Redesign of Cross Frame with Recognized Design Methods

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Faculty of Industrial Engineering, Mechanical Engineering and Computer Science
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30 ECTS thesis submitted in partial fulfillment of a
Magister Scientiarum degree in Mechanical Engineering

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Abstract

The aim of this research is to study and compare different design methods, choose a method for redesign and use a case study to evaluate the outcome. This thesis will help Marel on its journey to implement better design processes.

A literature review of five design methods was conducted and their tools and techniques explained. These methods are Six Sigma, Stage-Gate, Lean (Lean Product Development), Design Structure Matrix and Model Based Design.

This case study is a cross frame from StreamLine weldment, manufactured by Marel. The LPD and Model Based Design were evaluated to be the best-suited methods for this case study. The redesign was carried out by finding, identifying and closing Knowledge Gaps. In Model Based Design method a Finite Element Model and a Cost model were built to verify the results of the redesign.

The findings from this study show that appropriate design method can improve the quality of design work. The redesign is better qualified for cleaning and has less manufacturing cost.

Útdráttur

Markmið þessarar rannsóknar er að rannsaka og bera saman mismunandi hönnunaraðferðir, velja aðferð til endurhönnunar á þvergrind og meta hönnunina. Ritgerð þessi mun vonandi hjálpa Marel hf. í leit sinni að bættri hönnun.

Heimildavinna um fimm hönnunaraðferðir var unnin, tækni og verkfæri þeirra skoðuð og skýrð. Þessar hönnunaraðferðir voru Six Sigma, Stage-Gate, Lean (Lean Product Development), Design Structure Matrix og Model Based Design.

Viðfangsefnið var þvergrind úr StreamLine suðusamsetningu, framleitt af Marel hf . LPD og Model Based Design voru metnar hæfastar fyrir þetta viðfangsefni. Endurhönnunin var gerð með því að finna þekkingarbil, skilgreina þau og svo loka þeim. Í Model Based Design voru búin til Finite Element líkan og kostnaðarlíkan til að staðfesta niðurstöðuna.

Niðurstöður þessarar rannsóknar benda til að með viðurkenndum hönnunar aðferðum megi bæta gæði hönnunar. Endurhönnunin er betri með tilliti til þrifanleika og er jafnframt ódýrari í framleiðslu.

To my wife and children,

Thank you

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Last but not least I want to thank my family for doing everything possible and impossible to help me accomplish my goals.

1 Introduction

„Good design is good business“(Thomas J. Watson, n.d.). This is a concept many companies have realized but most struggle to make it happen. A lot of resources have been invested into various design departments to get newer, better or/and smarter solutions than already exist today. Some companies manage to produce a good design but others fail.

Marel is a leading producer of advanced equipment serving the fish, meat and poultry industry and it was founded in 1983 (Ólafsson & Hermannsdóttir, 2009). Since it was founded the company has been striving to produce the best designed equipment for the market. Marel is a multinational company with over 4000 employees in over 30 countries in 6 continents (Marel, n.d.).

One of Marel’s biggest challenges is to maintain the advantage they currently have over their competitors and to do so the company continuously has to design and produce innovative solutions for the market at affordable prices. Competitors are always trying to find ways to be faster, smarter and cheaper. Marel spends about 6-7% of their revenues in innovation every year but currently it looks like competitors are gaining momentum and thereby threatening Marel’s leading position (B. M. Karlsson, personal communication, March 17, 2014).

Marel’s team of designers have the aim to be leading in their field of expertise. The designing tools they use are similar to what other companies are using. The fact that Marel is losing its leading position is due to the fact that innovation is not providing enough new products. Marel has innovation processes that deal only with how to bring a product to the market but not how do design the product in a best way. Designers start the design process using SolidWorks without having all the necessary information needed and therefore a problem occurs late in the design process or when the equipment has been launched. This is a very time consuming and it is extremely costly to modify designs or built equipment late in the process (B. M. Karlsson, personal communication, March 17, 2014).

The aim of this research is to study and compare different design methods, choose a method to redesign a cross frame and evaluate the outcome. This thesis will hopefully help Marel on its journey to implement better design processes. The cross frame is a weldment in the StreamLine® flowline, it binds together the stations of the line. This item is a fundamental part in the structure of StreamLine® and it is designed to be stiff. It needs to be redesigned to lower costs and to increase the ability to clean the part, because cleaning is one of the most important things in food safety.

In this thesis five design methods will be examined. This will give basic understanding of the methods and act as a platform that can be used to take a decision about which approach is best suited to apply to the redesign. The methods reviewed are:

- Six Sigma
- Stage-Gate
- Lean(LPD)
- Design Structure Matrix
- Model-Based Design

When the design methods have been viewed and explained the case study item is introduced. The case study item is a cross frame from Marel which is a part of a flowline called StreamLine.

The method that was best suited was Lean product development. In that method Knowledge Gaps were used, gaps will be found, classified and closed. Model-based design will be used to verify the design, both finite element and cost models will be made

In the Methods chapter the design methods will be reviewed and explained. In the Results chapter the case study will be introduced, the methods fitted to the task and new design introduced and verified. Finally the Conclusion chapter is a summary of the work done and what can be done in the future to continue with this project.

2 Methods

There are many design methods to choose from and they all have the common goal of improving the design.

The focus areas of the methods are almost as many as the methods but the focus points that are most noticeable are cost, creativity and quality. In this chapter the following five design methods will be reviewed:

- Six Sigma
- Stage-Gate
- Lean (Lean Product Development)
- DSM
- Model-based design

The aim of this study is to identify the best suited design method for a redesign on a case study.

To gather information on the case study, interviews with Marel employees were carried out. The interviewing was based on ´native category´ approach (Buckley & Chapman, 1997; Harris, 2000), involving extensive conversations about beliefs and perceptions around non-directive questions rather than directed questions derived from theory. The interviews were partly structured to direct discussion to relevant topics, such as StreamLine and manufacturing tools and habits (Eisenhardt, 1989).

2.1 Six Sigma

The Six Sigma method is a project-driven tool to improve the organization's goods, services, and procedures by constantly reducing defects in the organization (Kwak & Anbari. 2004). Motorola in the 1980´s was the first one to use Six Sigma in a mass manufacturing environment for the purpose of meeting demanding quality targets (Harry, 2008). Six Sigma became a world famous winning formula that was later used by other corporations such as General Electric to restructure their company (Folaron & Morgan, 2003).

Six Sigma is originated from statisticians and statistics. It targets to have only 3,4 defects per million opportunities (DPMO) and for a very high quality control level 99.99966% opportunities are satisfactory. Some companies choose to use a less aggressive quality control but still rely on the sigma system. Those companies then use lower sigma numbers DPMO. For example 3 Sigma allows 66.810 DPMO, that is 93,3% satisfactory opportunities (Linderman, Schroeder, Zaheer & Choo, 2003).

In Figure 1 the relationship between process Sigma and DPMO can be seen.

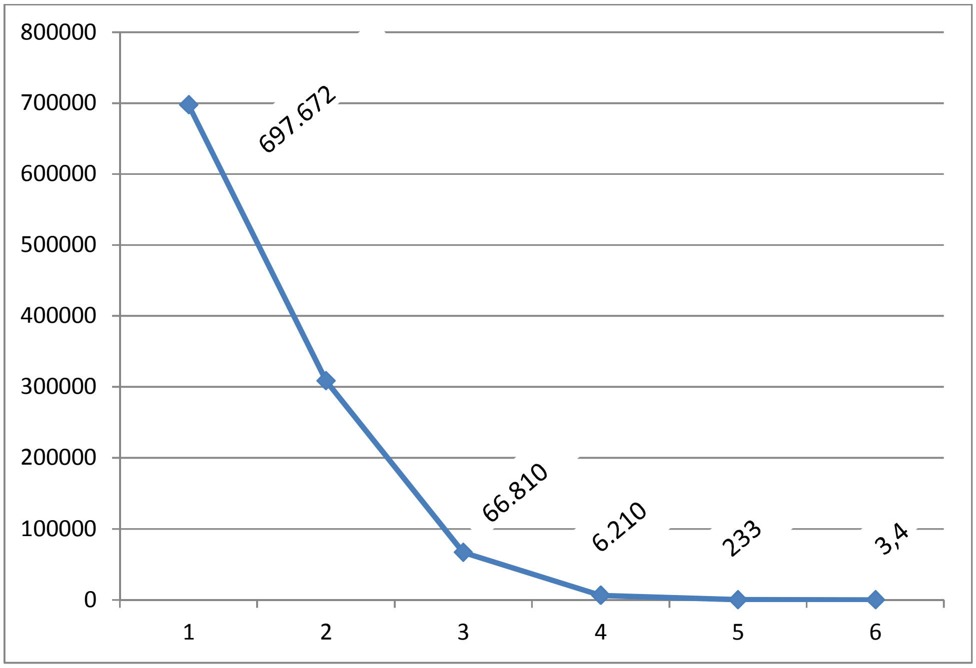


Figure 1: Relationship of Process Sigma, x-axis, and DPMO, y-axis. (Adapted from Linderman, Schroeder, Zaheer & Choo, 2003)

One of the cornerstones of Six Sigma is to get an organization on level of Sigma ability with the use of statistical tools and techniques (Antony & Banuelas, 2001).

One of the main principles of Six Sigma is that quality is everyone´s responsibility. The system has its own infrastructure that focuses on the individual who should possess each role. The infrastructure is as follows:

Steering team
- CEO and some or all members of the senior team
- Team is responsible for strategic decisions and therefore needs to:
  - Guide the Six Sigma change by creating a clear vision and mission and relate it to the projects in a visible manner
  - Observe and influence the development of projects
  - Have a clear overview of projects and their connections to goals
  - Synchronize cross-function events such as training

Champions
- Non-executive role within the Six Sigma team
- Supports the project and is a connection point to the Steering team

Master black belt
- A guide and a helping hand to the Black belts and Green belts. Master Black belt consults with Champions in order to provide projects with full support

Black belt and Green belt (Knowles, 2011)
- Project leaders and they are responsible for the results.

- Responsible for that the project follows the steps of the DMAIC process
- According to Keller (2010), Black belts and green belts must be:
    - Optimistic
    - Risk appetites
    - Interact well with others
    - Leaders

One of the main processes in Six Sigma is the DMAIC process. The name stands for: Define, Measure, Analyse, Improve and Control. This is used mostly with continuous improvements in manufacturing (Kwak & Antbari, 2006).

Design for Six Sigma is a methodology that locates flaws in current processes and it is used in design as well as it emphasises on purchaser´s feedback to the product. This methodology includes a process called, DMADV; Define, Measure, Analyse, Design and Verify (Knowles, 2011).

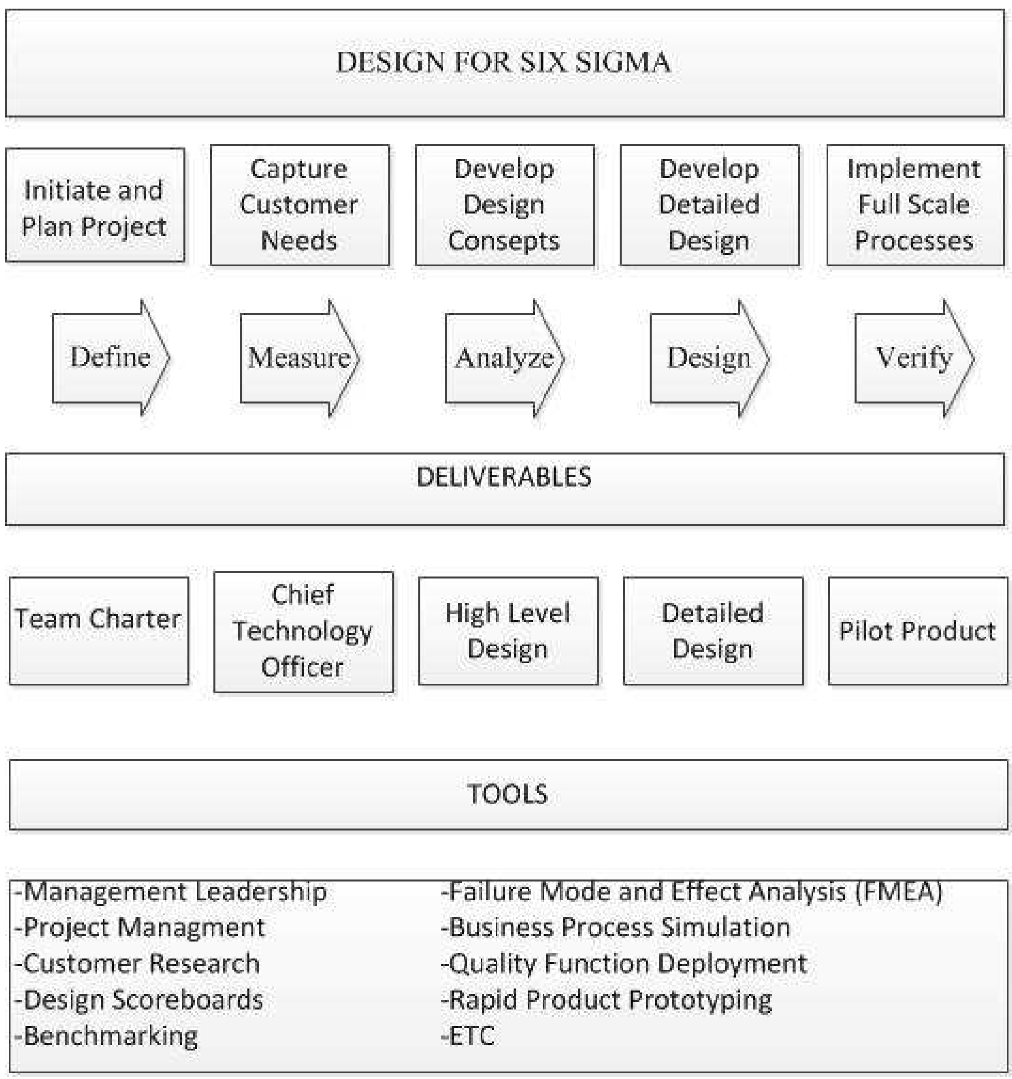


Figure 2: Design for Six Sigma. (Adapted from Kwak & Anbari, 2006)

Design for Six Sigma has many supporting tools as can be seen in Figure 2. These tools are used for different design applications. When using the tools it is necessary to hold the cornerstones of DFSS in place and that is, Define, Measure, Analyze, Design and Verify (Kwak & Anbari, 2006).

2.2 Stage-Gate

Stage-Gate was first used in 1988 by Cooper (2001) as a term to explain new way of innovation and he described it as a faster, better and more streamlined way to bring ideas to launch.

Stage-Gate is a roadmap to get new-product projects from idea phase to reality. In this method the total process is divided into stages, which are separated with management decision gates, see Figure 3. Cross functional teams must finish a set of activities in each stage so that the project gets to proceed to the next stage. If the project fails to finish the predefined sets of activities, the project is terminated (Copper & Kleinschmidt, 2001).

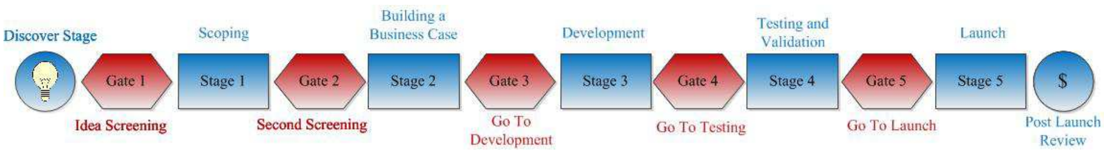


Figure 3: Stage-Gate process (Adapted from Product development institute Inc.®)

Within every stage a cross-functional team undertakes key activities to make sure the project is qualified to next stage. These teams are cross-functional because the activities in a stage are diverse. This is done so that there will not be too much emphasis on one aspect of the project in the beginning. That could leave the project owner with a very hefty bill on a project that will never work (Cooper, 2001).

Each step is more expensive than the previous one. This is because as the projects advances through more stages the uncertainty reduces and expenditures are allowed to rise (Cooper, 2001).

A traditional Stage-Gate model has 5 stages and 5 gates. This number is not cast in stone and the number of gates and stages can vary. In every stage certain activities must be completed and verified. The flow of product through the stages from idea to launch can be seen in Figure 4 (Cooper & Kleinschmidt, 2001).

The 5 gates are following:

Stage 0; Discovery: Activities done to find new ideas and openings.

Stage 1; Scoping: Fast and inexpensive estimate of technical- and marketing sides of the project. A SWOT analysis is completed. SWOT stands for Strengths, Weaknesses, Opportunities and Threads.

Stage 2; Building the business case and plan: In this stage the project is still in concept design and an accurate research must be done on every aspect of the project. If a project passes through this stage it goes from being in concept development to being developed. As this stage is large and important it is often split up to 4 phases:

1. Product definition and analysis
2. Building the business case
3. Building the project plan
4. Feasibility review

Stage 3; Development: In this stage the plans that have been made in previous stages are put into action. Further development and design of the project takes place in this stage, as well as the strategy for next stages is designed and plans such as manufacturing plan and, marketing launch and operational plan are made.

Stage 4; Testing and validation: In this stage the project is tested and validated. Not only is this done to the project but also to production/manufacturing procedures, customer recognition and finances of the project.

Stage 5; Product launch: Project is put to full production and marketing and sales team go in full action on promoting and selling (Cooper, 2001).

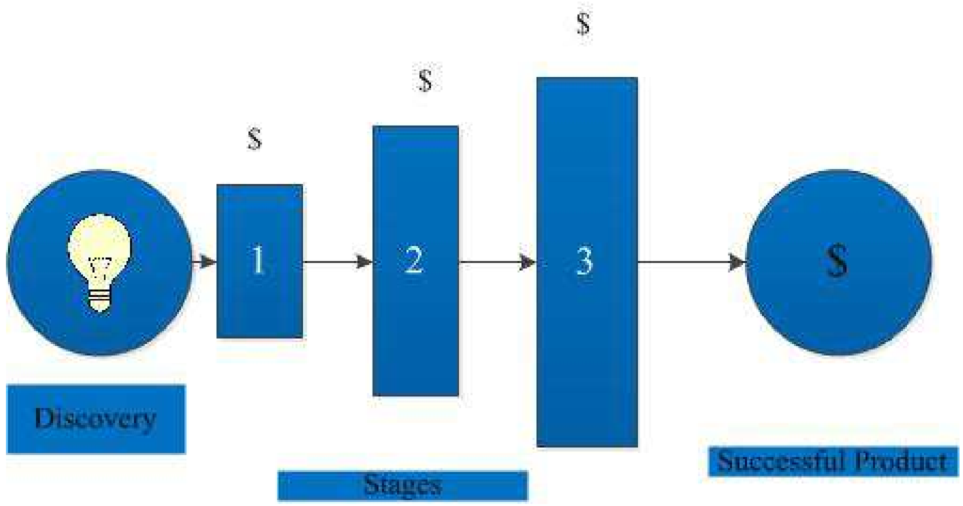


Figure 4: Shows the flow from idea to product through stages (Adapted from Product development institute Inc.®)

Within every stage there is a fixed set of activities to complete. The cross-functional team must complete the set of activities, analyse the outcome and finally form a suitable presentation with the deliverables, simplified version of this process can be seen in Figure 5 (Cooper & Kleinschmidt 2001).

Figure 5: Simplified process of what happens in a stage within Stage-Gate (Adapted from Product development institute Inc.®)

When going through a gate a project must fulfil certain demands to be allowed to proceed or else it is terminated or held back. The setup of gates is similar between gates. The deliverables from the presentation are compared to demands. From this comparison an outcome is made, this outcome has to have a firm result (go/terminate/hold/recycle) and a track onward, simplified version of this process can be seen in Figure 6 (Cooper, 2001).

Figure 6: Simplified process of what gates do in Stage-Gate (Adapted from Product development institute Inc.®)

The gates are the following:

Gate 1; Idea Screen: Here the idea goes through a light screening. In this gate the idea has to pass certain 'must-meet' and 'should-meet' criteria. These criteria could be for example, technical feasibility, alignment with the company's strategy and marketing attractiveness.

Gate 2; Second Screening: Here the idea is screened again. Extra information has been gathered in previous stage. Still the idea must pass through a certain 'must-meet' and 'should-meet' demands. These demands are stricter than in gate 1. After this gate the idea goes to stages that are more expensive for the company and therefore this screening must terminate bad ideas.

Gate 3; Go to Development**:** Here is the main gate in a lifetime of ideas. After this gate the company has to invest considerably to proceed with the idea. This gate is often nicknamed 'Sign off gate'.

Gate 4; Go to Testing: Here the development work is reviewed and everything is checked off to see if the product is as stage 3 demands.

Gate 5; Go to Launch**:** This is the last place where the project can be terminated. If it passes through this gate it proceeds to production and sales (Cooper 2001).

If the idea passes through all stages and gates than it will come out as a fully developed product that is ready for mass production and sales.

2.3 Lean

The birth of Lean predecessors was within Toyota around 1940. Toyota wanted to produce in a steady flow, which did not rely on long production runs to be efficient. They found a system called ´Toyota production System (TPS)´ and from that system Lean grew. TPS was built around the idea to produce many models in small amounts and not mass product (Ohno, 1988).

Lean got its own identity in an article named "Triumph of the Lean Production System," by John Krafcik (1988). The principles of Lean are:

- Identification of value
- Elimination of waste
- Generation of flow (Womack &Jones, 1996)

Main tools to be able to perform these principles are:

- Kanban
  Graphic sign to support stream by pulling invention through the industrial procedure as required by the customer. Kanban mean “card you can see” in Japanese. The name says it all because no item is made or moved without a card being made so that it is noticeable to everyone what and how things are done.

- 5 S’s
  Graphical method to keep the manufacturing floor under control. This is not just housekeeping, it is a method to have all items in place to eliminate the waste of looking for an item.

- Visual control
  Visual control is a technique where control of an activity or procedure is made easier or more effective by considered use of visual indicators. These indicators can be of many forms, from different colored uniforms for different teams to visual signs.

- Poke Yoke
  A fault proofing method that creates a visual signal that make mistakes stand out from the rest.

