic and the Netherlands.

Figure 1.1: An overhead sectional door with torsion springs, window sections and a pass-through door.

1.2 Project Description

This project is a part of the continual effort to effectivize and optimize the overhead sectional doors, and focuses on the two-inch guiding track in which the door section rollers travel when the door is moving. The main points of interest are in the material utilization and cost effectivization of the tracks. Additional goals with the project are increasing the assemblability of the tracks both in production and in installation, while meeting a competitive wind load rating. In order to provide an accessible solution for ASSA ABLOY, considerations are taken in regards to current manufacturing methods and facilities.

1.2.1 **Goals**

The aim of this thesis project is to provide insight into the demands on the roller tracks, with an emphasis on wind load and door weight load. The project further aims to provide suggestions on possible new generations of tracks, and to compare new concepts to the current design in terms of performance and cost. Manufacturing methods are to be considered and the compatibility of developed concepts with current manufacturing capabilities should be analysed. Lastly, the project should provide suggestions for further development and performance improvements.

1.2.2 Delimitation

Due to the time constraints on the project, the scope of the project must be limited. The cyclic loading of the bend of the track is not considered, and concept development of surrounding parts is limited and proposed as points of further development. Some consideration is taken in regards to immediately adjacent parts, but additional concept development was severely limited, due to manufacturing concerns, time constraints and the extent of product knowledge required in order to provide concepts of an acceptable depth.

2 Product Background

2.1 Company Presentation

ASSA ABLOY is a multinational group with divisions concerning locks, electronic entrance control, automated entrance systems, revolving and industrial doors, among others. The division concering the overhead sectional doors considered in this report is ASSA ABLOY Entrance Systems, situated in Landskrona, Sweden. In 2006, ASSA ABLOY Entrance Systems emerged as a division in the ASSA ABLOY Group, and currently employs over 14 000 people and offers a large variety of products ranging from retail oriented systems to entrances for heavy industry and mining. Servicing is also an important area for Entrance Systems, and more than 3500 service technicians are employed by the company. Products are distributed in more than 100 countries [1].

2.2 Current Product

One of ASSA ABLOY's most popular overhead sectional door families today is the OH1042. The OH1042 is available in several different configurations, where the door is lifted straight up (vertical lift), or at an angle between 5 and 90 degrees in 5 degree increments. The point at which the lifting direction is changed is also continuously variable, in order to fit the door to the specific building and not waste vertical space adjacent to the doorway. The customer can choose between different sections in the door, and the door can be customized with windows, pass-through doors and section frame material.

In order to customize the door, the customer may choose any door size up to a maximum of 8 meter width and 7 meter height. The maximum mass of a door is 550kg, and the sections have an approximate area density of 13 kg per square meter.

Furthermore, the new and growing product OH1142 shares many of the aspects of the OH1042, and some of the parts as well, with the notable difference of the OH1142 utilizing a motor and chain driven motion system, rather than a spring-loaded counterweight system.

2.3 Current Tracks in OH1042

Figure 2.1: J-Track holding one of the door rollers in place. The door roller is fixed on a hinge which connects two door sections.

J-tracks are used throughout all ASSA ABLOY overhead sectional door models. Their purpose is guiding the door rollers along the correct path as well as taking up wind loads and the weight of the door. Figure 2.1 shows a door roller being held in place by a J-track.

Figure 2.2 explains how J-tracks and neighboring parts are assembled together. The current track solution in OH1042 door models utilises a J-track for when the door travels both vertically and horizontally. The transition from vertical to horizontal movement and vice versa is facilitated by a *J-bend*. The *wall bracket*, sometimes referred to as *wall angle*, is fastened directly to a

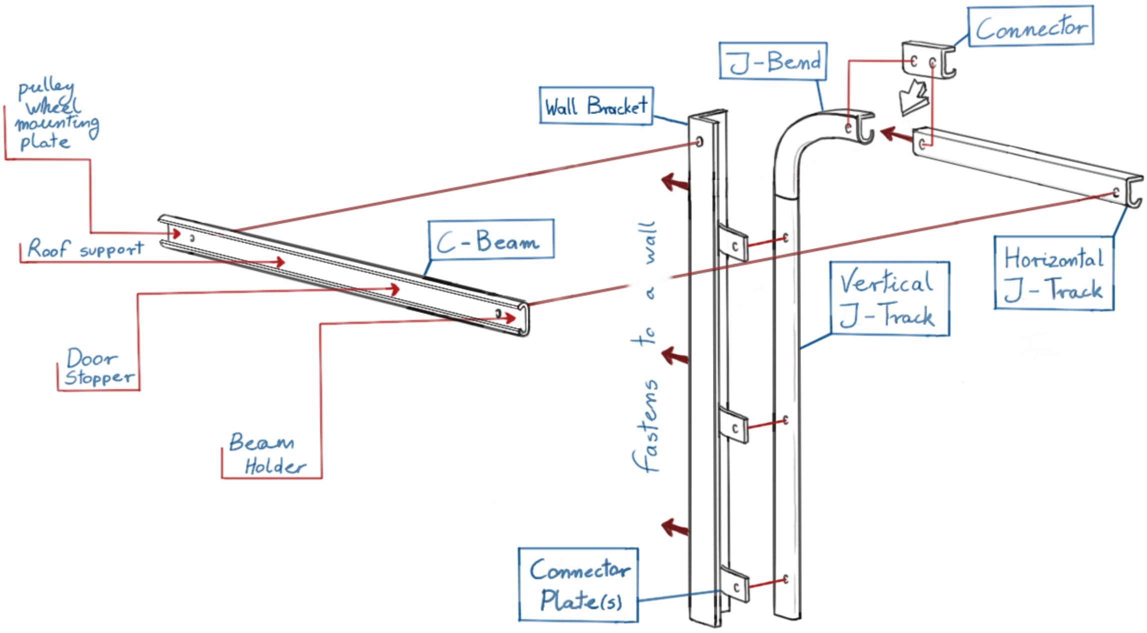


Figure 2.2: A conceptual representation of how the current J-tracks are assembled in relation to neighboring parts.

wall as shown by three arrows in the figure. The vertical J-track and wall bracket are connected together with several *connecting plates*. Finally the horizontal J-track and wall bracket are connected together with a *C-beam*. Apart from providing additional stiffness to the whole structure, the C-beam is used as a fastening point for several different parts, such as roof support beams, pulley wheels, door stoppers and others, dependent on the specific door model. These diverse parts are represented by the four red arrows pointing to the C-Beam in figure 2.2. Looking closer at the vertical supports and the means of fastening to the C-beam, a figure of the vertical supports can be seen in figure 2.3 and one of the ways to connect parts such as Pulley wheel holder, door stopper and counterweight beam holder to the C-beam can be seen in figure 2.4. Since the vertical supports need to be able to be mounted in several different angles according to which angle the track is protruding from the vertical wall, the interface between the vertical support and the track is with a single fastener of a different type than for the pulley wheel holder, door stopper and counterweight beam holder, shown in figure 2.5.

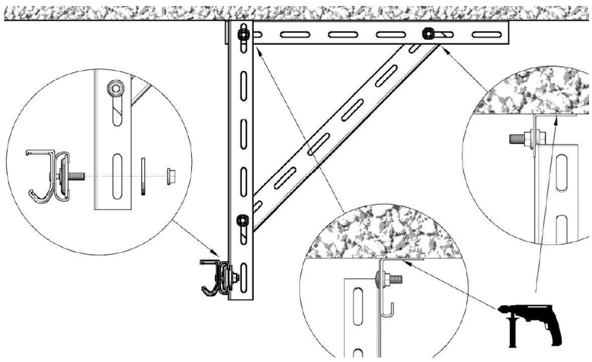


Figure 2.3: Vertical supports for the horizontal tracks.

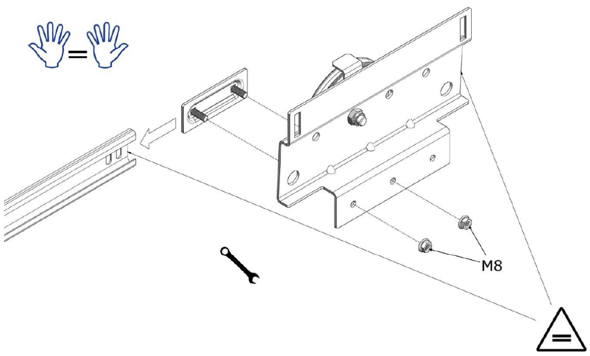
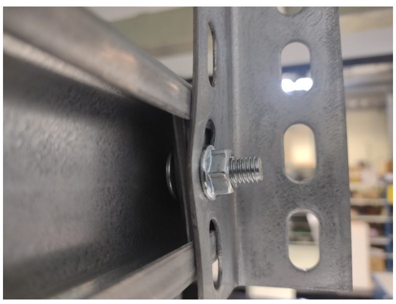
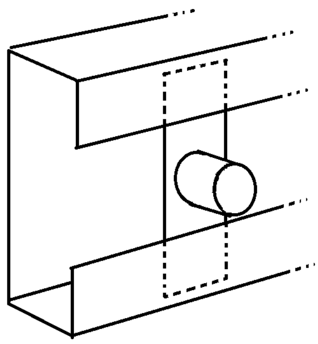


Figure 2.4: Connection between pulley wheel holder and C-beam.



(a) Picture showing how the vertical support is connected to the C-beam



(b) Sketch showing the C-beam connector piece used to fasten the vertical support to the C-beam

Figure 2.5: Figures showing the C-beam connection to the vertical support

2.4 Positioning of Tracks in Product Life Cycle

With the background of the company in mind, the current tracks can be considered to be in a mature product life cycle stage. This stage is often where either a replacement product is developed or a redesign of the current is done. Primarily, actions towards reducing costs, such as in manufacturing, transportation and product architecture, or actions towards performance improvement are taken [2]. Consideration must be taken to the cost differences between developing and implementing a new product or redesigning the current solution while maintaining interfacing parts and current architecture.

2.5 Mission Statement

Summarizing the company background and the current and upcoming product offerings, together with the company positioning, the mission statement presented in table 2.1 can be established to guide the development process of the product renewal project.

Table 2.1: Mission statement for the development of overhead sectional door tracks

Mission statement: Overhead sectional door tracks	
Product Description	A lightweight, material efficient and easily installable track for the rollers of an overhead sectional door
Benefit Proposition	- Better material utilisation - Decreased installation time - Reduced manufacturing costs
Key Business Goal	- Increase profitability of current doors - Reduce complexity of door architecture - Reduce environmental impact of manufacture and transportation
Primary Market	Industrial sector, warehouses, distribution centers and logistics hubs
Secondary Market	Consumer sector, garages and workshops
Assumptions and Constraints	- Manufactured in current facilities - Flatpackable - Compatible with the rollers in use currently - Compatible with all currently offered door sizes
Stakeholders	- Purchasers and users - Manufacturer - Installation and service operations - Distribution operations

3 Methodology

3.1 Product Development Methodology

The product developement approach used during this project was established and described by Ulrich and Eppinger [3]. In accordance with their structure, the process is divided into several steps in order to facilitate easier project management and increased progress trackability.

Activities that encompass the product developement process as described by Ulrich and Eppinger are presented in figure 3.1. First of the six phases of product developement is planning. The outcome of this phase during this project was a mission statement presented in section 2.5.

The second phase is called concept development. Figure 3.2 provides an overview of the different steps that are a part of the concept development step in the product development scheme. The activities involved in this phase are identifying customer needs for a target market, generating and evaluating product concepts as well as setting target specifications. Initially, the

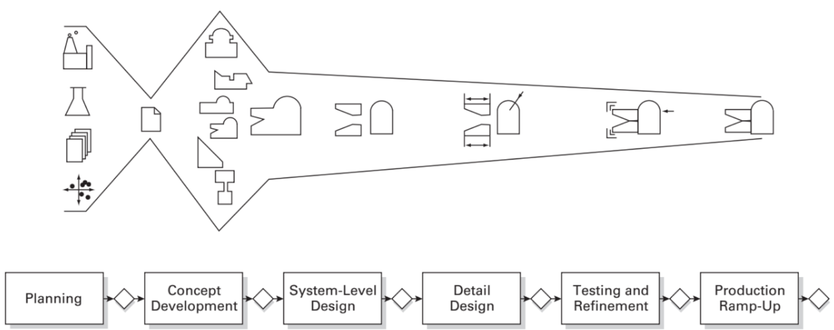


Figure 3.1: Product Development Process. (Ulrich and Eppinger, 2016, p.14)

customer needs are established by gathering and interpreting raw data from customers. The relative importance is established in order to prioritize functionality appropriately, and metrics associated to the needs are interpreted into target specifications. Following this, ideas for solutions to the problems stated in the customer needs are developed by using internal and external searches. The external search can consist of considering current products on the market and patent mining, searching for applicable solutions outside of the development team. Correspondingly, the internal search focuses on finding solutions within the development team, by using different creative methods and tools. The arrived upon concepts are tested and evaluated in order to exclude unsuitable concepts and gain further knowledge about the continuing concepts. A powerful tool for evaluating concepts is prototyping, where digital prototypes can provide a foundation for finite element analysis and physical prototypes can be subjected to tests and evaluation.

The third phase of product development is called system-level design. During this phase product architecture is defined and the product itself is decomposed into subsystems and components. Preliminary designs of key components are also created during this stage. Moreover initial plans for the production system and assembly are submitted. Usually the output of this phase is a geometric layout of the product, process flow diagram for the final assembly as well as a functional specification of product's subsystems.

The fourth phase of product development is called detail design. During this phase a complete product specification is produced, including geometry, tolerances, materials etc. The output of this phase is the *control documentation* for the product, which usually entails the CAD drawings which describe the geometry for parts that are to be manufactured, specifications for parts that are to be purchased as well as the process plans for the fabrication and assembly of the product.

The fifth phase of product development is called testing and refinement. It involves construction and evaluation of prototypes. There is a distinction between *alpha* and *beta* prototypes. Alpha prototypes may be made with materials and parts with the intended geometry but not fabricated with the manufacturing process intended for later commercial production. Beta prototypes on the other hand are usually built with parts supplied by the intended production processes, but may be assembled with methods other than those intended for the actual product.

The sixth and final phase of product development is called production ramp-

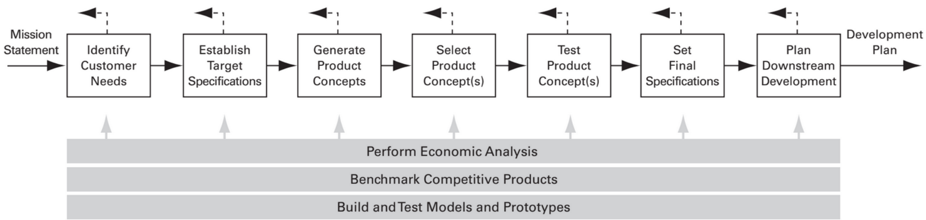


Figure 3.2: Concept Development Process. (Ulrich and Eppinger, 2016, p.16)

up. It includes training the workforce and resolving any remaining issues with the production process. Products made during this phase might be supplied to preferred customers in order to evaluate and identify any resolving flaws. The production ramp-up phase may with time be gradually transformed into ongoing production. During this transformation a product might be officially launched, making it available for widespread distribution.

3.2 Delimitations on the Ulrich & Eppinger Methodology

This project follows the Ulrich & Eppinger product developement method. Three out of the six phases were used in this work: planning, concept development as well as detail design. System-level design was deemed as not useful, as during this project the focus was on a subsystem (the tracks) of a larger product (the overhead sectional door). The goal of this project is to submit several product concepts that are to be further considered by ASSA ABLOY. As further development of this project is dependent on which concept is chosen, therefore the team will not be performing the last two phases of product development which are testing and refinement, and production ramp-up. Instead the focus will be on developing the concepts as well as presenting their strengths and weaknesses so that the company has enough information for a business decision to be made about the tracks.

4 Theory and Problem Formulation

In this chapter, the aspects considered as driving forces in the renewal project are explained, together with applicable theory and relevant scenarios. The wind load on the doors, as well as the suspension of the door is explained, and theory pertaining to the cost and assembly evaluation is presented.

4.1 Load Cases

Since the doors are either open or closed, or in the process of moving between the end points, considering the different load cases in those configurations falls naturally. In the closed configuration, the differential pressure caused by wind over the surface of the door is the primary force applied to the guiding tracks, while in the open position, the door weight itself becomes the primary load. Analysing the different loads and providing the worst case scenarios for each respective load case can serve as a basis for understanding the demands placed on the guiding tracks.

4.1.1 **Wind Load**

The wind load on a building is dependent on many factors, such as the surrounding topography, adjacent buildings or open areas, vegetation, and the natural windiness of an area [4]. The velocity of air moving around a building causes pressure buildups on the surfaces of the building, and on bendable surfaces such as doors or sheet metal walls, the enclosed volume of air inside the building functions as a damper on the pressure applied on the outer surface. In regards to that, the most simplified formulation of the wind load on a door is the pressure differential between the in- and outside of the door. Looking at the standard SS-EN 12424, the defining characteristic of wind re-

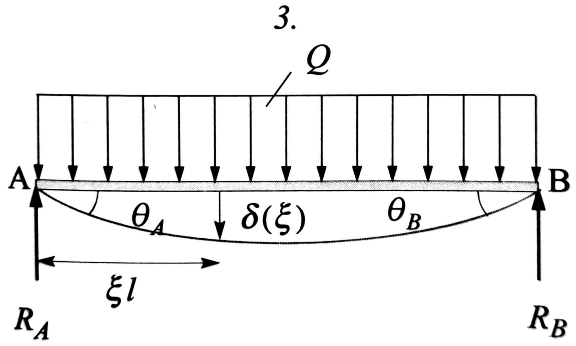


Figure 4.1: Beam bending problem with a distributed load between two supports [8].

sistance is the resistance to a distributed pressure over the door [5], and using the standard SS-EN 12444, the normal test procedure for determining wind load capacity is a simple beam bending problem with supported ends [6]. An illustration of the beam bending problem can be seen in figure 4.1. This simplification is useful, since the pressure can, with the help of Eurocode 1, be interpreted to a wind speed dependent on the building, surroundings and topography of the location of the door, but these factors influence the resulting pressure from a specific wind speed in such an extent that using wind speed as a metric is inaccurate and unhelpful [7].

Establishing a static and uniform pressure over the entire door in accordance with SS-EN 12424 and SS-EN 12444 gives the force imparted on the tracks as the resultant forces in the beam supports in figure 4.1. Here, the assumption is made that one end is fixed, although both ends of the door section have rollers that allow for some movement, as seen in figure 2.1. The worst case scenario in regards to wind load would be the largest door with maximized width, and for an 8 meter wide door, the width would be 5.3 meters to achieve the maximum allowable mass. With a total surface area of 42.3 square meters, class 3 of SS-EN 12424 would amount to a total wind load of 29.62 kN. This load would be concentrated over the shortest supporting beam, due to the lower height of the door, and thus maximizing the stress in the structure. Dividing up the load over two tracks, the resulting load would be 2.79 kN per meter track.

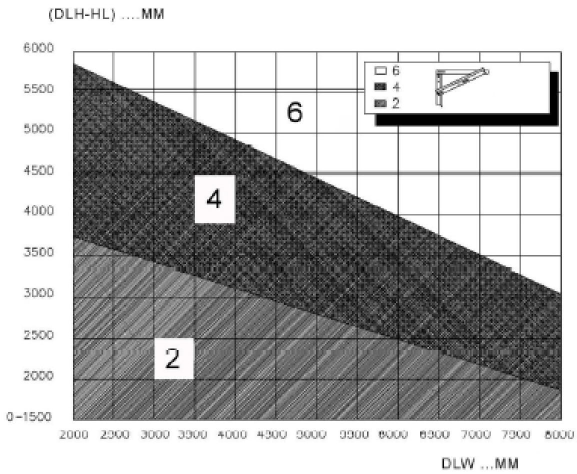


Figure 4.2: Diagram showing the number of roof supports required based on door dimensions, taken from ASSA ABLOY installation instructions.

4.1.2 Weight

When the door is open, the weight of the door must be supported by the tracks. Since the track beyond the door opening can be oriented in several different directions, ranging from following the vertical wall straight above the door opening to extending horizontally out from the wall just above the opening, the load on the tracks varies dependent on the angles. Because the door rests on rollers, any angle above the horizontal position would shift a portion of the weight to rest on the wall mounted track instead of the angled track. The maximum load on the angled track would then be in the case of a completely horizontal track, where the normal direction of the track surface aligns with gravity.

Extending the door horizontally requires supports from the roof to be installed, and the distance between supports is determined by the installation manual via the diagram shown in figure 4.2, where two supports means one on each track, not including the mounting point to the wall, four supports means two on each track, and consequently six supports means three on each track. The installation manual further specifies that the supports should be spaced evenly over the track length as the number of supports are increased.

In the diagram in figure 4.2, the measurements along the x and y axes are the door width and height respectively, and correspond to the weight of the door. Using a door with the maximum width gives the most pressure per meter height, and reading from figure 4.2, a door with the width of 8 meters would require a middle support at around two meters of height. Modelling a two meter track with only end supports and the mass corresponding to an 8 meter wide door would then give a sufficiently distressed system. The door would weigh 208kg, corresponding to a weight of 2043 N, or 1022 N per track.

4.2 Cost

According to Olsson, when the functionality of a product fulfills the needs of the customer, different renewal strategies need to be considered dependent on where in the life cycle the product is [2, p. 8]. As a product reaches maturity, the primary product renewal goals are to increase performance, reduce costs or introduce new functionality. With the aim of reducing costs, a holistic perspective on the product must be taken as early as possible. Figure 4.3 shows that the potential of reducing overall costs of a product is greatest early in the development process.

Sectioning costs into lifecycle costs, total costs and manufacturing costs, different aspects of the product can be attributed to different costs. Lifecycle costs include such factors as operating costs, transportation, disposal and recycling, as well as maintenance and service [9, p. 110]. Total costs include the manufacturing costs, and all administrative costs together with the development costs [9, p. 125]. Manufacturing costs include material costs, assembly and part production costs [9, p. 144].

