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# Volvo's next step in additive manufacturing Volvo's nästa steg inom additiv tillverkning

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## Sammanfattning

Ett av teknikens mest växande områden idag är additiv tillverkning med ett stort applikationsområde som bara växer. Additiv tillverkning är när man tillverkar komponenter genom att lägga till material istället för att avlägsna material för att tillverka en komponent. I samband med att tekniken utvecklas har additiv tillverkning blivit mer och mer vanligt inom industrin där dess applikationer kan spara företagen en stor summa pengar. Ett område där additiv tillverkning kan visas användbart är i produktionen på Volvo GTO, Umeå som är Volvos ledande tillverkare av lastbilshyttar. För att undersöka om additiv tillverkning kan sänka tillverkningskostnaden, öka kvalitén på produkten eller minska leveranstiden på fabriken så har utredaren genom att ha möten och diskussioner med anställda på fabriken försökt att hitta case där den additiva tekniken kan appliceras. Sex case hittades och undersöktes. Casen handlade bland annat om munstycken i tätningsslinan, vakumformningsmallar till snickeriet och fördelningsbrickor på målerirobotar. Casen utreddes genom undersökning och tester för att se vilken additiv teknik som passade bäst för just det fallet. När alla case hade undersökts klart så skapades det en investeringsprioritering för att skapa en plan för hur fabriken ska fortsätta sin satsning på den additiva tekniken. Ordningen på listan baseras på vad utredaren tyckte var viktigast och genomförbart. Ordningen blev: FFF-skrivare utan låst materialsystem, SLA-skrivare och sist hamnade MJF-skrivare. Det bedömdes även att fabriken kan spara in 423 384 SEK om året redan nu genom att utnyttja andra additiva tekniker än den som redan finns på plats i fabriken.

## **Abstract**

One of the fastest growing areas in the manufacturing industry today is additive manufacturing with a large application area that is only getting bigger. Additive manufacturing is when material is added instead of removed in order to produce a part. In connection with the technology being developed, additive manufacturing has become more and more common in the industry where its applications can save companies a large amount of money. An area where additive manufacturing can be shown to be useful is in the production at Volvo GTO, Umeå which is Volvo's leading manufacturer of truck cabins. To investigate whether additive manufacturing can reduce the manufacturing cost, increase the quality of the product or reduce the delivery time at the factory, the investigator has researched what possible cases related to additive manufacturing there is by having meetings and discussions with employees at the factory and finding where the additive technology could be applied. Six cases were found that were investigated. The cases included, among other things, nozzles in the sealing line, vacuum forming templates for the carpentry department and paint distributors on painting robots. The cases were investigated by examining and testing to see which additive technology is best suited for that particular case. When all cases had been investigated thoroughly, an investment priority list was created to create a plan for how the factory should continue its investment in the additive technology. The order on the list is based on what the investigator thought was most important and feasible. The sequence became: FFF printer without locked material system, SLA printer and a MJF printer. It was also found that the factory can save 423 384 SEK a year already by utilizing other additive methods than the one already in place in the factory.



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## Appendix A Customer adaptation

**Appendix B Nozzles in sealing line**

**Appendix C Wood workshop**

**Appendix D Distrubution disc**

**Appendix E Paint mixing rods**

**Appendix F Workflow**

# 1 Introduction

## 1.1 Background

Volvo's factory in Umeå manufactures all sheet metal parts and assembles all sheet metal parts and paints cabins for the company's trucks. The factory also presses sheet metal parts to other cab plants around the world.

The factory in Umeå is today a so-called Volvo Cab Competence Center within AB Volvo. It is especially important that the technology is at the forefront of Umeå, where, among other things, the additive production is suitable.

Today you also have a Volvo Production Pilot Plant in Umeå where they test to produce new cab models that have not yet been released on the market. Here too, it is important to be at the forefront of technology to be competitive in the production line of the future.

The company currently uses its own Fused Deposition Modeling (FDM) printer and orders printed components from subcontractors. The additive technology is constantly evolving, which gives rise to new opportunities that can bring additional competitive advantages for the company.

## 1.2 Aim

The aim for the project is to evaluate whether new additive technologies can reduce manufacturing costs, increase the quality of the products or reduce delivery time at the factory.

## 1.3 Goal

The aim of the project was to find areas where the additive manufacturing technique could be applied and where the existing printer was not sufficient.

# 2 Additive manufacturing

## 2.1 Methods

Additive manufacturing is when manufacturing components by adding materials instead of subtractive manufacturing such as milling and turning which are common manufacturing

methods. Additive manufacturing can take place in many different ways, and most of them have been considered in this project.

### **2.1.1 FFF/FDM**

Fused filament fabrication (FFF) is probably the most adopted method, as almost all hobby machines use this method. FDM is a trademark protected by stratasys. FDM is suitable for manufacturing mechanical components. [1] But the both use the same method to manufacturing parts. They both use a heated nozzle to extrude a heated plastic that is precisely deposited in layers. [2]

### **2.1.2 SLA/DLP**

Stereolithography (SLA), and digital light processing (DLP) both work by curing a photopolymer resin using UV light. The method often maintains a higher quality of the prints as it depends on the laser thickness of the SLA printer and the pixel size at the DLP which can be very small compared to an FDM nozzle. But often the materials are brittle and can be decayed by UV light. [3]

### **2.1.3 SLS**

Selective laser sintering (SLS) uses a laser like SLA but this laser is used to fuse a powder and that means that it has to be more powerful than the laser in a SLA printer. Since this method uses a powder there is no need for support material which enables bigger freedom when a part is designed.[4]

### **2.1.4 CFF**

Continuous filament fabrication (CFF) is a technology that is patented by Markforged. It utilizes the fact that it can embed fibers in the print so that it becomes a composite material with nylon as the matrix and the fibers as the reinforcement. Components can achieve the same strength as 6061-T6 aluminum in strength. The method is very suitable for mechanical components. [5]

### **2.1.5 MJF**

Mukti jet fusion (MJF) is a technology that is patented by HP. It works by spraying an agent on a layer of powder that causes it to absorb more heat than the powder around and then it drives a lamp over the entire bed and that melts the plastic that has been sprayed with the agent. [6]

### **2.1.6 CLIP**

Continuos Liquid Interface Production (CLIP) is the company Carbon's own patented solution for additive manufacturing. It works almost like a regular SLA printer, but instead has a special tray that allows for faster printing. [7]

## **2.2 Software**

To be able to compare different printers and materials, different programs have been used which will be presented below.

### **2.2.1 GrabCad Print**

GrabCad Print is Stratasys new print preparation software that is made for their printers. This program is used to convert the CAD files into work instructions for the 3D printer. and it only works with their own printer. [8]

### **2.2.2 Ultimaker Cura**

Ultimaker Cura is Ultimaker's print preparation software that is used to make CAD data for work instructions for the printer. Because Cura is an open source program, it can be used for most printers that accept standard G-code. And there is many other printer manufacturers that use Cura as a print preparation program. [9]

### **2.2.3 Formlabs PreForm**

PreForm is used to prepare files for Formlab's SLA printer. The program only works for Formlab's SLA-printers [10]

### **2.2.4 Markforged Eiger**

Eiger is used to prepare parts for Markforgeds printer. It is also in that program that the parts are reinforced with long fibers that are unique to this printer manufacturer. [11]



### 3 Method

The investigator tried to find what kind of needs the factory had by looking for cases where the existing technology was not able to fulfill the need. To find cases the investigator booked meetings with people from different departments. Where the department together with the investigator tried to find what needs that department had and if there was any case that was to be researched further.

Once a case had been found, the background to the case was first taken into account by gathering facts about the current problem. And based on that, it was decided which requirements there would be on the possible solutions. When the requirements were determined, the investigator could start to research which methods would fit that particular case. If possible, different methods were tested and compared to each other. And in some cases parts could be tested in production, see case about the nozzles in the sealing line in Appendix B. And if it did not work as it should, some parts could be modified and tested once more at a later time. Some parts needed to be crater tested which has the purpose of testing if the part affect the paint in a negative way. This is needed for all parts that touch or is in contact with something that touches the cab. The test was done by the color lab at the factory. And if the parts had to withstand thinner it was tested by submerging the parts in said thinner this was tested by placing these parts in thinner for at least 24 hours.

When the investigator felt satisfied with their solutions, an attempt was made to determine which method that was best suited to that particular case in a conclusion. One case did not really follow the same concept as the others as it was about the workflow itself during additive manufacturing and how it could be simplified, see case workflow in appendix F. In that case, various companies were contacted to investigate which software options exist. and then a flow chart was created for each and then it was established which solution the investigator thought to be the best solution.

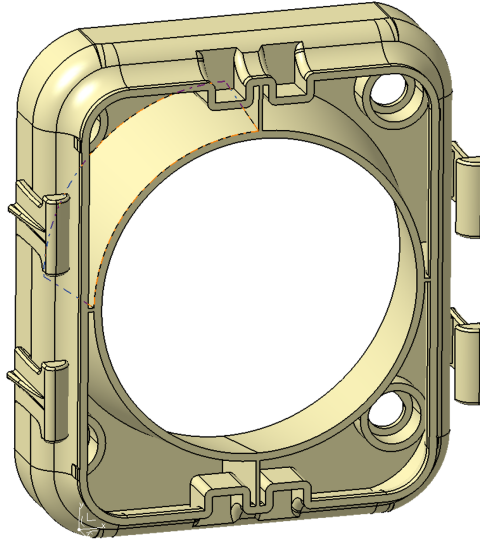
When all cases were completed, a priority list was made of proposed investments based on what the investigator thought the technology would be of use to the factory compared to the size of the investment.

### 4 Results

Since the investigator has come up with different solutions to different cases, the results will be presented separately.

## 4.1 Customer adaptation (Appendix A)

The component that can be seen in Figure 1 would cost 328 SEK when purchased from a subcontractor, which also includes dyeing of the component. The price for this component, if it was printed with a machine that would be owned by Volvo would be 260 SEK [12]. So the price difference is  $328 - 260 = 68$  SEK. The total price difference on 1016 components is  $1016 \cdot 68 = 69088$ kr.