- SMED
  Single Minute Exchange of Dies (SMED) is a manufacturing method for a quick turnover of tools. Turnovers can take a lot of time and that time is a waste and this method decreases that waste (Womack & Jones, 1996).

To eliminate waste is one of Lean’s main goals. Ohno (1988) defined seven types of waste, these types are the following:

- Transport
  Moving an item when it is not necessary

- Inventory
  Products not being used, just waiting

- Motion
  Employees walking when it is not needed

- Waiting
  Delay in production makes employees wait, change of shift makes production wait

- Overproduction
  Produce product that will not be used

- Over Processing
  Going too far with a product, adding extra to a product that the costumer is not willing to pay for

- Defects
  If a product has defects and needs to be reworked

The work of eliminating waste is a continuous quest and as techniques and every day working environment evolves new waste can be found. Emiliani & Stec (2004) presented the eighth waste to add to Ohno list and it is defined as:

- Behavior
  Behavior that does not add value for the customer

Even though it seems a negative approach, Lean is not only about eliminating cycle time, cost or waste. It´s main purpose is to maximize values by ensuring that efforts are put on the right places on the right time. Lean is a continuous quest to eliminate waste, and therefore add value, by any tool or technique (Aggrwal, 2013).

2.3.1 Lean Product Development (LPD)

Lean can be utilized in product development processes to enhance performances of departments.To be able to implement Lean in Product Development it is necessary to fully understand the concept and objectives of Lean (Aggrwal, 2013).

Traditional product development focuses on shortening cycle time while LPD focuses on eliminating waste in product development and by that adding value. Waste can be found in time, space, people, machines, information and more (Gershenson & Pavnaskar, 2003).

Sobek II (2012) defines good product development as the one that constantly produces profitable operational value streams. He defines LPD as “A system that consistently produces profitable operational value streams, that meet customer needs, while minimizing waste” (Sobek, 2012. page. 3).

Sobek II (2012) defined the 5 principles of LPD:

1. Rapid Learning Cycles
   Rapid learning is the key to a profitable innovation. Every employee must be steadily improved. That means improving their knowledge and ability to recognize problems, solve problems, gain knowledge in problem solving and share this knowledge with others (Sobek II, 2012).

This is a part of the PDCA process, Plan, Do, Check, Act. In each stage there are certain steps that have to be taken.

Plan

- Get all of the information and the right information
- Set goals and targets
- Create plans
- Discuss with others affected

Do

- Execute the implementation plan

Check

- Compare the results from Do to your Goals and targets
- Measure the outcome to see if it is sufficient

Act

- If targets are not meet do the PDCA again with modifications
- If targets are meet, criticize the process to learn from it and educate others on this outcome

This is the foundation in first principle. Problems should be divided into small cycles so that they can be addressed in details.

2. Teams of experts
Assemble team of experts in every field that will affect the project. The experts must gain knowledge with the step above. These experts work in a group so that focus shall be on all aspects of the project and not just one or two.

3. Entrepreneur System designer
This is the project leader, he must have a clear vision and knowledge of the customer needs. He works cross-functional with the experts. He is responsible for the new design, manages the project and creates the product vision.

For the ESD there are some tools that can be used, for example Project room and Team planning board. ESD must integrate both technical details and tasks of the project and deliver strong market performance.

4. Set-based concurrent engineering
There are some main principles of SBCE that have to be respected and used.

- Study first
- Optimize the system
- Assure practicality before commitment

Do not go on with just one idea, have a set of ideas and allow them to merge together to make the best solution (Sobek II, Ward & Liker, 1999).

Investing in knowledge is expensive but it will pay off because the true cost in product development projects are when changes must be done in late stages, see

Figure 7. Then it would have been better to have acquired the necessary knowledge beforehand (Söderberg, 2011).

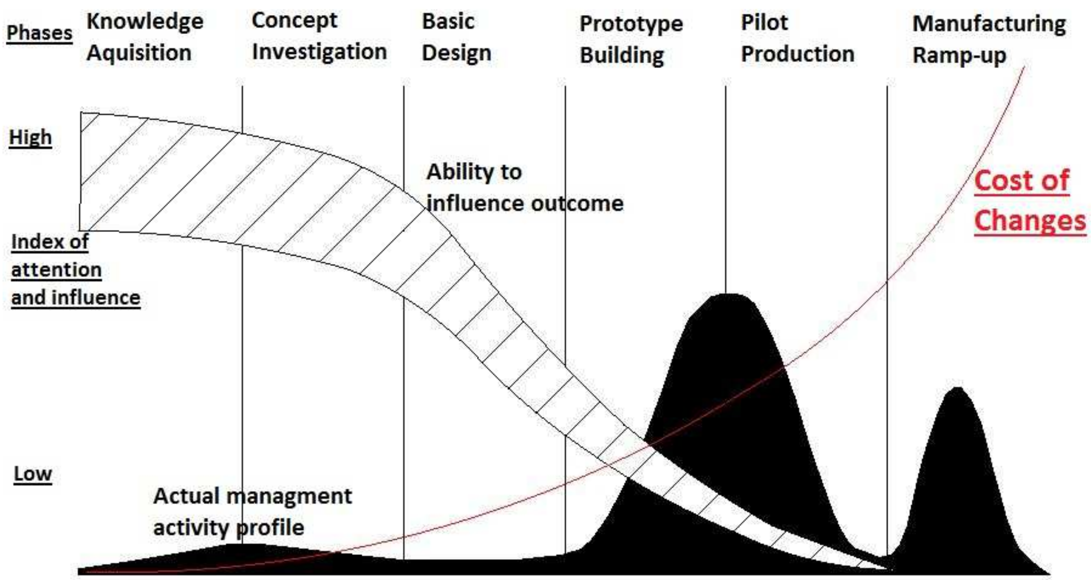


Figure 7: Chart showing cost of changes in design versus lifetime of project in design (Adapted from Wheelwright & Clark)

With many ideas working towards one solution it is likelier to find the ultimate solution than there is with Point-based methods (Sobek II, 2012). Figure 8 shows the difference in methods.

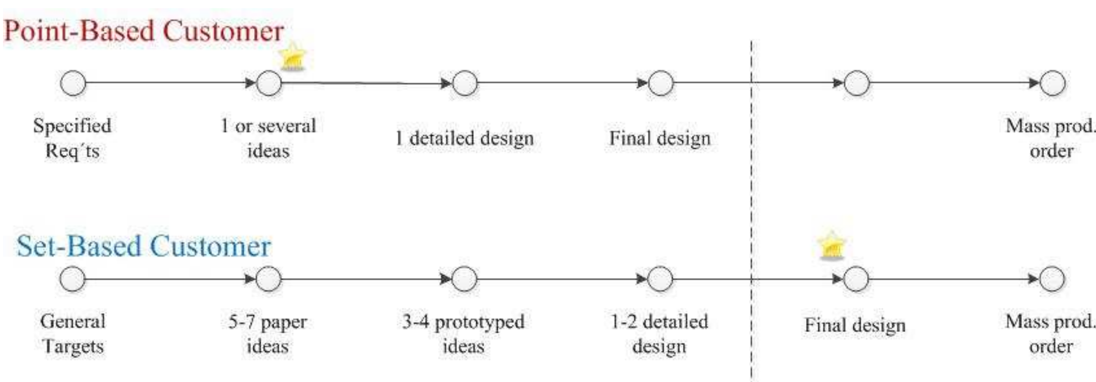


Figure 8: Difference between point-based and set-based design (Adapted from Sobek II, 2012)

5. Flow, pull and Cadence.
   Have a clear vision on how to let the project flow through design. Find and eliminate waste so the all efforts can go in designing (Sobek II, 2012).

Many tools have been taken from Lean manufacturing and altered to Lean Product development. Gershenson and Pavnaskar (2003) transformed some of Lean manufacturing methods to LPD, see Table 1.

Table 1: How Lean tools have been transformed into LPD (Adapted from Gershenson and Pavnaskar, 2003).

Lean manufacturing tool	**Analogous lean product development tool**
Value stream mapping	Product development value stream mapping
Just in time	Just in time product development
Pull system	Quick response product development
Kanban	GOLCAD
Load leveling	Design task heijunka
Pokayoke	Machigaiyoke
Single minute exchange of die	Single minute exchange of projects
Kaizen	Kaizen

Some tools have been made especially for LPD and one of these tools is Knowledge-Gaps (Radeka, 2014).

- Knowledge Gap

Knowledge Gap is the space between the current level of knowledge and the knowledge needed to solve a problem. To bridge that gap it is necessary to search and gain knowledge. In all design methods it is necessary to gain information but usually the information is solution/problem affected, therefore design teams go very soon to prototype phase. Often many Knowledge Gaps have not been closed before prototype phase is entered, resulting in unexpected situations later in the design process. Knowledge Gap method makes design teams front load but in the end it will diminish the likelihood of redesign in later stages of the design (Radeka, 2011).

In the start of projects the Knowledge Gap is big and as the search for answers continuous the Knowledge Gap only gets bigger because at the beginning all the unknown are not visible. But as the work goes on the Knowledge Gap slowly gets smaller and smaller, this can be seen on Figure 9.

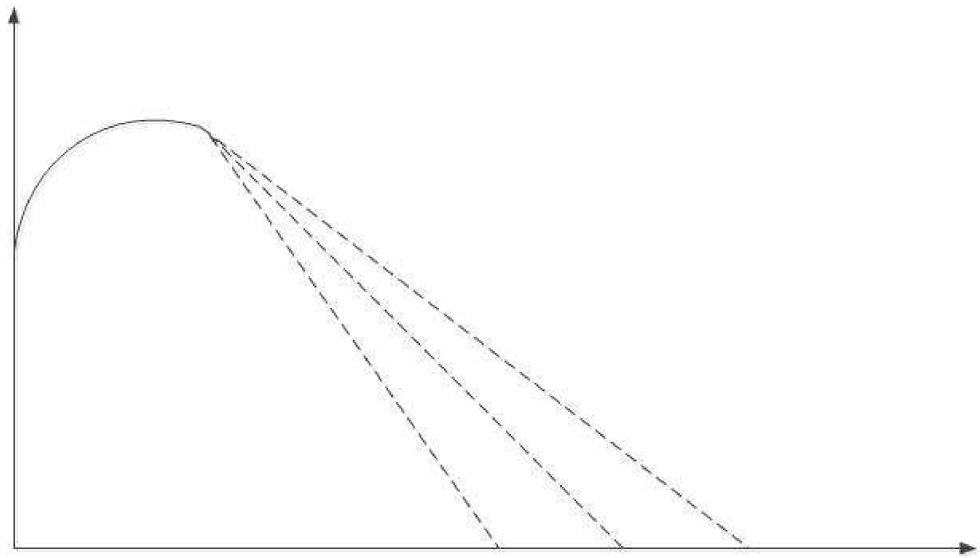


Figure 9: Relations between Knowledge Gaps and time, time is on X-axis. (Adapted from Holmdahl)

To identify all the Knowledge Gaps can be tricky but an open mind and multi-dimensional approach is a good start. Below are some ways to find Knowledge Gaps:

- Find all known Knowledge Gaps and list them up
- Study the previous versions or models, list up what makes this a “new” product. Also list up the specification of the new item, throughput, size or where changes should be made
- Study other design processes and try to see what Knowledge Gaps went missing in previous design
- Scrutinize the known Knowledge Gaps. Is it guaranteed that the information that the Knowledge Gap is built on is correct? If not find better information and write down a new Knowledge Gap (Radeka, 2011).

2.4 Design structure Matrix (DSM)

Design Structure Matrix (DSM) is a method to supervise and organize complex research and development projects (Danilovic & Browning, 2006).

Design has often been a black box for researchers because of its lack of scientific methods. Eppinger, Whitney & Gebala (1992) tried to explain and structure better design processes. They claimed that design activities were well recognized but not well understood. Their goal was to better the understanding of new and recognized design processes. Designers must be on a constant quest to improve and should ask questions like:

1. “Why does it take so long to develop each new generation of our product?”
2. “Which engineer functions might be combined to accelerate design process?”
3. “Where is communication most important?”
4. “What are the driving factors in our design problem?”
5. “How can we implement concurrent engineering?” (Eppinger, Whitney & Gebala, 1992, p.301)

To help in this quest a design management strategy was developed. By drawing up the design process into a clear array exemplify the complex inter-relations among the many design tasks that must be accomplished. Tasks in the design will be given a name. Then tasks are valued on dependencies between them and finally tasks must be classified (Eppinger, Whitney, Smith & Gebala, 1994; Steward, 1981):

- Parallel if the tasks can be run simultaneously and no data between tasks are needed
- Serial if one task can´t be run until another one is done, data must go from task A to task B before design on task B can start
- Coupled if information needs to go from task A to task B and again from task B to task A

In flowcharts it is not always obvious to see the right sequence of tasks. In the flowchart in Figure 10 it is maybe not easy to see how decision C has to be done before decision B and Decision E before Decision D. To simplify this, decisions/tasks are put in a design matrix, see Table 2.

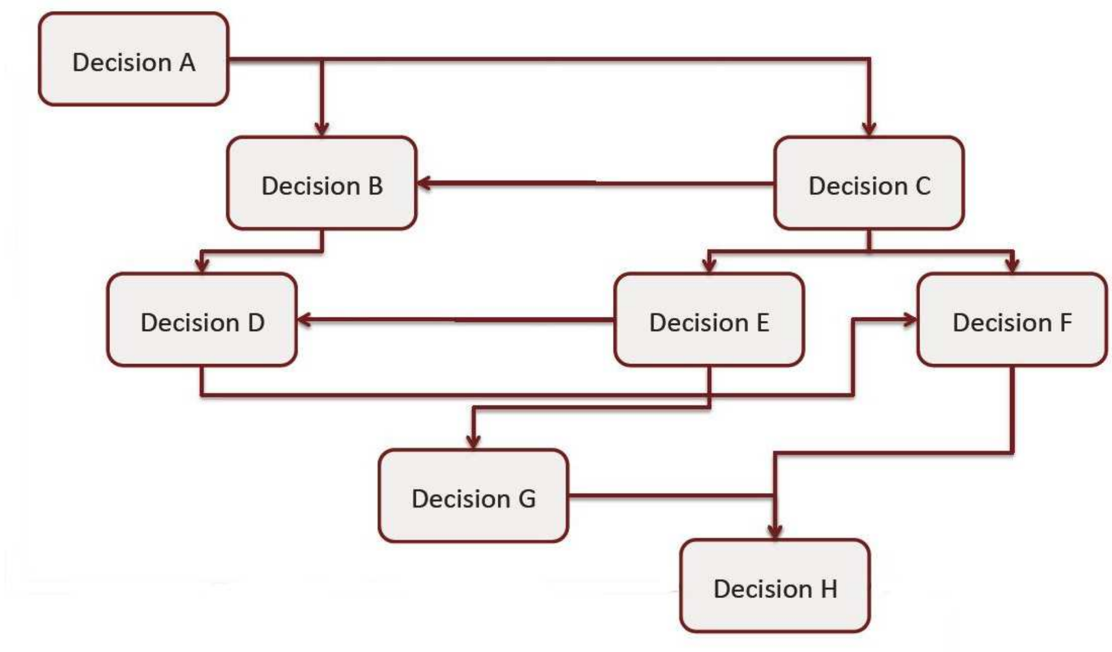


Figure 10: Flowchart of decisions in design process. (Adapted from Radeka, 2012)

Now the information on which decision is dependent on which decision is put in the matrix. Working in columns, identify the inputs for each decision or Knowledge Gap. Place Xs in the boxes with row entries that represent decisions that need to be made or Knowledge Gaps that need to close before we can finalize the decision in the column. In Table 2 the dependencies of decisions have been added in (Radeka, 2012).

Table 2: Tasks put in the matrix after dependencies. (Adapted from Radeka, 2012)

	Dec. A	Dec. B	Dec. C	Dec. D	Dec. E	Dec. F	Dec. G	Dec. H
Dec. A		X	X					
Dec. B				X				
Dec. C		X			x	X		
Dec. D						X		
Dec. E				X			X	
Dec. F								X
Dec. G								x
Dec. H								

Lines in the matrix represent decisions that are precursor to the decision in the columns. In the matrix here above, Decision C has to be done before Decision B, Decision E has to be done before Decision D. With this information the matrix can be rearranged so that Tasks/decision can be lined up better, see Table 3.

Table 3: Tasks rearranged in matrix after dependencies. (Adapted from Radeka, 2012)

	Dec. A	Dec. C	Dec. B	Dec. E	Dec. D	Dec. F	Dec. G	Dec. H
Dec. A		X	X					
Dec. C			X	X				
Dec. B					X	X		
Dec. E					X		X	
Dec. D						X		
Dec. F								X
Dec. G								X
Dec. H								

Now the matrix has been rearranged and then the way through the project is much clearer. It is also best to end on Decision H because that task has no output and is therefore not a precursor to any task/decision (Radeka, 2012).

2.5 Model Based Design

The origins of model based design can be tracked back to the early 90´s of last century. The big players in that field were the aerospace and automotive industries, which were trying to install microprocessors in their products. Designers in these sectors realized the benefits of simulating multi domain systems for the purpose of developing embedded controls (Lennon, 2007).

Methodology for model-based design is analyzing and predicting the behavior of a structure using a model. A structure or system has to have boundaries and a solution that is realistic and optimum. Usually modeling has four stages:

- Defining a model
- Building a model
- Verifying a model
- Analyzing a model (Jónsson, 2008)

When building a model it is necessary to withhold those four stages. But model-based design is a way of evaluating the model or problem that has been replicated by a model. The steps that have to be taken can be seen in Figure 11.

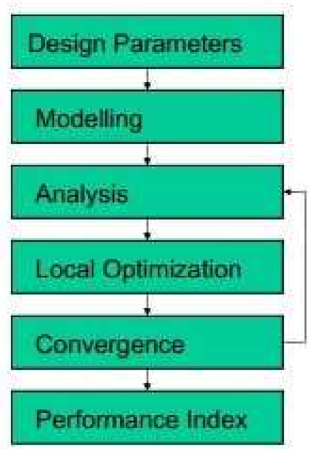


Figure 11: steps of model-based design (Adapted from Jónsson, 2008).

The rise of CAD/FEA software have made model based design easier. Designers can set models up easily and constantly test projects as they evolve. Requirements are set in the beginning of projects and they get tested so that mistakes or bad design are cut out early in the design process. It is very costly to do changes on latter stages of the design process (Lennon, 2007).

3 Result

To test the design methods it is good to have a case study to design and evaluate. In this chapter the selected case study, a cross frame, will be reviewed, design method will be fitted to the case study and finally the redesign is made.

3.1 Case Study

StreamLine is a trimming line for pork and cattle carcasses. The meat enters the production line and is weighted on the main belt. From there a specific piece of meat is put into a specific station. StreamLine is made up of multiple stations and in each station a trained meat tradesman works. The tradesman trims the piece of meat and sorts trim in 2-4 categories. The primal is put on a scale, in the station, and there it is ejected onto main belt again. From the station the piece could go to packing but it could also go into another station if it needs more cuts or more trimming. This is all monitored by the software that controls StreamLine, this process is fully automatic. Longest line that has been manufactured is 36 stations, which is about 40m from one end to another, this means that the main belt is over 80 meters long. Stations are on both sides of main belt see Figure 12.

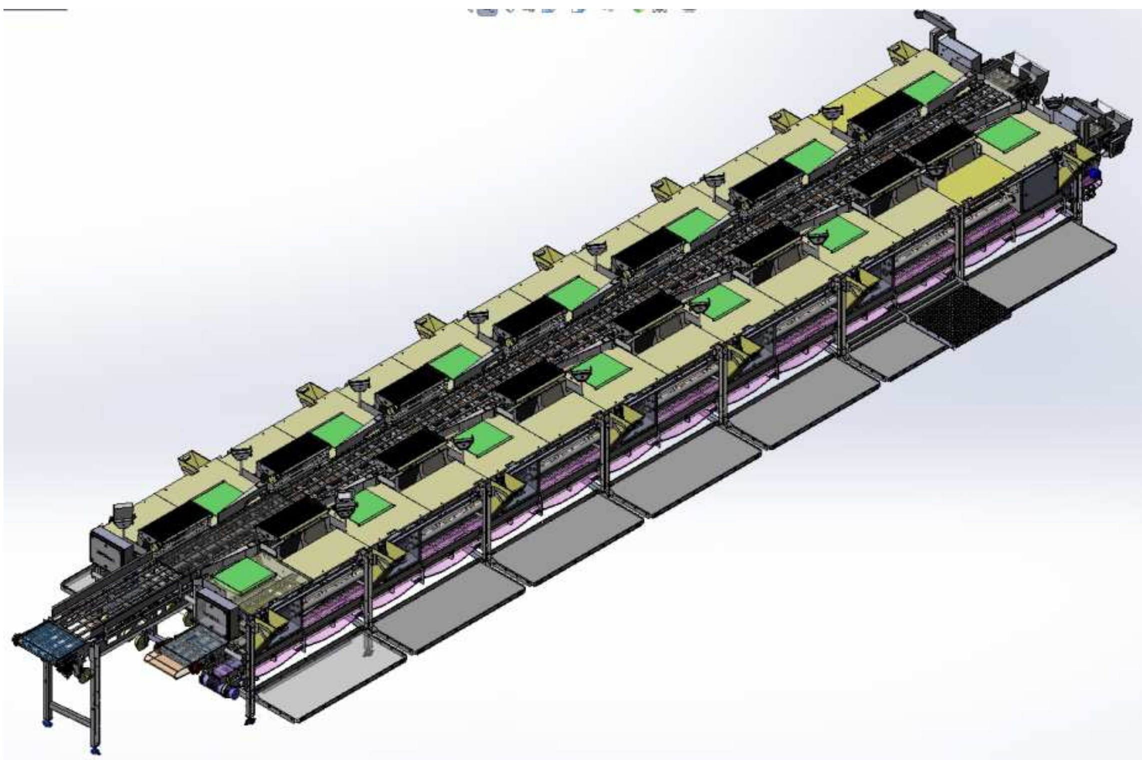


Figure 12: StreamLine with 14 stations.

As can be seen on Figure 13 stations have an arm that brings products to the station and a scale that weighs the product and puts it back on the main belt. To have such a complex mechanism it is necessary to have the foundations very stiff so that vibration will be minimized.