Following this, the largest impact on unit price for the tracks would be the manufacturing costs, but administrative costs and transportation would also reflect on the price. Costs for operating costs and service are negligible, since no maintenance on the tracks should be necessary, and recycling is today not a significant cost, due to the use of galvanized steel, which has an excellent recyclability. Products which are of a simple geometry and larger tend to have material costs that account for a larger portion of the manufacturing costs [9, pp. 176-177].

Production costs associated with a new product can be divided into one-time costs and costs for production of a specific lot size, according to Ehrlenspiel et al [9, pp. 154-155]. In the case of manufacturing costs, the one-time costs would include tooling for both manufacture and assembly, as well as the pre-production costs where the production line, tolerances, surface finishes and

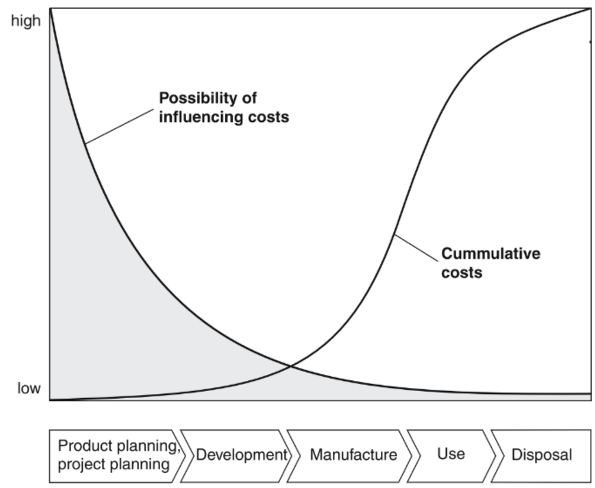


Figure 4.3: Potential to influence costs and cumulative costs of a product in different stages of the product life [9, p. 11].

prototypes are established and produced. The production costs in regards to lot size can be divided into one-time and per-unit costs, where one-time costs would be related to setup time where the machines and tools are prepared before and after production. All the costs spread over the lot size would result in an actual cost per part, and methods of reducing production costs can target different areas of cost [9, pp. 156-159]. Consequently, increasing the lot size would reduce cost per part.

4.3 Assembly

The analysis of the assembly is based on the method described by Boothroyd, Dewhurst and Knight, and the aim of the process is to establish an assembly time and design efficiency, and to provide a basis for comparison between different concepts and designs [10]. Using the assembly time, a comparison between assembly cost can be made between different concepts.

The process is based on determining the complete bill of materials, establishing the theoretical number of minimum parts, followed by setting the order of assembly. Every step of the assembly is then translated into a handling code and insertion code, each corresponding to an estimated time. The complete assembly time can then be determined, and by comparing that to an optimal 3 second time for every one of the theoretical minimum number of parts, an assembly design efficiency can be established.

The criteria for determining if the part is critical or if it is a candidate for elimination and integration is described by Boothroyd, Dewhurst and Knight [10, pp. 94-95]. If the part needs to move relative to other parts during normal operation, if the part necessarily needs to be of a different material than the other parts, or if the part must be separate in order to assemble the entire assembly, the part can be considered as critical and should be included in the theoretical minimum number of parts.

The factors impacting the handling time are primarily related to the size and symmetry of the item. If a component can be inserted incorrectly a number of different ways, the handling time increases, and conversely if it can be inserted correctly in multiple ways, the handling time decreases. The way to categorize the symmetry of a part is based on the symmetry around the axis of insertion, called β-symmetry, and around an axis perpendicular to the axis of insertion, called α-symmetry [10, pp. 97-101]. An example can be seen in figure 4.4. The insertion time is increased if tools or force is required, as well as if the part needs to be held while another part is fastened. The tables presented by Boothroyd et al containing handling and insertion times in regards to these aspects can be seen in appendix A. The tables are compiled from theory on what effect different aspects have on handling and insertion times, as described by Boothroyd et al [10, pp. 97-99, 105–118].

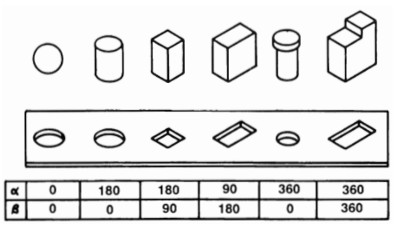


Figure 4.4: Part symmetry with α and β symmetry according to Boothroyd, Dewhurst and Knight [10, p.100].

Consequently, decreasing handling and insertion time and reducing the number of non critical parts increases design efficiency, which serves as a measure of how optimal an assembly is.

5 Customer Needs and Specifications

5.1 Customer Needs Methodology

Following the concept development process established by Ulrich and Eppinger, the initial phase of the process centers on identifying the customer's needs imposed on the product [3]. The primary goals of the process are to ensure that the product meets the customer needs, both latent and explicit. Furthermore, the needs provide a framework in which to compare generated concepts to each other, and can be further developed into product specifications.

To identify customer needs, raw data from customers must be gathered and interpreted. The needs are then organised into a hierarchy and sorted according to relative importance. A distinction between explicit and latent needs is made, where latent needs are needs that the customer haven't fully recognized as needs, and which are not fulfilled by existing products.

The raw data from customers can be gathered in a number of ways - interviews, focus groups, surveys and observing the product in use, according to Ulrich and Eppinger [3]. For this project, the main customer data was gathered from observing the product in use and interviewing key users. Due to the long installation time and complex interaction between parts of the door structure, the interview and product observation were combined and carried out in conjunction with the installation of different door models over a week. During this installation, three technicians with more than 70 years of collective experience shared their insights into the installation procedure, product developments during their tenure and their needs regarding many different areas of the overhead sectional doors. Viewing the tracks from the perspective of the doors as a whole system informs the limitations on geometry and tolerances.

5.2 Interpreted Customer Needs

The interpreted customer needs are divided into categories according to their area of influence, and are presented in table 5.1.

Table 5.1: Table containing the interpreted customer needs from interviews with key users and observing the product in use

Interpreted customer needs		No.
Structural	- The tracks withstand windloads on the door	1
	- The tracks withstand the door weight	2
	- The tracks withstand the acceleration of the door	3
	- The tracks withstand fatigue and corrosion	4
	- The tracks do not twist during installation or loading	5
Manufacture	- The tracks are easy to manufacture at scale	6
	- The tracks are manufacturable in variable lengths	7
	- The track assembly is easy and fast	8
	- The track are cheap to produce	9
Installation	- The tracks are easily installed	10
	- The track installation has large tolerances for non-ideal mounting situations	11
	- Alignment of track sections is easy	12
	- No special tools are required during installation	13
Architecture	- The tracks fit within the current architecture	14
	- The thinner the assembled tracks, the better	15
	- The more headroom that is available, the better	16

5.3 Specifications Methodology

Specifications can be understood as a translation the subjective customer needs into objective and precise target values that the design team can adhere to. Often times interpreted customer needs are too ambiguous and provide little specific guidance while designing and engineering the product. It is for this reason target specifications are established. They provide accurate and objective descriptions and demands of what the product has to do.

The practice of setting up target specifications consists of making of a list

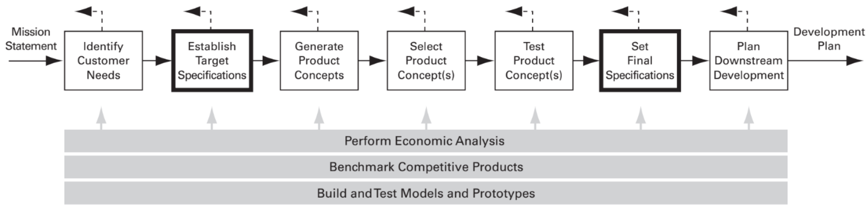


Figure 5.1: Product Development Process. (Ulrich and Eppinger, 2016, p.94)

of *metrics* and *target values* that the product should fulfill. For most metrics they are usually established based on the previously gathered customer needs. Metrics may be based on more than one need at the same time.

As seen in figure 5.1 product specifications might be revised later on during a project, referred to as setting final specifications. Such revisions usually happen as a result of new information and feedback gathered during product concept testing. In this chapter only the *establishment of target specifications* for this project will be described.

After preparing the list of metrics, the next step is to benchmark relevant competitive products on the market. This practice is used to better position one's own product in the market. Data to be benchmarked is primarily that concerning the metrics that were established in the previous step.

5.4 List of Metrics

The list of metrics in 5.2 was created from the previously established interpreted customer needs in table 5.1. The importance of various metrics in table 5.2 (shortened to Imp.) was established in relation to each other. Metrics with an importance of 5 are considered the be most important.

Table 5.2: Table containing specifications based on previously established customer needs

Metric No.	Need Nos.	Metric	Imp.	Units
1	1	Maximum Wind Pressure on the Door	5	Pa
2	1, 4	Cycles to Failure	4	Cycles
3	2	Maximum Door Weight	4	kg
4	1,2,5	Second Moment of Area	3	mm^4
5	4	Corrosion Resistance	3	mm/Year
6	6	Large Scale Manufacturability	3	Binary
7	7	Different Length Manufacturability	3	Binary
8	8,12	Ease of Track Assembly	3	sec
9	9	Track Manufacturing Cost	5	SEK
10	10	Ease of Track Installation	3	sec
11	11	Minimal Tolerances	4	mm
12	13	Special Tool Requirement	2	Subj.
13	14	Current Architecture Compatibility	5	Binary
14	15	Track Thickness	4	mm
15	16	Available Space Above Horizontal Tracks	3	mm

5.5 Benchmarking

The competition between overhead sectional doors centers primarily around how much the door extends beyond the actual door opening in the wall, called the daylight height and width respectively. An additional measurement of headroom exists for non-vertical doors - the space required over the door tracks to accommodate counterweight springs and door movement.

In march 2023 a couple of ASSA ABLOY employees conducted a benchmarking session where they examined and compared doors from two other companies. The investigating team at ASSA ABLOY was of the opinion that both ASSA as well as the other two companies were very similar when it came to the design of their overhead sectional doors. The designs of various systems as well as individual parts was more or less interchangeable in the vast majority of cases.

One direct inspiration taken from the results of this benchmarking session are the connector plate redesigns. Although originally the scope of this project was limited to the improvement of the overhead sectional tracks, the team decided to also develop concepts for new connector plates. This process is described more in depth in section 6.4.2.

5.6 Target Specifications

Table 5.3 showcases the previously established metrics as well as explanation and justification of each target value, in order of metric No.

No. 1: Maximum wind pressure value of 700MPa is based on the Swedish-European standard SS-EN 12424. The benefit of using data given by standards is reliability and time savings, and the standard allows for use in marketing materials.

No. 2: Cycles to failure metric value is based off an ASSA ABLOY product datasheet [11]. ASSA ABLOY offers warranty on their doors for 200 000 door cycles or a period of 10 years (under the condition that service/ replacement programs have been performed).

No. 3: 550kg is the maximal door weight that the tracks are supposed to withstand, according to the company. The value of 550kg will be used and treated as a worst case scenario later on during simulations and testing.

No. 4: The second moment of area is a geometrical property of a given cross section, and governs stiffness and deflection of a beam. The metric of second moment of area is primarily intended for the horizontal assembly, which currently consists of the horizontal J-track as well as the C-beam. As the goal of this project is to optimize the tracks it is expected that the second moment of area will be lower in the generated concepts. This is due to the fact that the combination of J and C tracks are seen as over-engineered, exceeding what is required by the load cases. The value of 123 000 mm^4 was calculated in SOLIDWORKS.

No. 5: Corrosion resistance has not been reported as a problem in the current design as the tracks are galvanized. To maintain corrosion resistance of future tracks the material they are made of must have similar corrosion resistance as galvanized steel. ASSA ABLOY also provide increased corrosion resistance in the form of coatings on their offerings, and as such, the chosen material should allow for extended increased corrosion resistance if necessary [11].

No. 6: Large scale manufacturability measures whether the current manufacturing facility meets the demand for the amount of tracks that ASSA ABLOY requires. One of the goals of this project is increasing manufacturability of the tracks, therefore designs that are easier to manufacture are desirable. Decreasing the number of parts and number of unique parts would increase manufacturability. The unit is set as binary to not reveal sensitive data.

No. 7: Different length manufacturability refers to the need for different track lengths depending on a given customer order, since all doors are made to fit the specific customer's needs. Naturally larger doors need longer tracks. This specification is binary and if the new tracks can be cut to different lengths with ease it will be fulfilled.

No. 8: A distinction is made between track *assembly* and track *installation*. Track assembly is done in the same factory that manufactures the tracks. Afterward the tracks are *assembled*, it together with other parts are shipped to the customer to be *installed* later on by the installation technician. The specification chosen to measure the metric "ease of track assembly" is the amount of individual steps this assembly process requires. The target specification for this metric is the current assembly time, and ideally, the new tracks should take less time to assemble.

No. 9: The cost for manufacturing can, according to Ehrenspiel et al, be approximated as proportional to the weight of used material together with assembly time, and reducing weight and assembly time would lower costs, with the target specification being lower than the current weight and assembly time [9]. The target specification for this metric is expressed in percentage of current cost and should be lower than 100 %.

No. 10: As mentioned above, track installation is different from track assembly, and is done on location for the client. Track installation target specification value is the current amount of steps needed and the new tracks are supposed to require less steps.

No. 11: Increasing the minimum tolerances allowable without reducing functionality would be a way to reduce costs, since the production costs would decrease. The target specification would be the same tolerances as for the current designs as a minimum, with an increase being desirable, but is expressed as subjective, due to the large variety of parts, measurements and assembly tolerances in all.

No. 12: Special tool requirement metric - there aren't any special tools required during the installation of the current tracks. New tracks also shouldn't require any special tools to be installed.

No. 13: Compatibility with current architecture refers to how many changes in the existing architecture are required when replacing the current track design with a new design. Ideally a new design should fit in very well and not require many changes. Some examples of what changes could be necessary when replacing track designs are the types of fasteners used, placement of holes for fasteners on various parts that are connected to the tracks or the attachment method for roof supports, door stoppers and other parts that are currently fastened directly onto the C-Beam.

No. 14: The current track thickness used in the OH1042 door models is 2mm. Ideally the new tracks should be thinner to save material and costs, although this is dependant on the new profile cross-section and should be decided upon during detail design.

No. 15: Available space above the tracks depends on the specific door model. It also depends on the door installation site - in some cases the client might have pipes or other features close to the ceiling. Therefore it is best to use as little room above the tracks as possible. It is why the new tracks should utilise as little of that room as possible, compared to the space that is used up by the current tracks. Currently, the door extends a minimum of 55mm above the track, and as such, that space could be used without increasing the required headroom

Table 5.3: Table containing metrics as well as target specification values that the new track designs should adhere to.

Metric No.	Metric	Units	Target Spec.
1	Maximum Wind Pressure on the Door	Pa	700
2	Cycles to Failure	Cycles	200 000
3	Maximum Door Weight	kg	550
4	Second Moment of Area	mm^4	< 123 000
5	Corrosion Resistance	Binary	Yes
6	Large Scale Manufacturability	Binary	Yes
7	Different Length Manufacturability	Binary	Yes
8	Ease of Track Assembly	Seconds	< 117s
9	Track Manufacturing Cost	Percentage	<100
10	Ease of Track Installation	Seconds	< 55 s
11	Minimal Tolerances	Subj.	-
12	Special Tool Requirement	Binary	No
13	Current Architecture Compatibility	Subj.	-
14	Track Thickness	mm	<2
15	Available Space Above Horizontal Tracks	mm	55mm

6 Concept Generation and Selection

6.1 Concept Generation Methodology

The third phase of the Ulrich and Eppinger method is concept generation, shown in figure 6.1. The purpose of the concept generation phase is to come up with several concepts that are then later evaluated. One may proceed with one or several concepts for further evaluation. Ulrich and Eppinger propose a five-Step method for concept generation. The five steps include clarifying the problem, internal and external search, systematic exploration and reflection on the solution and the process.

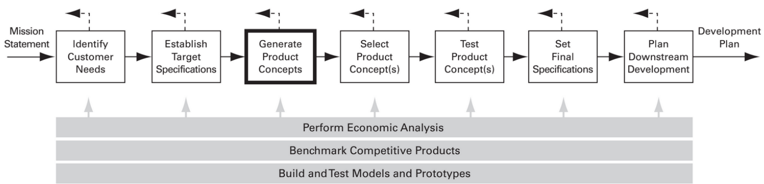


Figure 6.1: Concept development step 3 - concept generation. (Ulrich and Eppinger, 2016, p.118)

6.2 Clarifying the Problem

The tracks have three main functions. The first function of the tracks is to guide the door roller wheels. This is a vital must for the function of the door and it is what allows the door to be opened and closed in the first place. The second function is to provide structural support. The tracks are an integral and interlinked part within the overhead sectional door architecture. The third function is that the track should provide an attachment point for various important parts of the door, such as roof support beams and door stoppers.

6.3 Internal and External Search

An internal search means that ideas come from the preexisting knowledge of the product design team. An external search may include a variety of activities. In the case of this project the external search included interviews with lead users and a patent search.

The lead user that was interviewed is an ASSA ABLOY door installer with many years of professional experience in the industry. The interview was a week-long process, conducted in conjunction with the product design team observing and helping the installer during his work. This short term ”apprenticeship” allowed the team to gain deeper insight into how the doors are being put together and what the different door parts are meant to do.

In the case of this lead user has had several years of experience installing doors for ASSA ABLOY and therefore knew a multitude of current issues with the different door models as well as ideas for improvement that would help him and others like him during the installing process.

One of the current problems with the current door arises during opening. As the door leafs shift from horizontal to vertical position they are stopped by door stoppers. When that happens the C-beam upon which the door stoppers are mounted bends out. As the C-Beam and the horizontal L-Track are riveted together, those rivets tend to loosen with time and use. This causes a steadily growing gap between the C-Beam and the J-Track.

Another problem are the current manufacturing inaccuracies in J-Bends. Figure 6.2 shows how two bends-ends may differ between each other. The inaccuracies are however not limited to result in differences between separate

Figure 6.2: The inaccuracy in current bend-ends. The width of the bend-end on the left is 43mm and the one on the right 45 mm. According to schematics for the bend the width tolerance is supposed to be 42.3(+0/+0.7) mm.

parts - Even when looking at a singular bend, it's ends will differ in width. The discrepancies between bends and their ends result in increased installation time, as the installer is force to manually correct those manufacturing mistakes in order to be able to assemble the tracks.

Last major point brought up by the interviewed installer was the installation of the horizontal J-Track. Figure 6.3 shows that currently in order to install the horizontal J-Track an additional support from the roof is required. The installer expressed a wish for the need of an additional support to be eliminated.

The patent search resulted in an understanding that most door solutions use similar tracks, and very few utilize a unique technology for guiding the rollers. A withdrawn patent from 1999 shows a sliding solution rather than a rolling solution, but the geometry of the guiding track is very similar, as can be seen in figure 6.4 [13]. Part 17 in patent US20120222825A1 shows a similar geometry, as can be seen in figure 6.5 [14].

Internal search consisted of several sessions, both in group and individually.

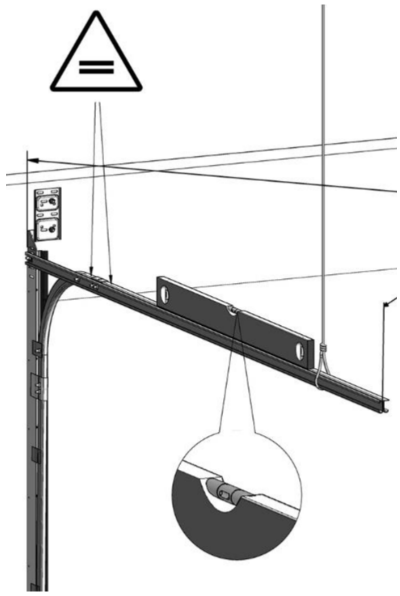


Figure 6.3: The current method of installing the horizontal J-Track requires temporary supports from the roof in the form of a rope or similar [12].

An initial brainstorming session jump-started the concept generation process. Ideas were added, subtracted and modified over time, and figure 6.6 showcases a finalized sketch with 9 concept as well as the original profile for the purposes of comparison. The current manufacturing method of tracks is sheet metal roll-forming. Note therefore that two of the concepts are meant to be extruded, as roll-forming them would be impossible. The following section 6.4.1 describes each concept more in-depth.

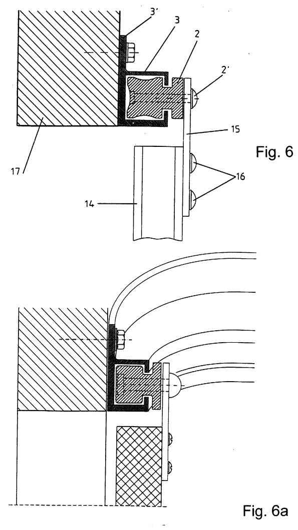


Figure 6.4: Figure from patent EP0931898A1 showing the cross section of the sliding track.

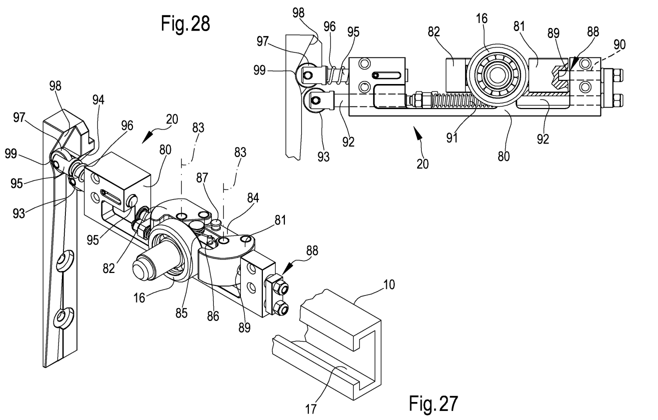


Figure 6.5: Figure from patent US20120222825A1 showing, amongst other parts, the guiding track as part 17.