**Figure 1:** Component that was used for the price comparison.

Printer manufacturer Carbon, which manufactures printers that uses the technology CLIP, was also contacted, but no solution was presented before the project ended.

Suggested solution: **MJF**

## 4.2 Nozzles in sealing line (Appendix B)

The "flatstream" nozzle that can be seen in Figure 20 in Appendix B, is currently purchased from a subcontractor for 300 SEK/pcs and these are usually changed every three weeks. The nozzle is printed in PA12 in a HP MJF printer. As the nozzle is changed every three weeks the monthly cost is  $\frac{(18 * 300)}{12} = 450$  SEK/month.

20 pieces of the "CEC" nozzle that can be seen in Figure 17 in Appendix B have been purchased since 2017-04 and the latest price of the nozzle was 19800 SEK and therefore it is a monthly cost of  $\frac{20 * 19800}{25} = 15840$  SEK. The ordering point for this item is 10 which gives a minimum storage cost of  $10 \cdot 19800 = 198000$  SEK.

The total monthly cost for these nozzles is  $450 + 15840 = 16290$  SEK.

In the case of nozzles in sealing line, two techniques were tested with good results which will be presented below.

#### 4.2.1 Nozzle "CEC"

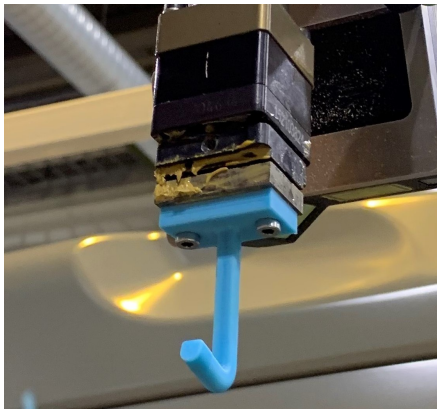
**FFF** Two "CEC" nozzles were printed on a FFF printer in PLA. The nozzles can be seen in the Figures 2, 3, 4, and 5.



**Figure 2:** The first "CEC" PLA nozzle mounted on the robot.



**Figure 3:** Sealing bead put down by the first PLA nozzle on a door.



**Figure 4:** The second "CEC" PLA nozzle mounted on the robot.



**Figure 5:** Sealing bead sprayed by the first PLA nozzle on a door.

The weight of the "CEC" nozzle used had a material consumption of 6 grams of PLA including support material according to the print preparation program Ultimaker Cura. And if you would use Ultimaker's PLA which costs 348 SEK/750 gram [13] the total cost of the nozzle would be  $\left(\frac{348}{750}\right) \cdot 6 \approx 2.8$  SEK per "CEC" nozzle.

**SLA** The nozzle was also printed in HTR (High Temp Resin) in an SLA printer. Picture of a nozzle mounted on a robot and an image of a sealing bead sprayed by the nozzle can be seen in Figure 6 and 7.



**Figure 6:** HTR nozzle mounted on robot.



**Figure 7:** Sealing bead sprayed by the HTR nozzle on a door.

#### 4.2.2 Nozzle "flatstream"

**FFF** The "flatstream" nozzle was also tested in a FFF-printer. Pictures of the nozzle mounted on the robot can be seen in Figure 8 and in Figure 9 a sealing bead sprayed by the nozzle can be seen.



**Figure 8:** Spray pattern "flatstream" PLA nozzle.

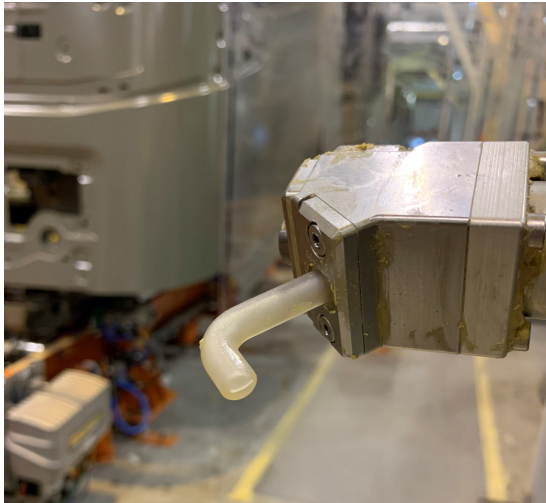


**Figure 9:** Sealing bead sprayed by the PLA nozzle.

The weight of the "flatstream" nozzle used had a material consumption of 2 grams PLA including support material according to the print preparation program Ultimaker Cura.

And if you would use Ultimaker's PLA which costs 348 SEK/750 gram it would give a cost  $(\frac{348}{750}) \cdot 2 \approx 0.9$  SEK per "flatstream" nozzle.

**SLA** Nozzles have also been printed in an SLA printer. Pictures of nozzles can be seen in the Figures 10 and the spray pattern of the nozzle can be seen in Figure 11 below.



**Figure 10:** "flatstream" nozzle mounted on the robot.



**Figure 11:** Spray pattern of Sprutbild "flatstream" HTR nozzle.

Since the spray pattern was too narrow the nozzle was not tested on a cab.

Estimated price of this nozzle was 9.7 SEK/pc when printed in HTR.

Suggested solution: **FFF**

### 4.3 Wood Workshop (Appendix C)

In the case about the wood workshop, the material price from different manufacturers was evaluated. The results from this investigation can be seen in table 1 below. All prices is in  $SEK/cm^3$ .

**Table 1:** Material price table. Prices from [14], [15], and [16]. An X in the table implies that there is no matching material available from the manufacturer.

Manufacturer\material	ABS	PC	Nylon	Ultem 9085
Stratasys	3.05	3.25	3.25	5.43
iSquared	1.80	2.11	X	3.46
Ultimaker	0.58	0.91	0.88	X



Suggested solution: **FFF (without a locked material system)**

#### 4.4 Distrubution disc (Appendix D)

It is usually renovated between about 50 and 100 pieces of distributor discs per year with an average renovation time of two hours per piece. And in addition, 36 new distributor discs were ordered in 2018. The spare part cost 5400 SEK the last time these were ordered. The cost of this will then be between  $100 \cdot 335 + 36 \cdot 5400 = 227900$  SEK and  $200 \cdot 335 + 36 \cdot 5400 = 261400$  SEK. which gives a minimum monthly cost of  $\frac{227900}{12} \approx 18992$  SEK. The ordering point in the warehouse inventory is at 10 pc. It gives a minimum inventory cost of  $10 \cdot 5400 = 54000$  SEK.

In this case, it was also tested if Formlab's HTR was able to handle the thinner used in the factory. The weight of a test piece can be seen in the table 2 below.

**Table 2:** Weight of nozzle before and after thinner. Values from table 17 in appendix D

Before	5,7442 g
After	5,7574 g
Difference	0,0132 g

The print was soft enough to be able to make scratch marks with a nail when it was taken up from the bath but it could not be done when the print had dried again.

Picture of a test print from a SLA printer in HTR material can be seen in Figure 12 below. The print was done by the company 3DVerkstan AB.



**Figure 12:** Distrubutor disc in HTR material.

The distrubutor disc could not be test fitted.

A package consisting of Formlabs Form 2 that was used to print the distribution disc above in Figure 12 together with the washing station and curing station costs at 3Dverkstan right now 41 496 SEK [17]. Formlabs has just released a new printer that costs 5000 SEK more [18] which gives a package cost of 46496 SEK. If this printer would only be used to produce this distribution disc the ROI (Return of investment) would be  $\frac{46496}{16290} \approx 2.9$  months. Or  $\frac{46496}{5400} \approx 9$  pc of distribution discs.

Suggested solution: **SLA**

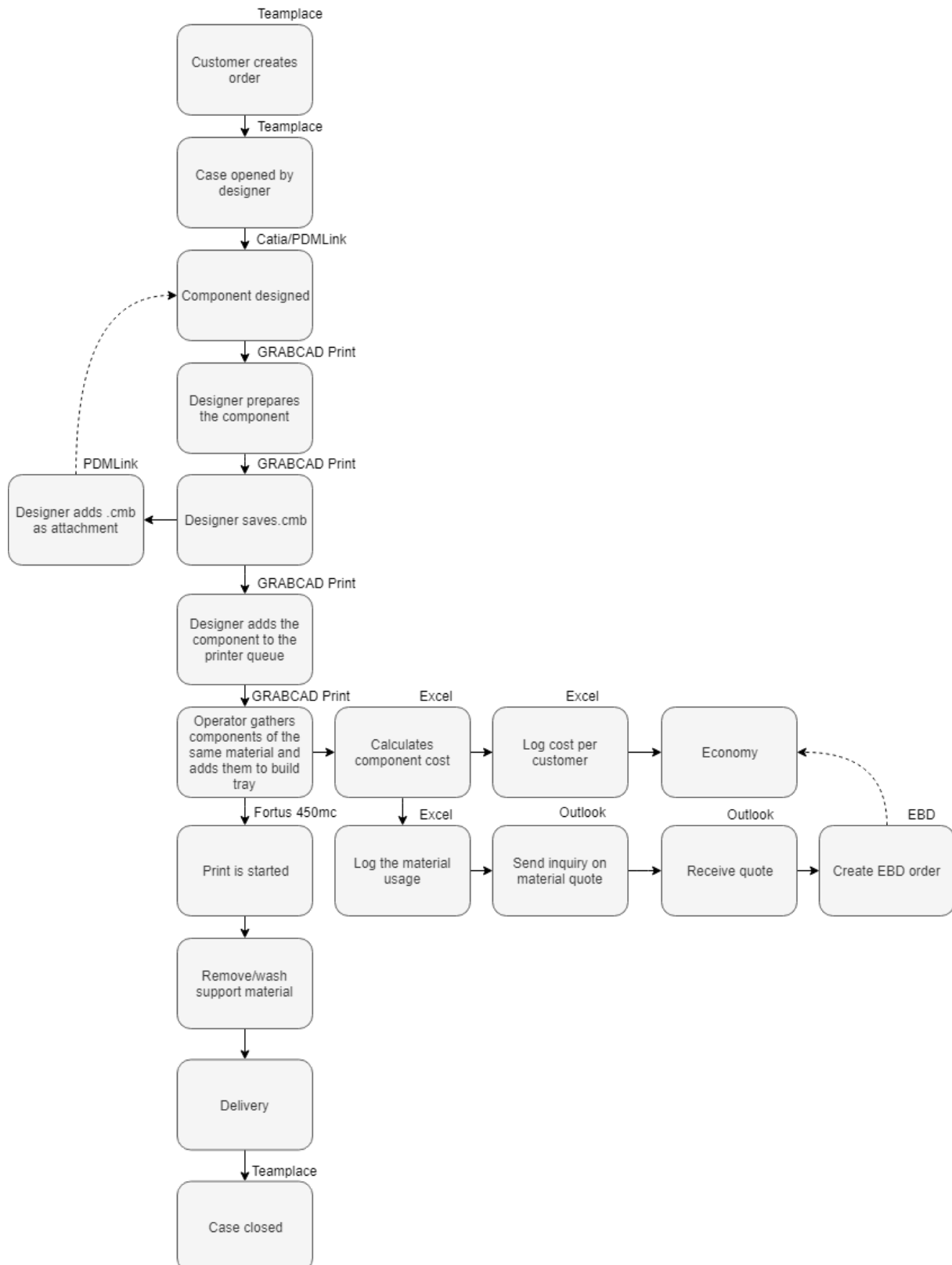
## 4.5 Paint mixing rods (Appendix E)