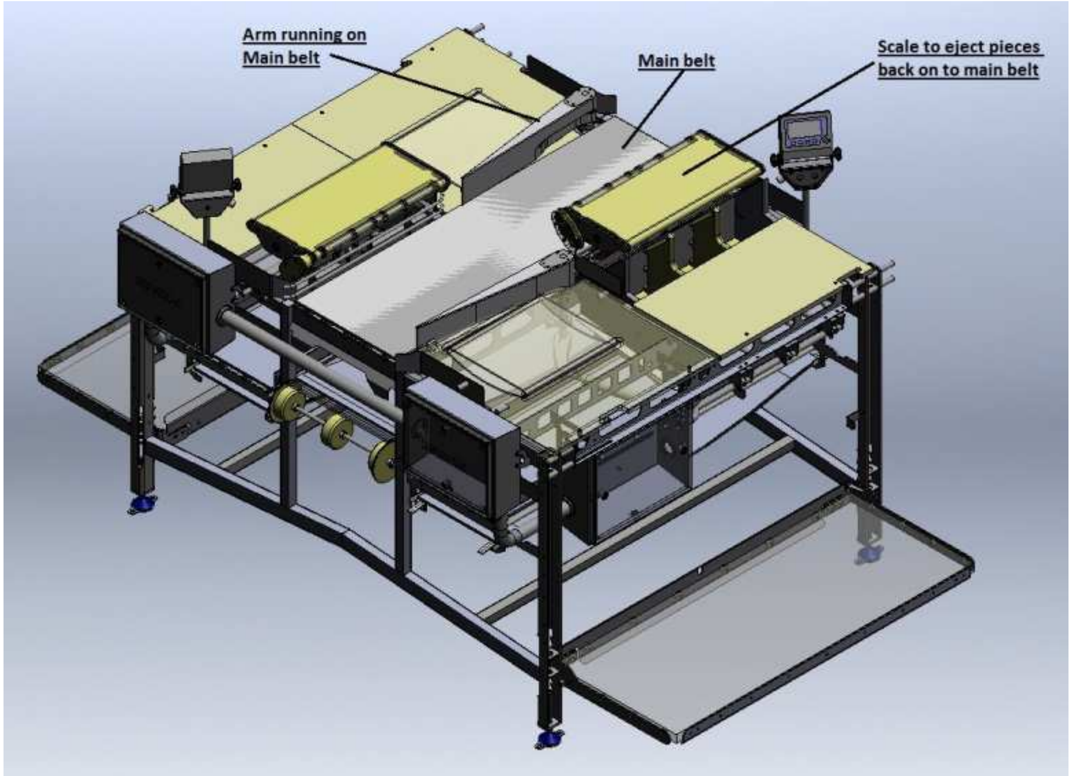


Figure 13: Dual station in StreamLine

When taking a piece of meat into a station the arm has to absorb high forces. The pieces can be up to 20 kg and friction to the belt can be high due to blood and the composition of meat. The air cylinders that control the arm movement have a radius of 20 mm and can produce force up to 600 Newton. Simultaneously the scale needs to weigh the product and then release it on to the main belt. The scale needs a stable environment, to be able to give correct weighing, therefore vibration shall be minimized (U. Grétarsson, personal communication, April 10, 2014).

In retrospect of this the weldment structure of StreamLine was designed to tolerate all this but there is a related issue that has to be addressed. Cleaning of the product line must be easy so that bacteria will not have an easy access to the final product. The rigid structure of the StreamLine has been seen as a disadvantage when it comes to cleaning.

In this project the cross frame of the StreamLine is redesigned. The original cross frame can be seen on Figure 14.

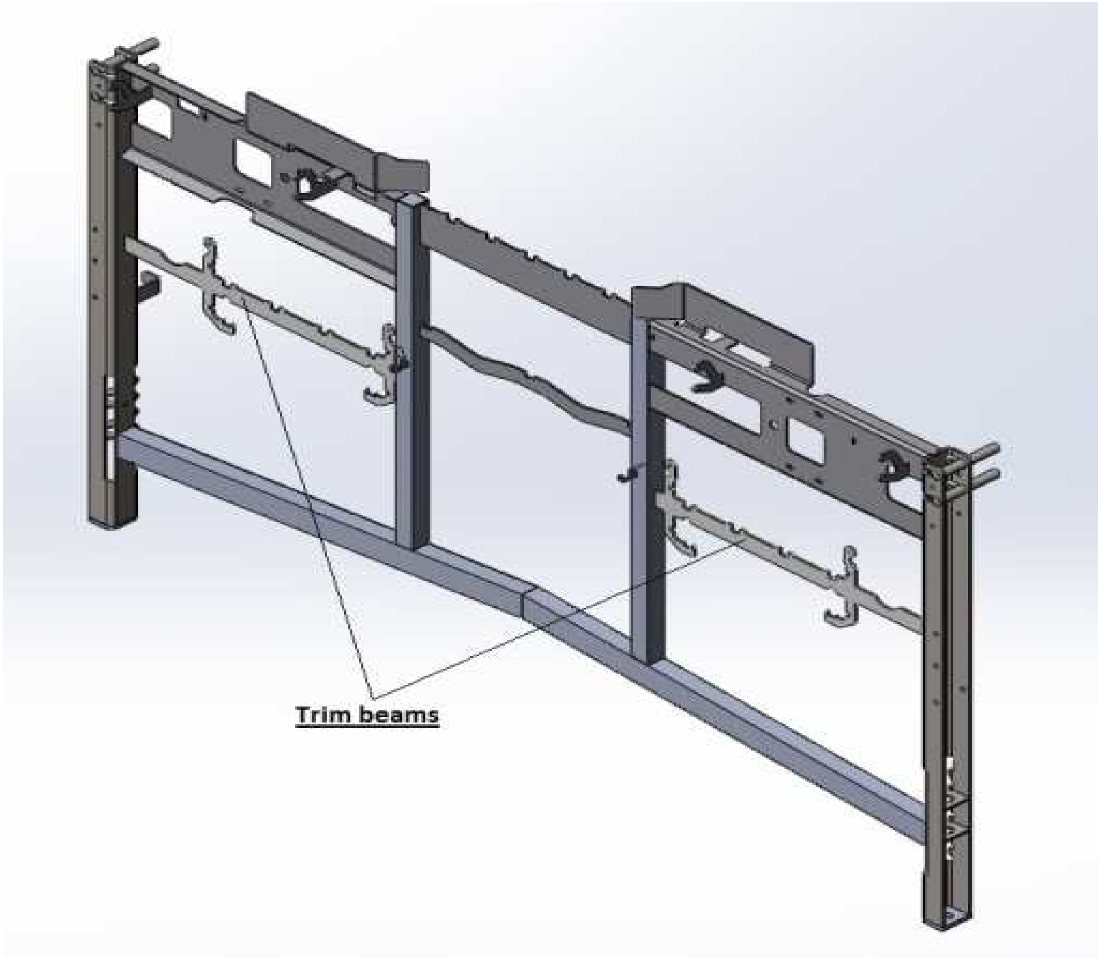


Figure 14: Cross frame of StreamLine weldment.

This cross frame is fundamental in the StreamLine structure. In the middle the main belt runs and on the main belt the arms run, they are fastened to the cross beam in cross frame and the conveyor sides. The steel on either side of the main belt is the cross beam for the trim belt. This trim belt gathers trim/waste from workers and this belt is a stop/start belt that will add to vibration on the line. The cross frame is made of many components, stainless steel plates of many thicknesses, 40x40 rectangular beams and axles.

The cross frame is built to be stiff in an environment where accuracy in weighing is as important as transport and moving of big pieces of meat, with all the friction involved. It has been seen that the cross fame has a complex structure and is therefore hard to clean and costly to built. These two factors weigh heavily in equipment sales for the food industry. With expensive equipment the payback time of the investment has to be shorter compared to the competitors to increase chances of selling. The other point is that after every shift the equipment is cleaned with hot water and soap. For some of the more complex installations this cleaning can take up to 4-6 hours. The cost of all this hot water is enormous and the factories also pay for every liter of water that goes down the drain. If the lines are easier to clean the payback time of the investment will be shorter and therefore more likely that Marel can sell this product (B. M. Karlsson, personal communication, March 17, 2014).

3.2 Evaluation of methods

To be able to get the most out of the cross frame redesign it is important to choose the best suited design method. The methods and their relevance to the case study will be evaluated. The outcome of this work will give the optimal design method.

Since there are many aspects to consider in this redesign, such as costs, time, customer needs and etc. it is hard to choose one method over another.

Six Sigma focuses on customer needs and its main goal is to hold defects to a minimum of a certain number (Linderman, Schroeder, Zaheer & Choo, 2003). If the utmost need of a customer works against companies internal processes or goals, it is not beneficiary for company to act on those needs. As pointed out in the previous Six Sigma review this process calls for a big infrastructure and to implement this on a project and a Six Sigma certificated person must be in charge. This infrastructure can lead to added bureaucracy and cost for the organization (Goh, 2010). It is very hard to implement the Six Sigma infrastructure and fill in all roles of Master, Black or Green belts. The method of Design for Six Sigma could maybe be used in this application when the redesign will be verified. Then the cross frame will be put through the steps of Define, Measure, Analyze, Design and Verify.

Stage-Gate process is a linear process and can be seen in Figure 3. The stage gate process is an improved way to bring ideas to production, a full innovation process (Cooper, 2001). The process is focused on minimizing cost for the organization, every stage has its criteria and the project must fulfill the criteria to being able to get to the next stage. This allows the organization to closely monitor current expenses and take an enlightened decision about whether to continue or terminate the project (Cooper, 2001). In every stage a cross functional team works on the project to prevent situations where one team spends a lot of time on the project before another team deems the project unfeasible. This process would be very good in big innovation projects like if the complete StreamLine would be redesigned. Then it would be easy to create cross functional teams and monitor the process with Stage-Gate. But in this project it could be assumed that all the work is done in one stage and to get through to the next stage it is necessary to fulfill the requirements set in ´Verify the design´ chapter.

Lean Product Development is a method that takes in the core of Lean, eliminating waste. Tools to eliminate waste can be for example Knowledge Gaps and PDCA circles. These processes are circular instead of linear and suit well on small projects. Knowledge Gaps allow the focus to be on the project rather than on a fixed process orientated around cost or customer needs only.

Design Structure Matrix (DMS) is a method to supervise and organize complex research and development projects (Danilovic & Browning, 2006). The process is made to value each component and its dependencies on other components in the life cycle of new products. Tasks or decisions are seated so that the first is first and last is last. This method eliminates the risk of not being able to take a decision because of its dependence on another decision later in the chain.

Model-based design is a method that can be used in all kind of applications. The model is based on a problem, this model is analyzed and verified to a set of requirements. If the model passes through the verification phase it is passed onto design but if not the model is restructured and analyzed again. By following this process it is easy to find flaws and correct them with minimum cost. Instead of continuing with a design only to find out that it is not the correct design. By that time a lot of money has been wasted and to correct the wrongs will cost even more.

The case study that has been chosen is fairly small and the designer will be working alone most of the time. With that in mind LPD has been selected as a main design method with emphasizes on Knowledge Gaps. To verify if the redesign meets all requirements the method of Model-Based Design will be used. By that method it can be seen if the Knowledge Gaps method has given a suitable result.

3.3 Knowledge Gaps

The first thing was to find the Knowledge Gaps. To find the Knowledge Gaps a brainstorming meeting was held with another designer. This designer has over 10 years of experience in working with the StreamLine. During this meeting a lot of ideas about possible knowledge gaps were discussed. The list below shows the gaps that were identified:.

- How much load must the cross frame stand
- What markets have and will this product be sold in
- What is approved material
- How can it be assembled, are there some assembling constrains
- How can it be manufactured, are there some manufacturing constrains
- How long does it take to assemble now
- What item does take longest in assembling
- What are the cleaning demands
- Do the cleaning demands vary between countries
- Size of components, max size of plates or beams on production floor
- Where do we need strength and where not
- Modular design?
- Are some forms prohibited
- What are the connection points
- Max size of assembly

- Assembling, robotics?
- How is it transported?
- Patent issues, some things to be aware of or to gain
- Are there some standard looks for this kind of Marel equipment? Some things that could affect the design

It is important to classify and categorize Knowledge Gaps once they are found, as can be seen in Table 4 below.

To categorize Knowledge Gaps it is necessary to be open minded and put emphasize on finding the best place for the Gap, sometimes a Gap could be in many categories. In this instance the categories were identified as Hygiene, Assembling and Other. Then the difficulties in finding the knowledge were classified from 1 to 3. Category 1 meaning that it would be fairly easy to find knowledge and 3 being very hard to gain this knowledge. To clarify how the knowledge should be gained, a column in the table describes the first action steps. Finally the priority of the Gaps was estimated, number 1 being the highest priority and 3 the lowest priority.

Table 4: Knowledge Gaps table

	Knowledge Gaps	**Classification**			**Action to close Gap**	**Priority**		
	Hygiene issues	1	2	3		1	2	3
1	What markets have and will this product be sold in		X		Study IC-Meat business plan and look at previous sales			X
2	What is approved material			X	Find standards about food safe material	X		
3	What are the cleaning demands		X		Read hygiene standards	X		
4	Do the cleaning demands vary between countries		X		Read hygiene standards from different countries		X	
5	Modular design?	X			Study IC-Meat policy on modular design		X	
6	Are some form prohibited		X		Hygiene standards will clarify this		X	
	Assemblying issues							

7	How much load must the cross frame stand		X		Find connections and calculate strength in those connection points		X	
8	Where do we need strength and where not		X		Find critical strength locations, Study if strength can be lower some places but raised on others			X
9	How can it be assembled, are there some assembling constrains		X		Hygiene standards, describe best way of assembling, welded, bolted or other	X		
10	How can it be manufactured, are there some manufacturing constrains	X			Marel work floor constrains	X		
11	How long does it take to assemble now		X		Take time on how long it takes to assemble current cross frame	X		
12	What item does take longest in assembling		X		Find critical parts in current cross frame		X	
13	Max size of assembly	X			Find constraining components		X	
14	Size of components, max size of plates or beams on production floor		X		Constrains on plates, beams or another material that is used in cross frame	X		
	Other issues							
15	What are the connection points	X			Study current StreamLine lines and find connection points to other machines, stations or anything that can affect cross frame		X	
16	Assembling, robotics?			X	Study size of robot in Marel, Talk to head of Robotic weldment department			X

17	How is it transported?		X		Inspect how StreamLine is transported now and how a new design can make life easier		X	
18	Patent issues, some things to be aware of or to gain			X	Talk to Patent master, and read patents.	X		
19	Are there some standard looks for this kind of Marel equipment? Some things that could affect the design	X			Talk to PTC in Marel to clarify this	X		

In Table 4 Knowledge Gaps have been classified, actions found to close them and they have been prioritized. When starting to work on those actions it is good to realize that some gaps have greater involvement in the project than others. This involvement is a combination of classification and priority. The first gaps that are solved are the ones who have high priority and high classification number. These are the gaps that have the greatest involvement in the project. After this is done the gaps that have high priority and medium classification are found and then down the scale from there.

Patent issues, some things to be aware of or to gain

The StreamLine has active patents and some competitors have some patents but the patent expert in Marel says there is no risk of violating a patent in this design and also there is no opportunity to apply for patent in this design.

What is approved material

According to EHEGD (European hygienic engineering & design group) (2004) material used in equipment for food processing must be NON-toxic. The food can not be able to absorb any chemicals/particles of the material. The material must not include mercury, lead, cadmium or arsenic. Aluminum is not suited in applications. Zinc coated material are also not suited. Plastics are allowed but there porosity must be checked because if the plastic is porous they can absorb micro-organism, which will lead to added germ count. Stainless steel is recommended as an excellent corrosion resistance material. This harmonies well with constrains that Marel warehouse sets, since they make most of the equipment from stainless steel and High Density plastics (EHEDG Guidelines, 2004; Food Code 2013).

What are the cleaning demands

Cleaning standards are detailed in EHEGD and FDA (Food and Drug Administration) and there it is written that surfaces shall be smooth and design of equipment shall be smooth. Sharp corners shall be avoided and all closed surfaces (EHEDG Guidelines, 2004; Food Code 2013).

How can it be assembled, are there some assembling constrains

Cleaning standards demand that closed spaces shall be minimized. If two assemblies are bolted together the surfaces that are put together do create a closed surface. To eliminate this kind of closed surfaces it is recommended to weld all connecting parts. Also it shall be noticed that threads on bolts are very hard to clean and should be avoided (EHEDG Guidelines, 2004).

How long does it take to assemble now

Assembling time of the current cross frame was measured. Total time in SMC was hard to estimate because components are cut out of many different plate thicknesses. SMC is always fully loaded and to wait for next piece in the cross frame will only make time for other projects. It will still add to the work done there to have to change between plate thicknesses because to bend plates a certain bottom tool is used. This bottom tool is fixed on thicknesses and therefore there is a waste in changeover time when changing pieces and rearranging in the bending machines. Assembling time was timed and total time of assembling a cross frame were 5 hours and 10 minutes. In this paper assembling times were broken down in following items see Table 5.

Table 5: Assembling time of cross frame

Job done	Time
Cutting and cleaning of rectangular beams	40 min
Welding lids on rectangular beams	20 min
Welding of steel axles and lids in legs	55 min
Welding of rectangular beams together	1 hour and 20 min
Welding of all items in cross frame	1 hour and 55 min
Sum	5 hours and 10 min

To place the pieces together when they are well constructed is a job that takes only around 2 hours (welding of all items in cross frame). Total time of work that is done to rectangular beams is 2 hours and 20 min. From this information it can be seen that there is defiantly room for improvements.

Size of components, max size of plates or beams on production floor

Since material has not been decided it is hard to predict max size of it. In most cases the plates, both plastic and steel, come in 1,5m x 3,0m. Rods and beams usually come in 3,0m long pieces.

How can it be manufactured, are there some assembling constrains

This redesign is made for Marel and they have their own manufacturing floor, it is a constrain to use the tools they are equipped with. Turning and Milling Center (TMC). Marel has a very good Sheet Metal Center (SMC), with three laser cutters to cut steel from plates and many bending machines to bend plates. The assembling team which includes 3 welding robots has been awarded for fine craftsmanship. Marel has very good contracts with all major suppliers of material in Iceland.

Are there some standard looks for this kind of Marel equipment? Some things that could affect the design

After discussion with Product technology center (PTC) it was clear that there are no constraints regarding looks on weldments in Marel.

Do the cleaning demands vary between countries.

EHEGD and FDA are the major players on this market and their standards set the tone for other countries. Meat producers outside Europe and America strive towards entering the European and American market. Therefore manufacturers in others countries have to fulfill the standards of EHEGD and FDA.

Are some forms prohibited

Hygiene standards do not prohibit any forms of components but they demand easily cleanable surfaces and no creeps or forms where dirt or germs can hide in cleaning. Therefore it is good to avoid hollow spaces which would hinder cleaning. Rectangular beams have hollow spaces but are usually closed up, it has happened that welds have failed such that inside of beams have opened up allowing for germs and bacteria to thrive there. There is no way of cleaning the inside of a rectangular beam so there is a higher risk of infecting the meat product.

How much load must the cross frame stand

The force that works on the cross frame mainly affects the connection points. The motor ends in both trim and main belts are fastened on the cross frame.

The motor end on the main belt weighs about 50 kg but can carry a piece up to 20 kg. Total weight of the end is calculated 100 kg with safety factors. The end is connected to the rectangular beams in current design. This connection bears high loads but there is a conveyor frame on the other side of this rectangular beam, this conveyor frame adds support to the cross frame.

The motor end of the trimbelt is fastened to the leg and rectangular beam. This motor end weighs about 62 kg but can carry batches up to 8 kg and therefore the total weight is 100 kg with safety factors. The current method of fastening the motor end to the cross frame creates a big momentum on the cross frame.

The criteria is the same for stress if the material in the cross frame is the same on both connecting points. But the deformation is not the same, the trim motor end is fastened on the last cross beam on the trim belt and that beam supports the side guards. The side guards are sensitive to inaccuracy and therefore much smaller deformation is allowed in the trim belt than in the main belt.

Constraints of main belt is that the stress may not go above approved maximum stress of the selected material. Maximum deformation is often found by the rule L/400. A deformation of this size cannot be seen by the human eye. In the trim belt the demands are the same regarding stress but deformation can´t exceed 1mm and desired value is 0,5 mm (U. Grétarsson, personal communication, April 10, 2014).

What item does take longest in assembling

In assembly the rectangular beam part is very time consuming as seen in Table 5. It is necessary to cut the beams by hand into correct measurement. The beams have to be welded together without any welding guides which makes it a lot trickier than welding plates that have welding guides, see Figure 15.

How is it transported

StreamLine is transported between locations in containers but to bring the whole line into a container can be a tricky task. Supports on wheels are put under the line and it pushed into a container. These supports can´t be put directly under the feet and therefore they have been put on the rectangular beam next to the feet. These beams lie with a 5° angel on horizontal level and therefore they are very hard to clamp/fasten under the line.

Modular design

StreamLine is a modular design that is built up of modules (stations) that consist of smaller modules. These modules should be able to fit too many other modules in the StreamLine. The cross frame is one of those modules and is vital that the connections points stay unchanged after redesign.

Max size of assembly

The only constraint on size of the cross frame is that it must fit into a container, max width 2.350 mm and max height 2.700mm.

What are the connection points

Major connection points are following: axles on top of legs, main belt, trim belts and rectangular beam under for stiffness of the weldment structure of StreamLine station. Minor connections are bolted connection with buffer chute and support for the cutting table.

Assembling, robotics?

This design shall take into consideration robotic welding.

What markets have and will this product be sold in

StreamLine has been sold in Europe, Asia, North-America, South-America and Oceania. Europa and Oceanic are the main markets but history tells us the scope is the whole world.

Where do we need strength and where not

As pointed out here previously the main forces act on connection points.