6.4 Generated Concepts

6.4.1 Generated Track Concepts

The nine generated concepts are presented in figure 6.6. Below are short descriptions of these concepts.

J Expanded: The ordinary J-profile with added space for fasteners inside the track, eliminating the need for an external fastening geometry.

’J Expanded: Similar to the J Expanded but with an added flange on top. The purpose of the flange is to increase the overall bending stiffness of the profile.

C/J Extruded: Integrating the J and C profiles, and manufacturing the profile with metal extrusion, to have a varied material thickness across different parts of the geometry, while still retaining compatibility with all current hardware.

C/J Integrated: The same integration of the J and C profiles, but manufactured by roll forming of metal sheets.

J + J: Doubling up the J profile, and using a J in place of a C to mount to. This in order to decrease the number of different profiles.

C over J: Integrating the C profile in the J profile and locating it on top of the J. This gives an increase of bending stiffness while retaining hardware compatibility and reducing the overall number of parts.

‘J: The J profile with an extended flange for mounting on top of the “roof” of the J. Holes for fasteners in the flange. This increases stiffness and provides a mounting spot for hardware. Similar hardware can be used, with an eliminated need for blind fasteners.

t Extruded: The same principle as the ‘J, but the flange is placed above the back of the J, allowing roof support struts to extend below the roof of the J, but necessitates manufacturing via extrusion.

t Rolled: The same concept as above, but modified to work with roll forming, at the cost of doubling up material in the flange.

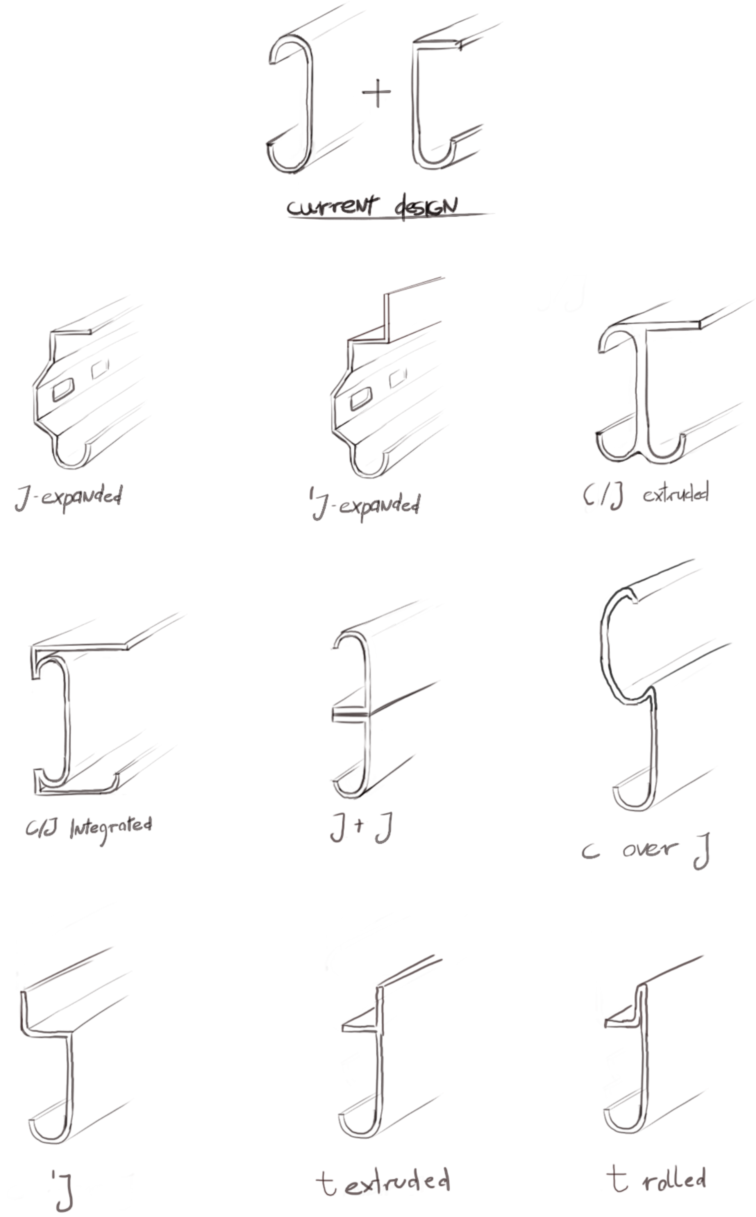


Figure 6.6: The current design and the nine generated concepts. Note that ”C/J extruded” and ”t extruded” profiles are not roll-formable

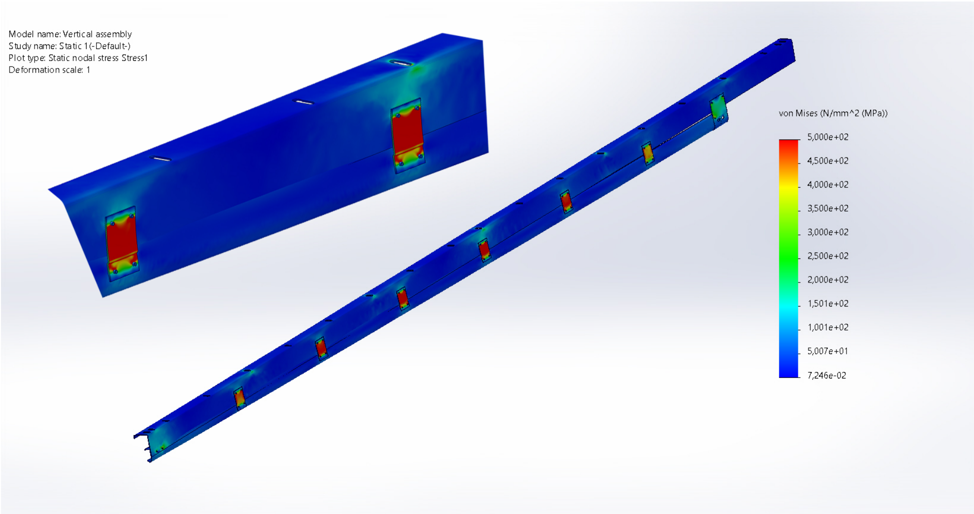


Figure 6.7: Qualitative stress distribution in the vertical track assembly due to wind load. Connector plates have noticeably higher stress levels than the J-Track or wall bracket.

6.4.2 Generated Connector Plate Concepts

During the course of the project the team realised that the current connector plates might be the weak points when it comes to the vertical section of the door, as opposed to the track itself being a weak point. Connector plates are a series of plates that connect the vertical J-Track to the wall bracket (figure 2.2 schematically showcases this).

This realization occurred after some initial simulations on the vertical door assembly performed in SOLIDWORKS simulation module. These results are shown in the qualitative figure 6.7, where it can be seen that stresses in the connector plates are noticeably higher that within the J-Track or the wall bracket. The stress levels in the figure are not considered accurate, but serve to illustrate problem areas.

Although the original mission statement for this project was to work on improving the roller tracks themselves, the team wanted to at least make a suggestion for possible improvements. Therefore a small session was held during which two concepts for improved connector plates were created.

Figure 6.9 showcases the two generated concepts. A common feature between the two concepts is the U-shaped bend in the middle of both plates. The purpose of this bend is to increase the bending stiffness of the plate and reducing

Figure 6.8: A current connector plate. Note how the geometry of the connector plate connects the wall bracket and the vertical J-Track.

the maximum stress levels that are experienced by the connector plates.

As shown in figure 6.8 the connector needs to accommodate the ”height difference” between the wall bracket and vertical J-Track. This is where the two concepts differentiate. The ”Stamped Connector Plate” concepts proposes to alter the plate geometry by the process of stamping. The ”Connector Plate with Washers” concept suggest instead to simply use washers to accommodate the height difference between the wall bracket and vertical J-Track.

6.4.3 Horizontal Track Connector

One of the purposes fulfilled by the C-profile is connecting the horizontal track assembly to the wall angle and vertical assembly. Integrating that functionality in a connector bridging the transition between the bend and horizontal track would maintain functionality while reducing the number of different parts. Further developing the new connector to include functionality from other parts in the overarching door architecture could reduce the total number of parts in the OH1042 catalogue, such as including mounting geometry for wire pulleys and counterweight springs, for example.

An example of a concept connector designed during a previous summer project

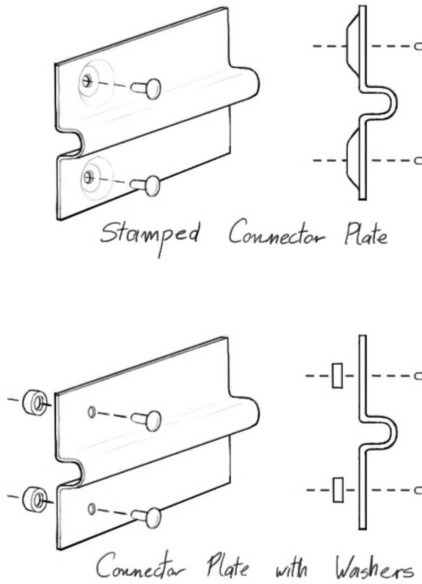


Figure 6.9: A sketch showing the two connector plate concepts.

at ASSA ABLOY can be seen in figure 6.10.

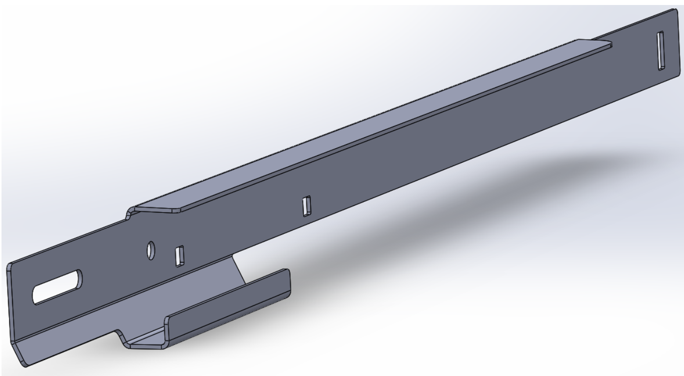


Figure 6.10: A concept connector with the ASSA ABLOY part number Kx60995.

6.5 Concept Selection Methodology

Concept selection is the process of evaluating generated concepts, which is the fourth step in the Ulrich and Eppinger method, seen in figure 6.11. Crite-

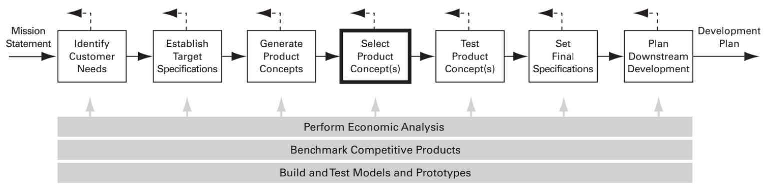


Figure 6.11: Concept development step 4 - concept selection. (Ulrich and Eppinger, 2016, p.147)

ria for evaluation are taken mainly from the previously established customer needs. During concept selection the strengths and weaknesses of different concepts are discussed, and one or a few concepts make it past the selection stage and into testing.

It was decided that the nine generated J-Track concepts would be evaluated in relation to the current 1042 track design. The current track design as well as the nine concepts can be seen in figure 6.6.

In order to rank the generated concepts a decision matrix was used. The purpose of a decision matrix is to compare different alternatives, with one design being chosen as reference. One by one each criteria for each concept is assigned a plus or minus depending on how well the concepts fulfil the criteria relative to the chosen reference design.

The reference design chosen is the current rail design that ASSA ABLOY uses in their 1042 door models (42mm door thickness).

6.6 Screening Matrix

The criteria seen in the screening matrix are weighted on a scale of 1-5, where the higher number is more desirable. The reference design, the current assembly, is given a reference 3 in every category, and all concepts are compared to it. A beneficial rating in weight corresponds to a lower weight.

- **Weight:** Self-explanatory, the less material used the better the score.
- **Compliance:** The compliance of the structure and its stiffness-to-weight ratio. This criterion also serves as a measure of how effective the design is in using material to counteract bending and twisting.
- **Assembly:** Covers the assembly right after manufacturing and before

Table 6.1: Decision matrix for the nine generated roller track concepts. It was decided that three highest scoring concepts would be developed further

	Current Design	J Expanded	'J Expanded	C/J Extruded	C/J Integrated	J + J	C Over J	'J	t Extruded	t Rolled
Weight	3	5	5	4	3	3	4	3	4	4
Compliance	3	4	5	4	3	4	4	4	5	5
Assembly	3	5	5	4	4	3	4	5	5	5
Manufacturability	3	3	3	2	3	4	3	3	2	3
Architecture Compatibility	3	3	2	3	3	1	2	2	2	2
Sum	15	**19**	**20**	**17**	**16**	**15**	**17**	**17**	**18**	**19**
Continue?	x	Yes	Yes	x	x	x	x	x	x	Yes

transportation, as well as installation of the tracks on site.

- **Manufacturability:** This criterion is mainly concerned with the ease of producing a given concept with equipment that is currently in place. This means that if a concept cannot be manufactured with tools that are used to produce the current 1042 rails then it receives an unfavourable rating.

- **Architecture Compatibility:** How compatible are the new designs together with the old parts? This criterion penalises designs that don't work as well as the current way of mounting to the C-track.

During this process of concept selection, the evaluated aspects are *limited to the cross section shape and attachment interface*, not the larger assembly and structure of the doors. This is because the team felt that such a limitation was necessary because otherwise the amount of details to consider would be too large. An example of things that are not taken into account are the various elements that are today fastened to the C-Beam, as shown in figure 2.2. By going away from the current J+C design that is in place today, an alternative fastening method would need to be developed for elements such as roof supports or door stoppers, but as mentioned before this was not taken into consideration in order to limit the amount of variables in the concept selection process.

6.6.1 Comprehensive Concept Selection Discussion

J expanded: This profile eliminates the need for the C bracket, and as such reduces the amount of superfluous material drastically, increasing the score in both weight and material usage. The profile requires no assembly in the factory, but is not as easy as the C-profile to install on site. Manufacturing is penalised due to the presence of holes, and the hole making process reduces the buy-to-fly material ratio. Compatibility with current architecture is roughly equal to the current solution, because screw fasteners are used. However, the blind fasteners must be replaced with fasteners that fit inside the track without interfering with the rollers.

'J expanded: This profile eliminates the C bracket, and adds a vertical flange on top of the J to increase bending stiffness. No walls are doubled, increasing the score for weight, and with the added height, compliance is increased. No assembly in the factory is required, and with access from both sides of the fasteners, installation is simplified, increasing the score for assembly. Manufacturing is done via roll forming, just as the current design, but with the added hole making in the flat piece of sheet metal prior to bending. The mounting point is not moved, and the same type of fastener can be used, retaining the high score in architecture compatibility, with a penalisation for the added flange which might interfere with the current design of door stopper.

J/C extruded: The profile retains the C bracket, located at the same spot as in the current design, and by utilising the possibility of having a varied thickness in the cross section, weight and compliance is increased compared to the current design. The assembly score is increased due to the profile not needing any assembly in production. Manufacturability is penalised due to the method of manufacturing being extrusion.

J/C integrated: The back of the C is eliminated, but the top and bottom of the C are double thick instead, which should correspond to roughly the same weight as the current design. Likewise, the compliance of the cross section should be very similar to the current design. No fasteners or assembly in the factory is needed, which is an improvement over the current design. Manufacturing is done with the same roll forming machines as are available today, which corresponds to the value of the current design. Since the C profile is the same as the current design, and it is located in the same place as well, which means the compatibility is identical.

J+J: This profile is based on using two J brackets instead of J+C. The weight should be similar to the current design, but the compliance is increased, due to the increased height of the cross section. Assembly is similar to the current design, since a similar assembly would be required in production, and the installation should be similar to the current design as well. Manufacturability is increased, due to the elimination of the C bracket completely, reducing the overall number of parts. Architecture compatibility is severely reduced, since the current fasteners cannot be used to attach anything to the J bracket, and the height of the J bracket on top would interfere with other parts.

C over J: The top of the J and and the bottom of the C are the same piece of metal, which removes one short side and all fasteners, reducing weight. Compliance of the concept should be increased, due to the increased rigid slab action of the long and thin profile, which reduces the deflection from a bending moment. Also, twisting is reduced, due to the decreased distance between the support and imparted force. No assembly is required, and manufacturing is done with the same machines as the current design. Penalisation is done to the interface, since the C moves from its original position, which necessitates downstream changes on accessories.

'J: This profile is the J bracket with an added flange on the top left of the J, with holes for fastening. Weight is good, since no walls are doubled, and compliance is good due to the increased height. No assembly in production is needed, and access from both sides during installation raises the score for assembly. Manufacturability is similar to the current design, since the method of manufacture is roll forming with pressed holes. Architecture compatibility is reduced due to the height required on the raised flange, as imposed by safety requirements on the roof mounted supports.

t extruded: This profile takes the 'J and moves the flange with mounting holes to the rear side of the J. Weight is limited, since no double walls exist, and with the possibility of a variable cross section thickness, the compliance is good. No assembly is required, and accessibility during installation is good. Manufacturability is penalised due to the manufacturing method. Architecture compatibility is good, since the same fasteners can be used and the protrusion of the flange can be reduced when the roof supports can be mounted on the rear of the J, however, a deduction must be made due to the increased height of the cross section.

t rolled: Very similar to the extruded version, with the key differences being an increased manufacturability, since the manufacturing method is roll forming. The increased weight due to the double folded flange is considered negligible.

7 Test of Concepts

7.1 Concept Testing Methodology

In many cases the test of concepts occurs as a cooperation between the design team and customers from the relevant market sectors. No matter in which way the test is conducted, the design team's goal is often to generate feedback from the customers that can aid in further development and narrowing down of current concepts.

Due to the tracks being only a subsystem in the larger product of sectional overhead doors, potential customers will not be involved in product testing in this project. Instead the concept testing will mainly be performed by the means of simulation and digital prototyping.

The purpose of digital prototyping in this project is to gather data about strength and stiffness of the developed concepts, in order to better understand their strengths and weaknesses in relation to each other as well as the current J+C track design.

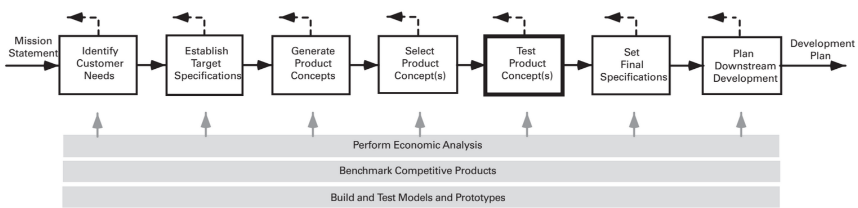


Figure 7.1: Concept development step 5 - Test Product Concept(s). (Ulrich and Eppinger, 2016, p.168)

7.2 Digital Prototypes

Drawing up the selected concepts in CAD allows for easy simulations in order to find out more about the functionality of the concepts. Comparing to simulations made on the current design, conclusions on relative performance can be drawn and problematic areas can be identified. All simulations were conducted using SOLIDWORKS 2022 Premium software. Primarily, the supports used are fixed, sliding and bearing. Fixed supports limit displacement of nodes in all directions, while sliding supports limit the movement of nodes to a plane. Bearing supports only support in compression, and only in the direction of compression, which resembles the support from bearings, pins and fasteners. In order to identify eventual stress singularities, the stress hotspot diagnostic tool in SOLIDWORKS was used. This iterates the mesh refinement and determines whether or not the results are dependent on mesh size, which is common on sharp geometries and discrete changes in loads.

7.3 Vertical Track

Initially, an assembly of the entire vertical track assembly was made, and a simulation of a wind load was conducted. Figure 7.2 shows the results from this simulation. The results from this simulation should be seen as qualitative rather than quantitative, since the simulation was simplified in order to reduce computational time, with fixed wall support and bonded contacts between rivets and sheet metal. This simulation also showed stress hotspots, but due to the computational time required by the large assembly, further refinements were made on smaller simulations instead.