The case about the paint mixing rods was started late in the project and as such it was not researched as well as the other cases. But it was found that the SLA method would probably be the best solution.

Suggested solution: **SLA**

## 4.6 Workflow (Appendix F)

In the case about the workflow different workflows made by different software producer were evaluated. The suggested solutions workflow can be seen in 13. The biggest time saver was that the designers could prepare their own part. The rest of the workflows can be seen in the appendix F



**Figure 13:** Suggested workflow when using Grabad Print.

Suggested solution: **GrabCad Print**

## 4.7 Summary

A summary of the results can be seen in the table 3.

**Table 3:** Summary of the results.

Case	Solution
Customer adaptation	MJF
Nozzles in sealing line	FFF
Wood workshop	FFF
Distribution disc	SLA
Paint mixing rods	SLA
Workflow	GrabCad Print

## 4.8 Recommended order of investments

In table 4 the recommended order of investments be seen. It is prioritized by the investigator based on what kind of needs the method can fulfill compared to the size of the investment.

**Table 4:** Recommended order of investments.

Nr.	Printer	Size of investments
1	FFF printer without locked material system	60-80 kSEK
2	SLA printer	40-60 kSEK
3	MJF printer	3.5 MSEK [19]

## 5 Discussion

Since the case has different parts, they will be discussed separately.

### 5.1 Customer adaptation (Appendix A)

In the case of the customer adaptation, the proposed solution became the purchase of an MJF printer from HP. This is because the department is already quite good at using additive manufacturing today. So to be able to take the next step an investment need to be made. This investment could be difficult to justify at present if you only compare the price savings you would get. The biggest advantage of having your own printer would be the shortened lead times, which would enable more designs to be tested before the final



design is chosen. Which would be desirable since this department has a very narrow time span to make the adaptation. But if more prototypes could be tested before the final design is determined, I believe that it could lead to a better product and ultimately a satisfied customer.

## 5.2 Nozzles in sealing line (Appendix B)

In the case of the nozzles in the sealing line, both an SLA printer and an FFF were tested. The factory already uses a nozzle that is printed in a MJF printer, so it was assumed that it would be able to manufacture the other nozzles that was tested. Both SLA and FFF gave a good result when tested on a cab which can be seen in the Appendix B.

But when SLA printers were tested, High Temp resin was used, which is a resin that can withstand higher temperatures than other resins, but it also could withstand chemicals best according to Formlabs, which was important as it was difficult to find out which solvent used in the PVC based sealants sprayed on the cabs. But this resin is also more brittle than other resins which made the parts too brittle to be used in production, even though the quality of the print was the best of all the nozzles that was printed. There have been research done if some other resins could be suitable and the TFD80 [20] resin from 3Dresyns is a possible candidate. But further research would need to be done before a SLA printer could be used for this.

The best nozzles that would be able to be used in production were printed in PLA on the university's printer with a 0.25mm material nozzle. An employee at the sealing line said that the results was so good that it could be used during production.

Regardless of whether or not OEM (Original Equipment Manufacturer) are displeased over the choice of changing the nozzle, the area should be investigated further regardless. If OEM would prefer to continue the development of nozzles, one would then expect them to redesign their current product to match the economic benefit of the nozzle presented in this case.

## 5.3 Wood workshop (Appendix C)

In the case of the wood workshop, various materials were examined to see which one was the most cost effective. It turned out that the material cost could be reduced to less than a third if a printer that did not have a locked material system would be used. It was difficult to calculate what ROI of such an investment would have since the investigator did not get any information on how many templates that could be manufactured over a specific time span. But there was potential to save money in this area as it used to take about a week for an employee of the wood workshop to manufacture these templates. A designer would probably be able to produce a CAD-model of a template in under a day and then depending of the size of the template the manufacturing time would differ. But it would still be cheaper than to manufacture the templates by hand.

## 5.4 Distribution disc (Appendix D)

In the case of the distribution disc, both SLA and FDM were tested, where the prints on the part in the SLA print did not become optimal. But if you get to test a few more times then it should not be a problem to get to the print to an acceptable state.

The distribution disc that was printed in a FFF printer was printed in ULTEM 9085 as it was the only material that the existing printer could use that withstood the thinner used during the process. This print needed to use support material that could not be removed without damaging the part.

The investigator suggests the SLA method because of the superior surface finish compared to the FFF method.

In this case there's also the risk that the OEM is displeased with the choice of changing the distributor disc, the area should be investigated further regardless.

## 5.5 Paint mixing rods (Appendix E)

This case kind of reminds of the distributor disc case since they are both components that can be found in the painting robots. And both need to withstand the thinner that is used throughout the painting process.

Only the FFF printing method was tested in this case since it arose during the last legs of the project. And as such there was no time to research this case as much as the others. And as such there was no time to test if the printed parts would function as intended.

But since these parts also are in the path of the paint the SLA method is recommended.

## 5.6 Workflow (Appendix F)

The suggested solution to the workflow was to start using GrabCad Print. This is the solution that is best suited for the printer that is in place today. But this solution only works for Stratasys own machines, which would mean that if you buy another printer that is not manufactured by Stratasys then another print preparation software must be used. Which is basically inevitable since all major printer manufacturers have their own print preparation softwares. The biggest change with the proposed solution is that designer have to prepare their own component and with that the designer can choose what kind of characteristics the component shall have.

After a meeting with the investigator and an employee at the factory, Stratasys has begun to develop a solution from the feedback that has come from the project. And will be added as a module to the existing GrabCad software. This means that this solution will probably be even better in the future as it contains much of what the factory needed

from it's workflow.

## 5.7 Recommended order of investments

The recommended investment order was determined on the basis of how much benefit the investigator thought the factory could get from the proposed printing method compared to the purchase cost. MJF is the largest investment, but the investigator believes that it can be more difficult to implement because GTT (Group Trucks Technology), GTS (Group Trucks Sales) and GTO (Group Trucks Operations) could all use it. GTT would use it to test printing prototypes, GTS would use it to manufacture customizations that GTT has designed and printed prototypes of, and the GTO could print various components (for example, the nozzles used in Appendix B).

The SLA printer should also be investigated more closely to see whether the materials can handle what they are exposed to. Although HTR withstood the thinner, it became a little soft on the surface, but it was also an extreme case when it was immersed in thinner for 35 hours. But it would still have to be investigated before an investment takes place.

The prices are based on the purchase of an Ultimaker S5 with accessories as the FFF printer and a Formlabs Form 3 with accessories as the SLA printer. And the MJF printer is an HP 4200 where the price is a price indication from the company PLM Group.

## 6 Conclusion

If you look at the recommended investment order that can be found in Table 4 there are two investments that are smaller. So the investigator proposes that these two to be implemented in the near future as cases that could use them already exist. The MJF investment is larger and should therefore be investigated more closely before an investment is made.

The factory can save  $(18992 + 16290) \cdot 12 = 423384$  SEK a year if they adopt the proposed additive methods in this report. And that is only from two of the cases (Distributor discs and nozzles in sealing line).

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# Appendix A

## Customer Adaptation

### 1 Background

CA (Customer adaption) at the factory designs and manufactures many special parts for Volvo's customers. Since these adaptations usually have very short lead times, the production must be very fast and often and the series quite small which means that 3D printing fits very well as a manufacturing method. CA Already use 3D-printing extensively, most parts are ordered from a subcontractor who uses a MJF machine from HP. The ordered components are very high quality and usually delivered within 2 weeks.

There are special cases as there can be lots of cabs, or a part that is used on many customizations since a larger series of printed parts need to be manufactured. One part that is often used is the adapter for XENON lamp in BOC (Black Of Corner), and there have been thousands of them printed.

The CA has tried to print on the existing printer but the surface finish has been too low quality for what they need.

Delivery time is an important aspect for CA since they often do not have a long lead time to deliver the finished cab. So the reliability of the printer must be very high. The department usually has about 10 weeks from when they receive the order until the cabin is to be delivered.

Something that the department likes about the subcontractor is that they give good feedback on how the parts look and whether the parts can be printed an function as intended or not. The short delivery time also means that they do not want to spend time preparing the parts themselves. Their prints must be able to withstand tight tolerances and they must be able to maintain the same tolerances if the component is to be printed again, as components may be reused in other customizations.