To cut assembly time it is necessary to look at all the aspects of this list. Both work that is done in supporting cells as SMC and TMC and manual assembling. Hygiene standards clearly state that closed spaces shall be avoided and design shall be focused on eliminating sharp corners where germs could accumulate. From this knowledge it will be the main aim to eliminate all closed space and that includes the rectangular beam. Since the cross frame will be made out of solid items only, no closed spaces. It is good to try to have plates of the same thicknesses, which will reduce waste in SMC. It is also very important to try to have a welding guides, to make the plates fall together like Lego™, see Figure 15. This will help the employee that is welding, he does not have to measure or adjust the assembly. All assembling shall be welded and not clamped or bolted.

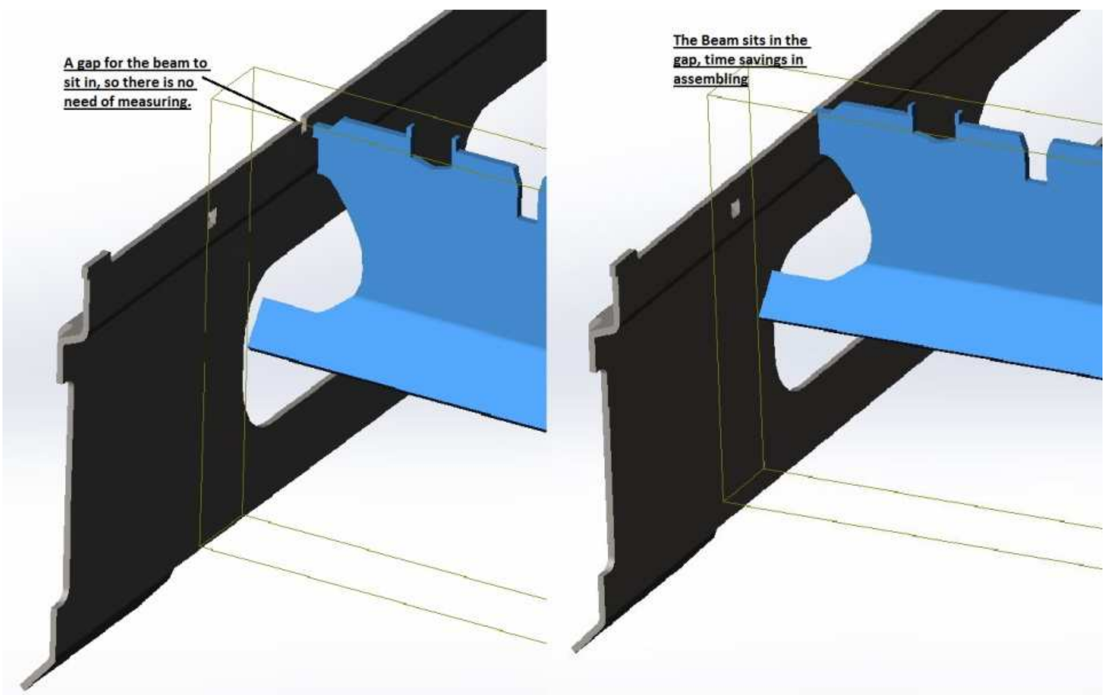


Figure 15: Plates are cut so that they can be easily put together, no measuring, welding guides, fits just like LEGO™

3.4 Redesign

Having the new item made of solid parts only will result in a big challenge in strength issues. The rectangular beam is the fundamental item in strength in the current cross frame. Steel rods do not bring a lot of strength unless it is in compression or tension so it is an obvious choice to have this made of steel plates. It would be preferred to have only one thickness of the plates because it will reduce waste in assembling.

The first task is to replace parts in the cross frame with stainless steel plates. The strength constraints can be set when the material has been chosen. The allowable stress in 304 steel is 297 MPa (Outo kumpu, n.d.).

In order to identify how thick the plate must be the assembly team of StreamLine was interviewed. The conclusion of that interview was that when a casted static support is used the thickness of the plates must be 5mm. The aim is to have the cross frame made of 5mm thick plates (B. Jónasson, personal communication, 25. April, 2014).

As stated previously, strength issues are mostly in connection points. These connection points are the connections between cross frame and motor ends on trim belt and main belt. The motor end on trim belt is shown in Figure 16 and Figure 17

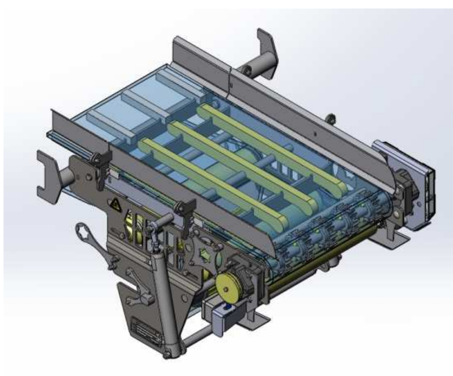


Figure 16: *Trim motor end*

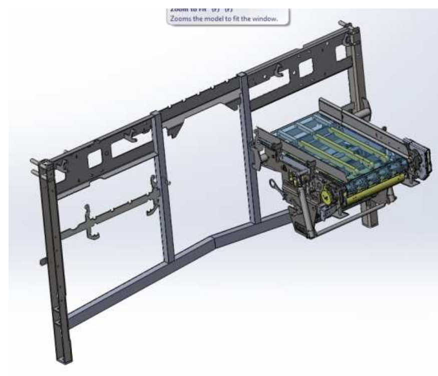
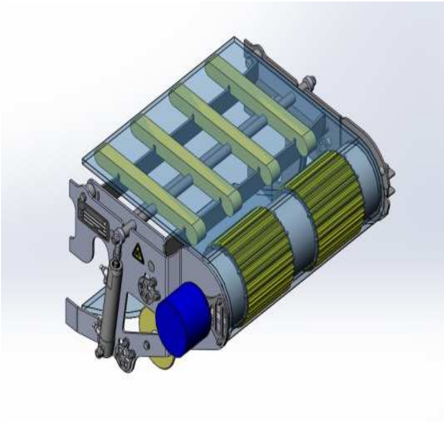


Figure 17: *Trim motor end on cross frame*

In current design the end is fastened on the cross frame with a 2 point connection. One point connecting on the leg and the other on the vertical rectangular beam. These connections are connected together by Ø40x4mm steel pipe.

The other connection point is the motor end on main belt. That end can be seen in Figure 18 and Figure 19.



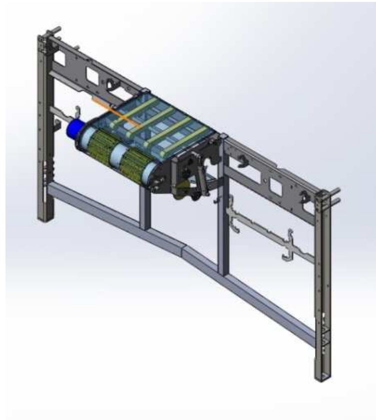


Figure 18: *Motor end on main belt*

Figure 19: Motor end on CF

The motor end is connected to the cross frame on the vertical rectangular beams. On the other side of the cross frame a conveyor is fitted and that will structure the cross frame a bit.

The first idea of new cross frame was to replace the rectangular beams with solid plates like previously has been mentioned. Similar height was used on the new plates as is on the current plates. This was done in 3 separate plates. Picture of new design can be seen in Figure 20.

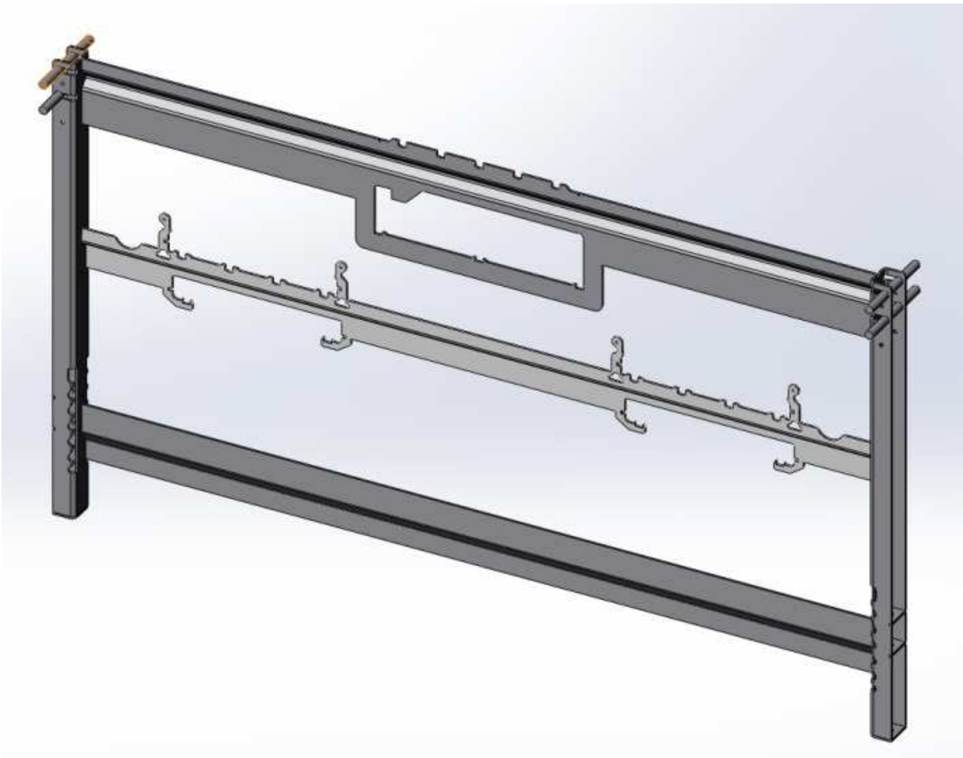


Figure 20: Cross frame with 3 plates instead of rectangular beams

With this design all plates are 5mm thick which will lead to reduction of cost in SMC and items are put together with welding guides, so the assembling personnel do not have to measure or cut anything, see Figure 15. All components will come fully cut and bent out of SMC and it is only necessary to weld them together.

3.4.1 Finite Element Modeling

To verify that this design is strong enough before any further designs are made a finite element model was made. This model was made in a program called Ansys, the method of this program is explained in Ansys Theory reference.

The cross frame does not stand alone to withstand the forces that work on it. It is one piece of a bigger puzzle. To be able to analyze the cross frame it is necessary to realize and state all the parts that connect and hold the cross frame in its place. When all fastening points have been defined, the forces have to be defined also.

Constraining points in this cross frame can be seen on Figure 21.

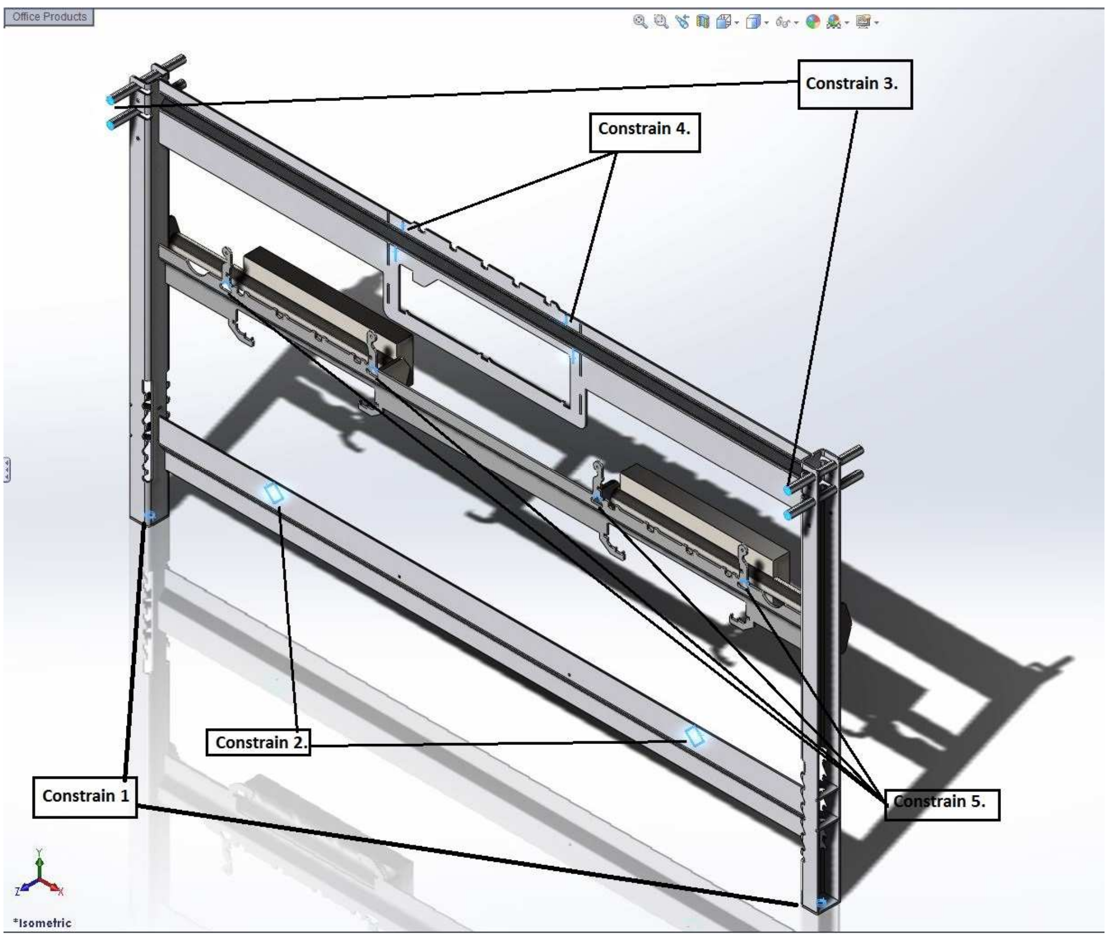


Figure 21: Constrains in cross frame, for Ansys modeling

Constrains that can be seen in Figure 21 are not all fixed supports. Definition of these constrains can be found in Table 6.

Table 6: Constrains in cross frame for Ansys modeling.

Item/constraint	**Action**
Constrain 1	Bottom of leg, fixed support in all directions. Leg is bolted to the floor
Constrain 2	Supporting beam between two cross frames, constrained in Z-direction, free in other directions
Constrain 3	End of axles, which connect cross frame to U-beam in front of StreamLine station. These axles are constrained in Z-direction, free in other directions. Both ends of axles are constrained.
Constrain 4	Conveyor frame connection to main beam, constrained in Z and X direction, free in Y direction.
Constrain 5	Axle holes in trim beam, constrained in Z direction but free in other directions

When the cross frame is fully constrained, forces are applied. The driving forces in this instance are, as stated previously, the motor ends that are fastened on the cross frame.

The trim motor end has calculated weight, m, of 100 kg. A replica of the motor end was made so that the end itself would not be the center of attention when analyzed. Center of mass of the motor end (l) was found in, 0,40 m from connection points. The moment, M, that a mass of that size will create can be found by using eq. 1.

$$M = m * g * l \quad (1)$$

The total moment in this case is:

M = 393 Nm

Since a replicated motor end was made, the force was to be recalculated. Same moment applied on the trim beam but the length to the force was shortened. Force working on the new motor end was calculated from

$$F = M/l_2 \quad (2)$$

Where M comes from Eq. 2 and l_2 = 0,11 m.

F = 3571 N

Value for the force which is applied to the replicated motor ends is 3600 N. How this is done can be seen in Figure 22.

The motor end on main belt is welded straight on the main beam and it´s connections do not cause any complication. The moment that works on the main beam is calculated from eq. 1 but now the length, l, to the center of gravity is 0,14m and the mass, m, is 100 kg.

Total moment of main belt motor is:

$$M = 137{,}48\ \text{Nm}$$

Value used in Ansys is 140 Nm. The force is applied as shown in Figure 22.

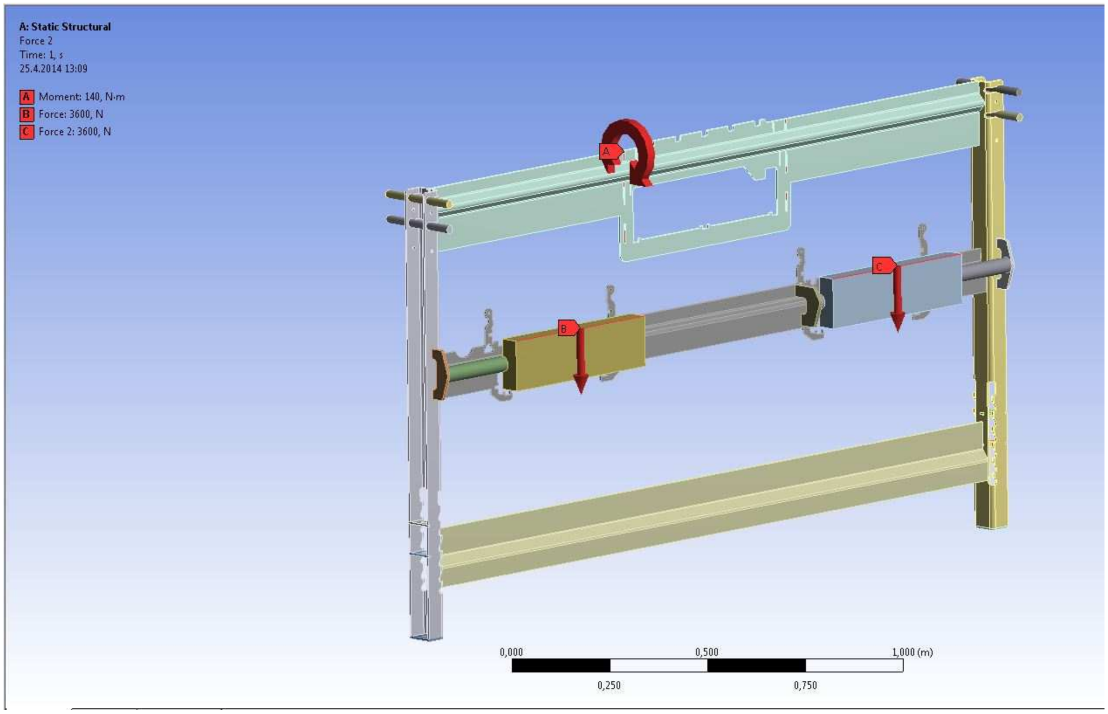


Figure 22: Forces and moments applied to cross frame.

In finite element analyses it is necessary to divide the volume into smaller parts in order to being able to calculate the stress and deformation. This process is called meshing, the project is divided into small areas and stress and deformation are calculated in each of the areas. Combined stress and deformation are then found by adding all the small areas together. The meshing of the cross frame was done by Ansys and results can be seen on Figure 23.

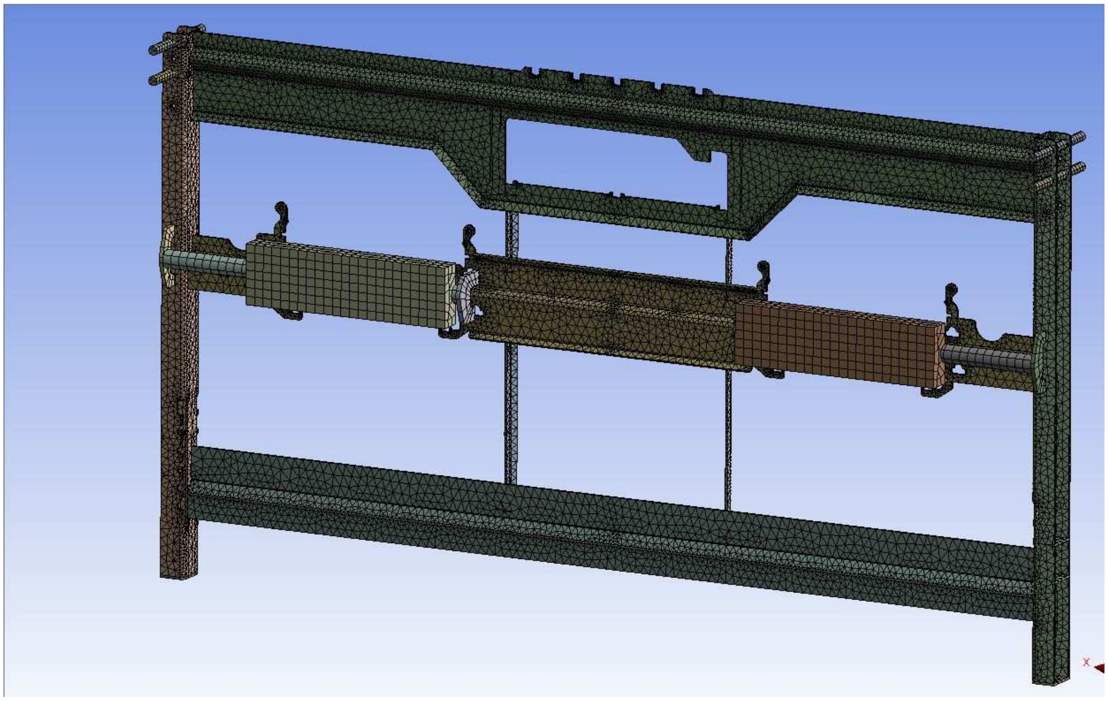


Figure 23: Cross frame with mesh

Meshing was deemed sufficient because when the mesh was enlarged the difference in equivalent stress only varied by 2,4% and the maximum deformation varied by 1,9%. Cross frame with enlarged meshing can be seen in Figure 24.