With an evenly distributed wind load corresponding to that of an 8 meter wide and 3.5m tall door, the levels of stress in the connector plates exceed 500 MPa, indicating that plastic deformation occurs. The offset between the load and the connecting plate means a bending moment acts on the weakest part of the plate, and a need for a stiffer connecting plate can be seen. Continuing the investigation in the current design and isolating the track, the design can be condensed down to a segment between two connecting plate halves. Reducing the load accordingly and considering the connecting plates as immovable contact supports, the resulting stress levels can be seen in figure 7.4. Here, it can be seen that the stress is concentrated on the forward lip of the track, and the displacement of the lip magnified by a factor of 10 can be seen in figure

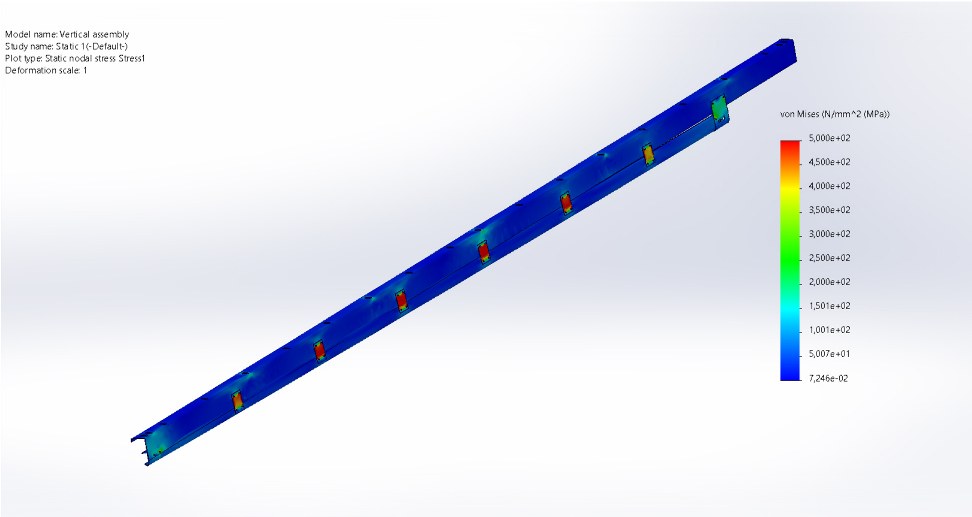
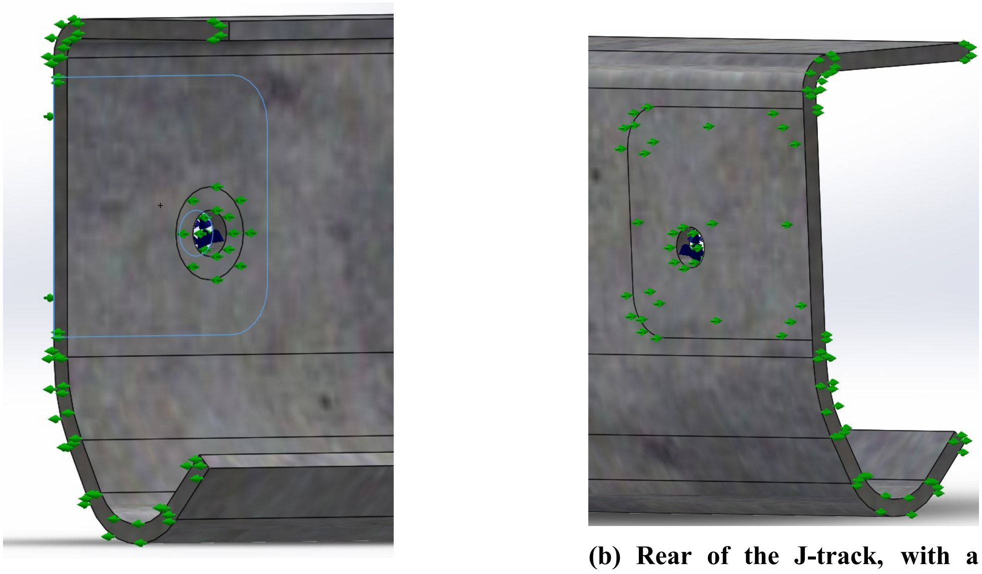


Figure 7.2: Stress in the vertical track assembly due to wind load.

7.5. The boundary conditions for one side used in the vertical assembly can be seen in figure 7.3, where areas that allow for sliding in the plane are denoted by green arrows and bearing supports are denoted by blue arrows. The corresponding boundary conditions was used on the other side of the track.

The analysis of the track segment was made by using bearing supports in the rivet holes, and sliding support surfaces where interactions between track, connector plate and rivet head are. The load imparted on the track corresponds to the maximum wind load on an 8 meter wide door with a height of 60 cm, the same as the length of the track segment being analysed. In order to remove singularities in the simulation, the force is imparted over a centralised strip of a width of 5 mm. The simulations were redone over two sections of track, corresponding with 120 cm of track with the same boundary conditions and loads replicated over both sections, and the stress remained the same.

Seeing the stress concentration on the lip of the track, and the buckling-like deformation of the lip, an addition of an outwards flange on the lip was made, and the resulting stress distribution can be seen in figure 7.6. The resulting profile is named J with flange. Here, the maximum stress is significantly lowered, and the maximum stress is located on the boundary to the sliding support of the connector plate. The displacement of the track is reduced by 0.3 mm. The added mass of the flange corresponds to an increase of 5.8%, while the maximum stress level is reduced by 24.4%.



(a) Front of the J-track, with a split-line area corresponding to the size of the rivet head.

(b) Rear of the J-track, with a split-line area corresponding to the supporting area of the connecting plate.

Figure 7.3: Boundary conditions of the small vertical track section, where green arrows signify areas that allow for node movement in the plane, but not perpendicular to the plane, and blue arrows signify bearing supports, which only offer support when pushed.

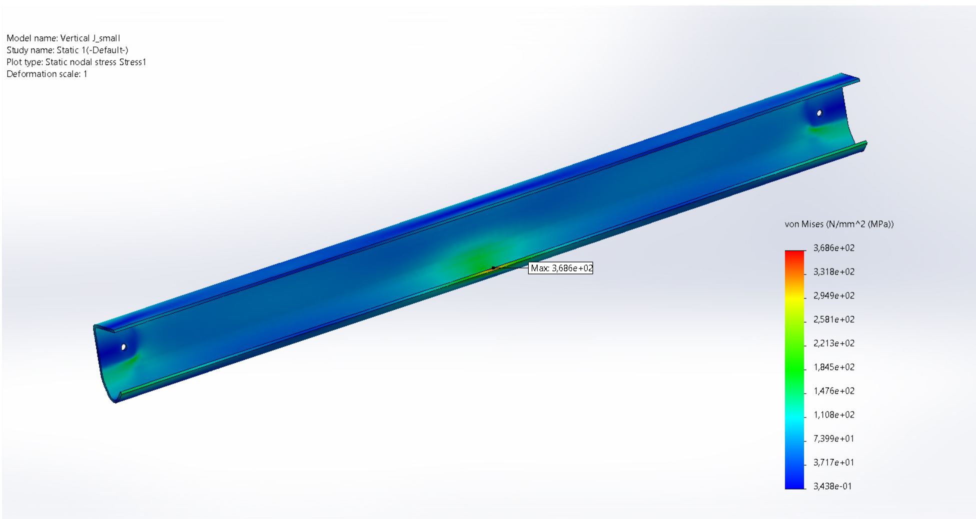


Figure 7.4: Stress distribution in a small section of the vertical roller track due to windload imparted by a central roller at the furthest possible distance from supporting connector plates.

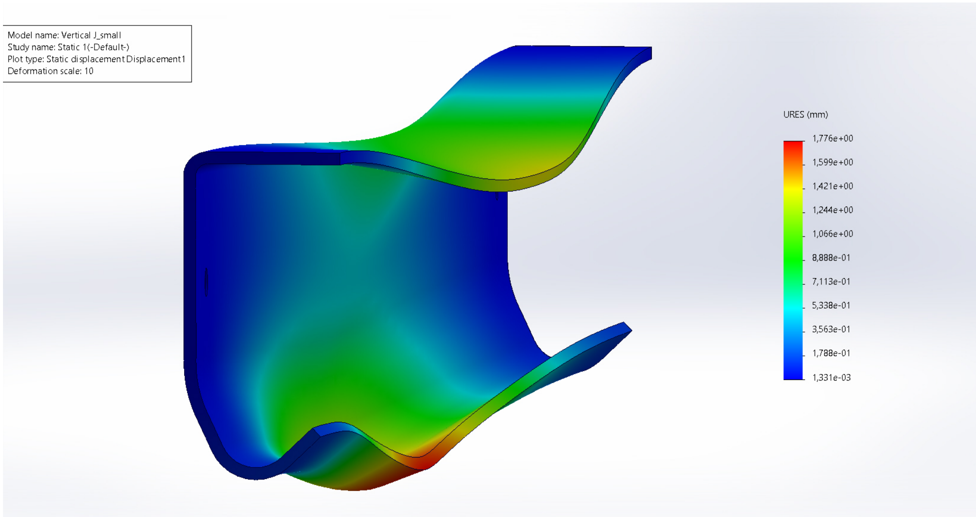


Figure 7.5: Displacement of the vertical track when exposed to a windloaded roller magnified by a factor of 10.

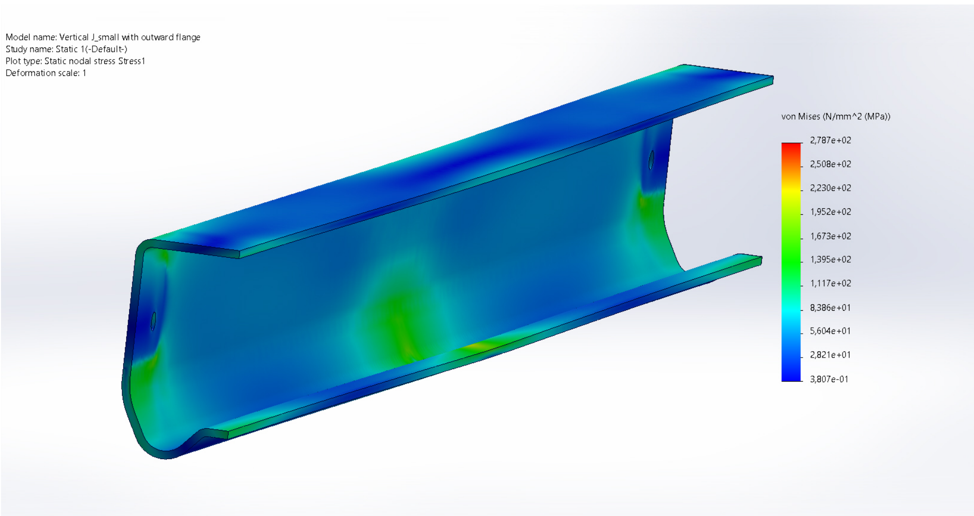


Figure 7.6: Stress distribution in a small section of the vertical roller track with added outward flange due to windload imparted by a central roller at the furthest possible distance from supporting connector plates.

Continuing with the connector plate, the analysis was simplified to include only the connector plate, replacing the track with the force and torque incurred from 60 cm track, since the distance between connector plates is 60 cm. Supporting the connector plate are two bearing supports and two sliding supports representing the rivet head and wall angle respectively.

Looking at the current design first, the stress distribution can be seen in figure 7.7 and the resulting displacement can be seen in figure 7.8.

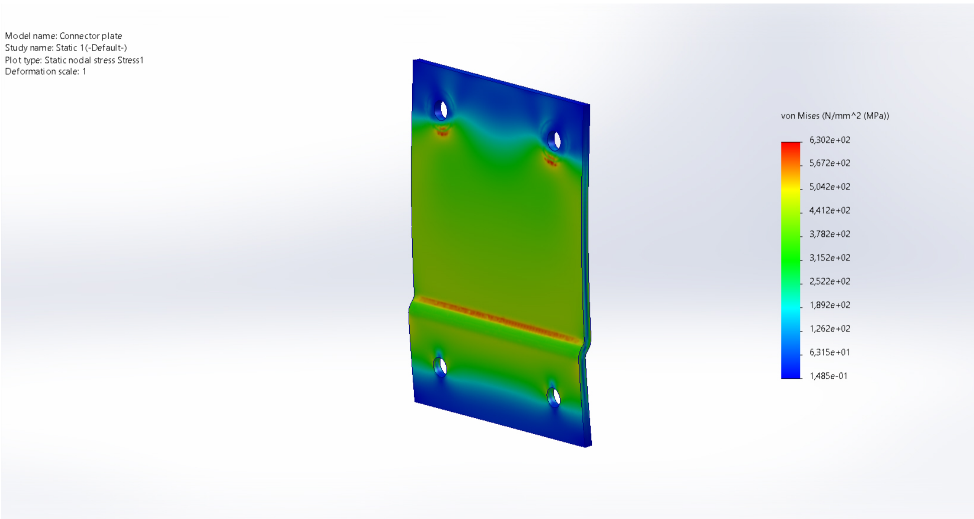


Figure 7.7: Stress distribution in a connector plate due to the maximum wind load on a 60 cm long track.

From this, the conclusion can be drawn that the connector plate is reacting like a linear spring, and thus, the addition of a spine as seen in figure 6.4.2 should stiffen the construction and reduce stress in the part, by increasing the second moment of area of the cross section. Using the same supports and load case as in the above simulation, the resulting stress distribution with an introduced spine can be seen in figure 7.9 and corresponding displacement in figure 7.10.

The addition of the spine reduces the maximum stress by around 126 MPa, and the displacement is reduced by 85 %. A table with comparison between the maximum stress and mass in percent of current design of J and J with flange, as well as the connector plate and the concept connector plate can be seen in table 7.1

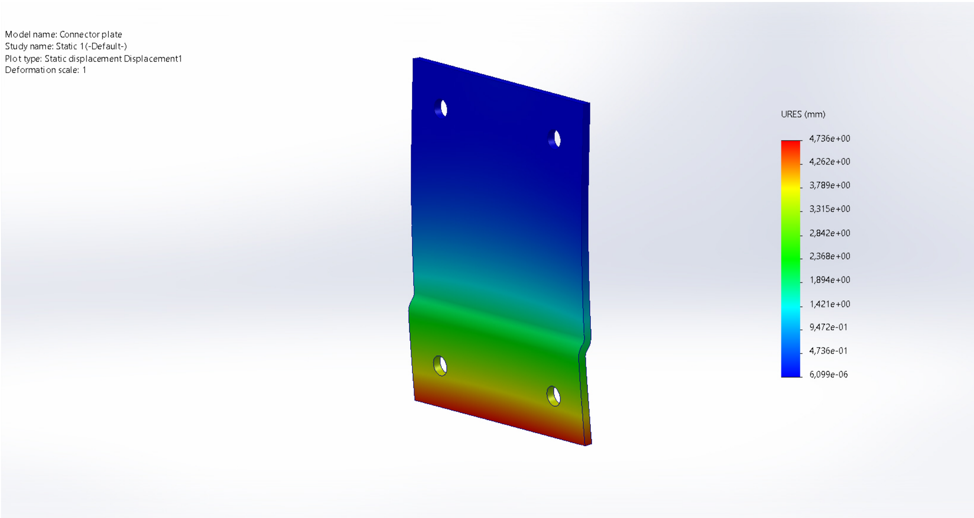


Figure 7.8: displacement of a connector plate due to the maximum wind load on a 60 cm long track.

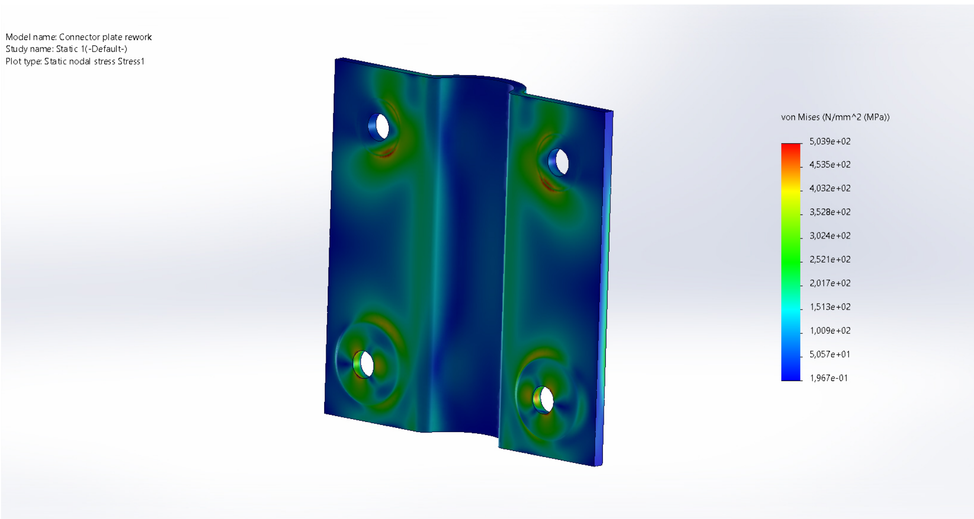


Figure 7.9: Stress distribution in a connector plate with an added spine due to the maximum wind load on a 60 cm long track.

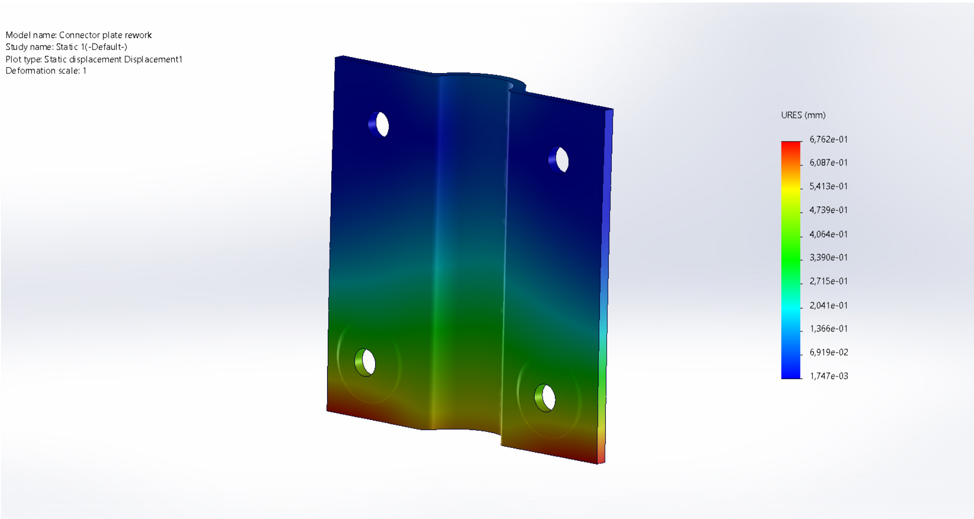


Figure 7.10: displacement of a connector plate with an added spine due to the maximum wind load on a 60 cm long track.

Table 7.1: Maximum stress and percentage of mass of the current design comparison between J and J with flange, as well as connector plate and the concept connector plate.

Concept	Maximum stress [MPa]	Mass percentage of current design
J	369	100 %
J with flange	279	105.9 %
Connector plate	630	100 %
Concept plate	504	110.3 %

7.4 Horizontal Track

Calling the assembly the ”horizontal track” might be a bit misleading, since the assembly should be able to be mounted at various angles from the wall as well, but since the maximal load on the track is experienced in the horizontal configuration, the name fits the analysis.

The simulations were set up with fixed cross sections at the outer end of the track, the bottom of the track bend and the end of the connecting piece fastening the track to the wall assembly. The load was distributed evenly across the concave surface in the bottom of the track, oriented downwards. A schematic figure of these boundary conditions is presented in figure 7.11. Since the length of the tracks are 2 meters, the magnitude of the load is determined by the weight of an 8 meter wide door. As described in 6.4.3, the C profile serves the purpose of connecting the track to the wall angle, and that function could be integrated in the connector. A placeholder connector, called the concept connector, connecting the track, bend and wall angle together, is used, but further refinement on that part is needed. The bend used is the same bend as in the current design.

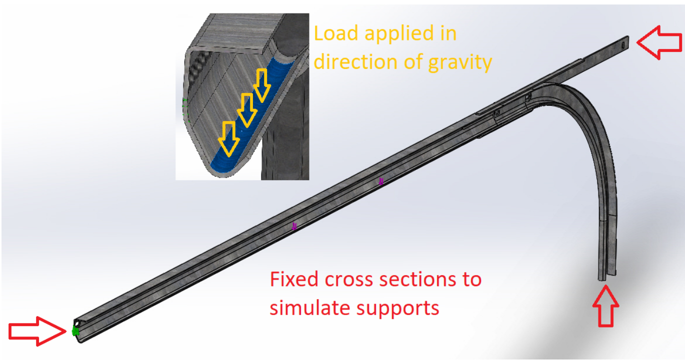


Figure 7.11: Locations of fixed cross sections in red and distributed load in orange.

Looking at the current design, the stress distribution can be seen in figure 7.12, where the rivets connecting the C and J profiles are experiencing the highest levels of stress. The profiles experience a maximum stress of about 130 MPa. The displacement of the track in the assembly can be seen in figure 7.13.

Continuing with selected concepts, the stress distribution in the J-expanded

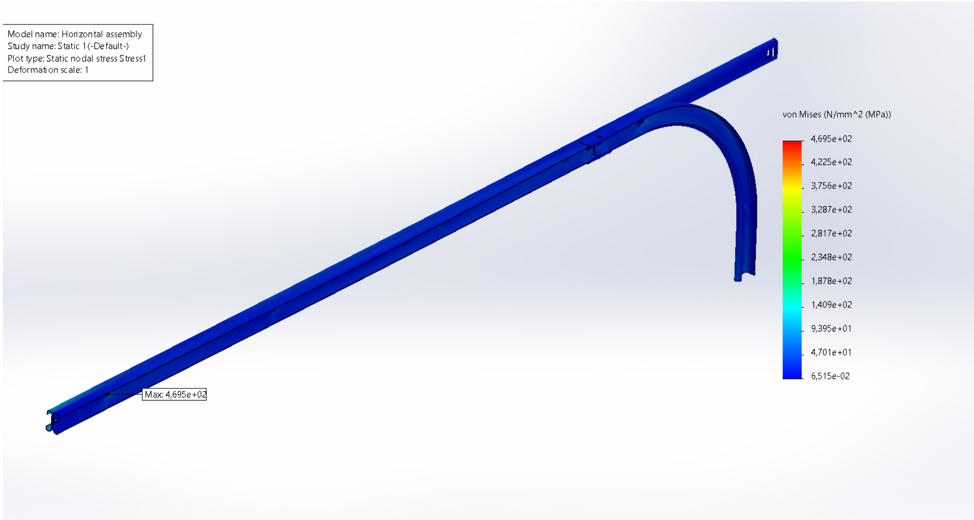


Figure 7.12: Stress in the current horizontal assembly with a distributed load corresponding to an 8 meter wide door.