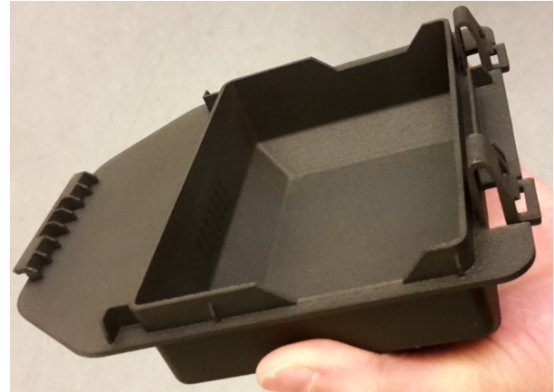
CA would also like to be able to print in a soft material.

Pictures of what kind of products that CA prints can be seen 14 and 15.

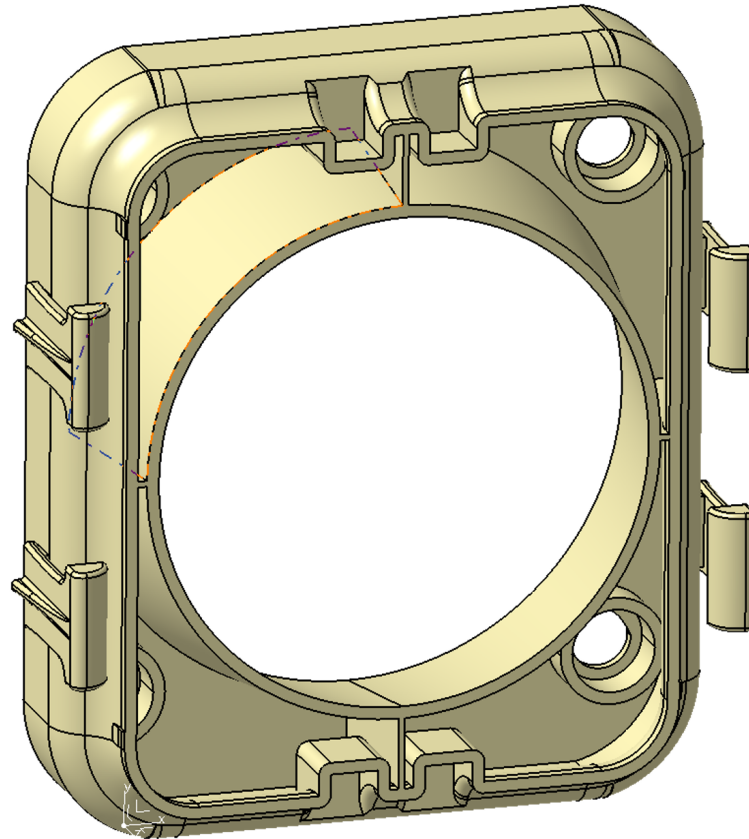
In order to be able to compare the techniques, price has been checked on the component that is shown in the figure 16.



**Figure 14:** Example of 3D-printed part, component can be seen in gray.



**Figure 15:** Example of 3D-printed part.



**Figure 16:** Component that was used for the price comparison.

## 2 Requirements

See table 5 for the requirements of the case.

**Table 5:** Requirements specification.

Nr	Requirement	Comment
1	High precision	Components could use tight tolerances, snap fits is often used
2	Good surface finish	The surface finish from the existing printer has not been good enough.
3	Strong parts	The parts is often end use parts.

### 3 Possible solutions

The requirements of the case makes that the method they are after is leaning more towards SLS or MJF than FFF, although FFF can cope with all requirements in many cases. But since there are often parts that are made to be injection molded as modified, there are often small details that FFF would not be able to handle. And FFF cannot cope with the production rate that may be needed.

#### 3.1 HP MJF

As the existing parts are usually printed in one of HP's MJF printers, it is known that it already meets all the requirements this case has. So the next step in this solution is to buy a printer so that you can reduce the component cost and the manufacturing time. However, HP's machines cannot use any material other than PA12 at present. This machine costs around 3.5 MSEK [19].

A price been requested from the company PLM Group which sells the HP 3D printer on what the component in the figure 16 would cost if it were printed with a HP 4200. The result was about 260 SEK/pc [12]. However, this is without sandblasting and staining. Staining is needed only if the component is visible from the inside of the cab, which this component will not be.

If one were to order the component from a subcontractor who uses a MJF printer, it would cost 328 SEK, which also includes dyeing the component. Which if you compare with the price it would cost if you had your own printer then the difference is  $328 - 260 = 68$  SEK. The total price difference of 1016 components is therefore  $1016 * 68 = 69088$  SEK.

#### 3.2 Carbon CLIP

Carbon's technology could work for this department as it can be used to make smaller part series, which can happen in the department. However, it does not use the same technology that the subcontractor uses today. But with Carbon's technology you can print in soft material already now which was a wish from CA. But as this method is similar to SLA it does not have same design freedom as the HP's MJF which is a disadvantage for this

method.

There has been a conversation with Carbon during the project but a sample part did not make it to the investigator before the project ended.

## 4 Conclusion

CA is a department that is very used to 3d printing and it comes naturally to them. So to take the next step for them, an investment must be made. I think the technology that fits CA is the best HP's MJF solution. Partly because it is the one that is usually used in current cases so the CA knows how it works and knows about what it can handle. And the cheaper machines have too little building space for it to fit CA. However, HP's machine cannot print in a soft material yet.

Since the MJF printer is expensive the ROI can be pretty long if you only take the price difference of ordering the components from a subcontractor versus manufacturing them in their own MJF printer. But what could be improved with their own machine is that the delivery time could be much shorter from about 1-2 weeks to usually less than a day or two. And with it even being able to test more prototypes before the final design is determined. Today that may not be possible to test several different prototypes since the delivery time is too long in most cases to allow for it. In the end, I believe that this can lead to a better end product and ultimately a more satisfied customer. And it could open the doors to increase the customization possibilities when the designers get to test more ideas. The printer could also be used by several different departments

## Appendix B

### Nozzles in the sealing line

#### 1 Background

The sealing line uses nozzles to spray sealant on the cabs, these must be very precise as the openings are very narrow. The sealant is PVC-based and uses solvent to make it sprayable, the sealant later hardens in the oven as the cab goes through them. These nozzles are very expensive to buy new. And therefore they want to make them themselves

The factory already is using a version of the "flatstream" nozzle (can be seen in figure 20) which is printed by a subcontractor on a MJF printer by HP. As the sealant is quite abrasive the nozzles need to be changed every three weeks. Which gives a yearly consumption of 18 nozzles. And with a cost of 300 SEK each, it gives a monthly cost of  $\frac{(18 * 300)}{12} = 450$  SEK/month.

20 pieces of the "CEC" nozzle that can be seen in figure 17 has been bought since 2017-04 and the latest price for the nozzle was 19800 SEK. That gives a monthly cost of  $\frac{20 * 19800}{25} = 15840$  SEK. There is always at least ten of these nozzles in inventory which gives an inventory cost of  $10 * 19800 = 198000$  SEK.

These two nozzles together have a total monthly cost of  $450 + 15840 = 16290$  SEK.

In figures 18 and 19 sealing beads sprayed by the original "CEC" nozzle.

In figure 20 the spray pattern of the current MJF nozzle can be seen.



**Figure 17:** Original nozzle, "CEC"



**Figure 18:** Sealing bead sprayed by the original nozzle on a door



**Figure 19:** Sealing bead sprayed by the original nozzle on a trunk lid.



**Figure 20:** Spray pattern of the original nozzle, "flatstream"

## 2 Requirements

See table 6 for the requirements of the case.

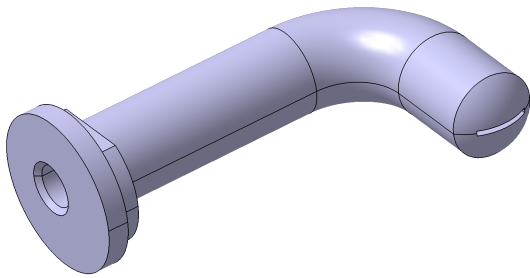
**Table 6:** Kravspecifikation.

Nr	Requirements	Comment
1	High precision	The openings of the nozzle needs to be very precise
2	Durable	The sealant is abrasive.
3	Chemical resistance	The sealant is solvent based.

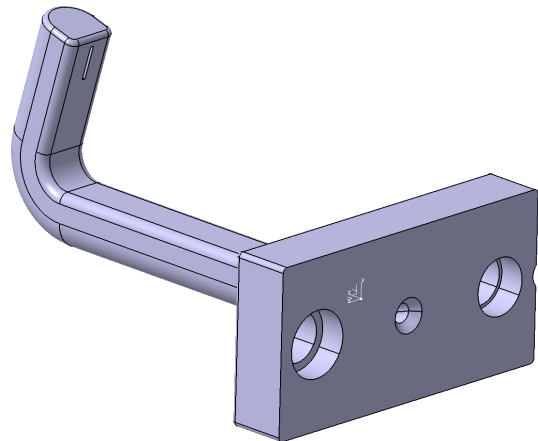
### 3 Possible solutions

The requirements placed on this case actually fit several techniques. HP's MJF is already in use today so we already know it works for this application. So in this case I have investigated which other methods would work.

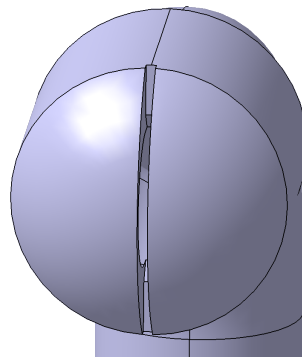
In the figures 21 och 22 The cad models that was used be seen. In figure23 the opening of the ordinary "flatstream" nozzle be seen.



**Figure 21:** CAD-model of nozzle "flatstream".



**Figure 22:** CAD-model of "CEC" munstycke.



**Figure 23:** The opening of the "flatstream" nozzle.

### 3.1 FFF with a 0.25mm nozzle

Components have been printed in PLA into an external printer. PLA is a plastic that is quite hard but brittle. which hopefully gives it a good resistance to the sealant. The plastic has been tested and it is able to withstand the solvent in the sealant.