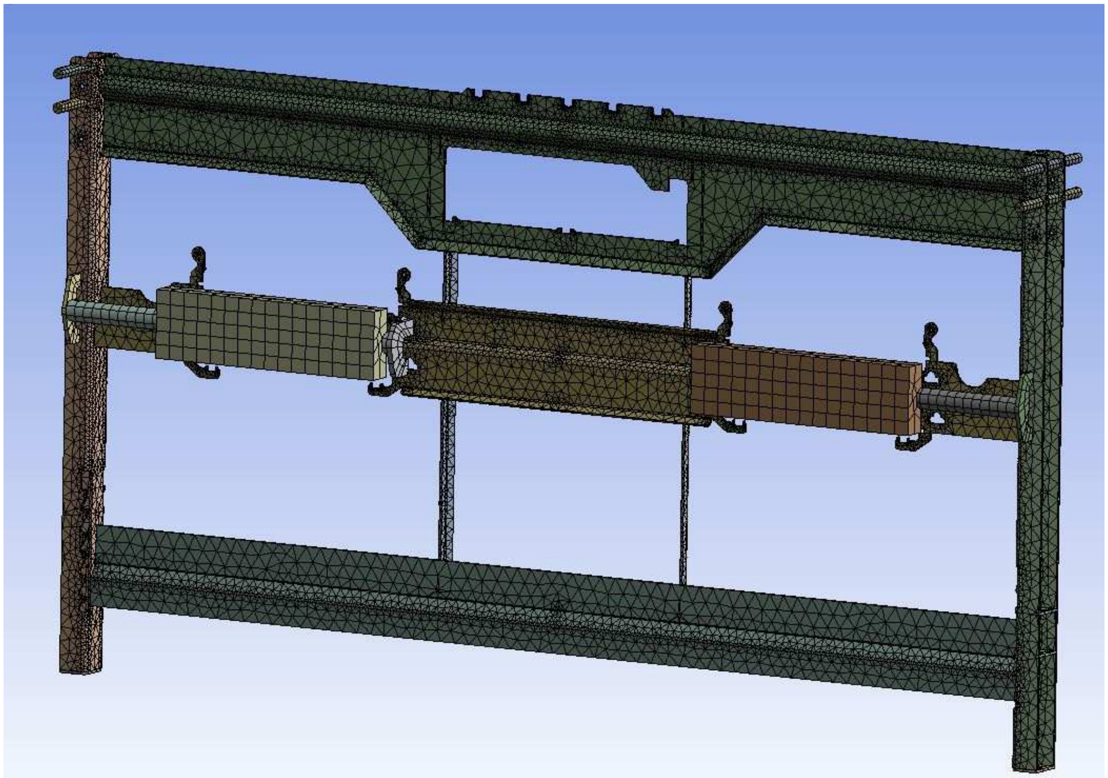


Figure 24: Cross frame with enlarged mesh.

3.4.2 Verify design

To verify the new design the finite element model, that was explained in the chapter above, was analyzed. The model was put through a PDCA circles to iterate the best design. A plan was drawn out, the model was created and checked to see if it fulfilled the requirement set and finally an appropriate response was made to the findings. A new design will be created if the model fails but if it passes the model is not changed.

The maximum deformation, δ_{max}, and the equivalent stress, σ, were found.

- δ_{max}: 4,19 mm
- σ: 934,70 MPa

Most of the stress is on the trim belt connection, as can be seen on Figure 25. The deformation is both in supporting unit for main belt and in the trim connection, see Figure 26.

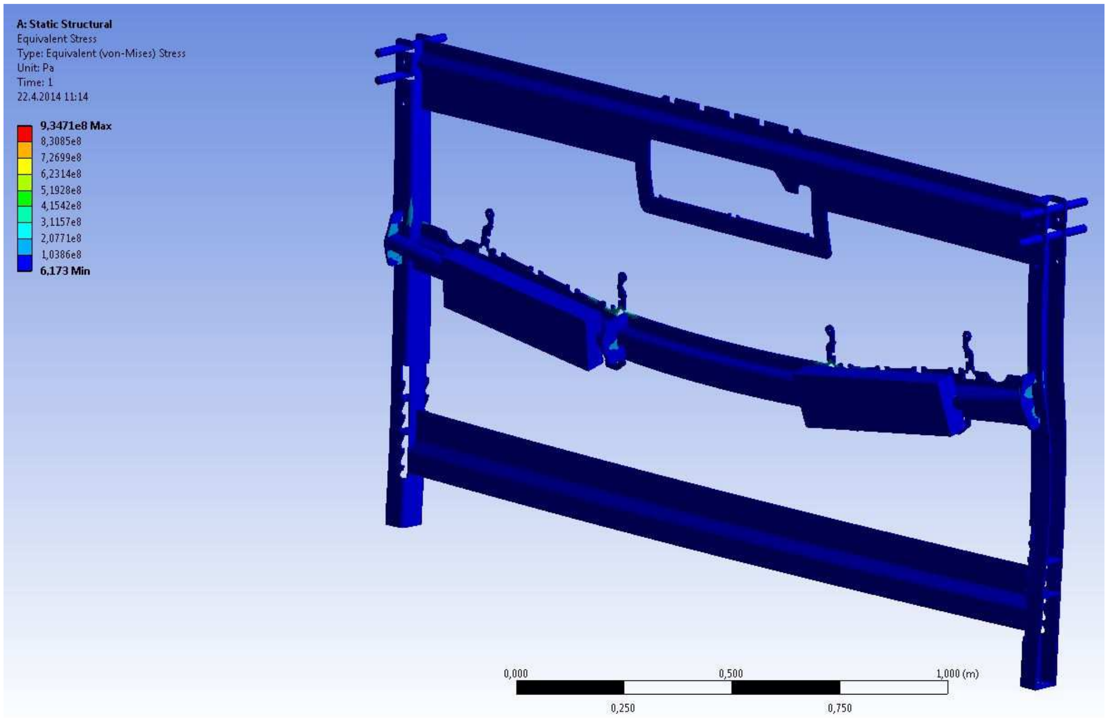


Figure 25: Equivalent stress, σ, in cross frame

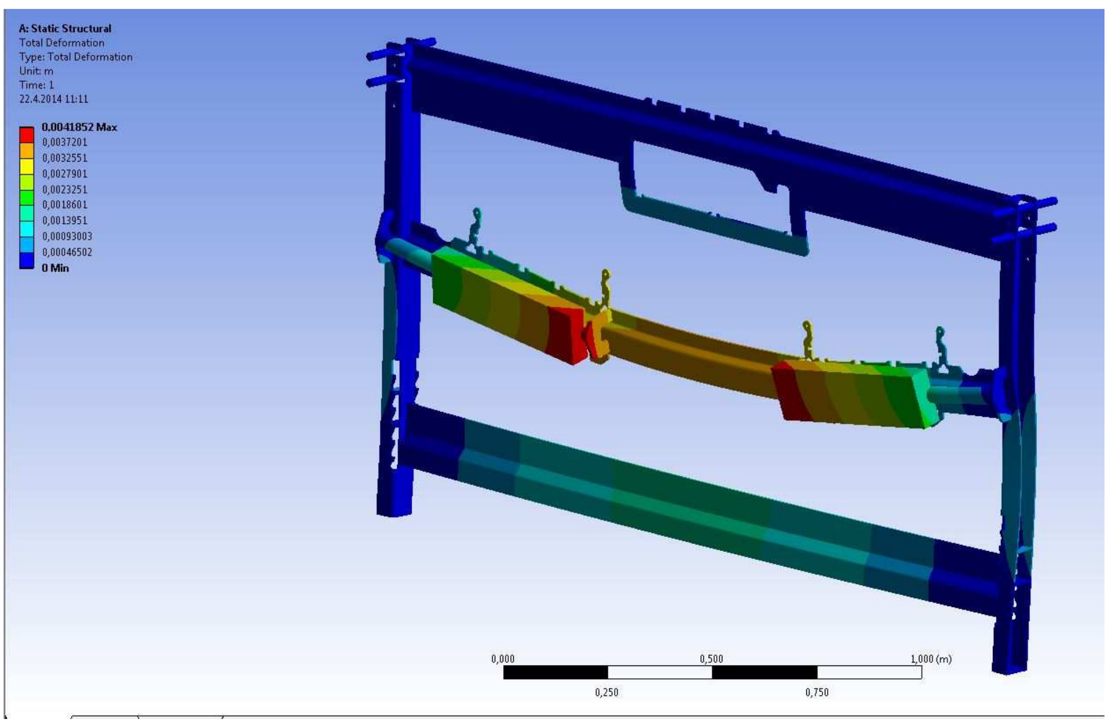


Figure 26: Total deformation, δ, in cross frame

If Figure 25 is zoomed in it can be seen that the stress is mostly around the Ø20mm axle holes in the trim beam, see Figure 27.

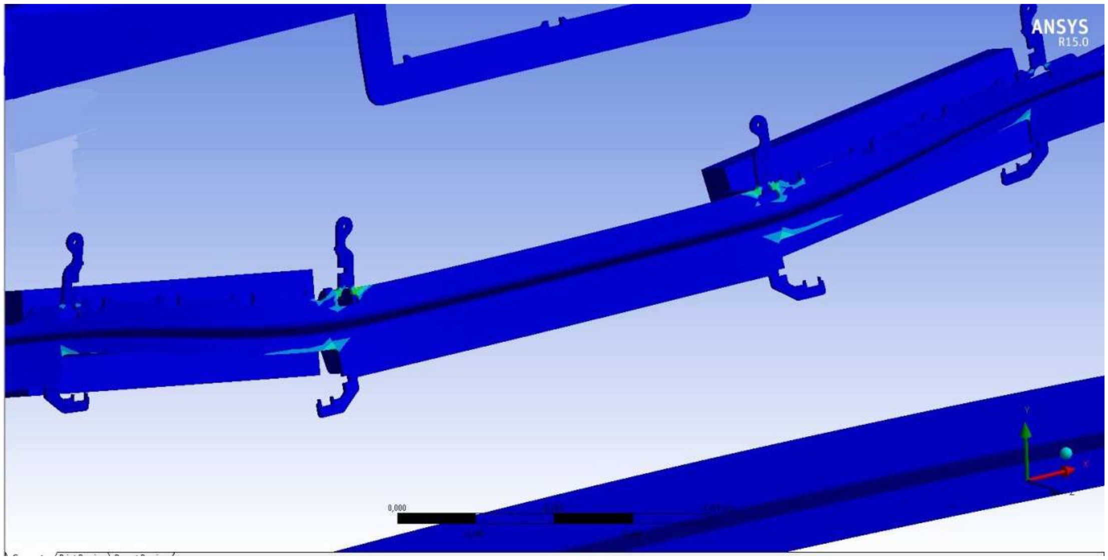


Figure 27: Stress distribution in trim beam

The stress in the beam is above acceptable limits (297 MPa) and the deformation also (1,0mm). From that information the design was altered and extra axles in the trim beam were added. This will give the lower side of the trim beam added support.

New design can be seen in Figure 28.

Figure 28: Cross frame with 8 holes for axle connection

Trim beam before and after changes can be seen in Figure 29 and Figure 30.

Figure 29: Trim beam before changes

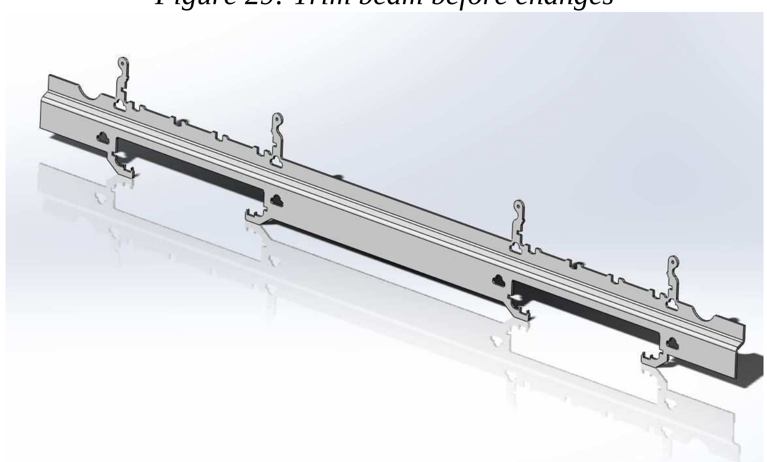


Figure 30: Trim beam after changes, holes added in lower part

This cross frame was put through the same test as the previous design. Total deformation and stress are:

- δ_{max}: 3,69 mm
- σ: 525,6 MPa

The stress distribution in the cross frame can be seen in Figure 31.

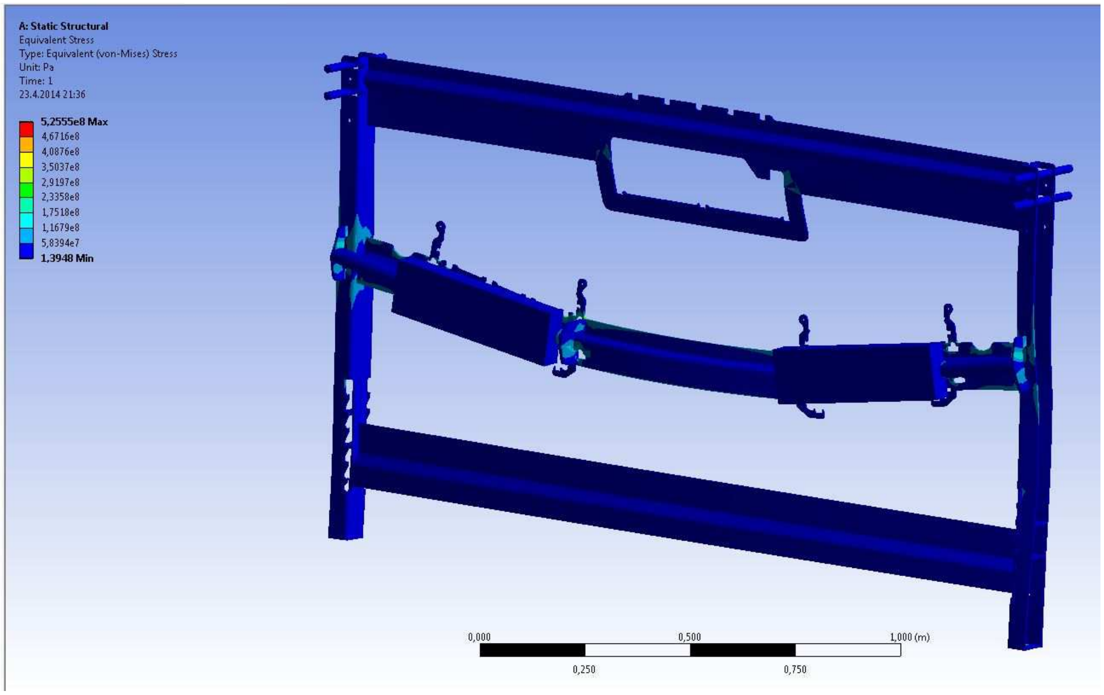


Figure 31: Stresses in cross frame with 8 holes in trim beam

The stress has lowered after the axles were increased from four to eight. Deformation of the cross frame can be seen in Figure 32.

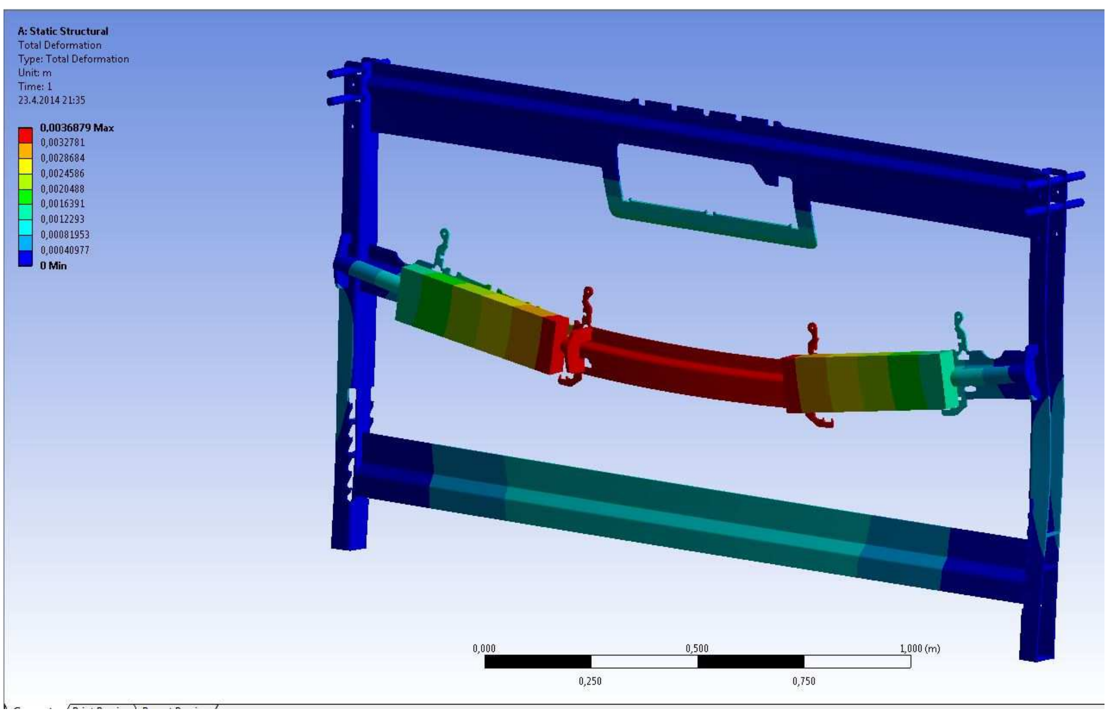


Figure 32: Total deformation in cross frame with 8 axle holes

This design does not fulfilling requirements so it needs to be put through a PDCA circle. Even though most of the deformation is in the trim beam it can not be ignored that there is deformation in the support of main belt. This deformation can be addressed by adding a bend to the main beam. To support the trim beam better bents were placed in the middle part and extra steel added around the upper axle holes. Trim beam before changes can be seen in Figure 30 and after changes in Figure 35. The main beam before and after changes can be seen in Figure 33 and Figure 34.

Figure 33: Main beam before changes

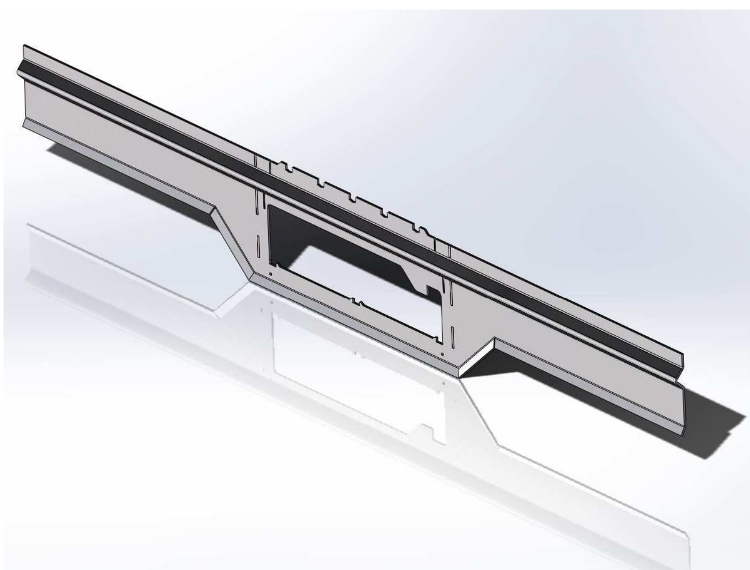


Figure 34: Main beam after changes, bends added underneath

Figure 35: Trim beam after changes, bends added over and under in middle

Cross frame with these changed parts can be seen in Figure 36.

Figure 36: Cross frame with added bents in trim and main beams

This cross frame was put through the same test as the previous design. Total deformation and stress are:

- δ_{max}: 2,92 mm
- σ: 634,6 MPa

The stress and deformation is well above required values. How stress and deformation were in the cross frame can be seen in Figure 37.

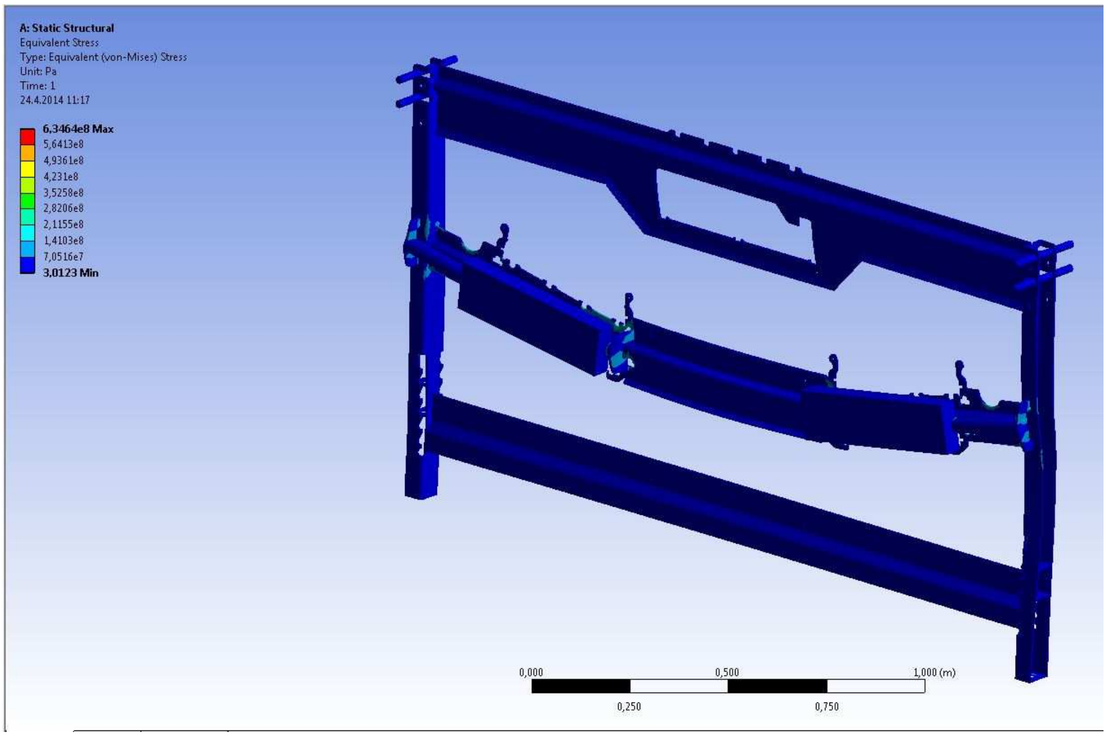


Figure 37: Stress distribution in cross frame with beam supported with bends

Deformation of the steel in the cross frame can be seen in Figure 38.