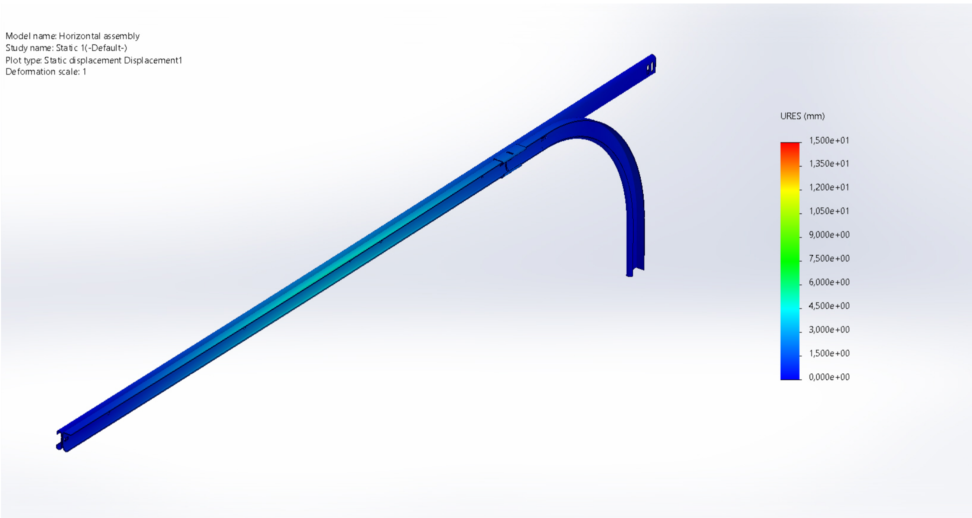


Figure 7.13: displacement of the track in the current horizontal assembly due to the distributed load corresponding to the weight of an 8 meter wide door.

track can be seen in figure 7.14. Looking at the displacement, seen in figure 7.15, the displacement compared to the current design has almost tripled, from 4.5 mm to 11.5 mm.

Introducing the 'J-expanded profile, where an added flange increases the height

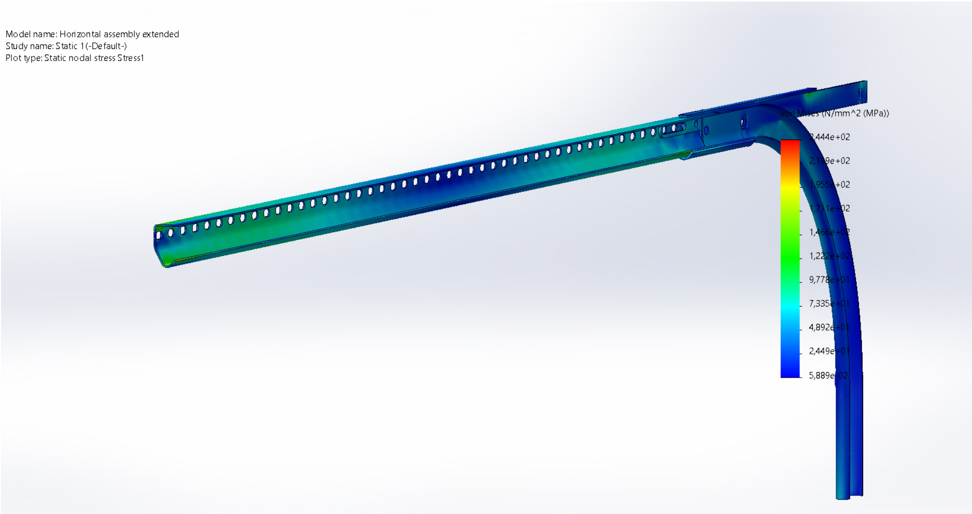


Figure 7.14: Stress in the J-extended track assembly due to door weight.

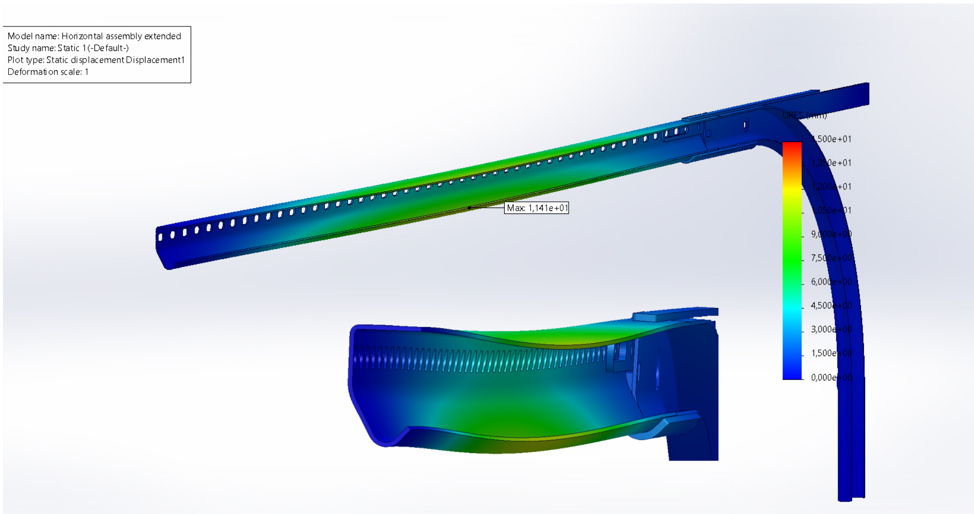


Figure 7.15: Displacement in the J-extended track assembly due to door weight.

of the cross section of the J-expanded profile, the stress distribution can be seen in figure 7.16 and the displacement in figure 7.17. Here, it can be seen that the displacement occurs on more on the flange than the bottom of the track, where the door would be moved, and the stress in the profile is reduced compared to the J-expanded.

Moving the flange to the spine of the J, and relocating the fastening holes

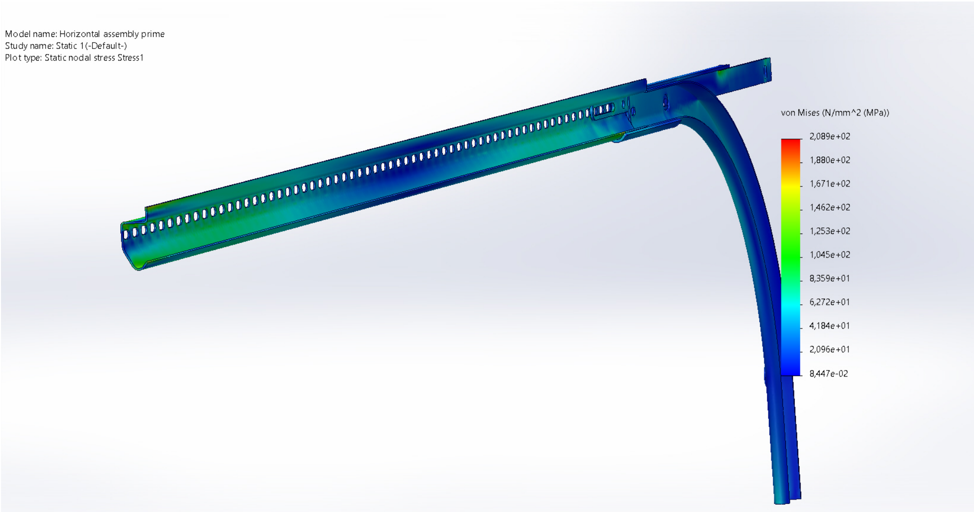


Figure 7.16: Stress in the 'J-extended track assembly due to door weight.

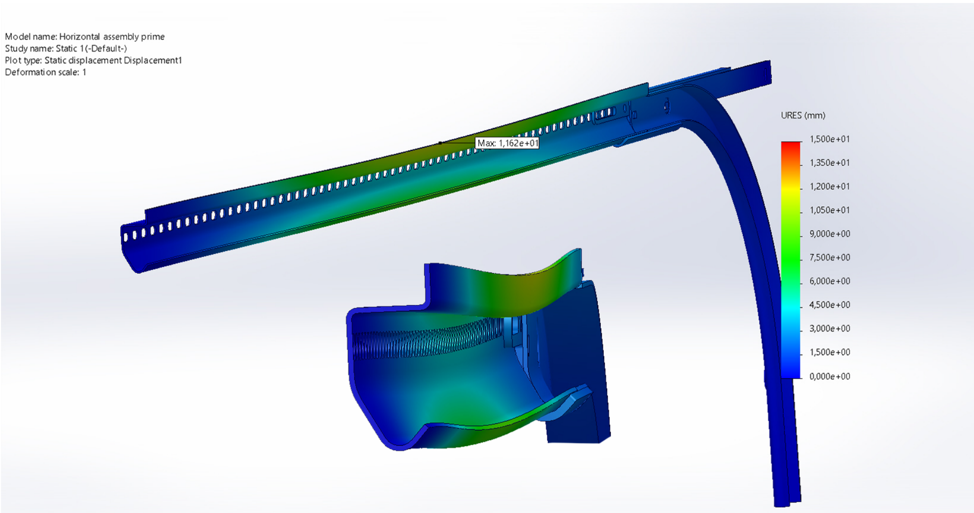


Figure 7.17: Displacement in the J'-extended track assembly due to door weight.

outside of the J allows for the profile to be slimmer, since no allowance for fasteners needs to be taken, and the resulting profile in the shape of lower case t is analysed next. The stress distribution can be seen in figure 7.18 and the displacement in figure 7.19. Here, the stress levels are further reduced, and the displacement is likewise reduced, due to the decreased torque imparted on the profile. Since the sideways distance between the mounting geometry and the load is reduced, the fulcrum the load is acting on is shortened.

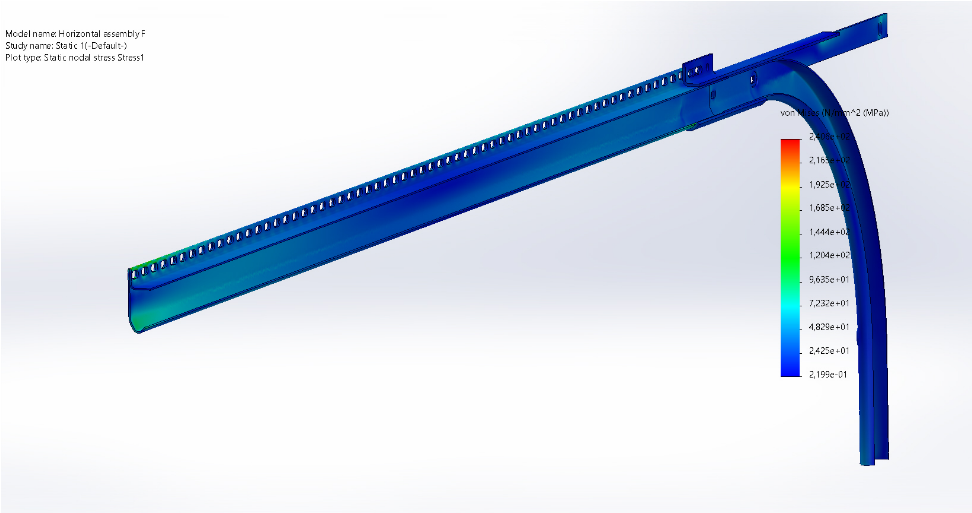


Figure 7.18: Stress in the t-track assembly due to door weight.

Using just the current J profile without the C, the stress distribution can be seen in figure 7.20 and the displacement can be seen in figure 7.21.

Finally, the J with flange introduced for the vertical assembly is tested, and the stress distribution can be seen in figure 7.22 and the corresponding displacement can be seen in figure 7.23.

Using the isolate tool in SOLIDWORKS, the stress levels in only the track assembly can be studied. Since the connector to the wall angle shows regions of high stress, unchanging between some configurations, only observing the track gives a more comparative result until further development of the connector is made. Compiling the data from the different analyses, the maximum stress of each track can be seen in table 7.2. The single J profile and J with flange are added in table 7.2 to serve as comparisons .

Every concept is tested with the same sheet metal thickness of 2 mm, which is the thickness of the current design. The material used today is EN 10346 - DX51D+Z275-N-A-C, which is a galvanized construction steel with a yield strength of 270-500 MPa. This large span in the material properties of the steel reduce the requirements on the producer, making the steel cheaper to buy, but poses issues with optimizing the selected concepts. Using the lower bound of 270 MPa as a target, it can be noted that the current design approaches a safety factor of two, while J expanded has a safety factor of 1.33. However,

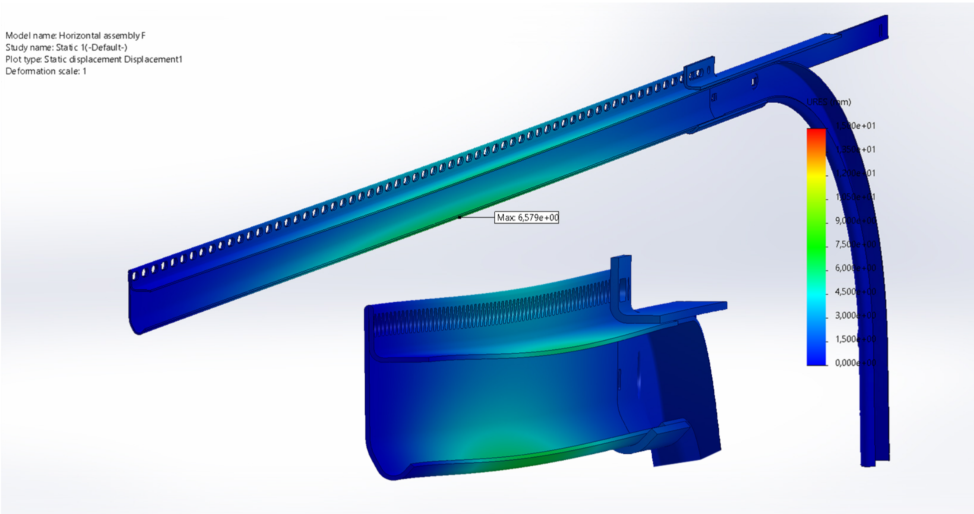


Figure 7.19: Displacement in the t-track assembly due to door weight.

Table 7.2: Maximum stress, maximum displacement and mass percentage of the assemblies including the bend and concept connector compared to the current design under a simulated load corresponding to the weight of an 8 meter wide door.

Track configuration	Maximum stress [MPa]	Maximum displacement [mm]	Mass percentage of current design
J+C	141	5.17	100%
J	177	8.63	73.9 %
J expanded	203	11.41	75.1 %
’J expanded	171	11.62	80.2 %
t-track	190	6.58	90.2 %
J with flange	169	8.24	77.1 %

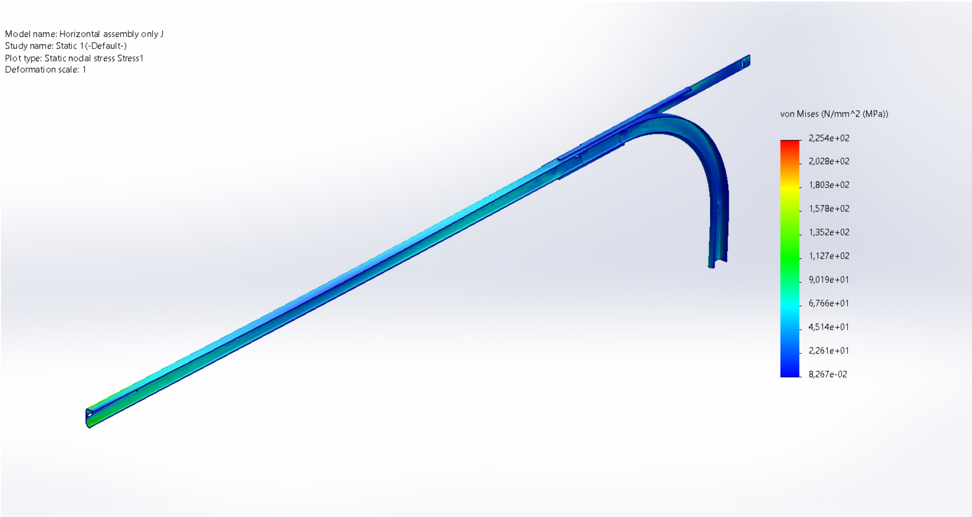


Figure 7.20: Stress in the J track without C profile due to door weight.

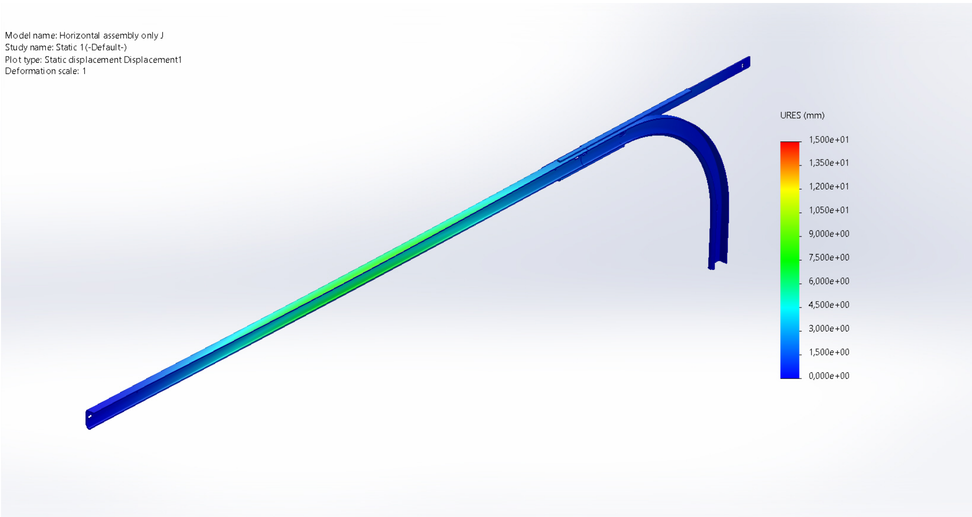


Figure 7.21: Displacement of the J track without C due to door weight.

the thickness of the sheet metal can be adjusted during detail design to reach the required safety factor.

Conducting the same simulations for longer length tracks, and adding the additional supports in accordance with figure 4.2, the stress in the tracks does not change significantly compared to the shorter tracks. Using a track length of 6 meters, and the corresponding door width of 2 meter, the total load per track decreases to 765.2 N, and using only a midpoint bearing support in ad-

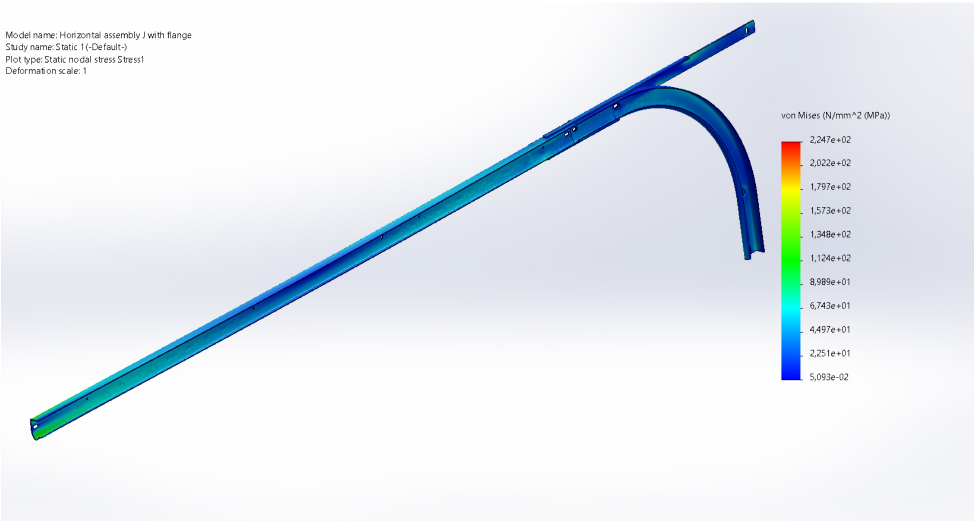


Figure 7.22: Stress in the J with flange track due to door weight.

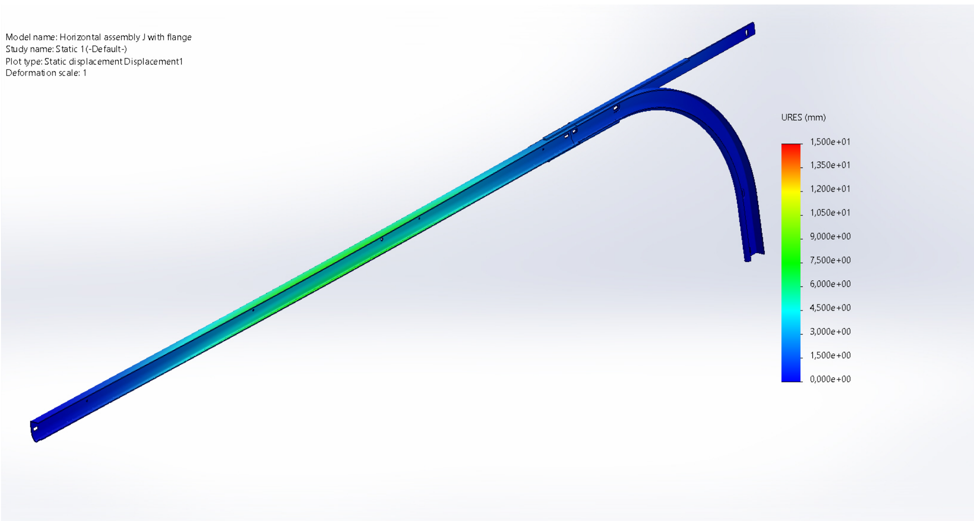


Figure 7.23: Displacement of the J with flange track due to door weight.

dition to the end supports, instead of the by figure 4.2 required one third and two third supports, the stress levels in the tracks are similar to the shorter tracks, with concentrations on the points of vertical support.

8 Detail Design

8.1 Detail Design Methodology

Previous chapter concluded the second part of the product development process, namely concept development. Usually after the conclusion of concept development, system-level design would take place. However seeing as this project is focused on a subsystem (the tracks) of a larger product (the overhead sectional door), the system level design step was deemed inappropriate for this project and therefore not included.

The detail design phase includes the complete specification of the geometry, material and tolerances for the different parts in a product, as well as identification of all the standard parts. Process plan and tooling are also established and designed during this stage.

During this project the detail design step will entail an analysis of the current manufacturing method for profiles, as well as an investigation into whether the newly generated concepts may be made using existing methods and machines. Next the assembly process is examined and lastly a short economic analysis is performed. Broad material selection focusing on material families will be described in the next chapter.