**Nozzle "CEC"** The "CEC" nozzle has been tested with good results, see figure 25, 26 and 27 below.

A second test of the "CEC" nozzle where settings were changed during manufacturing and what made the biggest difference was the speed that was used when printing the actual opening. The nozzle can be seen in the figure 28. With the new nozzles the result was better than the first test. Sealing bead sprayed by the second nozzle can be seen in figures 29, 30 and 31.

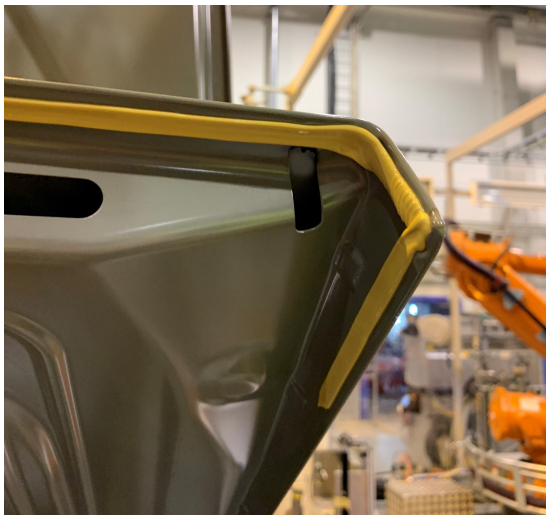




**Figure 24:** PLA Nozzle mounted on the robot.



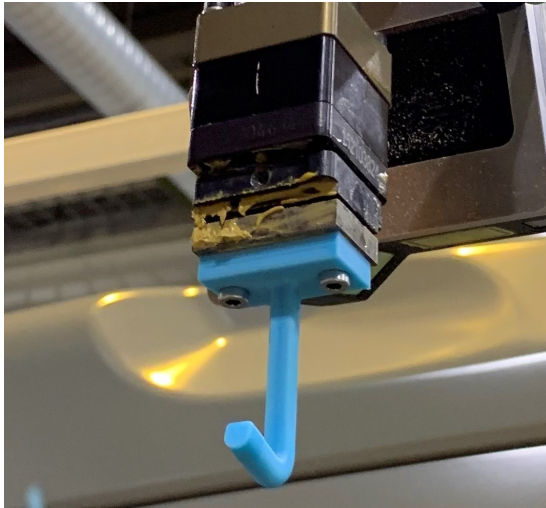
**Figure 25:** Sealing bead sprayed by the PLA nozzle on a door.



**Figure 26:** Sealing bead sprayed by the PLA nozzle on a trunk lid.



**Figure 27:** Sealing bead sprayed by the PLA nozzle on a door.



**Figure 28:** PLA Nozzle mounted on the robot.



**Figure 29:** Sealing bead sprayed by the PLA nozzle on a door.



**Figure 30:** Sealing bead sprayed by the PLA nozzle on a trunk lid.

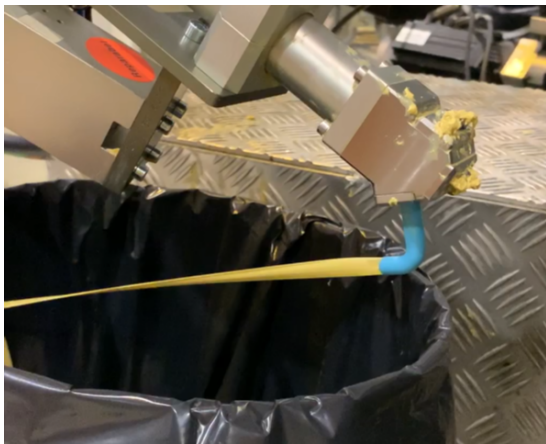


**Figure 31:** Sealing bead sprayed by the PLA nozzle on a door.

The weight of the "CEC" nozzle used had a material consumption of 6 grams of PLA according to the print preparation program Ultimaker Cura. And if you would use Ultimaker's PLA that costs costs 348 SEK/750 grams [13] the nozzles would cost  $\left(\frac{348}{750}\right) \cdot 6 \approx 2,8$  SEK a piece.

**Nozzle "flatstream"** A "flatstream" nozzle has also been tested on the robot. The spray pattern of this nozzle is a little bit narrower than the nozzle used today, see figure 32. The nozzle was tested on a cab and the result was satisfactory. But, as you can see, a little sealant leaked see figure 33, The nozzle leaked slightly but it would be a easy fix as the base prably was too thin.

The weight of the "flatstream" nozzle used had a material consumption of 2 grams PLA including support material according to the print preparation program Ultimaker Cura. And if you would use Ultimaker's PLA which costs 348 SEK/750 gram [13]. So give it a cost of  $(\frac{348}{750}) \cdot 2 \approx 0.9$  SEK per "flatstream" nozzle.



**Figure 32:** Spray pattern of "flatstream" nozzle.



**Figure 33:** Leaking nozzle "flatstream".

### 3.2 SLA with High Temp Resin

The nozzles have been printed in HTR (High Temp Resin) in a Formlabs 2 which is an SLA printer. The printing has been done by the company 3Dverkstan. HTR was chosen because as it had the best chemical resistance of all Formlabs resins [21]. This method has a higher resolution than both FDM and SLS which makes it suitable for this type of application. But often, the prints is a bit more brittle than prints made in an FDM or SLS printer.

**Nozzle "CEC"** The "CEC" nozzle was printed and tested in the same way as the FFF printed parts. The result was satisfactory, even though the robot warned that it had sprayed too much sealant. In figure 34, the HTR nozzle can be seen when it is mounted on the robot. In figure 35, 36, and 37, sealing bead sprayed by the nozzle can be seen.





**Figure 34:** HTR nozzle mounted on the robot.



**Figure 35:** Sealing bead sprayed by the HTR nozzle on a door.



**Figure 36:** Sealing bead sprayed by the HTR nozzle on a trunk lid.



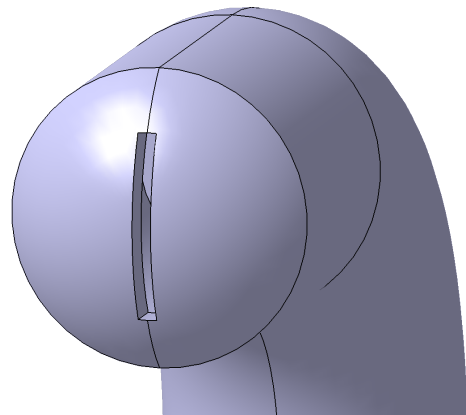
**Figure 37:** Sealing bead sprayed by the HTR nozzle on a door.

Estimated cost of HTR nozzle: 9.7 SEK.

**Nozzle "flatstream"** As seen in figure 38 the spray pattern is a bit too narrow if you compare it to the original nozzle in figure 20. And as such it was not tested on a cab. If you compare the figure 39 with 23 you can see the difference in the CAD-models which probably is the cause of the too narrow spray pattern.



**Figure 38:** Spray pattern of "flatstream" nozzle.



**Figure 39:** The opening of the printed "flatstream" nozzle.

## 4 Conclusion

The "CEC" nozzle that was printed in the PLA was tested directly on the cabs twice and it was a very good result. An employee that works in the sealing line. thought that if you would tune the settings the nozzle would work as good as the original nozzle.

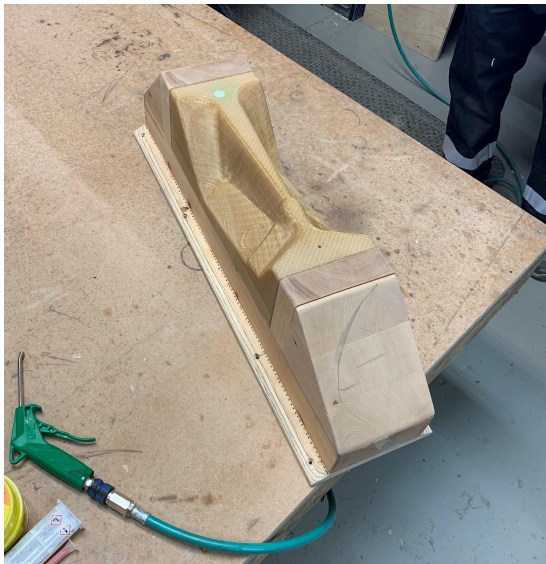
A package with the Formlabs Form 2 that was used to print the nozzles above, the printer together with the washing station and curing station costs at 3Dverkstans webshop right now 41 496 kr [17] but Formlabs has just released a new printer that costs 5000kr more [18] which gives a package cost of 46496kr. with the existing monthly cost, the ROI on this printer if only these nozzles will be manufactured will be  $\frac{46496}{16290} \approx 2,9$  months.

## Appendix C

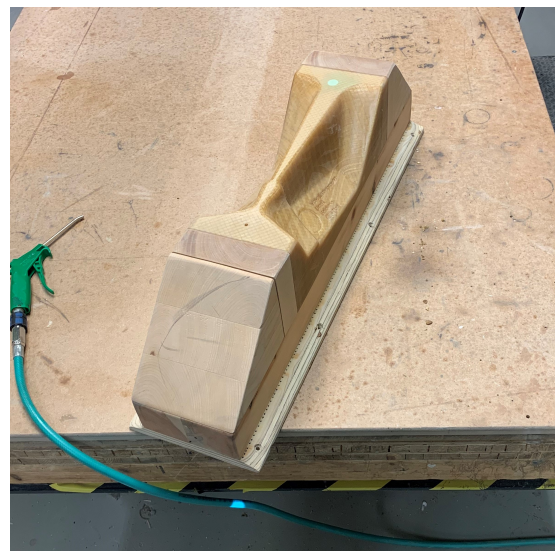
### Wood workshop

#### 1 Background

The wood workshop manufactures vacuum mold templates. These are usually manufactured by making a template in wood by hand which is then used to vacuum mold plastic parts from ABS sheets that are 4 or 6 mm thick. The ABS sheet is about 170° c during the vacuum forming. When the wood workshop manufactures its templates in wood, it usually takes about a week for a person to make a template. The templates can have a size of up to 160x100x30 (cm). Figure (fig: box form1) and 41 shows a template that has been tested to print and then simpler forms have been added to get the final shape needed. The printed component cost about 8000 SEK and was printed in Ultem 9085.