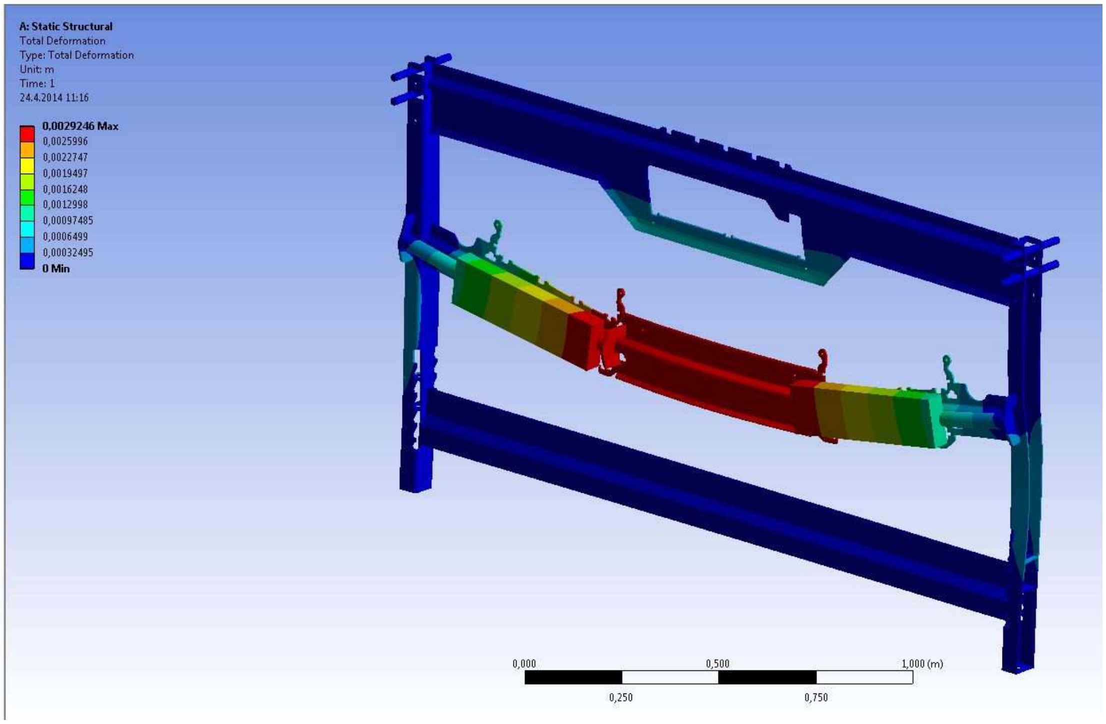


Figure 38: Deformation in cross frame with beam supported with bends

This new design improves the results but it is not sufficient. There is not much stress or deformation in main beam or bottom beam. Possible the solution to this is to bind all beams together like the rectangular beam did before. It was decided to have two steel plates welded to all beams so that they would work in harmony.This design can be seen in Figure 39.

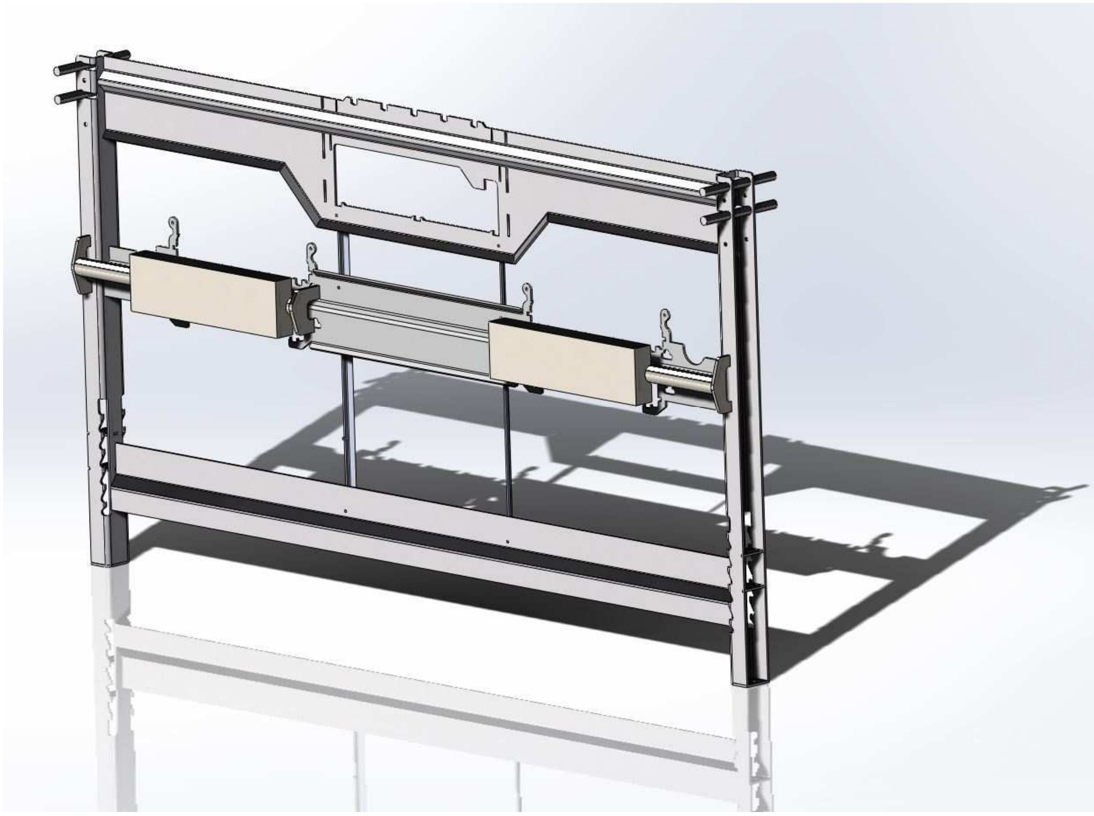


Figure 39: All three beams bound together in the cross frame

This cross frame was put through the same test as the previous design. Total deformation and stress are:

- δ_{max}: 0,59 mm
- σ: 283,7 MPa

The stress distribution in the cross frame can be seen in Figure 40.

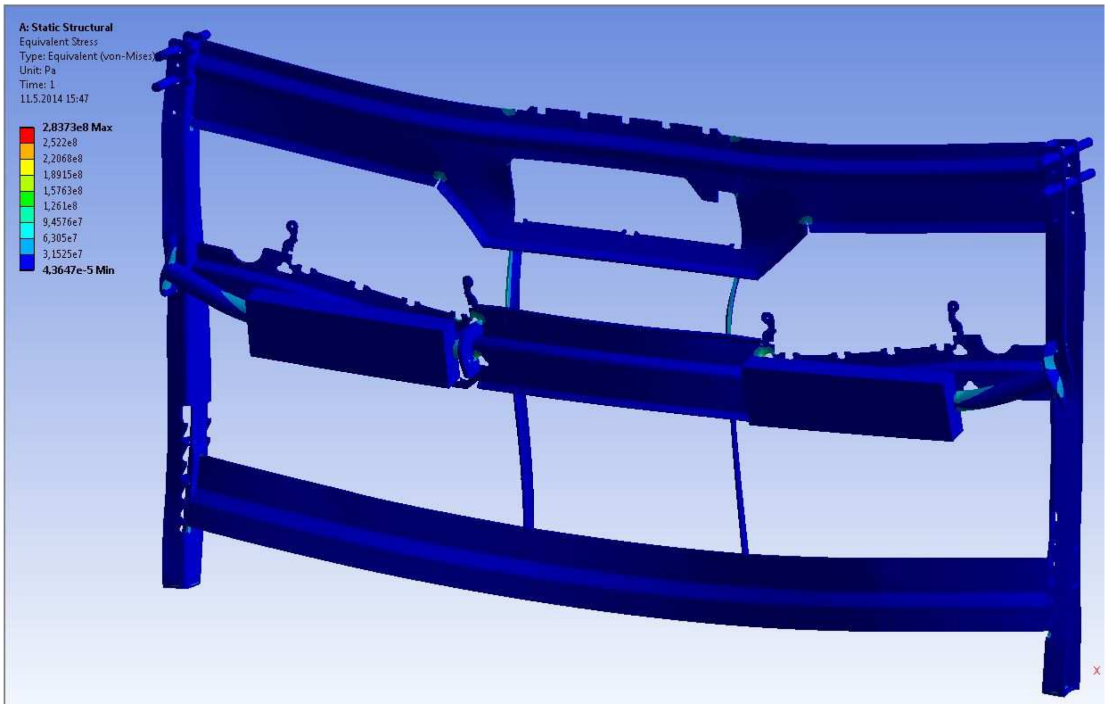


Figure 40: Stress distribution in cross frame with all beams bound together

Deformation of the steel in the cross frame can be seen in Figure 41.

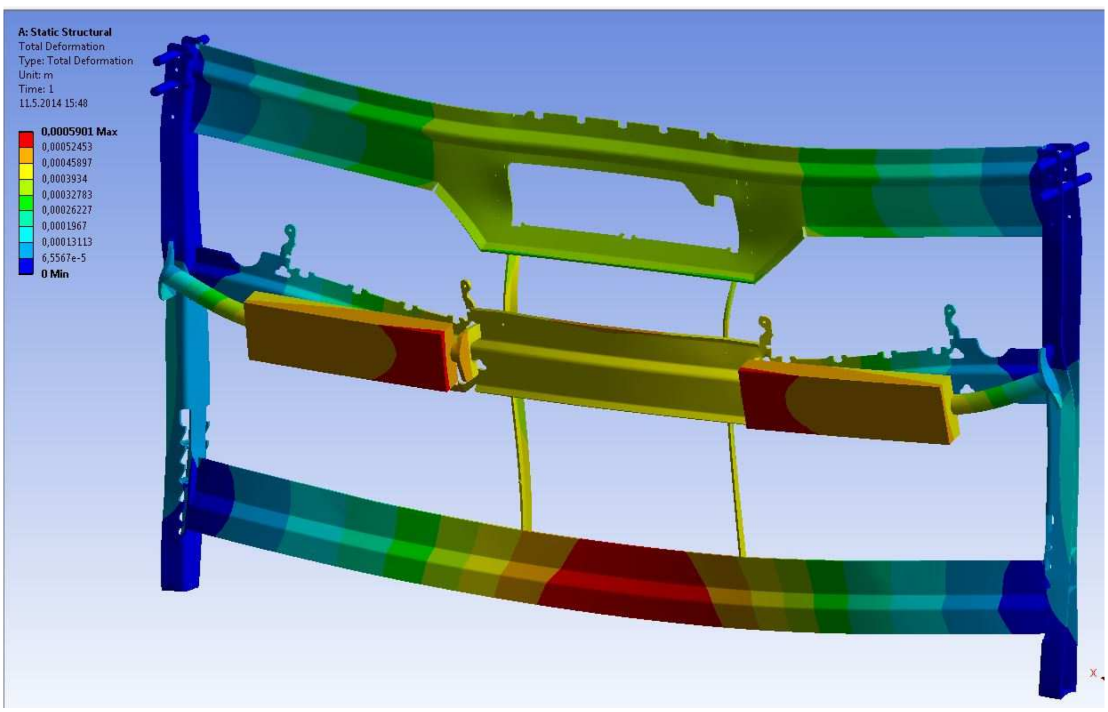


Figure 41: Deformation in cross frame with all beams bound together

This version of the cross frame satisfies the pre given specification on equivalent stress and maximum deformation. The cross frame has been made of solid plates and all closed spaces eliminated by removing the rectangular beam. Resulting in a cross frame that has much better cleaning abilities, with no discount given on strength.

Drawings and manufacturing data of this cross frame can be seen in Appendix A.

3.4.3 Cost estimation

When this design is evaluated the cost needs to be reviewed closely. As stated previously the main cost is in welding time and preparation time, both in welding and in supporting centers. The material cost can´t be omitted since the cost per kg of steel for Marel is about 3€/kg (Ö. Kristjánsson, personal communication, April 25, 2014).

Table 7: Weighed of steel in cross frame and material cost

	Mass [kg]	Cost [€]
Old design	46,9	140,7
New design	58,9	176,7

To find the total cost of the cross frame it is necessary to calculate welding time, T, on the cross frame. Welding time can be calculated from the amount of welding millimeters, i, in assembly (S. J. Árnason, personal communication, April 25, 2014) see eq. 3:

$$T = i / 25 \frac{mm}{min} \quad (3)$$

In the new design the total amount of welding millimeters is

- i: 3750mm

Then the total welding time can be calculated from eq. 3

- T: 150 minutes

There is always some preparation time when welding and estimated preparation time of this new assembly is around 15 min (M. Traustason, Personal communication, April 25, 2014). From that information the total assembling time after pieces arrive from SMC is about 2 hours and 45 min. A comparison of welding times between the old and the new design can be found in Table 8

Table 8: Comparison of welding time on old and new design

Task	**Time**	
	Old design	**New design**
Cutting and cleaning of rectangular beams	40 min	-
Welding lids on rectangular beams	20 min	-
Welding of steel axles and lids in legs.	55 min	55 min
Welding of rectangular beams together	1 hour and 20 min	-
Welding of all items in cross frame	1 hour and 55 min	2 hours and 45 min
Total time	5 hours and 10 min	3 hours and 40 min

The time savings of this new cross frame is 1 hour and 30 minutes. The standard rate for manhour in welding is about 100 €/hour. From that number the total savings in manpower on cross frame is about 150 €. In Table 9a summary of this cost can be seen.

Table 9: Summary of cost

Item	Old design [€]	New design [€]
Labor cost	515	365
Material cost	140,7	176,7
Total Cost	655,7	541,7

This cost difference, of 114 €, is only on one cross frame and the smallest amount that has gone in production is 3 cross frames in StreamLine. Usually the number is somewhere around 20 cross frames per StreamLine.

Calculated savings on the cross frame is 114 € but then the cost of handling the material and material efficiency is not calculated. The new design cuts all the material from one plate and uses 40,1% of a whole plate to do this. The actual efficiency of the cutting is 27,7 % so only 12,4 % of the plate goes in the bin, see appendix B. With the old design, steel was cut from plates, 2 mm, 4 mm, 6 mm and 10 mm thick. Since there are always other projects going on in SMC it is not hard to fill the plates with items from those projects. If the old design would be cut by a contractor it would cost a lot to have such a bad efficiency of the plates, see Appendix B.

4 Conclusion

The aim of this research is to study and evaluate different design methods. Choose a method and redesign a cross frame with it and evaluate the outcome.

Five different design methods were looked at and reviewed. These methods were fitted to the cross frame that was to be redesign. The methods that were best suited were Lean Product Development (LPD) and Model Based Design. LPD has many tools and techniques, the tools that were used in this paper were Knowledge Gaps and PDCA circles. Using Knowledge Gaps makes design teams front load information, but in the end it will diminish the likelihood of redesign in later stages of the design. In product development learning can be expansive but it will pay off because the true cost in projects is when changes must be done in late stages. It will surely pay of to spend time in the design stage to learn all that was needed before starting.

Knowledge Gaps raised questions that needed to be answered. When the questions were answered redesign could begin. To verify that the design would fulfill all constrains, set by Knowledge Gaps, Model Based Design was used. Two models were made; finite element model and a cost model. These models gave a rough idea about whether design would meet demands. If the model did not meet demands PDCA circles were used to improve the design and model was run again. The first three models failed to meet the constraints as they failed the structural test. The fourth model in the other hand was a success in all accounts.

To evaluate the outcome of this new design it is necessary to know the demands of the market. The main issues in designing for the food industry are related to hygiene and as in many designs, the cost. The new cross frame is more hygiene than the old one since the design eliminates closed spaces. Cost estimates indicate that the new design is cheaper than the old one. It is difficult to estimate the cost of components or handling time in this new design. To cut these components from 5mm steel plate instead of many thicknesses will be beneficiary if the cross frame was the only equipment in manufacturing. The case is that Marel always has many productions in at the same time. Therefore it is not as trivial to think about plate efficiency or handling time in SMC.

Other matters that were improved from older design is that the bottom beam has a horizontal lower face where transportation wheels can be placed. The new cross frame has welding guides and therefore it is easy to fasten it to a plate with the idea to use a robot for welding.

The final conclusion is that to design a product using a well-known design method is likely to give better results than current design methods.

In order to verify the total cost it is necessary to follow components through the whole process and measure the time it takes to do each task. Whether to continue with this project is now in the hands of Marel.

The results show that current design can be improved by using LPD and Model Based Design. This knowledge leads to the conclusion that these methods could be used on other products and in a bigger projects, for example to redesign the StreamLine with all its components and functions. In larger projects more methods, such as DSM, could be used.

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Appendix A

MARELGARÐABÆR

0099-X20-90092-01	*Cross frame for StremLine*

[WW=Workshop Welding] [WA=Workshop Assembling] [TM=Turning & Milling] [SM=Sheet Metal] [PU=Purcased part]

Date:	Height:	Resp:	Customer:	Sales ID	ocation:	Nr:
24.4.2014		siha	University of Iceland		IS	1

Nr.	*Item number:*	*Qty:*	*Item name:*	*Size:*	*PP ID:*	*Version*	*Mark*
1	0099-X20-90092-01	1 stk	Cross Frame in StreamLine		WW	1	
1.1	0099-X20-20648-01	1 stk	Main beam		SM	1	
1.2	0099-X20-20556-01	2 stk	Fundament for manual platform H=1160		SM	1	
1.3	0099-X20-20580	1 stk	Lower plate		SM	1	
1.4	0099-X20-20581	1 stk	Crossbeam for trim conveyor thermodrive		SM	1	
1.5	0099-X20-20646-01	2 stk	Plate		SM	1	
1.6	0099-X20-20646-02	4 stk	Plate		SM	1	
1.8	0099-X20-20649-01	1 stk	Supporting beam		SM	1	
1.9	0099-X20-20649-02	1 stk	Supporting beam		SM	1	

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Page 1 of 1

MARELGARÐABÆR

0099-X20-90092-01	*Cross frame for StremLine*					Workshop welding

[WW=Workshop Welding] [WA=Workshop Assembling] [TM=Turning & Milling] [SM=Sheet Metal] [PU=Purcased part]

Date:	Height:	Resp:	Customer:	Sales ID	ocation:	Nr:
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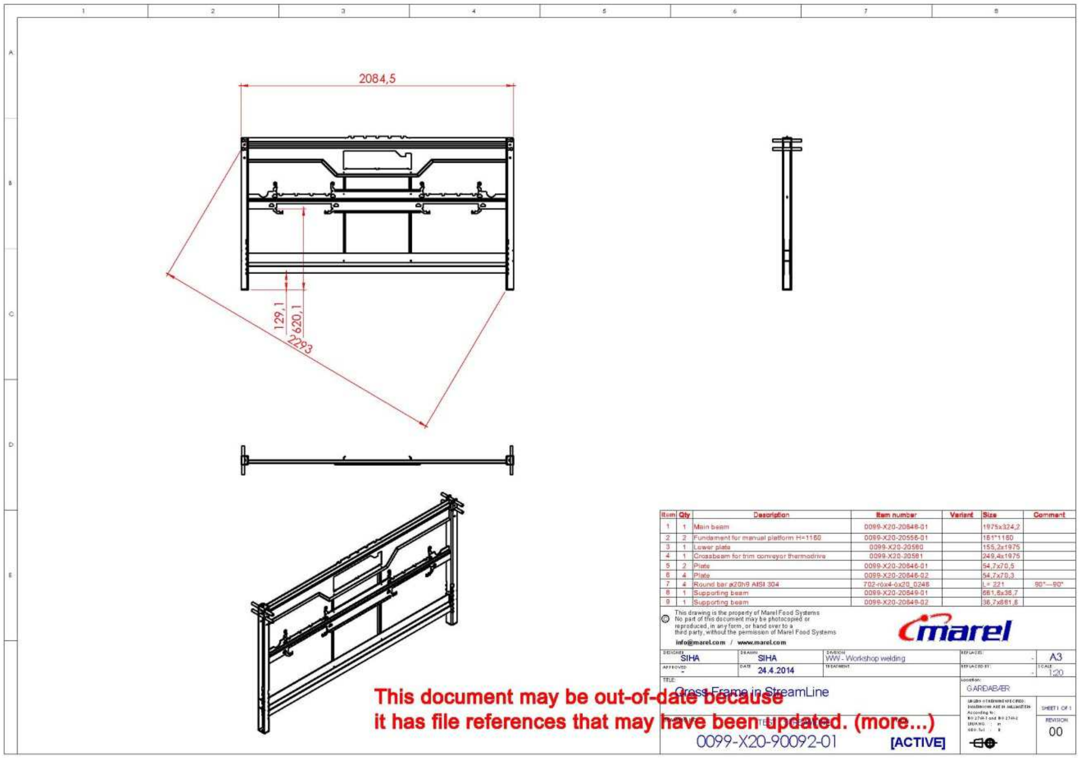
1	0099-X20-90092-01	1 stk	Cross Frame in StreamLine	WW	1


2084,5
129,1
620,1
2293
Item Qty Description Item number Variant Size Comment
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2 2 Fundament for manual platform H=1160 0099-X20-20556-01 161*1160
3 1 Lower plate 0099-X20-20580 155,2x1975
4 1 Crossbeam for trim conveyor thermodrive 0099-X20-20581 249,4x1975
5 2 Plate 0099-X20-20846-01 54,7x70,5
6 4 Plate 0099-X20-20846-02 54,7x70,3
7 4 Round bar ø20h9 AISI 304 702-röx4-öx20_0246 L= 221 90°—90°
8 1 Supporting beam 0099-X20-20849-01 861,6x36,7
9 1 Supporting beam 0099-X20-20849-02 36,7x861,6
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info@marel.com / www.marel.com
DESIGNER SIHA
DRAWN SIHA
DIVISION WW - Workshop welding
A3
APPROVED -
DATE 24.4.2014
SCALE 1:20
TITLE: Cross Frame in StreamLine
Location: GARÐABÆR
SHEET 1 OF 1
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0099-X20-90092-01
[ACTIVE]
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it has file references that may have been updated. (more...)