8.2 Manufacturing

Today ASSA ABLOY tracks used in their overhead sectional doors are acquired from an independent company . That company designs, procures, manufactures and distributes hardware parts for overhead sectional doors. The team interviewed their production quality manager and he provided information about the manufacturing plant, the available machines and their specifi-

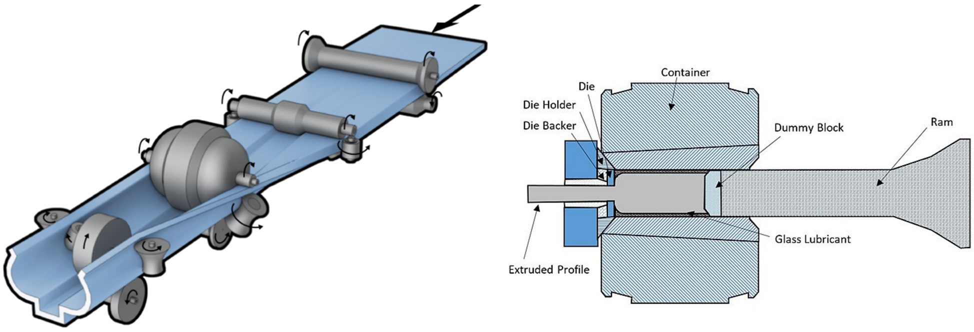


Figure 8.1: Two illustrations showcasing the roll forming process and the extrusion process, respectively [15] [16].

cations and capabilities as well as provided feedback on how manufacturable the proposed concepts are.

8.2.1 Roll forming and Extrusion Processes

Both roll forming as well as extrusion manufacturing processes were considered when discussing the manufacturing of overhead sectional door tracks. Sheet metal roll forming is the current method of manufacturing tracks. As noted in section 6.3 two of the generated concepts were not able to be roll-formed, therefore metal extrusion was considered. This section will provide basic information about the two manufacturing methods. Figure 8.1 illustrates roll-forming and extrusion processes, respectively.

Roll forming is a continuous forming method for manufacturing sheet metal profiles. The desired cross section is gradually formed as the sheet metal passes through successive rolls. Rolls are grouped into *roll stations* or *stands* and a given roll forming machine can only support a limited amount of stands. Aside from a maximum number of stands, every roll forming machine is also limited by the maximum width of plate that it can handle. Roll forming machines can be grouped into two categories: *fixed* and *adjustable*. Fixed roll forming machines are designed to manufacture only one specific roll formed profile, with the upside being an optimized production and reduced machine complexity. Adjustable roll forming machines on the other hand are able to produce different profiles using the same machine. This is accomplished by changing rollers in the machine, making it more flexible but less optimized compared to the fixed counterpart. When preparing a profile for roll forming, the deformation must be divided into one step per stand, and each step would

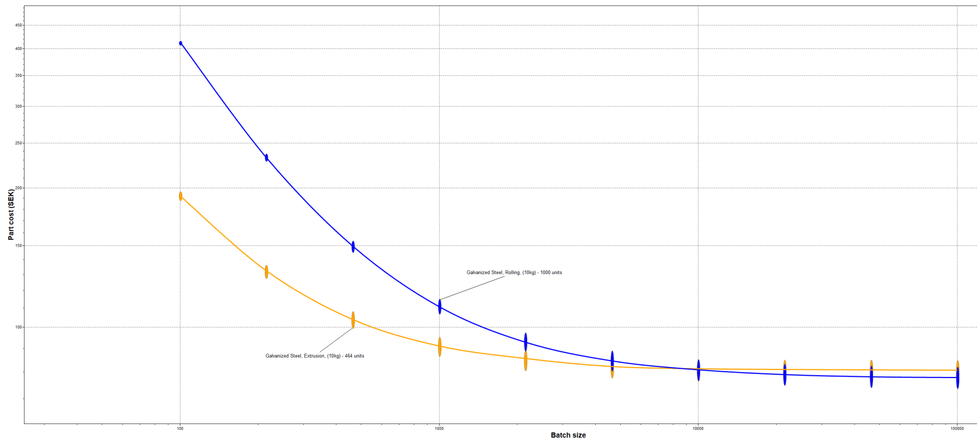


Figure 8.2: A comparison of part cost between extrusion and roll-forming manufacturing processes. Blue: roll-forming, orange: extrusion. Breaking point at around ten thousand profiles.

correspond to a certain level of stress. The process of roll forming can be illustrated by a diagram showing the different steps overlayed on each other, called a flower diagram.

Metal extrusion is a forming process in which a metal billet (either hot or cold) is forced through a die. After the extrusion the material is of the same shape as the die. Metal extrusion processes can be distinguished into five categories: hot, warm and cold extrusion, as well as friction extrusion and microextrusion. During hot metal extrusion, the feed metal is being heated to above the recrystallisation temperature. The softened material is then pressed through a die. In the cold metal extrusion process the billet is instead left at or around room temperature, instead needing higher pressures to extrude the material [17].

Figure 8.2 shows a graph generated using Ansys Granta software. Part cost estimation function in Granta was used to generate the material records in the figure. Then the records were plotted onto the part cost - batch size chart and lines connecting the data points were drawn.

8.2.2 Current Roll Forming Capabilities

In the company's factory there are several roll forming machines, with three of them being fixed. These three fixed roll forming machines are currently producing J and C profiles, as well as the wall bracket profiles, with one profile being produced per machine. As mentioned in 8.2.1, a fixed roll forming machine is specialised in manufacturing only one type of profile, unlike an adjustable machine.

The three fixed roll forming machines that the company owns today have the the maximum capacity of 12 stands and a distance between the stands of 260mm. Manufacturing of a J profile requires 10 stands, leaving 2 free for possible minor modifications to the J-Profile. According the the production quality manager each fixed machine is on average rolling below the maximum capacity, meaning that each machine has the ability to produce more track per day if a need would arise.

8.2.3 **UBECO PROFIL Analysis**

A roll forming analysis of the four profile concepts was performed using a roll form design software - UBECO PROFIL. PROFIL allows for creation of flower diagrams and split flower diagrams. When designing a flower diagram in PROFIL there are two important parameters that influence the result - stress and material. The material chosen within the software dictates the ultimate tensile strength, which in turn influences how much the material may be bent without breaking or cracking while going through a given stand. The second important parameter to input into the software is distance between stands. This parameter also influences how much the material may be bent per stand.

The current material used in tracks is EN 10346 - DX51D+Z275-N-A-C, a hot-dip galvanised steel. Mechanical properties of this material are a yield of min. 140 MPa and an ultimate tensile strength of 270-500 MPa [18]. As the value range of the material's ultimate tensile strength is quite vast, within the UBECO PROFIL software a material with an UTS of 380 MPa was used (385 is the value right in-between 270 and 500). However, the roll forming steps presented by UBECO PROFIL could be further improved on, for example following the methodology described by Paralikas et al, but feedback from the manufacturing company would be crucial to the production process [19].

Four flower and split flower diagrams were created in the software - one for each of the proposed concepts. Figures 8.3 through 8.6 showcase these diagrams along with stresses in the material being bent for each roller stand.

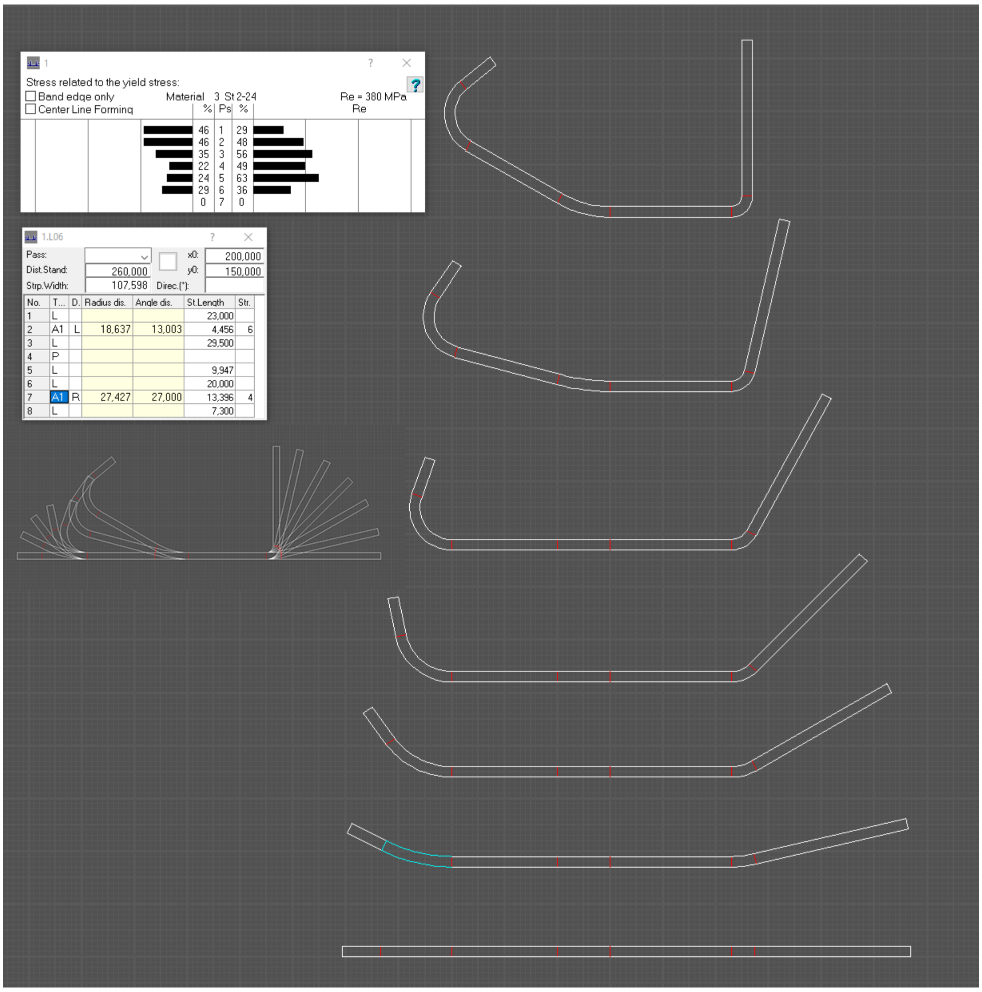


Figure 8.3: Flower and split flower pattern for the J Extended profile. 6 stands required to manufacture.

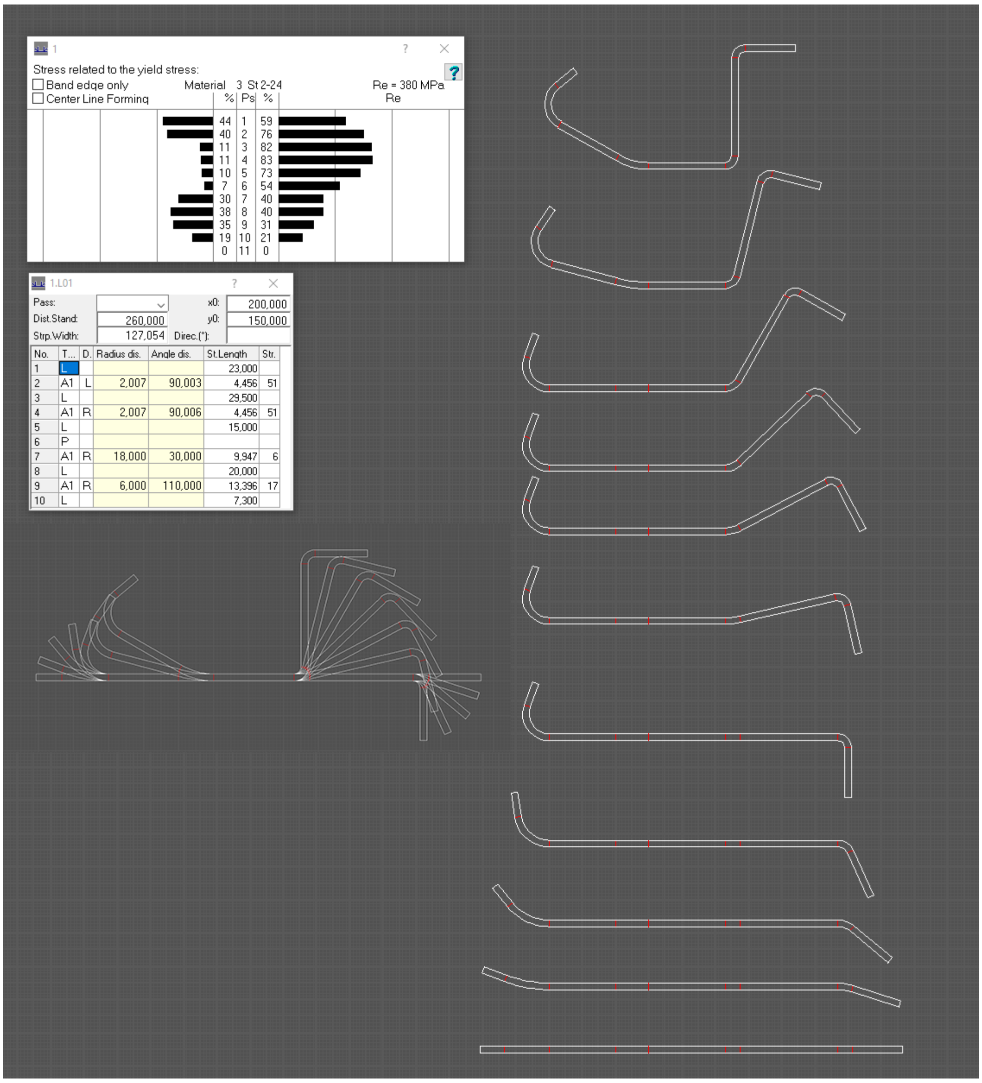


Figure 8.4: Flower and split flower pattern for the 'J Extended profile. 10 stands required to manufacture.

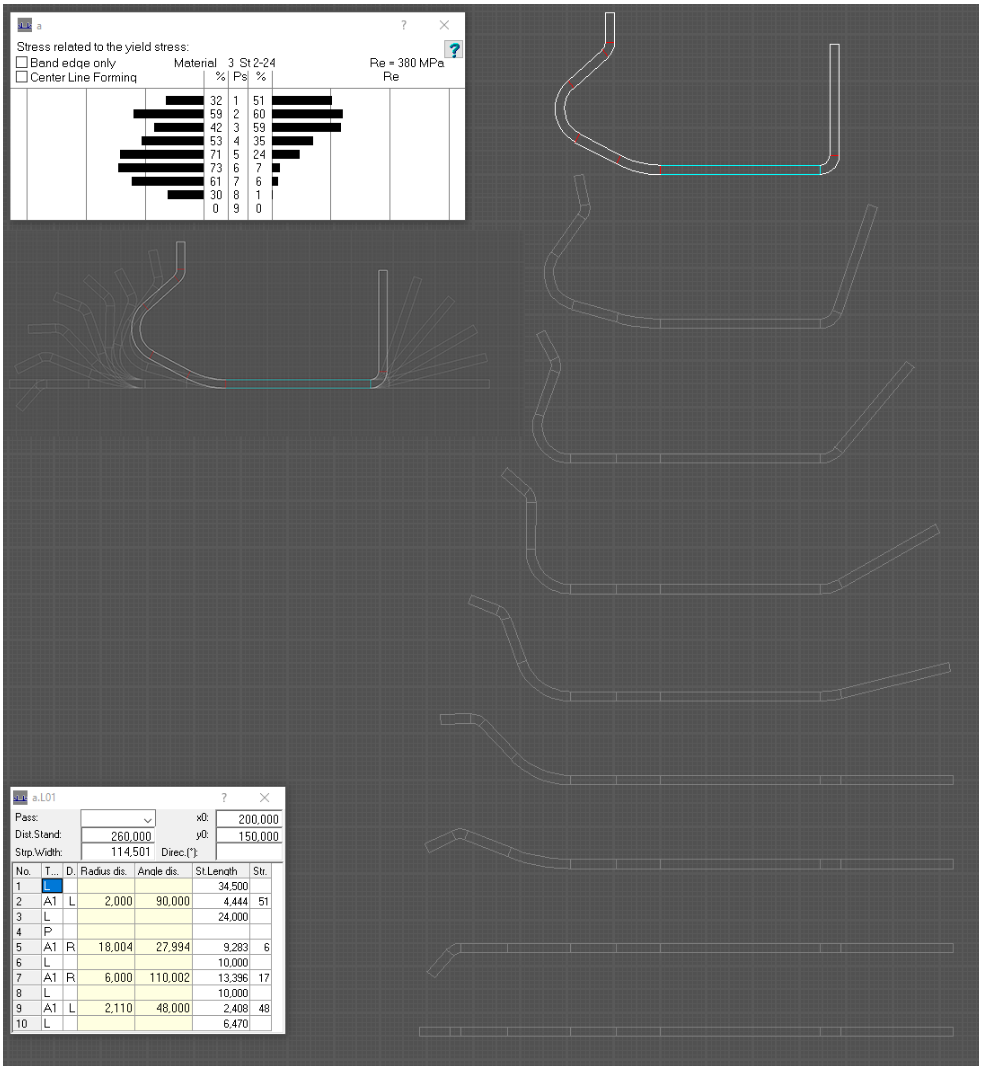


Figure 8.5: Flower and split flower pattern for the J-Flange profile. 8 stands required to manufacture.

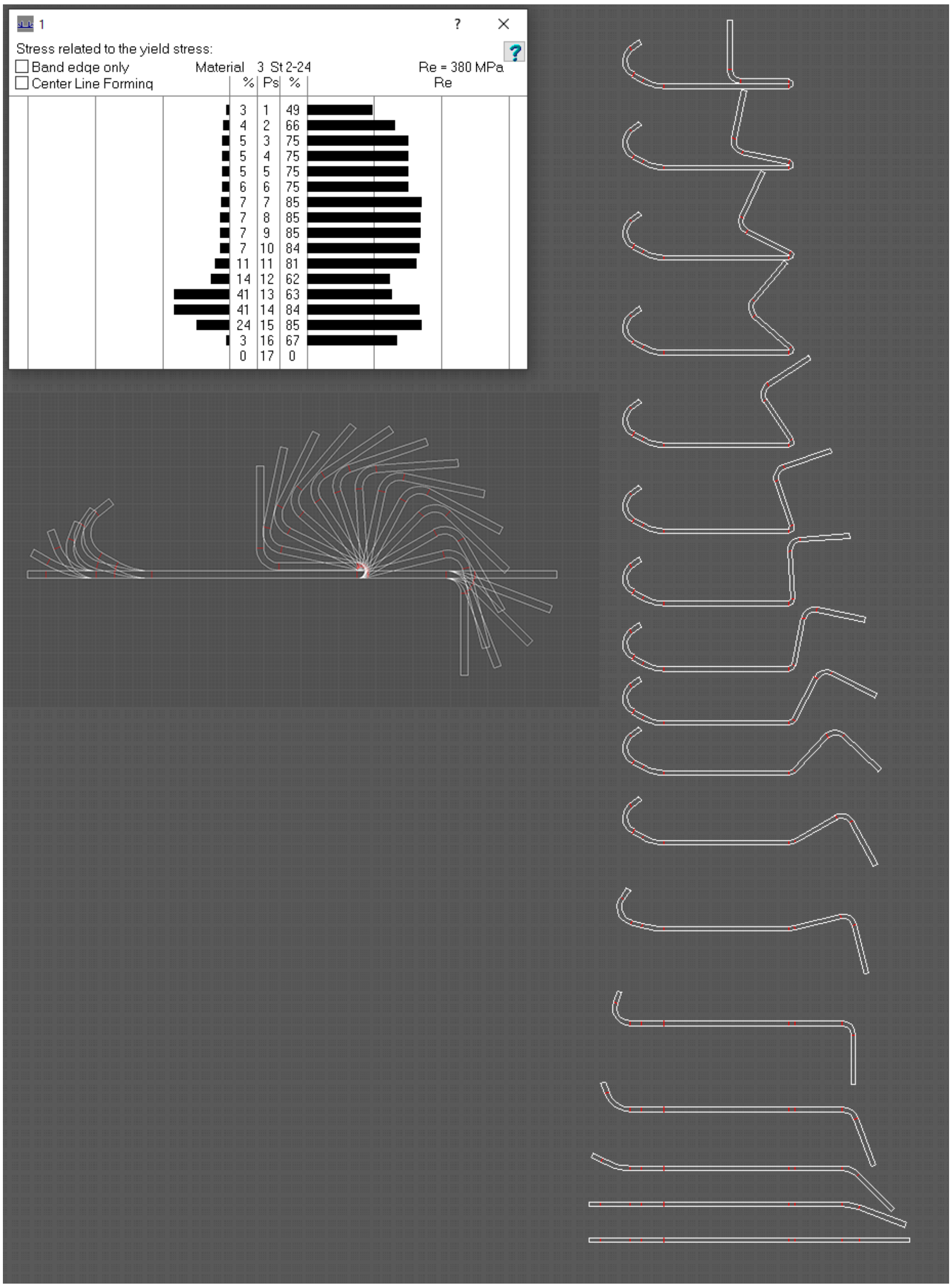


Figure 8.6: Flower and split flower pattern for the t profile. 16 stands required to manufacture.

8.3 Assembly

By dividing up the complete assembly from manufactured parts to a working and installed door into steps done in factory and steps done on site, the overview of the process can be more easily grasped. Looking at the horizontal assembly, the bill of materials is presented in table 8.1 the steps done in factory can be seen in table 8.2. The amount of fasteners used and presented in table 8.1 is dependent on the length of the track, and should be rounded to the next natural number.

Table 8.1: Bill of materials for the horizontal track assembly, together with the wall bracket required for installation.

P/n	Name	Number of parts	Assa Abloy part number
1	J-track	1	D001019490
2	C-profile	1	D001020157
3	Connector	1	D001018907
4	Rivet	1 + Length/0.6	D001018023
5	M8 flange nut	1 + Length/1.25	D001148378
6	M8x18 bolt	1 + Length/1.25	D001017984
7	M8x18 bolt	3	D001017984
8	M8 flange nut	3	D001148378

Table 8.2: Assembly sequence in factory for the current design with handling and insertion codes and times, as well as total time according to the process of Boothroyd, Dewhurst and Knight [10].