**Figure 40:** Printed template with simpler shapes in wood.



**Figure 41:** Printed template with simpler shapes in wood.

#### 2 Requirements

See table 7 for the requirements of the case.

**Table 7:** Requirements specification

Nr	Requirements	Comment
1	Temperature resistance	The ABS-sheet is 170 °c
2	Cost effective	The templates can be big.

### 3 Possible solutions

#### 3.1 Printer without a locked material system

The template that was tested to be printed was very expensive and not so cost effective if you compare against a cheaper printer that can print with cheaper material. But because the templates will be exposed to a temperature that is usually above the glass transition temperature of 3D-printed plastic. It requires the use of plastics with higher glass transition temperatures, such as the PC tested that was used during this case, which has a glass transition temperature of 112 degrees [22]. Because it can be quite large parts, a larger nozzle can be used to reduce the manufacturing time in an FFF printer. And since these parts can be so large, there are not so many printers that can print these components in a single print. But this can be solved by dividing the parts then put together. Since these molds can become very large, printing can take several days, but since this can be done without supervision, it will still be cheaper than a person to manufacture a template from wood.

#### 3.2 Third party material for the existing printer

Another possible solution to this problem could be to buy material that is not manufactured by Stratasys to reduce the cost of the printed parts. It functions by using a chip that pretends to be an original chip that fools the printer that it is a original spool of material in the printer

### 4 Price comparison

To be able to compare the prices, a CAD-model was made of a "worst case" scenario and then the parts was prepared in their respective print preparation software. For Fortus 450mc, GrabCad Print was used and for Ultimaker S5, Ultimaker Cura was used. The template that was compared was 1600x1000x100 (mm) with protruding parts of 50 mm. The model that was designed had, with ease, be able to be made in another way, especially since there were a few pieces that were just a straight cube. If it would have been manufactured for real then these pieces could have been made of wood and only

pieces that had had any special shape were 3D-printed. The material was chosen for PC since it has a glass transition temperature of about  $110^\circ$  [22] which is almost what the temperature is on the ABS sheet when it is formed. So if the template is thick enough it should not deform.

A comparison has also been made on the component shown in figure 1. Price of the existing component can be seen in table 8 below. This component has previously been manufactured by wood workshop personnel. It took about a week for them and then the personnel cost for that is  $40 \cdot 335 = 13400$  SEK. So even though the component was printed in the ULTEM 9085, it was cheaper than if it were made by hand.

The electricity consumption cost is not included in the comparisons.

**Table 8:** Price of Ultem template.

Stratasys Ultem 9085			
Part	Model material ( $cm^3$ )	Time(h)	Price/ $cm^3$
1	1470	23	5.43
Price total (SEK)		7982.1	

An overall material price difference has also been done, it can be seen in the table 9 below. X means that there is no corresponding material. All prices is shown in  $SEK/cm^3$

**Table 9:** Material price table. Prices from [14], [15] och [16]

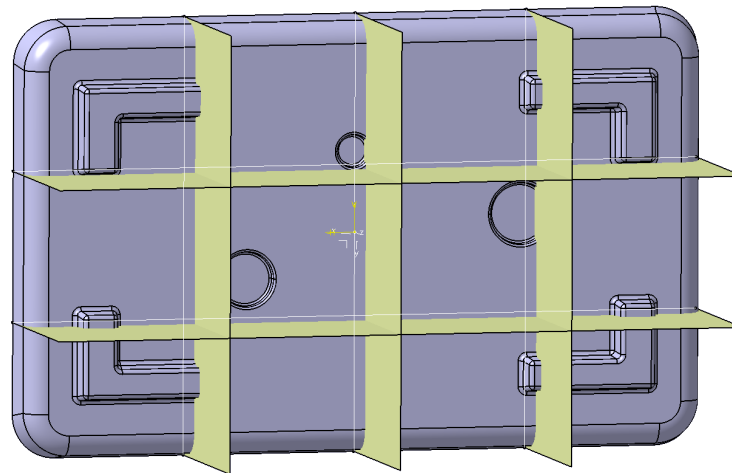
Manufacturer\material	ABS	PC	Nylon	Ultem 9085
Stratasys	3.05	3.25	3.25	5.43
iSquared	1.80	2.11	X	3.46
Ultimaker	0.58	0.91	0.88	X

## 4.1 Worst Case

### 4.1.1 Fortus 450mc

In order to be able to print the entire template, it needed to be split up to fit on the build tray. For Fortus 450mc, it needed to be divided into 12 pieces. The prices have been checked for both stratasys own material and isquared's refill material. The total price can be seen in the table 10 and 11 below.





**Figure 42:** CAD-model of the template used for the price comparison. In yellow it can be seen how the part was split to fit on Fortus 450mc:s build tray.

**Table 10:** Price with Stratasys PC.

Stratasys PC			
Part	Model material ( $cm^3$ )	Time(h)	Price/ $cm^3$
1	3688	42.5	3.25
2	3336	36.5	
3	3300	38	
4	3323	37	33.5
5	3273	35	
6	3015	33.5	
7	3327	37	34.5
8	3253	34.5	
9	3016	33.5	
10	3689	42.5	37
11	3335	39	
12	3334	37	
total	39889	446	

Price total(SEK) **129 639**  
 Manufacturing time (days) **18.6**

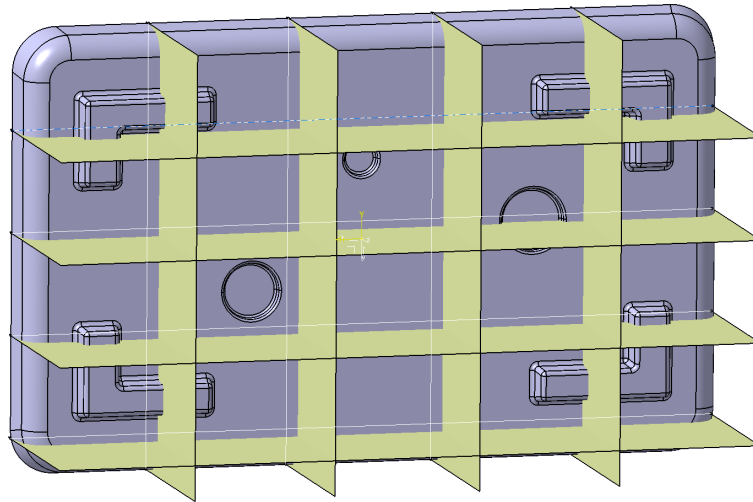
**Table 11:** Price with iSquareds PC.

iSquared PC			
Part	Model material ( $cm^3$ )	Time(h)	Price/ $cm^3$
1	3688	42.5	2.11
2	3336	36.5	
3	3300	38	
4	3323	37	33.5
5	3273	35	
6	3015	33.5	
7	3327	37	34.5
8	3253	34.5	
9	3016	33.5	
10	3689	42.5	37
11	3335	39	
12	3334	37	
total	39889	446	
Price total (SEK)	<b>84 166</b>		
Manufacturing time (days)	<b>18.6</b>		

In this case it would be  $129639 - 84166 = 45473$  SEK cheaper with iSquareds refill material.

#### 4.1.2 Ultimaker S5

As the S5 has a smaller build tray, it was needed to divide it into more pieces than for the 450mc. Prices have only been examined for ultimakers own materials. But there are cheaper manufacturers of materials. A total of 25 pieces were needed, as can be seen in figure 43. The total price can be seen in the table 12



**Figure 43:** CAD-model of the template used for the price comparison. In yellow it can be seen how the part was split to fit on Ultimaker S5:s build tray.

**Table 12:** Price with Ultimakers PC.

Ultimaker PCA			
Part	Model material ( $cm^3$ )	Time(h)	Price/ $cm^3$
1	1026.4	31	0.91
2	1075.0	33	
3	1035.8	32	
4	1142.6	35	
5	370.9	12	
6	1082.5	33	
7	1069.6	33	
8	1081.5	33	
9	1140.1	35	
10	428.5	13	
11	984.6	30	
12	1047.5	33	
13	1104.6	33	
14	1038.9	32	
15	411.5	13	
16	1079.4	33	
17	1061.7	33	
18	1061.6	33	
19	1133.3	35	
20	428.5	13	
21	1058.8	33	
22	1098.2	34	
23	1062.9	33	
24	1172.6	35	
25	383.6	12	
total	23580.6	725	
Price total (SEK)	<b>21458</b>		
Manufacturing time (days)	<b>30.2</b>		

## 4.2 Existing template

### 4.2.1 Fortus 450mc

The existing template did not need to be divided for the print in Fortus 450mc. Prices have been checked with both stratasy's own material and iSquared's third-party material. The total price can be seen in the table 13 and 14 below.

**Table 13:** Price with Stratasys PC.

Stratasys PC			
Part	Model material ( $cm^3$ )	Time( $h$ )	Price/ $cm^3$
1	1637	22	3.25
Price total (SEK)		<b>5320</b>	

**Table 14:** Price with iSquareds PC.

iSquared PC			
Part	Model material ( $cm^3$ )	Time( $h$ )	Price/ $cm^3$
1	1637	22	2.11
Price total (SEK)		<b>3454</b>	

#### 4.2.2 Ultimaker S5

Since the existing test print was a bit too big for S5's building plate, it was divided into 2 parts. The total price can be seen in the table 15 below.