MARELGARÐABÆR

0099-X20-90092-01	*Cross frame for StremLine*					**Sheet metal work**

[WW=Workshop Welding] [WA=Workshop Assembling] [TM=Turning & Milling] [SM=Sheet Metal] [PU=Purcased part]

Date:	Height:	Resp:	Customer:	Sales ID	ocation:	Nr:
24.4.2014		siha	**University of Iceland**		IS	1

1	0099-X20-20580	1 stk	Lower plate	Sheet 5,00 mm 1.4301/AISI 304 2B	SM	1	
2	0099-X20-20581	1 stk	Crossbeam for trim conveyor thermod	Sheet 5,00 mm 1.4301/AISI 304 2B	SM	1	
3	0099-X20-20646-01	2 stk	Plate	Sheet 5,00 mm 1.4301/AISI 304 2B	SM	1	
4	0099-X20-20646-02	4 stk	Plate	Sheet 5,00 mm 1.4301/AISI 304 2B	SM	1	
5	0099-X20-20648-01	1 stk	Main beam	Sheet 5,00 mm 1.4301/AISI 304 2B	SM	1	
6	0099-X20-20649-01	1 stk	Supporting beam	Sheet 5,00 mm 1.4301/AISI 304 2B	SM	1	
7	0099-X20-20649-02	1 stk	Supporting beam	Sheet 5,00 mm 1.4301/AISI 304 2B	SM	1	
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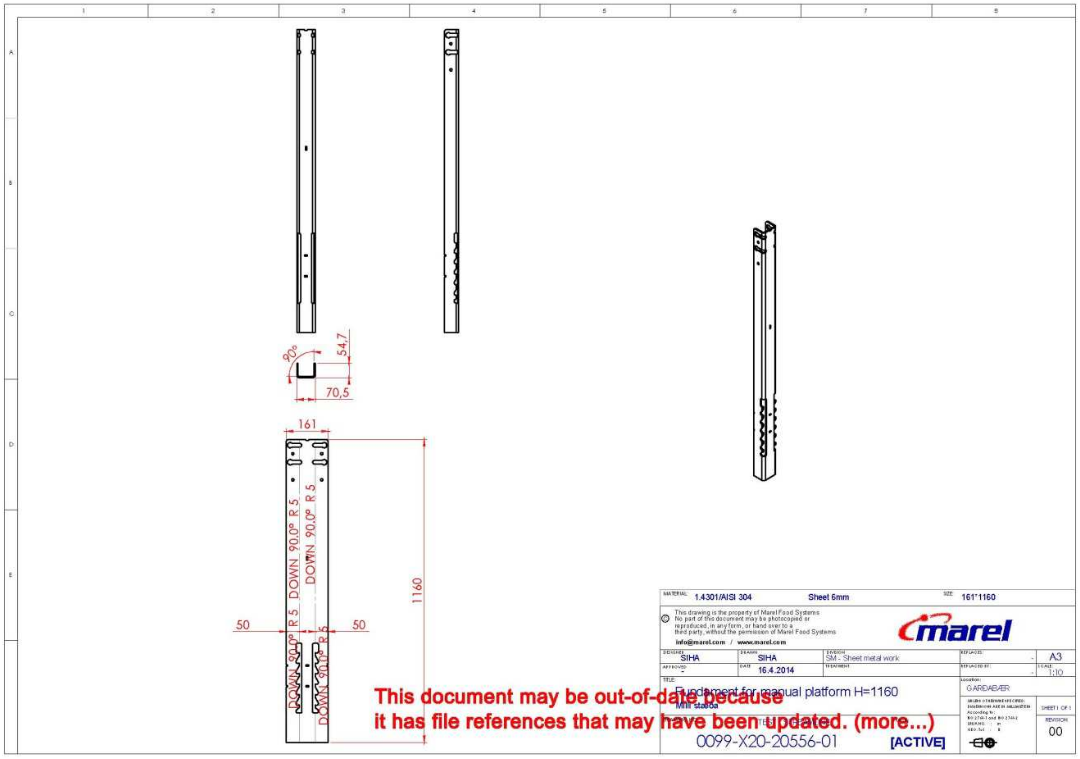
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info@marel.com / www.marel.com
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SM - Sheet metal work
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Fundament for manual platform H=1160
GARÐABÆR
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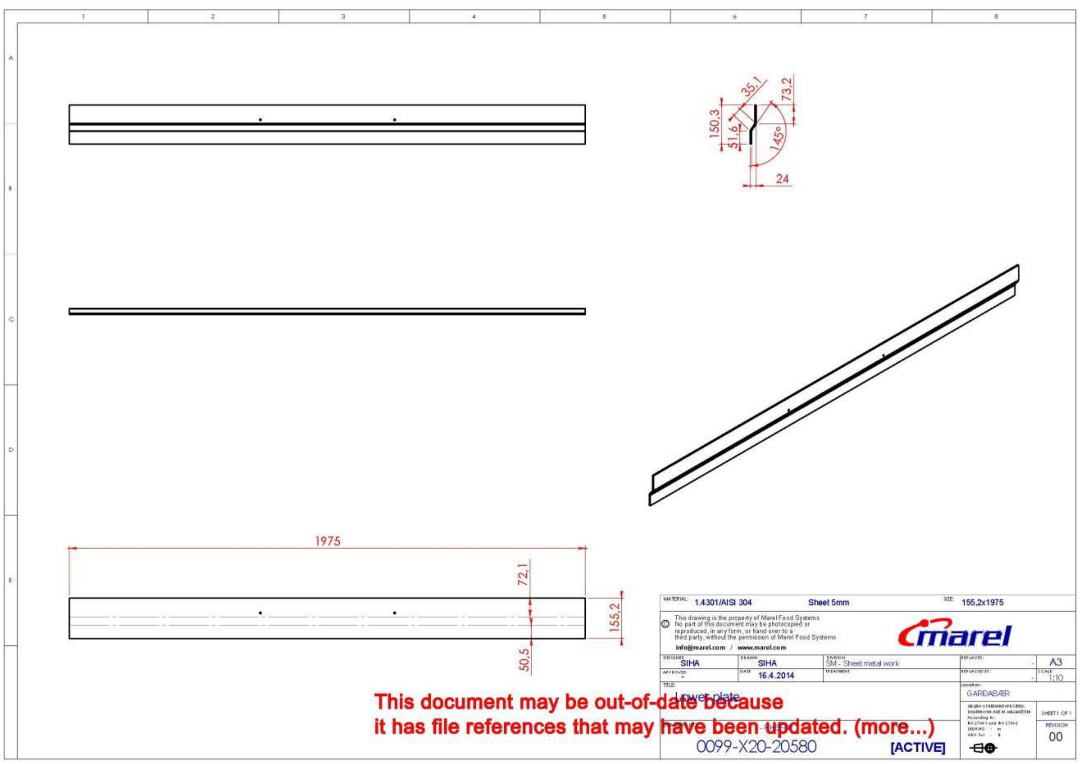
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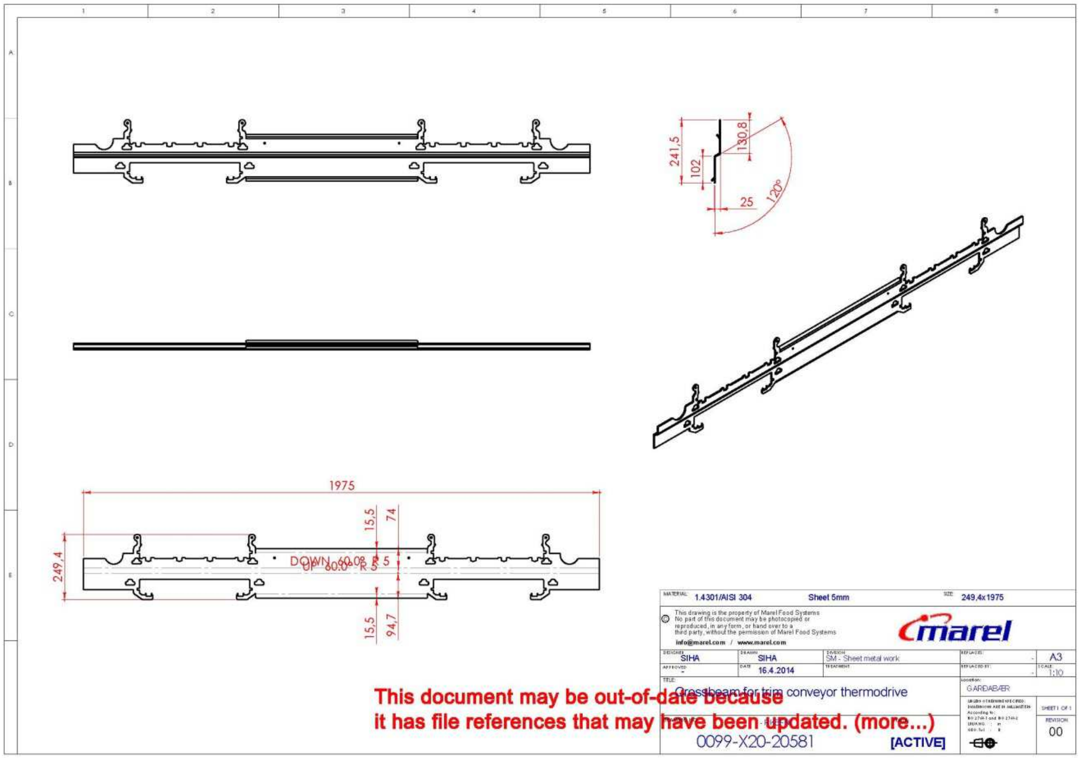
it has file references that may have been updated. (more...)
0099-X20-20580
[ACTIVE]
00



1975
249,4
241,5
102
130,8
25
120°
15,5
74
94,7
DOWN 60.0° R 5
UP 60.0° R 5
MATERIAL: 1.4301/AISI 304
Sheet 5mm
249,4x1975
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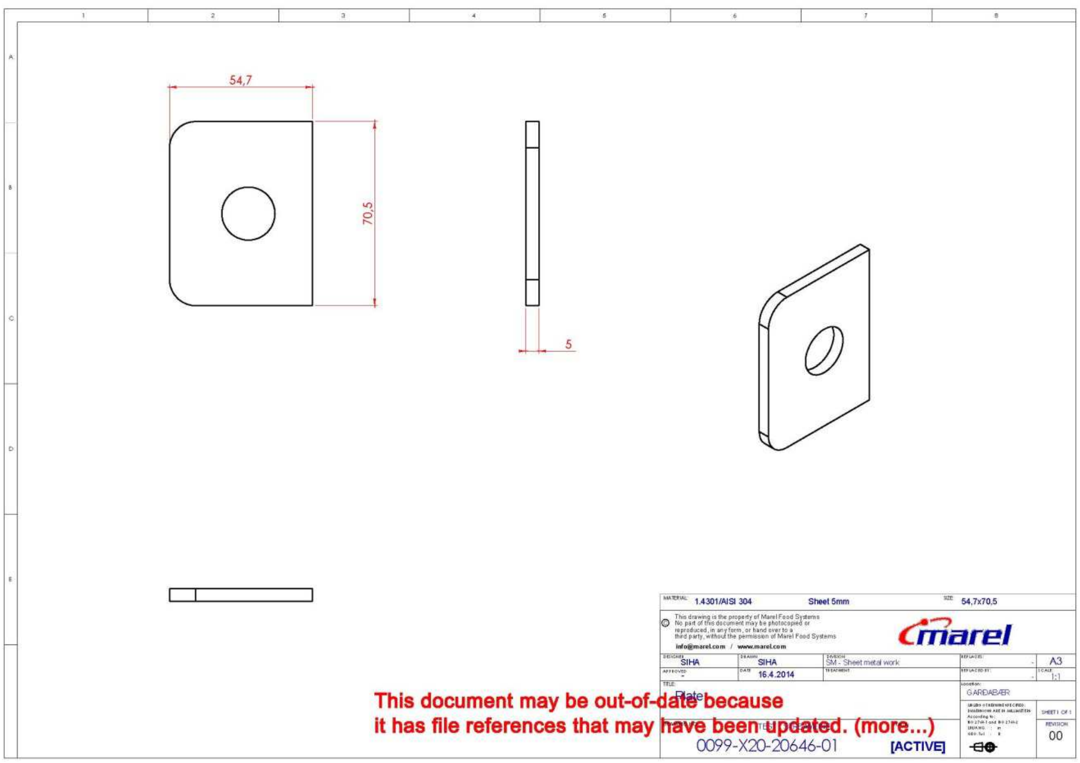
SIHA
SIHA
16.4.2014
SM - Sheet metal work
A3
1:10
Crossbeam for trim conveyor thermodrive
GARDABÆR
00
0099-X20-20581
[ACTIVE]
This document may be out-of-date because
it has file references that may have been updated. (more...)



54,7
70,5
5
MATERIAL: 1.4301/AISI 304
Sheet 5mm
54,7x70,5
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SIHA
SIHA
16.4.2014
SM - Sheet metal work
A3
1:1
Plate
GARDABÆR
00
0099-X20-20646-01
[ACTIVE]
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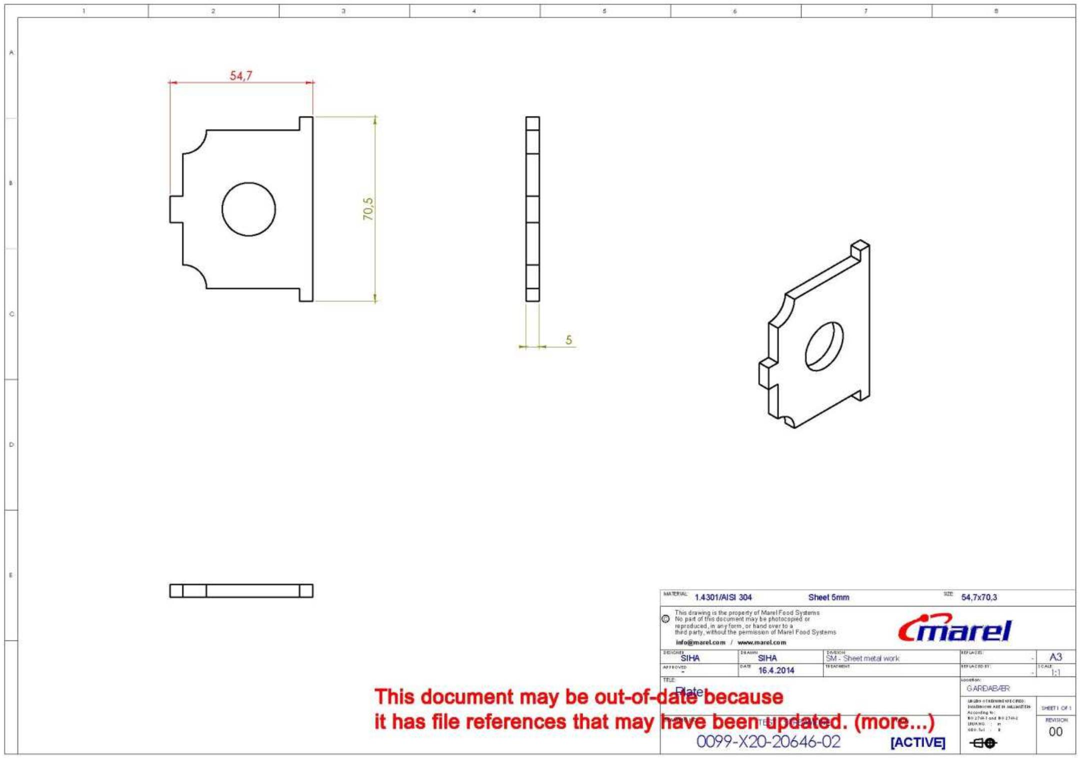
it has file references that may have been updated. (more...)


54,7
70,5
5
MATERIAL 1.4301/AISI 304
Sheet 5mm
SIZE 54,7x70,3
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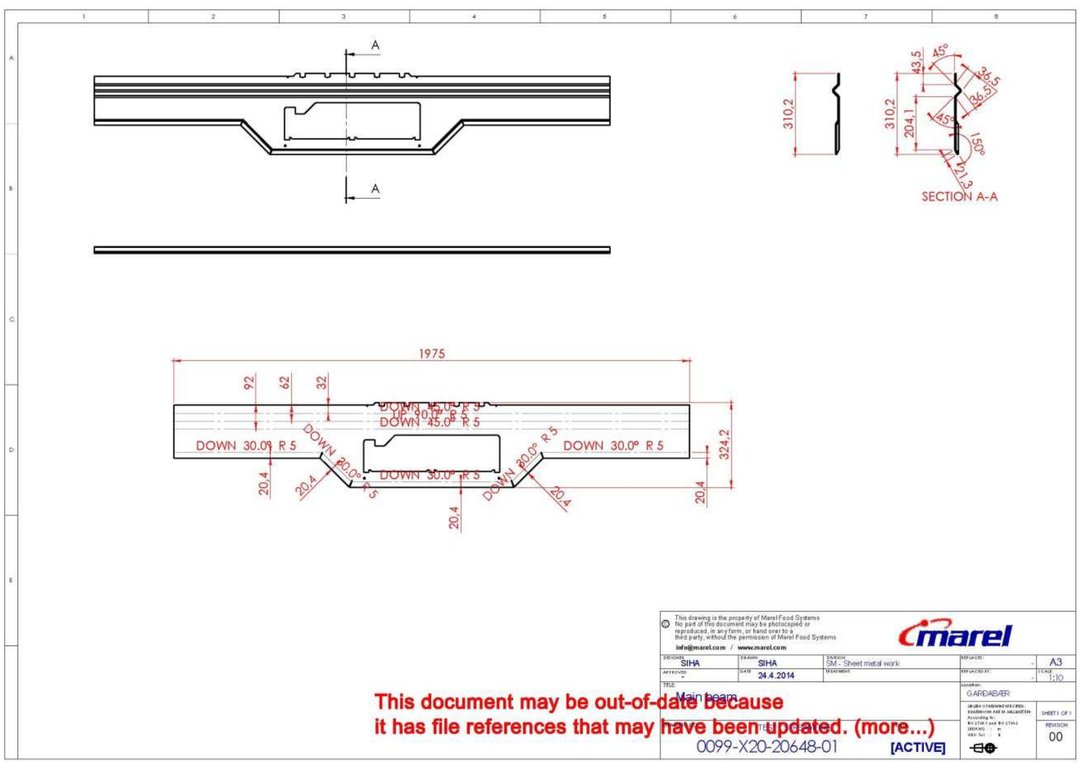
marel
SIHA
SIHA
SM - Sheet metal work
A3
16.4.2014
1:1
Plate
GARDABÆR
This document may be out-of-date because
it has file references that may have been updated. (more...)
0099-X20-20646-02
[ACTIVE]
SHEET 1 OF 1
00


A
A
310,2
310,2
204,1
43,5
45°
45°
36,5
36,5
150°
21,3
SECTION A-A
1975
92
62
32
DOWN 30.0° R 5
DOWN 45.0° R 5
UP 90.0° R 5
DOWN 45.0° R 5
DOWN 30.0° R 5
DOWN 30.0° R 5
DOWN 30.0° R 5
DOWN 30.0° R 5
20,4
20,4
20,4
20,4
20,4
324,2
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marel
SIHA
SIHA
SM - Sheet metal work
A3
24.4.2014
1:10
Main beam
GARDABÆR
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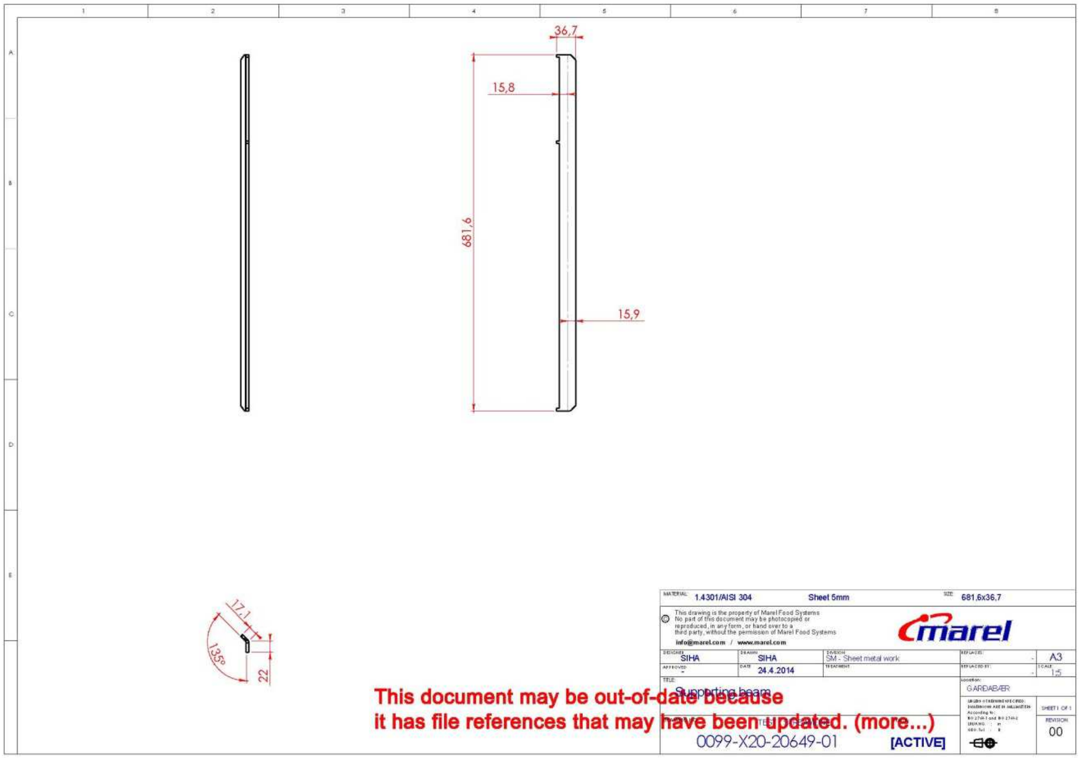
it has file references that may have been updated. (more...)
0099-X20-20648-01
[ACTIVE]
SHEET 1 OF 1
00


36,7
15,8
681,6
15,9
17,1
135°
22
MATERIAL: 1.4301/AISI 304
Sheet 5mm
SIZE: 681,6x36,7
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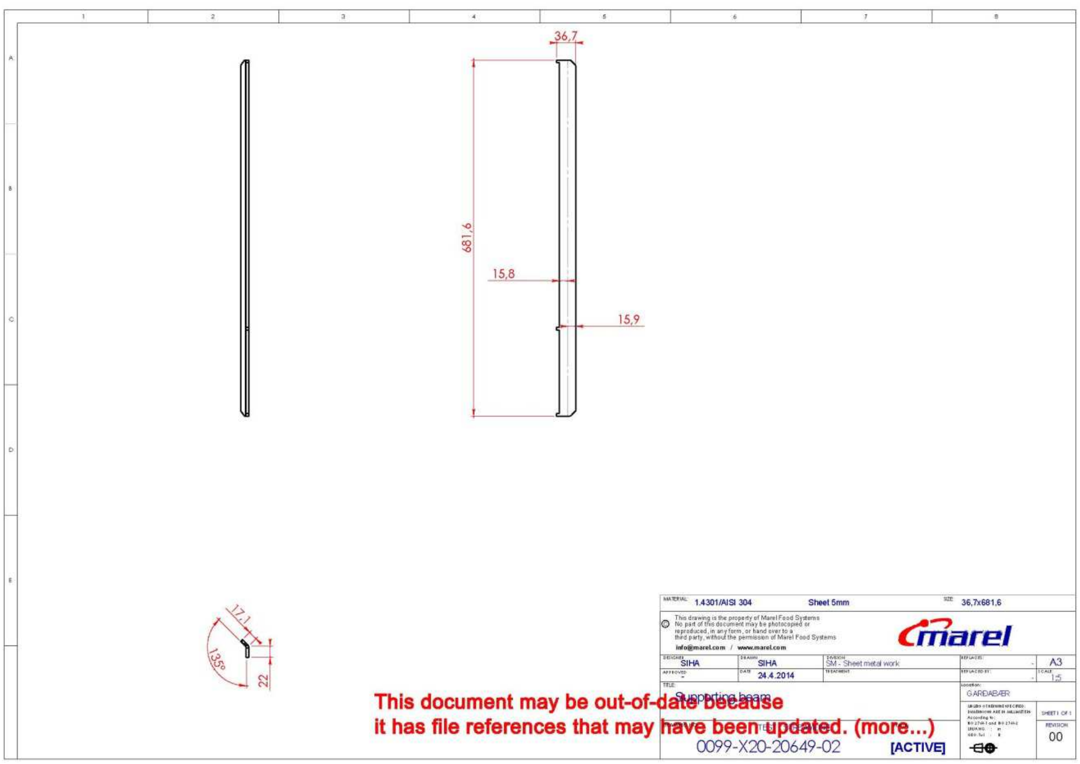
info@marel.com / www.marel.com
DESIGNER: SIHA
DRAWN: SIHA
DIVISION: SM - Sheet metal work
A3
APPROVED: -
DATE: 24.4.2014
SCALE: 1:5
TITLE: Supporting beam
Location: GARDABÆR
SHEET 1 OF 1
REVISION: 00
0099-X20-20649-01
[ACTIVE]
This document may be out-of-date because
it has file references that may have been updated. (more...)