P/n	H. code	H. time	I. code	I. time	Total time	Nbr of pts
1	91	3 s	00	1.5 s	4.5 s	1
6	12	2.25 s	00	1.5 s	3.75 s	1 + Length/1.25
3	32	2.7 s	00	1.5 s	4.2 s	1
2	91	3 s	00	1.5 s	4.5 s	1
5	12	2.25 s	38	6 s	8.25	1 + Length/1.25
4	12	2.25 s	35	7 s	9.25	1 + Length/0.6
		Total time needed: $34.45 + 25.02 \cdot$ Length seconds				

In this assembly, only the J-track and C-profile are considered critical parts, since the J-track can be considered the main component in the assembly, and the offset offered by the C-profile is required for installation. Neither the rivets or the fasteners should be considered critical, since there is no need for them to be separate parts. Continuing the assembly sequence by introducing the installation stage, the portion of the assembly done on site, the assembly sequence is presented in table 8.3, with the vertical track assembly disregarded.

Table 8.3: Installation sequence on site with handling and insertion codes and times, as well as total time according to the process of Boothroyd, Dewhurst and Knight, with the assembly from factory as part 9 [10].

P/n	H. code	H. time	I. code	I. time	Total time	Nbr of pts
9	83	5.6 s	06	5.5 s	8.5 s	1
7	12	2.25 s	06	5.5 s	7.75 s	3
8	02	1.88 s	38	6 s	7.88 s	3
		Total time needed: 57.99 seconds				

In order to compare concepts to the current design, the standard comparison door of a height of 3.5 meter is used, and the total assembly time and design efficiency of that length is established. This is presented in table 8.4. The door height of 3.5 meters and width of 3 meters is used as a reference door at ASSA ABLOY, since it follows the most commonly used dimensions of a docking door.

Introducing the three concepts suggested, the assembly done in factory would be dramatically reduced. With the elimination of the C-profile, the need for any fasteners to join the J-track and the C-profile is likewise eliminated. Combining the connector and the need for an offset surface to mount to the wall angle, one part is eliminated completely. The assembly would then require fasteners for connecting the vertical assembly, new connector and the new J-track, which would fall under the installation time. Keeping the J-track separate from the connector during shipping and prior to installation would reduce the length requirements on the transported package posed by the track

Table 8.4: Summarised assembly and installation time and design efficiency for the current design with a standardised height of 3.5 meters.

Total assembly time	174.69 s
Number of parts	25
Number of critical parts	2
Design efficiency	3.43%

assembly. This would however move one fastener from assembly to installation, but would reduce the need to hold the long track in the correct orientation while fastening the track to the vertical assembly. In all, the assembly in factory would be eliminated, with the concept connector and four screws with nuts being needed for installation, as shown in table 8.5.

Table 8.5: Installation sequence for the new concepts, with the concept connector as part 10 and concept track as part 11.

P/n	H. code	H. time	I. code	I. time	Total time	Nbr of pts
10	03	1.95 s	06	5.5 s	7.45 s	1
11	91	3 s	06	5.5 s	8.5 s	1
7	12	2.25 s	06	5.5 s	7.75 s	4
8	02	1.88 s	38	6 s	7.88 s	4
		Total time needed: 78.47 seconds				

Since the installation and assembly of the new concepts are length independent, the summarised assembly and installation time and design efficiency can be seen in table 8.6.

The handling and insertion times provided by Boothroyd, Dewhurst and Knight are based on experimental studies, and can be used to estimate assembly times [10, p. 93]. However, the installation of the door tracks offer challenges not accounted for in the tables provided by Boothroyd et al, such as time for positioning and operating lifting platforms. By keeping the concept connector separate from the track, the installation technician should be able to connect the horizontal and vertical assemblies without supporting the weight of the horizontal track extended out into the unsupported space below the ceiling. Currently, some technicians solve this issue by running a supporting rope from the ceiling as a temporary support. This adds time to the installation, and with the two screws in the concept connector, the track can be fastened with one, rotated to the correct orientation and slid into place to finally be fastened with the second screw.

Table 8.6: Summarised assembly and installation time and design efficiency for the concept design.

Total assembly time	78.47 s
Number of parts	10
Number of critical parts	2
Design efficiency	7.65%

Furthermore, the installation of the ceiling supports and the door stopper today require the use of a blind fastener that is rotated into place in the C-profile and held until the nut is screwed down in front of it. This poses handling issues, since reaching the correct orientation of the blind fastener is hard to do, and must be done by feel instead of sight. In the proposed concepts, this blind fastener is substituted with a regular fastener, reducing the handling and insertion time according to Boothroyd et al with a total of 4.8 seconds per fastener [10].

8.4 Economic Analysis

The economic analysis aims to explore how the four developed profiles may benefit the company by saving costs when it comes to the amount of material used, reduced amount of parts (mainly various fasteners) while assembling and installing as well as the reduced assembly and installation times.

The material cost comparison was carried out under the assumption that the same material would be used for the new profiles. With this assumption in place the amount of material used for each profile compared to the old design could be established simply by comparing the profile areas.

Data concerning the amount of parts in the assembly was taken from and discussed in chapter 8.3. The economic analysis self is presented in table 8.7. Key takeaways from this table are the rows with percentage values.

Note that table 8.7 specifically deals with the horizontal J+C track assembly. There is only one concept in place as a possible replacement for the vertical J Track - the J with flange. Comparing the 186mm^2 area of J with the 197^2 area of J with Flange - the J with flange uses 6% more material than J. The assembly, installation as well as part number would remain the same in the vertical assembly.

Table 8.7: Economic Analysis. The blue column represents the current horizontal track design (J+C). The following four columns thereafter are the new designs that are being compared to the *horizontal* J+C track.

	J+C (horizontal)	**J Expanded**	**'J Expanded**	**t**	**J with Flange**
Area [mm^2]	325	200	228	273	201
Area in relation to J+C	**100%**	62%	70%	84%	62%
Assembly Time [s]	116.7	0	0	0	0
Assembly time in relation to J+C	**100%**	0%	0%	0%	0%
Installation Time [s]	57.99	78.47	78.47	78.47	78.47
Installation time in in relation to J+C	**100%**	135%	135%	135%	135%
Number of Parts	**25**	10	10	10	10

9 Material Selection

9.1 Material Selection Methodology

The current material used in the manufacture of all track profiles is EN 10346 - DX51D+Z275-N-A-C, which is a hot-dip galvanised steel. This chapter is an exploration of possible alternative material families that may be used instead of steel.

The material selection process will be performed according to what Ashby presents in his book, specifically in chapter 4 where the basics are explained [20]. The following section 9.2 will go through the material selection process, although without an in-depth explanation of the process itself. The material selection will be limited to the horizontal track assembly, with the horizontal track being treated as a beam in bending.

9.2 The Ashby Method

The horizontal track assembly has two important tasks to accomplish. The first task is guiding the door roller wheels so that the door can be opened and closed. The second task is withstanding design loads, which are caused by the weight of the door blades. During loading the tracks can be considered as beams in bending.

To ensure that the tracks can perform the first task of guiding the door wheels successfully, the track shouldn't deflect too much. Low deflection of the tracks is also a necessity to ensure structural integrity of the whole door assembly. Therefore stiffness will be one of the constraints. To ensure the fulfillment of the second task of withstanding the design loads, the track should be strong enough. Therefore strength will be the second constrain. Reduction

Table 9.1: Design requirements for a cheap, strong, and stiff beam

Function	Beam
Constraints	Length L specified
	Stiffness
	Strength
Objectives	Minimize the cost, C
Free variables]	Cross-section area of beam, A
	Choice of material

of cost will be the objective. This means that both stiffness and strength will be desirable, but only at a low cost. Table 9.1 summarizes this information.

With the design requirements in place, the next step is to establish what the material indices are. By using Ansys Granta EDUPACK software the material indices M1 and M2 are given by:

$$M1 = \frac{E^{1/2}}{C_m \rho}$$

$$M2 = \frac{\sigma^{2/3}}{C_m \rho}$$

where C_m is cost per kilogram. Figures 9.1 and 9.2 showcase the parameters that were inserted into the material index finder in the software, in order to obtain the material indices (referred to as performance indices in the software).

The material cost (the objective) will be minimized by maximizing the material indices M1 and M2. To that end graphs shown in figures 9.3 and 9.5 are plotted. The relation between Young's Modulus and cost/kg times density expressed by M1 is expressed as a constant

$$\frac{E^{1/2}}{C_m \rho} = Constant$$

This condition becomes, on taking logs,

$$Log(E) = 2Log(\rho) + 2Log(C_m) + 2Log(Constant)$$

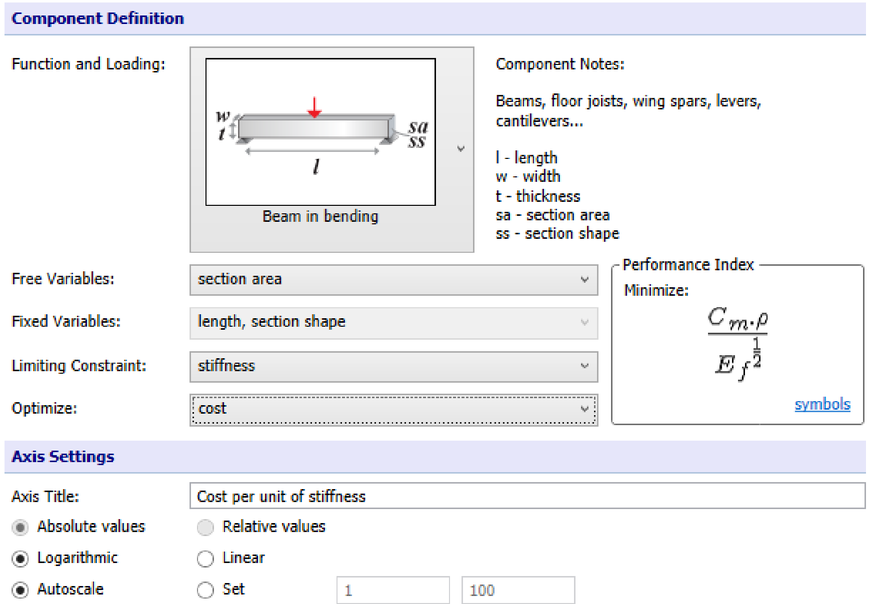


Figure 9.1: Setting used to get the material (performance) index M1 with stiffness being the limiting constraint.

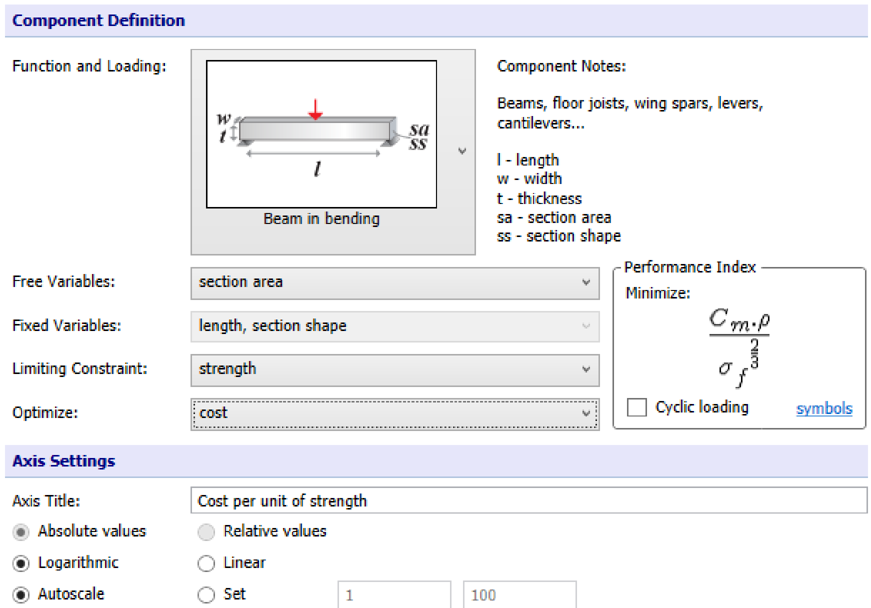


Figure 9.2: Setting used to get the material (performance) index M2 with strength being the limiting constraint.

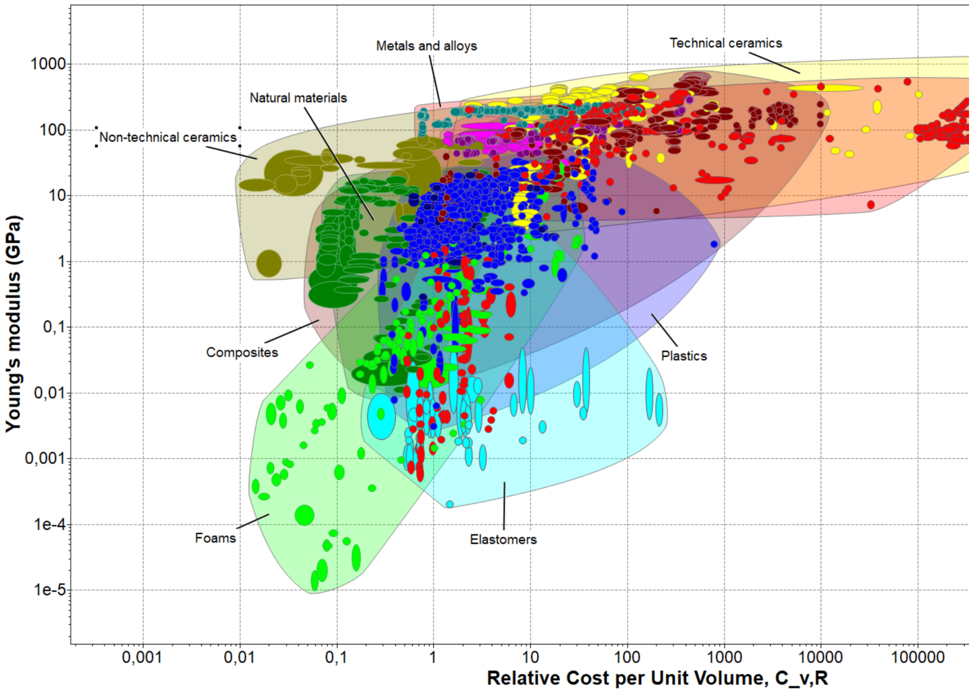


Figure 9.3: Graph plotting Young's Modulus against Relative Cost per Unit Volume.

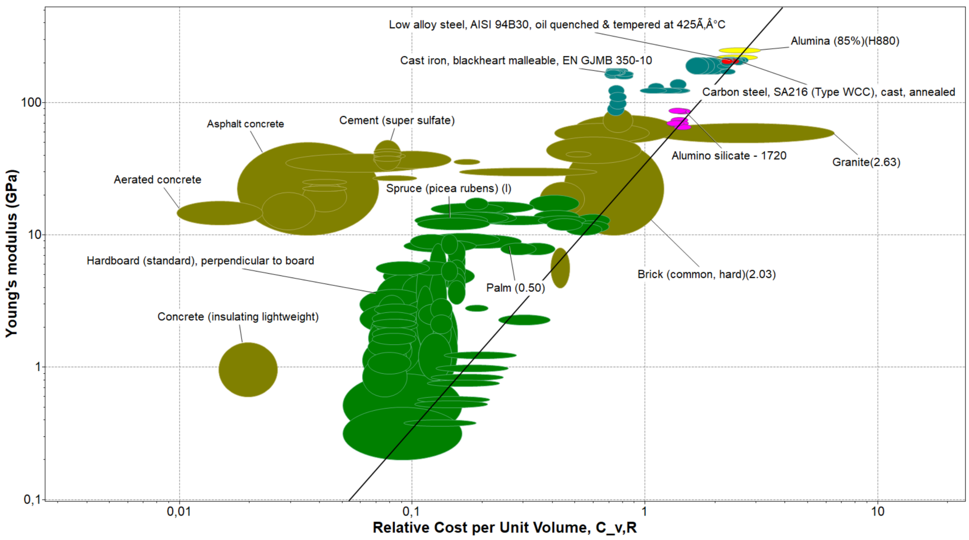


Figure 9.4: Graph plotting Young's Modulus against Relative Cost per Unit Volume. This is the same graph as in figure 9.3, but with the introduction of a selection line based on M1. Slope = 2

This equation describes a line with a slope of 2. Using a similar process the equation M2 gives a line of slope 1,5. These lines are referred to as *selection guidelines*, and they give the slope of the family of parallel lines which belong to their respective material index. Figures 9.4 and 9.6 are graphs utilizing selection guidelines. They provide an easy to read overview of what materials best fulfill given criteria. Materials along the line can be said to perform equally well, while materials above the line perform even better. The area above the line is also known as the *search area*.

Lastly, the x-axes of the graphs in figures 9.3 to 9.6 are not expressed as density times cost per kilogram as might be expected from the material indices M1 and M2. Instead an alternative unit is defined, relative cost per unit volume C_v, r.

$$C_v, r = \frac{Cost/kg \ \times \ Density\, of\ Material}{Cost/kg \ \times \ Density\, of\ Material} \text{ [20, p. 95]}$$

This is done in order to correct for inflation and difference in currencies between different countries.

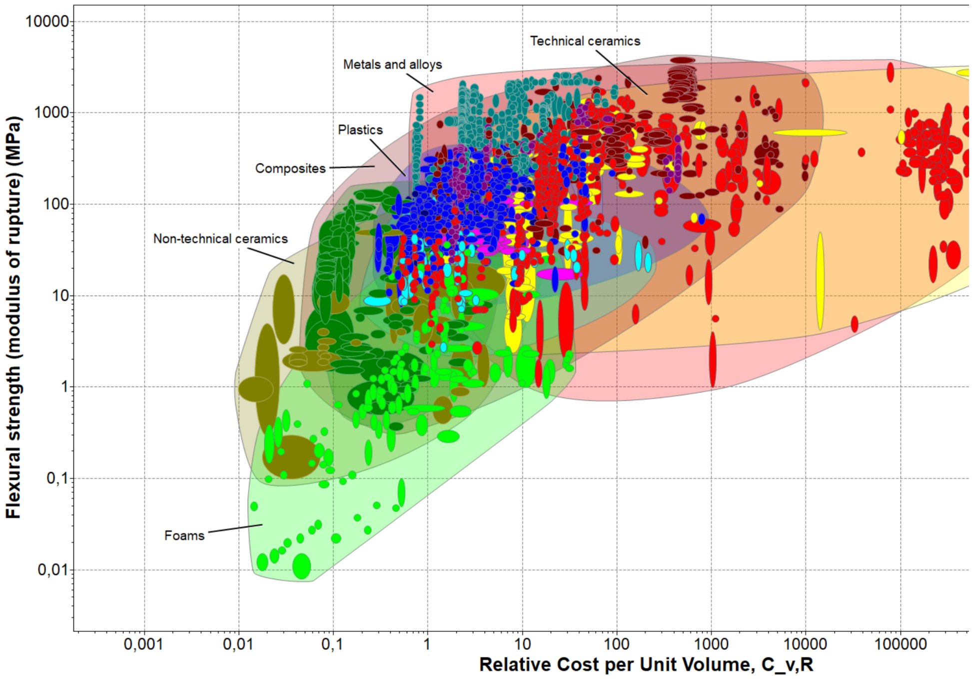


Figure 9.5: Graph plotting Flexural Strength against Relative Cost per Unit Volume.

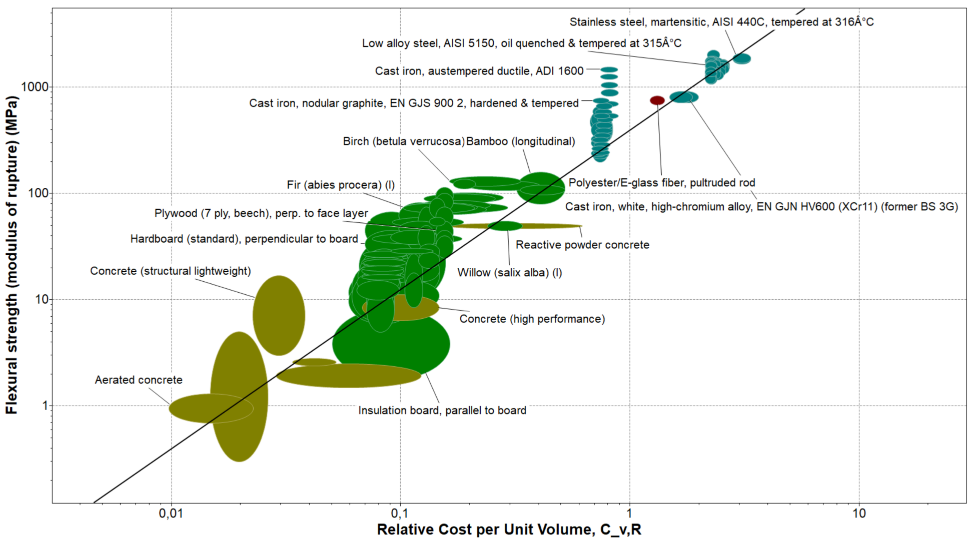


Figure 9.6: Graph plotting Flexural Strength against Relative Cost per Unit Volume. This is the same graph as in figure 9.5, but with the introduction of a selection line based on M2. Slope = 1.5

9.3 Conclusions

Figures 9.4 and 9.6 feature similar types of materials in their respective search areas. Three dominant material families can be observed in these figures: non-technical ceramics (yellow-brown), natural materials (green) as well as the metals and alloys group (cyan). The non-technical ceramics group mainly features building materials such as concrete, cement and brick. The natural materials group mainly features various types of wood and the metals and alloys group include cast irons as well as steels.

Overall the non-technical ceramics as well as natural material groups are not a good choice of material for the manufacture of guiding tracks, mainly because of the difficulties of shaping those materials into tracks. In addition they appear low on the y-axes in both charts, meaning that their overall Young's modulus and stiffness are lower compared to metals.