**Table 15:** Price with Ultimakers PC.

Ultimaker PC			
Part	Model material ( $cm^3$ )	Time( $h$ )	Price/ $cm^3$
1	458	14	0.91
2	489	15	
Price total (SEK)		<b>863</b>	

## 5 Conclusion

If third-party material were to be used for the existing printer, then the material cost would be reduced, but if it was to manufacture templates for the wood workshop, another cheaper printer should probably be used. Since wear parts and spare parts for the existing printer are very expensive compared to other printers. And it will take a lot of time by the printer that can be used to print parts in more exotic materials.

Although iSquared's material prices are cheaper than stratasys materials, ultimakers own materials are much cheaper anyway. Ultimaker's material cost is about one third of

Stratasys. Ultimaker can also print in other materials than their own where there are materials that are even cheaper. But 30 days manufacturing time is not quite reasonable, but then it probably does not have to be made as large a template as the one tested. It could also be solved by purchasing two or more of these printers.

The settings used in the pricing estimation were tried to be kept as similar as possible, but it was not possible to reduce the infill more on grabcad print. Which meant that the components prepared in grabcad print weighed more than Ultimaker's printed components.

## Appendix D

### Distrubution discs on painting robots

#### 1 Background

The painting robots use a distribution disc that is currently made of plastic and metal. The disc has a nozzle in the middle that lets through 5-10% of the paint. This nozzle can get clogged during painting of metallic colors as the metallic particles in the paint can get stuck in the nozzles. If the nozzle becomes clogged, it may cause the paint to spray back into the turbine which spins the distribution tray. If there is color in the turbine then it must be replaced and then repaired, a new turbine costs about SEK 25,000. In 2018, 6 turbines were sent for renovation because of this. If a turbine has to be replaced, production may need to be stopped and this is obviously not desirable.

When manufacturing new ones, the new nozzles should be without the nozzle in the middle. According to an employee at maintenance at the painting department, it has been tested to print the lower part of the disc without the nozzle in the disc, that had a cone that is used so all the paint spray out on the side instead

If the discs have become clogged then they are usually taken apart and renovated. It is usually renovated between about 50 and 100 pieces of distribution discs per year with an average renovation time of two hours per piece. And in addition, 36 new distribution trays were ordered in 2018, which as a spare part it costs 5400kr the last time these were ordered. The cost of this will then be between  $100 \cdot 335 + 36 \cdot 5400 = 227900$  SEK and  $100 \cdot 335 + 36 \cdot 5400 = 261400$  SEK. Which gives a minimum monthly cost of  $\frac{227900}{12} \approx 18992$ . Ten of these discs is kept in inventory and that is an inventory cost of  $10 \cdot 5400 = 54000$  SEK.

The original disc can be seen in figure 44 and 45.



**Figure 44:** Original distribution disc.



**Figure 45:** Original distribution disc.

## 2 Requirements

See table 16 for the requirements of the case..

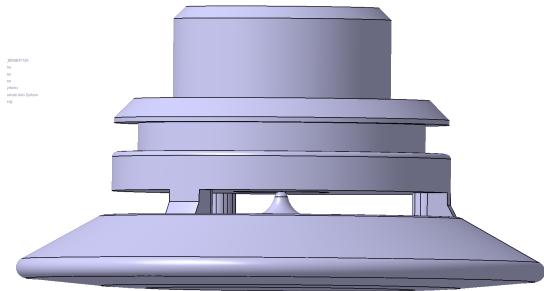
**Table 16:** Requirement specification.

Nr	Requirement	Comment
1	Surface finish	As to not change the spray pattern.
2	Tight tolerances	So it doesn't leak paint.
3	Chemical resistance	The part is washed in thinner during the process.

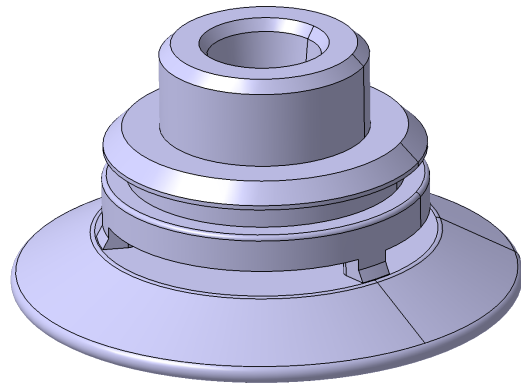
## 3 Possible solutions

To be able to evaluate the different methods, the disc has been designed in the CAD software CATIA V5. Some modifications have been made but otherwise it has been attempted to be kept as close to the original as possible. A wish from maintenance technicians was to remove the nozzle in the middle where the particles stick and instead use a cone that distributes all the paint on the sides, the cone can be seen in figure 46 and in figure 47 then the entire component can be seen.





**Figure 46:** CAD model of the part that was printed.



**Figure 47:** CAD model of the part that was printed.

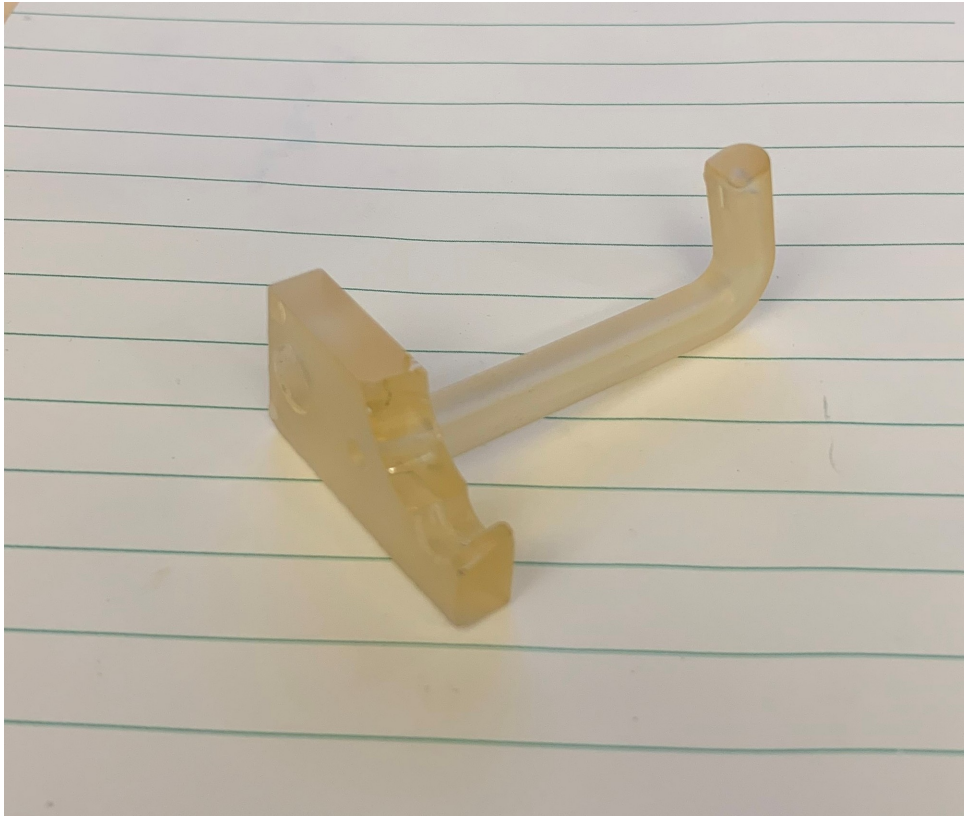
### 3.1 Formlabs SLA with High Temp Resin

Since the nozzle requires good surface finish and tight tolerances, the SLA method would be suitable for this component. 3Dverkstan have tested to print this component. The company used a Formlabs Form 2 and their HTR material. HTR was chosen because it was the material that managed chemicals best suited due to its chemical resistance [21]. To test if the resin could withstand the thinner used, a broken nozzle was submerged in thinner for about 35 hours. The nozzle was weighed before being submerged and then weighed again after. The weights of the nozzle before and after can be seen in table 17 below, and images of the nozzle used can be seen in the figure 48 below.

**Table 17:** Weight of the nozzle before and after thinner

Before	5,7442 g
After	5,7574 g
Difference	0,0132 g

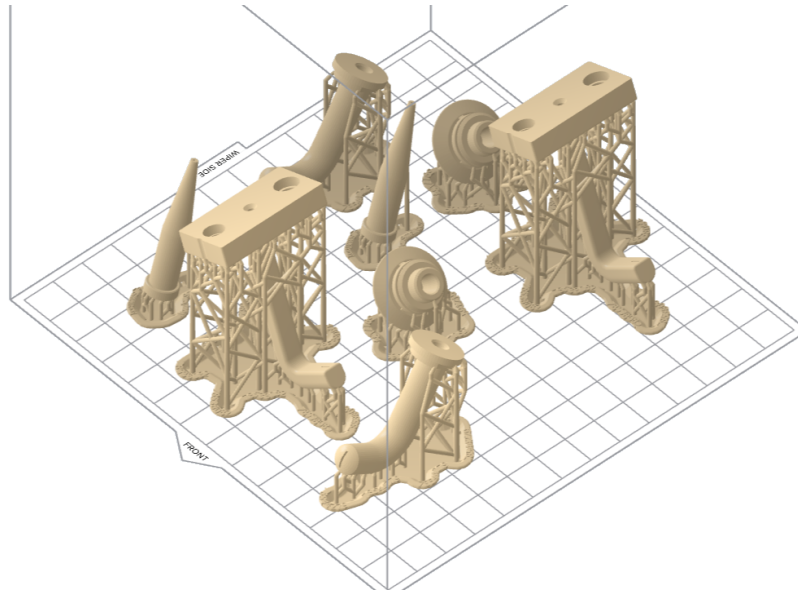
As can be seen above, the printed part barely picked up any thinner, but the surface was a little softer than usual and you could make shallow marks in the component with a fingernail. However, it could not be done when the component had dried again.