36,7
681,6
15,8
15,9
17,1
135°
22
MATERIAL: 1.4301/AISI 304
Sheet 5mm
SIZE: 36,7x681,6
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info@marel.com / www.marel.com
DESIGNER: SIHA
DRAWN: SIHA
DIVISION: SM - Sheet metal work
A3
APPROVED: -
DATE: 24.4.2014
SCALE: 1:5
TITLE: Supporting beam
Location: GARDABÆR
SHEET 1 OF 1
REVISION: 00
0099-X20-20649-02
[ACTIVE]
This document may be out-of-date because
it has file references that may have been updated. (more...)

Appendix B

002-0852 Page 1

JETCAM - CNC PROGRAMMING SYSTEM

SOFTWARE v16.25.10 : P10-80010807-003260

DATE : Thu May 08 07:38:27 2014 UNITS : MM

*** SETUP - SCHEDULE FOR : BYSTRONIC LASER (pp 24020) ***

0099-X20-90092-01 PRG. No. : Not Used

FILE NAME : 002-0852 FORRITARI : None

MATERIAL CODE : AISI 304 THICKNESS : 5.0

SHEET SIZE : X = 3000.0 Y = 1500.0 No. of SHEETS : 1

COMPONENT(S) :

(1)	0099-x20-20556-01	: Size 1160.0 X 161.0,	Number = 2
(2)	0099-x20-20580	: Size 1975.0 X 149.737,	Number = 1
(3)	0099-x20-20581	: Size 1987.0 X 249.426,	Number = 1
(4)	0099-x20-20646-01	: Size 70.5 X 54.7,	Number = 2
(5)	0099-x20-20646-02	: Size 70.5 X 54.7,	Number = 4
(6)	0099-x20-20648-01	: Size 1975.0 X 324.23,	Number = 1
(7)	0099-x20-20649-01	: Size 681.6 X 36.698,	Number = 1
(8)	0099-x20-20649-02	: Size 681.6 X 36.698,	Number = 1

Sheet Usage Efficiency (Rectangular) : 41.7%
Sheet Usage Efficiency (actual) : 29.8%

***** RUN TIME ESTIMATION - Subroutines *****

SINGLE HITS	= 0
NIBBLE HITS	= 0
TOTAL DISTANCE TRAVELLED	= 23386.23
TOOL CHANGES	= 0
CNC PROGRAM SIZE	= 38530
TOTAL TIME per SHEET	= 12min, 18sec

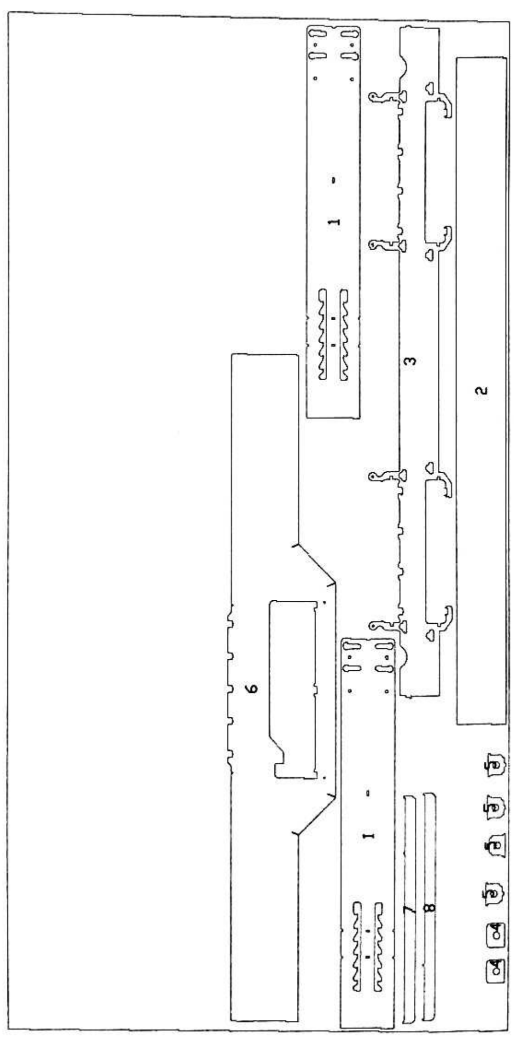
CLAMPS : None

******** TOOL ASSIGNMENT LIST ********

TOOL DESCRIPTION	ANGLE	DIE CLEAR.	STATION
===> Profiling Used In This Job <===			

REMARKS :

File: 002-0852 - (J:\Laser\002\002-0852.LCC)
Scale (approx.) : 1 To 11.4187



~~002~~-0855 Page 1

2mm 0099-X20-90091-01

JETCAM - CNC PROGRAMMING SYSTEM

SOFTWARE v16.25.10 : P10-80010807-003260

DATE : Thu May 08 07:51:34 2014 UNITS : MM

*** SETUP - SCHEDULE FOR : BYSTRONIC LASER (pp 24020) ***

PRG. No. : Not Used

FILE NAME : 002-0855

FORRITARI : None

MATERIAL CODE : AISI 304

THICKNESS : 2.0

SHEET SIZE : X = ~~500.0~~ 3000.0 Y = ~~500.0~~ 1500.0

No. of SHEETS : 1

COMPONENT(S) :
(1) 014-0001-22730005 : Size 39.0 X 39.0, Number = 2

Sheet Usage Efficiency (Rectangular) : ~~1.2%~~ 0.06%
Sheet Usage Efficiency (actual) : ~~1.2%~~ 0.06%

***** RUN TIME ESTIMATION - Optimised *****

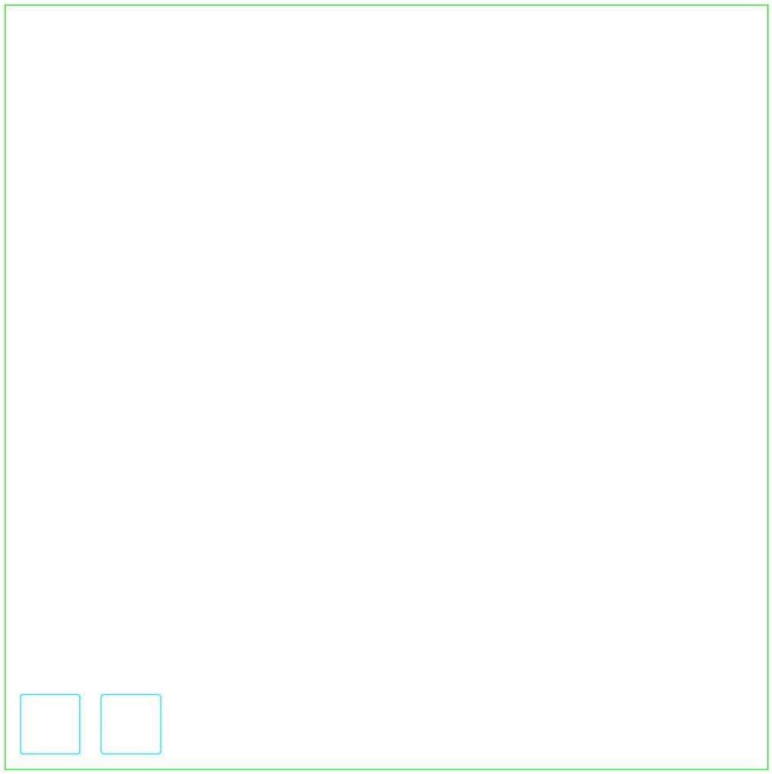
SINGLE HITS	= 0
NIBBLE HITS	= 0
TOTAL DISTANCE TRAVELLED	= 754.16
TOOL CHANGES	= 0
CNC PROGRAM SIZE	= 427
TOTAL TIME per SHEET	= 5sec

CLAMPS : None

******** TOOL ASSIGNMENT LIST ********

TOOL DESCRIPTION	ANGLE	DIE CLEAR.	STATION
===> Profiling Used In This Job <===			

REMARKS :



002-0857 Page 1

JETCAM - CNC PROGRAMMING SYSTEM 4mm 0099-X20-90091-01

SOFTWARE v16.25.10 : P10-80010807-003260

DATE : Thu May 08 07:58:39 2014 UNITS : MM

*** SETUP - SCHEDULE FOR : BYSTRONIC LASER (pp 24020) ***

PRG. No. : Not Used

FILE NAME : 002-0857 FORRITARI : None

MATERIAL CODE : AISI 304 THICKNESS : 4.0

SHEET SIZE : X = ~~1000.0~~ 3000.0 Y = ~~1000.0~~ 1500.0 No. of SHEETS : 1

COMPONENT(S) :
(1) 0020-010-20723 : Size 686.0 X 280.0, Number = 2
(2) 0020-010-20732-01 : Size 535.0 X 182.4, Number = 1

Sheet Usage Efficiency (Rectangular) : ~~48.2%~~ 10.7%
Sheet Usage Efficiency (actual) : ~~35.6%~~ 7.9%

***** RUN TIME ESTIMATION - Subroutines *****

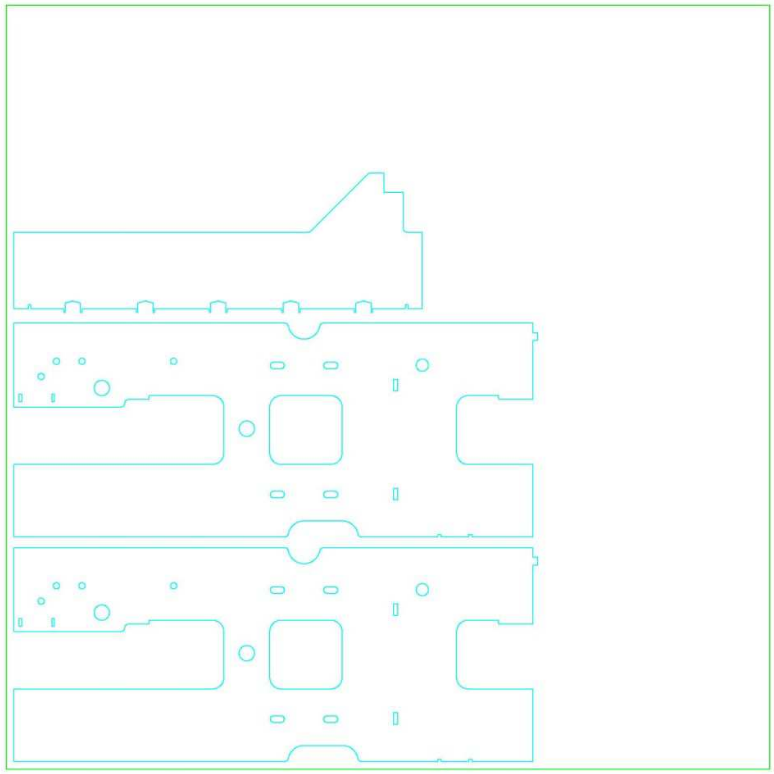
SINGLE HITS	= 0
NIBBLE HITS	= 0
TOTAL DISTANCE TRAVELLED	= 5407.852
TOOL CHANGES	= 0
CNC PROGRAM SIZE	= 9845
TOTAL TIME per SHEET	= 3min, 9sec

CLAMPS : None

******** TOOL ASSIGNMENT LIST ********

TOOL DESCRIPTION	ANGLE	DIE CLEAR.	STATION
===> Profiling Used In This Job <===			

REMARKS :



002-0853 Page 1

JETCAM - CNC PROGRAMMING SYSTEM

SOFTWARE v16.25.10 : P10-80010807-003260

DATE : Thu May 08 07:44:17 2014 UNITS : MM

*** SETUP - SCHEDULE FOR : BYSTRONIC LASER (pp 24020) ***

5mm 0099-X20-90071-01 PRG. No. : Not Used

FILE NAME : 002-0853 FORRITARI : None

MATERIAL CODE : AISI 304 THICKNESS : 5.0

SHEET SIZE : X = ~~800.0~~ 3000.0 Y = ~~500.0~~ 1500.0 No. of SHEETS : 1

COMPONENT(S) :

(1) 0020-010-20855 : Size 686.0 X 216.5, Number = 2
(2) 0099-x20-20600-01 : Size 535.0 X 53.348, Number = 1
(3) 020-0014-2245 : Size 60.0 X 55.5, Number = 4

Sheet Usage Efficiency (Rectangular) : ~~84.7%~~ 7,5%
Sheet Usage Efficiency (actual) : ~~24.6%~~ 2,2%

***** RUN TIME ESTIMATION - Subroutines *****

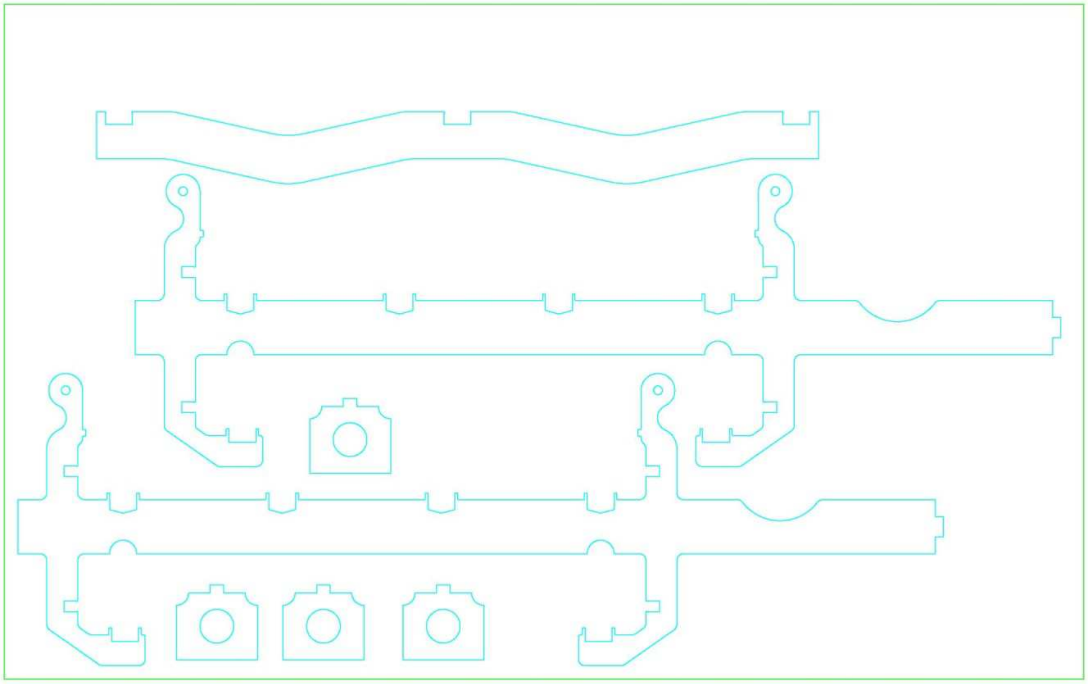
SINGLE HITS	= 0
NIBBLE HITS	= 0
TOTAL DISTANCE TRAVELLED	= 3730.004
TOOL CHANGES	= 0
CNC PROGRAM SIZE	= 11556
TOTAL TIME per SHEET	= 2min, 58sec

CLAMPS : None

******** TOOL ASSIGNMENT LIST ********

TOOL DESCRIPTION	ANGLE	DIE CLEAR.	STATION
===> Profiling Used In This Job <===			

REMARKS :



0~~02~~-0858 Page 1

6mm 0099-X20-90091-01

JETCAM - CNC PROGRAMMING SYSTEM

SOFTWARE v16.25.10 : P10-80010807-003260

DATE : Thu May 08 08:10:05 2014 UNITS : MM

*** SETUP - SCHEDULE FOR : BYSTRONIC LASER (pp 24020) ***

PRG. No. : Not Used

FILE NAME : 002-0858 FORRITARI : None

MATERIAL CODE : AISI 304 THICKNESS : 6.0

SHEET SIZE : X = ~~1300.0~~ 3000.0 Y = ~~500.0~~ 1500.0 No. of SHEETS : 1

COMPONENT(S) :
(1) 020-0014-31250001 : Size 1160.0 X 161.0, Number = 2

Sheet Usage Efficiency (Rectangular) : ~~57.5%~~ 8.3%
Sheet Usage Efficiency (actual) : ~~54.8%~~ 7.9%

***** RUN TIME ESTIMATION - Subroutines *****

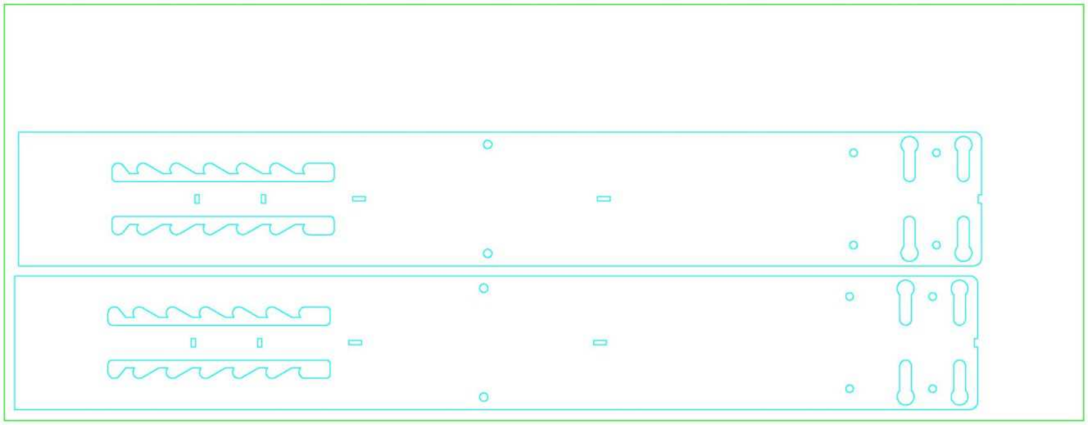
SINGLE HITS	= 0
NIBBLE HITS	= 0
TOTAL DISTANCE TRAVELLED	= 7242.437
TOOL CHANGES	= 0
CNC PROGRAM SIZE	= 6141
TOTAL TIME per SHEET	= 4min, 42sec

CLAMPS : None

******** TOOL ASSIGNMENT LIST ********

TOOL DESCRIPTION	ANGLE	DIE CLEAR.	STATION
===> Profiling Used In This Job <===			

REMARKS :



002-0854 Page 1

10mm 0099-X20-90091-01

JETCAM - CNC PROGRAMMING SYSTEM

SOFTWARE v16.25.10 : P10-80010807-003260

DATE : Thu May 08 07:48:48 2014 UNITS : MM

*** SETUP - SCHEDULE FOR : BYSTRONIC LASER (pp 24020) ***

PRG. No. : Not Used

FILE NAME : 002-0854 FORRITARI : None

MATERIAL CODE : AISI 304 THICKNESS : 10.0

SHEET SIZE : X = ~~800.0~~ 3000.0 Y = ~~500.0~~ 1500.0 No. of SHEETS : 1

COMPONENT(S) :
(1) 0020-001-20191 : Size 72.0 X 54.5, Number = 2

Sheet Usage Efficiency (Rectangular) : ~~2.0%~~ 0,18%
Sheet Usage Efficiency (actual) : ~~1.9%~~ 0,17%

***** RUN TIME ESTIMATION - Subroutines *****

SINGLE HITS	= 0
NIBBLE HITS	= 0
TOTAL DISTANCE TRAVELLED	= 1103.209
TOOL CHANGES	= 0
CNC PROGRAM SIZE	= 518
TOTAL TIME per SHEET	= 41sec

CLAMPS : None

******** TOOL ASSIGNMENT LIST ********

TOOL DESCRIPTION	ANGLE	DIE CLEAR.	STATION

===> Profiling Used In This Job <===

REMARKS :

File: 002-0854 - (J:\Laser\002\002-0854.LCC)
Scale (approx.) : 1 To 3.0450