Cast irons look promising at first glance, having overall a lower relative cost per unit volume values compared to steels, while maintaining same values of young's modulus and strength. However cast irons are known to be strong in compression while weak in tension, making them a liability as guiding tracks. Therefore steel seems to be the overall best material choice for this application, having excellent manufacturability as well as good mechanical properties.

10 Results

10.1 Wind Load

In order to increase wind load resistance, the added flange improves the capacity of the guiding track, but the weakest link in the structure is the connector plates attaching the guiding track to the wall angle. Adding a spine to the connector plate increases the rigidity and offers the most decrease of stress in comparison to mass increase. however, the concept tested still resulted in plastic deformation. The results from the simulations done on the track and connector plate can be seen in table 10.1.

Table 10.1: Maximum stress and percentage of mass of the current design comparison between J and J with flange, as well as connector plate and the concept connector plate.

Concept	Maximum stress [MPa]	Mass percentage of current design
J	369	100 %
J with flange	279	105.9 %
Connector plate	630	100 %
Concept plate	504	110.3 %

10.2 Horizontal Assembly

The concepts developed show stress levels that do not cause plastic deformation under load, and all proposed concept use less material than the current solution. The deflection of the tracks is, however, increased compared to the current design. The results from the simulations conducted on the different concepts and current design can be seen in table 10.2. The profile J extended shows a significant reduction in mass, while keeping well below the material limit for plastic deformation. Lower stress is seen in both the J profile and the J with flange, with even lower mass, but these have no means of fastening to surrounding architecture. The deformation of the 'J extended profile is larger in absolute terms, but lower in the area supporting the load, where it is displaced approximately 9.15 mm. The maximum deformation seen in the 'J extended occurs on the ridge.

Table 10.2: Maximum stress, maximum displacement and mass percentage of the assemblies including the bend and concept connector compared to the current design.

Track configuration	Maximum stress [MPa]	Maximum displacement [mm]	Mass percentage of current design
J+C	141	5.17	100%
J	177	8.63	73.9 %
J extended	203	11.41	75.1 %
'J extended	171	11.62	80.2 %
t-track	190	6.58	90.2 %
J with flange	169	8.24	77.1 %

10.3 Manufacturing

Table 10.3 shows the results of the analysis performed on the four proposed track concepts. Based on the available roll forming equipment, the t-track is the only profile not manufacturable with the machines used today.

Table 10.3: Maximum stress, maximum displacement and mass percentage of the assemblies including the bend and concept connector compared to the current design.

	Amount of roll-forming steps (amount of stands)
J extended	6
'J extended	10
t-track	16
J with flange	8

10.4 Assembly

Using the proposed concepts for the horizontal assembly, the assembly time is eliminated, but the installation time is increased by 35 %. The total time needed, including assembly and installation, is for the average 3.5 meter tall door is reduced by 55 %. A summary of assembly times for the current and concept designs can be seen in table 10.4.

Table 10.4: Summarised assembly and installation time and design efficiency for the current design and concept design with a standardised height of 3.5 meters.

Total current assembly time	174.69 s
Number of current parts	25
Number of critical parts	2
Design efficiency	3.43%
Total concept assembly time	78.47 s
Number of concept parts	10
Number of critical parts	2
Concept design efficiency	7.65%
Time reduction	55 %
Design efficiency increase	123 %

10.5 Summary

The weakest link in the wind resistance is the connector plate, which would see reduced stress with an added spine, and an added flange to stiffen the track would also contribute to wind resistance.

The three main concepts for horizontal tracks, the J extended, 'J extended and the t-track resist plastic deformation at a reduced weight, while requiring a reduced assembly time. The most cost effective solution would be the J extended, while 'J extended provides lower stress and deformation.

11 Discussion

11.1 Methodology

Following the product developement model established by Ulrich and Eppinger provided a useful framework for the project, and establishing the customer need and target specifications early helped inform the concept testing and system level design. Furthermore, the established specifications should allow for a better detail design of the chosen concept.

Project timelines and preliminary planning of the project can be found in appendix B. The initial planning of the project was broad by design, since many of the planned activities were to be based on the information gained in previous steps. The interviews conducted early in the project led to many of the generated concepts, and the customer needs that were found influenced the direction of the project and required placing delimitations as the scope of the project grew. An early ambition in the early stages of the project was to produce physical prototypes for testing and verification, but as interviews with manufacturing experts resulted in doubts on the manufacturability, the focus shifted to gaining information on the roll forming and conducting simulations of the process. Due to this, digital prototyping was all that reasonably could be fit into the project timeline. By having used the framework of Ulrich and Eppinger, the project was positioned in a way that could adapt to these necessary changes. The staging of the different interviews conducted was due to scheduling issues from working in different countries. Having several segments where benchmarking was done was due to the competition analysis done by ASSA ABLOY. As the results of the analysis was made available, further revision to the established benchmarks needed to be made.

11.2 Simulations

The accuracy of the simulations can be considered accurate enough prior to detail design. The results from the simulations are mesh independent and the loads imposed on the models are reasonable representations of the loads experienced in use. The dynamic loads imparted by the moving door have not been simulated, and should be the focus of the development of the bend and concept connector. Using fixed supports in the simulations led to a reduced accuracy of the results, but serve to provide a sufficient basis for concept testing.

During detail design of the chosen concept, an extended digital prototype with contact supports and modelled roof supports should provide better and more accurate results, allowing for tuning of the material thickness to reach the desired safety factor. These tests would require more extensive computation power in order to be time efficient. Constructing a physical prototype would allow for verification of simulation results, which should be a priority.

11.3 Manufacturing

The discussion about manufacturing includes the choice of process, material and machines to make a given profile. The proposed new profiles represent new opportunities not only in performance, but also in economical viability. Their different designs have various consequences when it comes to what can be done with existing manufacturing machinery, and some profiles are more viable than others in this regard.

Two manufacturing methods were considered during this project: sheet metal roll forming as well as metal extrusion. Based on a short GRANTA analysis it was deemed that roll forming outperforms extrusion when it comes to large production volumes. Additionally, since roll forming is the current manufacturing method used today to produce the tracks means that no costly changes have to be made. When it comes to material selection, the Ashby charts made during the material selection process confirm steel as a suitable material for the purpose of guiding tracks.

The manufacturing costs would be very dependent on whether or not the profile would require new roll forming machines J-Flange is the only profile out of the four final concepts that is feasible to start manufacturing with minimal changes of equipment, and thus minimal costs. The current fixed J-Profile roll forming machines have two (out of twelve) stands empty, thus allowing the manufacture of this profile with the design and purchase of only two additional rollers.

Another concern that the production quality manager shared with the team is that their company sells their J-Profiles to firms other than ASSA ABLOY. This means that any new profiles would also have to be of interest to other companies, and J-Flange is best fit in this regard because of the minimal departure from the original J-Track design.

The J-Extended and ’J-Extended profiles are theoretically possible to manufacture on the current machines, however the current ten rollers that are installed in the machine today are specifically designed for the manufacture of the J-Profile. Given that both J-Extended and ’J-Extended have different geometries compared to the J-Profile it means that all rollers would have to be replaced with new ones, specifically designed for the manufacture of the extended profiles.

Lastly the t-profile requires by far the biggest amount of rollers. It is probably the only profile concept that could not possibly be manufactured by the current 12-stand machine today. A different machine or a different profile manufacturer would be required in order to create the t-profile.

11.4 Assembly

Removing the need for assembly at the factory would reduce manufacturing costs, and allowing the installation technician to install the tracks without the need for temporary supports from the roof would reduce installation time on site, even with the addition of the extra fastener.

The installation procedure on site is not especially well modelled by Boothroyd et al, since the framework established is in reference to factory workers working in a controlled environment at a designated station with potential fixtures and tools within easy reach. The work environment for installation technicians can vary wildly, and unforeseen circumstances such as other construction work or electrical installations can impact the time required to conduct certain steps. However, reducing the amount of work needed to be done via lifting platforms will significantly impact installation time.

The cost associated with assembly is hard to quantify precisely, since it is impacted by several factors, such as social fees, tooling, workspace and fixtures on the factory side, on top of wages. Installation costs would be different from assembly costs, since the value generated by the installation must offset the cost of transportation of the technician as well as the increased cost of setting up a temporary workstation on site. Since the time on site is more costly than time in factory, any time savings on the overall installation should be prioritized. The proposed concepts for the horizontal assembly would, contrary to the results from the Boothroyd et al analysis, reduce installation times based on the removal of the temporary support, but also since the use of a normal fastener rather than the blind mounted fastener for the vertical supports and the door stopper wound reduce the overall installation time.

12 Conclusions

12.1 Final Recommendation

Ideally, one profile for both the vertical and horizontal could be used, since the lot size of the production runs would increase, and thereby reduce the per-unit costs. The J with flange solves the most issues, with a reasonable stress level in both the vertical and the horizontal assemblies. However, there is no way to attach the vertical supports to the profile without interference with the rollers, since there is no extra space in the J. If space was added, some of the advantages of the profile in the vertical assembly would be negated, since the connector plates would experience an increased torque due to the wind load, which would place further demands on the geometry and materials. Due to this, a single profile is hard to recommend. The gain from adding the flange is noticeable, but depending on the results of the connector plate development, the extra mass and incurred extra cost might be better spent on the connector plates. The recommendation would be to keep the J profile until more data is available.

In the horizontal assembly, the recommended profile would be the 'J-expanded, due to the low stress level, low displacement of the roller surface and low mass. The maximum displacement of the profile is high, but it occurs on the ridge of the profile and not where the door rests on it, lowering the displacement of the actual door. With cost reduction proportional to the mass of the profile, the per-unit price is approximately 20 % lower, if the concept connector and track bend is included, and the weight of the guiding track itself is approximately 30 % lower. With the revised assembly, an even lower per-unit price is expected, due to the reduced need for tooling, parts and labour. Additional savings could be achieved by shipping the horizontal assembly in a shorter format, shrinking the requirements on packaging size and thus lowering shipping costs.

12.2 Further Development

Continuing the development of the concepts, the manufacturing of the profiles should be considered further. The discussion addressed some of the issues in the development, such as manufacturability and the machine capacity. In order to establish a start-up cost of the potential change in profile, the cost of manufacturing new rollers and further manufacturing preparations required should be established, preferably in concert with the current manufacturer. A physical prototype of the selected concept should be constructed, and simulation results should be verified. The assembly sequence should be verified and timed in order to establish more precisely how much time has been saved, and feedback from installation technicians should be gathered.

An important aspect of the further development of this project is the life expectancy of the tracks. More specifically, the bend between the vertical and horizontal assemblies. The cyclic loading of the bends may potentially lead to material fatigue, and as the speed of the door increases with the OH1042S, the stress in the material increases. Constructing a physical profile would allow for cyclic testing and a life expectancy could be established.

J with flange in its current form is only suitable for the vertical assembly. Further development of the J with Flange profile, especially finding a way of mounting it in the horizontal assembly might be a desirable prospect as it would allow one and the same type of profile to be used in both vertical and horizontal assemblies. Using only one profile for both vertical and horizontal assemblies would remove the need to produce two profiles as is the case today (J profile for vertical, J+C for horizontal). Costs can be reduced if only one type of profile is to be manufactured, instead of two. Potentially, the profile could be expanded to allow room for a fastener, but that would introduce a bigger bending moment on the connector plates of the vertical assembly, or an external bracket hooking around the J could be developed. However, this bracket was excluded from the concept development in this report due to the lack of side-loading support.

Material selection is another aspect that could potentially be explored further. Given data from the already performed virtual testing as well as to be performed physical testing, it might be of relevance to look for a steel grade that optimally fits with the new design, property and economy-wise. The trade would be between an optimized roll forming setup and a lower material cost.

12.2.1 **Connector Plate**

The development of the connector plate should be with the aim to eliminate plastic deformation of the connector plate. The current manufacturer is intending to add sheet metal press forming machines in their facility, and the capacity of the future machines could influence manufacturable geometries.

12.2.2 **Horizontal Track Connector**

Integrating the functionality from more parts into the horizontal track connector could reduce the overall parts count of the entire OH1042 architecture, and thus reduce costs further. The development requires extensive experience with the product catalogue and configuration possibilities of the OH1042. Further needs on the track bend between the vertical an angled track indicated the need of a continuously adjustable angle between the vertical an angled track, instead of discrete angle changes of 5°, and it is possible that the continued development of the horizontal track connector could provide opportunity to fulfill that need. Interviews with engineers involved in the product development of the current tracks indicate that fatigue testing showed potential problems with the cyclic load of the bend, since most of the acceleration of the door happens in the bend, and the horizontal track connector could possibly alleviate some of the stress in the track.

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A Assembly Time Table

Handling times from Boothroyd et al used to calculate assembly times of different concepts and designs is presented in figure A.1, and insertion times in figure A.2. The tables are compiled from theory presented by Boothroyd [10, pp. 97-99, 105–118].

MANUAL HANDLING—ESTIMATED TIMES (seconds)

Key

ONE HAND

		parts are easy to grasp and manipulate					parts present handling difficulties (1)				
		thickness > 2 mm			thickness ≤ 2 mm		thickness > 2 mm			thickness ≤ 2 mm	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts can be grasped and manipulated by one hand without the aid of grasping tools: (α+β) < 360°	0	1.13	1.43	1.88	1.69	2.18	1.84	2.17	2.65	2.45	2.98
360° ≤ (α+β) < 540°	1	1.5	1.8	2.25	2.06	2.55	2.25	2.57	3.06	3	3.38
540° ≤ (α+β) < 720°	2	1.8	2.1	2.55	2.36	2.85	2.57	2.9	3.38	3.18	3.7
(α+β) = 720°	3	1.95	2.25	2.7	2.51	3	2.73	3.06	3.55	3.34	4

ONE HAND with GRASPING AIDS

		parts need tweezers for grasping and manipulation								parts need standard tools other than tweezers	parts need special tools for grasping and manipulation
		parts can be manipulated without optical magnification				parts require optical magnification for manipulation					
		parts are easy to grasp and manipulate		parts present handling difficulties (1)		parts are easy to grasp and manipulate		parts present handling difficulties (1)			
		thickness > 0.25mm	thickness ≤ 0.25mm	thickness > 0.25mm	thickness ≤ 0.25mm	thickness > 0.25mm	thickness ≤ 0.25mm	thickness > 0.25mm	thickness ≤ 0.25mm		
		0	1	2	3	4	5	6	7	8	9
parts can be grasped and manipulated by one hand but only with the use of grasping tools: α ≤ 180°, 0 ≤ β ≤ 180°	4	3.6	6.85	4.35	7.6	5.6	8.35	6.35	8.6	7	7
α ≤ 180°, β = 360°	5	4	7.25	4.75	8	6	8.75	6.75	9	8	8
α = 360°, 0 ≤ β ≤ 180°	6	4.8	8.05	5.55	8.8	6.8	9.55	7.55	9.8	8	9
α = 360°, β = 360°	7	5.1	8.35	5.85	9.1	7.1	9.55	7.85	10.1	9	10

TWO HANDS for MANIPULATION

		parts present no additional handling difficulties					parts present additional handling difficulties (e.g. sticky, delicate, slippery, etc.) (1)				
		α ≤ 180°			α = 360°		α ≤ 180°			α = 360°	
		size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm	size > 15 mm	6 mm ≤ size ≤ 15 mm	size < 6 mm	size > 6 mm	size ≤ 6 mm
		0	1	2	3	4	5	6	7	8	9
parts severely nest or tangle or are flexible but can be grasped and lifted by one hand (with the use of grasping tools if necessary) (2)	8	4.1	4.5	5.1	5.6	6.75	5	5.25	5.85	6.35	7

TWO HANDS required for LARGE SIZE

		parts can be handled by one person without mechanical assistance									two persons or mechanical assistance required for parts manipulation
		parts do not severely nest or tangle and are not flexible								parts severely nest or tangle or are flexible (2)	
		part weight < 10 lb				parts are heavy (> 10 lb)					
		parts are easy to grasp and manipulate		parts present other handling difficulties (1)		parts are easy to grasp and manipulate		parts present other handling difficulties (1)			
		α ≤ 180°	α = 360°	α ≤ 180°	α = 360°	α ≤ 180°	α = 360°	α ≤ 180°	α = 360°		
		0	1	2	3	4	5	6	7	8	9
two hands, two persons or mechanical assistance required for grasping and transporting parts	9	2	3	2	3	3	4	4	5	7	9

Figure A.1: Handling times in relation to part symmetry and size.

MANUAL INSERTION—ESTIMATED TIMES (seconds)

Key: PART ADDED but NOT SECURED

		after assembly no holding down required to maintain orientation and location (3)				holding down required during subsequent processes to maintain orientation or location (3)			
		easy to align and position during assembly (4)		not easy to align or position during assembly		easy to align and position during assembly (4)		not easy to align or position during assembly	
		no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)	no resistance to insertion	resistance to insertion (5)
		0	1	2	3	6	7	8	9
addition of any part (1) where neither the part itself nor any other part is finally secured immediately: part and associated tool (including hands) can easily reach the desired location	0	1.5	2.5	2.5	3.5	5.5	6.5	6.5	7.5
part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access or restricted vision (2)	1	4	5	5	6	8	9	9	10
part and associated tool (including hands) cannot easily reach the desired location: due to obstructed access and restricted vision (2)	2	5.5	6.5	6.5	7.5	9.5	10.5	10.5	11.5

Key: PART SECURED IMMEDIATELY

		no screwing operation or plastic deformation immediately after insertion (snap/press fits, circlips, spire nuts, etc.)		plastic deformation immediately after insertion						screw tightening immediately after insertion (6)	
				plastic bending or torsion			rivetting or similar operation				
				easy to align and position during assembly (4)	not easy to align or position during assembly		easy to align and position during assembly (4)	not easy to align or position during assembly			
		easy to align and position with no resistance to insertion (4)	not easy to align or position during assembly and/or resistance to insertion (5)		no resistance to insertion	resistance to insertion (5)		no resistance to insertion	resistance to insertion (5)	easy to align and position with no torsional resistance (4)	not easy to align or position and/or torsional resistance (5)
		0	1	2	3	4	5	6	7	8	9
addition of any part (1) where the part itself and/or other parts are being finally secured immediately: part and associated tool (including hands) can easily reach the desired location and the tool can be operated easily	3	2	5	4	5	6	7	8	9	6	8
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access or restricted vision (2)	4	4.5	7.5	6.5	7.5	8.5	9.5	10.5	11.5	8.5	10.5
part and associated tool (including hands) cannot easily reach desired location or tool cannot be operated easily: due to obstructed access and restricted vision (2)	5	6	9	8	9	10	11	12	13	10	12

Key: SEPARATE OPERATION

		mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-mechanical fastening processes (part(s) already in place but not secured immediately after insertion)				non-fastening processes	
		none or localized plastic deformation				metallurgical processes					
							additional material required				
		bending or similar processes	rivetting or similar processes	screw tightening (6) or other processes	snap fit, snap clip, press fit, etc.	no additional material required (e.g. resistance, friction welding, etc.)	soldering processes	weld/braze processes	chemical processes (e.g. adhesive bonding, etc.)	manipulation of parts or sub-assembly (e.g. orienting, fitting or adjustment of part(s), etc.)	other processes (e.g. liquid insertion, etc.)
		0	1	2	3	4	5	6	7	8	9
assembly processes where all solid parts are in place	9	4	7	5	3.5	7	8	12	12	9	12

CHART 2-2

Figure A.2: Insertion times in relation to handling difficulties.

B Distribution of Work

B.1 Work Distribution

Area of work	Work distribution	
	Kilian Gülich	Jakub Śnieżek
Analysing Current Design	50%	50%
Interviews	60%	40%
Customer Needs	50%	50%
Concept Generation	50%	50%
Benchmarking	50%	50%
Digital Prototyping	70%	30%
Simulations	50%	50%
Material Analysis	30%	70%
Manufacturing Analysis	40%	60%
Assembly Analysis	70%	30%
Report	50%	50%
Presentation	50%	50%

Table B.1: Work Distribution

B.2 Project Plan

The preliminary project plan that was presented in the beginning of the project is presented in figure B.1 and the actual project timeline is presented in figure B.2. Discussion of the project plan and preliminary plan is done in section 11.1.

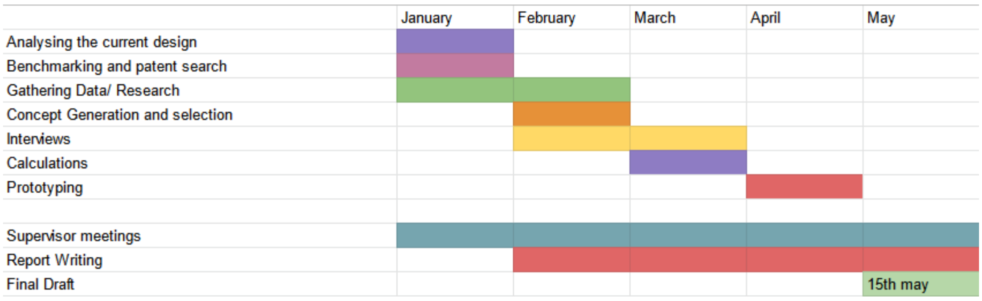

Figure B.1: Preliminary project plan from the start of the project.

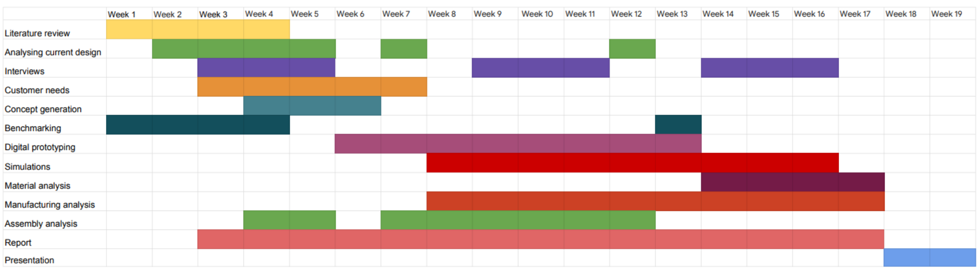

Figure B.2: Project timeline.