**Figure 48:** Broken nozzle that was used during the test.

A package consisting of Formlabs Form 2 that was used to print the distribution disc above in figure 12 together with the washing station and curing station costs at 3Dverkstan right now 41 496 SEK [17]. Formlabs has just released a new printer that costs 5000 SEK more [18] which gives a package cost of 46496 SEK. If this printer would only be used to produce this distribution disc the ROI (Return of investment) would be  $\frac{46496}{18992} \approx 2.6$  months . Or  $\frac{46496}{5400} \approx 9$  pc of distribution discs.

To print the distribution disc, HTR was used which costs 1992 SEK/liter. And 3Dverkstan printed the parts, several components were printed at the same time as can be seen in figure49. A total of 39mL resin including support material was used. it is a total of 8 components that are printed and for the sake of simplicity, it is estimated that all components used the same amount of resin. And that gives a material cost of the parts  $\frac{39}{8} = 4,875$  mL  $1,992 \cdot 4,875 = 9,7$  SEK per component. So, if it is usually used about 150 pcs in one year, the total spare part cost will be  $150 \cdot 9,7 = 1455$  SEK.



**Figure 49:** Components on build tray that was printed by 3Dverkstan on a Formlabs Form 2.

### 3.2 HP MJF

MJF would also suit this component even though the surface isn't as smooth as an SLA printed part. But it can handle all the small details that the component requires. And can keep the tolerances required. The file has been sent to the company PLM Group, which has made a cost estimation for the disc and the cost per component was 14.07 SEK [23]. But this component can also be ordered from a subcontractor who uses this printer.

## 4 Conclusion

This component requires a technology that is not available at the company, which means that you need to buy a machine or order from a subcontractor. In this case, you can save a great deal of money by moving from the current component that requires 50-100 renovations per year and purchasing 36 spare parts. Instead, uses a component that will not have to be cleaned since it does not have the nozzle that gets clogged and if it has to be cleaned in any way it is probably enough that it is run in the existing washing station that the robot uses. Which saves both maintenance time and there are less cabs that need to be repainted and less turbines that need renovating. And since it cannot get any particles in the nozzle, the component can be washed in thinner to be cleaned during the process.

The print was not really optimal from the SLA printer, but I think that if you try to print it a few more times and get the settings right, then the prints will be good enough. Otherwise you could split the parts and make the disc in two parts.

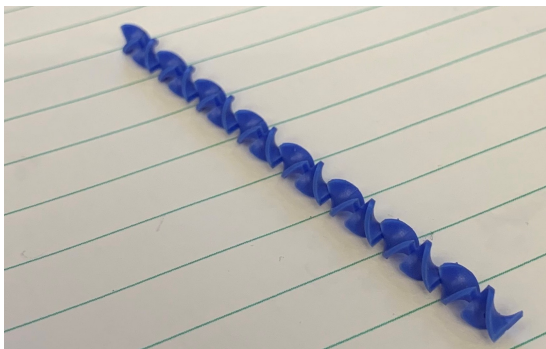
In this case, I recommend that an SLA printer be purchased, partly because it again serves the investment cost in less than 3 months, and once it is in place, it can be used to manufacture other components that need the high precision, see, for example, the case about the nozzles in the sealing line.

## Appendix E

### Paint mixing rods

#### 1 Background

The painting robots uses two mixing rods that is used to mix hardener and paint during the painting process. Right now, the measuring robot is painting at maximum speed, which means that the pumps must work at the maximum pressure. So in order to be able to run the painting robot faster, the internal resistance must be reduced so that the flow can increase. The mixing rod that can be seen in the figure 50 is a rod with 16 smaller spirals in itself. To reduce the resistance of the paint robot, the technicians want to reduce the number of spirals. The component that can be seen in figure 51 is a piece of tube with a mixing rod inside. With this component you want to enlarge the tube and make a wider mixing rod as there is room for this. There is also the possibility of going from two parts to one.



**Figure 50:** Original mixing rod with 16 spirals.



**Figure 51:** Original mixing rod with tube. Mixing rod can be seen in blue.

#### 2 Requirements

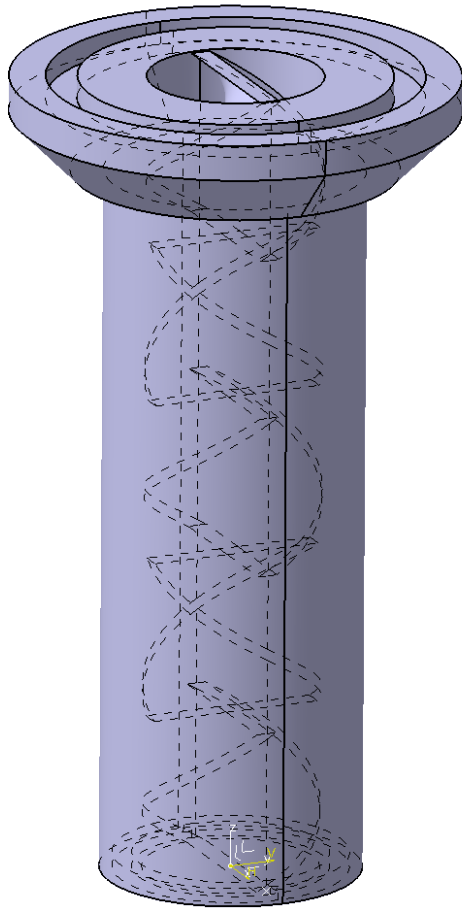
See table 18 for the requirements of the case.

**Table 18:** Requirements specification.

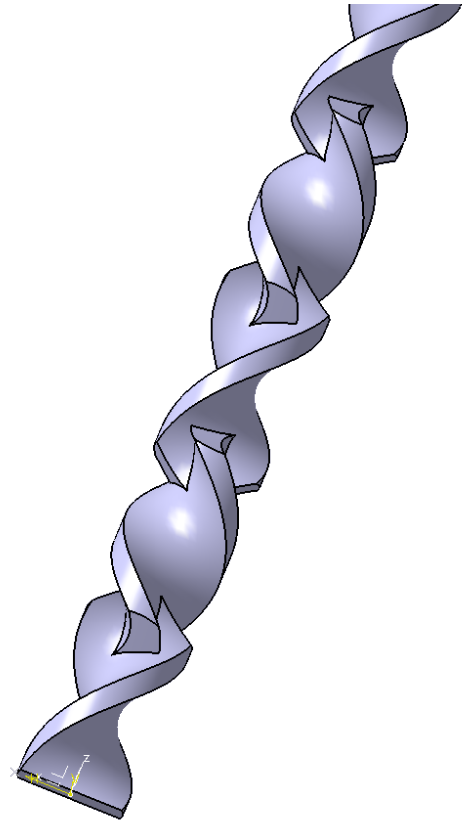
Nr	Requirement	Comment
1	Surface finish	So the paint wont get stuck during the color change
2	Tight tolerances	The part is friction fit.
3	Chemical resistance	The parts is washed in thinner during its use in production.

### 3 Possible solutions

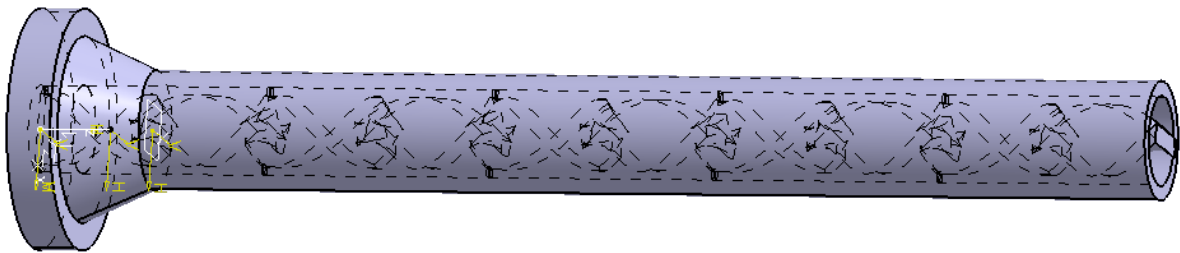
In order to evaluate the different methods, the mixing rods have been designed in the CAD program CATIA V5. Because the parts consist of very small details, it must be a very accurate printer, which means that the solution leans more towards SLA or SLS rather than FFF. The CAD models that have been made can be seen in figure 52, 53 och 54. As can be seen in figure 52, the tube and the mixing coil are now integrated in the same component. In figure 42, the long mixer spiral is shown with a support tube that will simplify the printing when it is printed in an FFF printer.



**Figure 52:** CAD-model of the short mixing rod with tube.



**Figure 53:** A part of the long mixing rod.



**Figure 54:** Long mixing rod with support tube.

### 3.1 SLA

SLA would be well suited to these components because of the good surface finish and the ability to cope with small details. The surface finish can be very important in this case as it would reduce the risk that paint might get stuck in the layer lines that occur on a part printed in an FFF printer. Since these parts also have to pass thinner, they would also have to be printed in, for example, Formlabs' HTR, which was examined in the case

with the distribution plates. But in this case the brittleness is no problem as the parts would not be subject to any kinds of load that would shatter the component.

### 3.2 SLS/MJF

SLS/MJF would also be a good method for printing these mixing rods. Especially since it does not require any support material. But as this case was a late addition to the project it was not researched further.

### 3.3 FFF

FFF could also fit these components. Prints have been made in both the existing printer in ULTEM 9085 and an external printer. To investigate which materials could be used for these components, several materials were tested by placing them in thinner for at least 24 hours. The results of the test can be seen in table 19 below.

NOK (Not OK) means that the parts cracked or softened in the thinner.

**Table 19:** Thinner resistance.

Material	Result
PLA	NOK
Ultimaker PC	NOK
Ultimaker CPE	NOK
ULTEM 9085	OK
Ultimaker Nylon	OK

## 4 Conclusion

In this case, you are not looking to save money on spare parts costs but instead you could reduce the load on the paint pump and therefore you could paint faster. But since the case was started in the later stages of the project it was not researched further and therefore the parts were not test fitted on the robot.

In this case, one has to do the product development for OEM, which is unavoidable in this case when one is already painting quickly as it is possible with the equipment you have. So to paint faster you have to upgrade some parts.



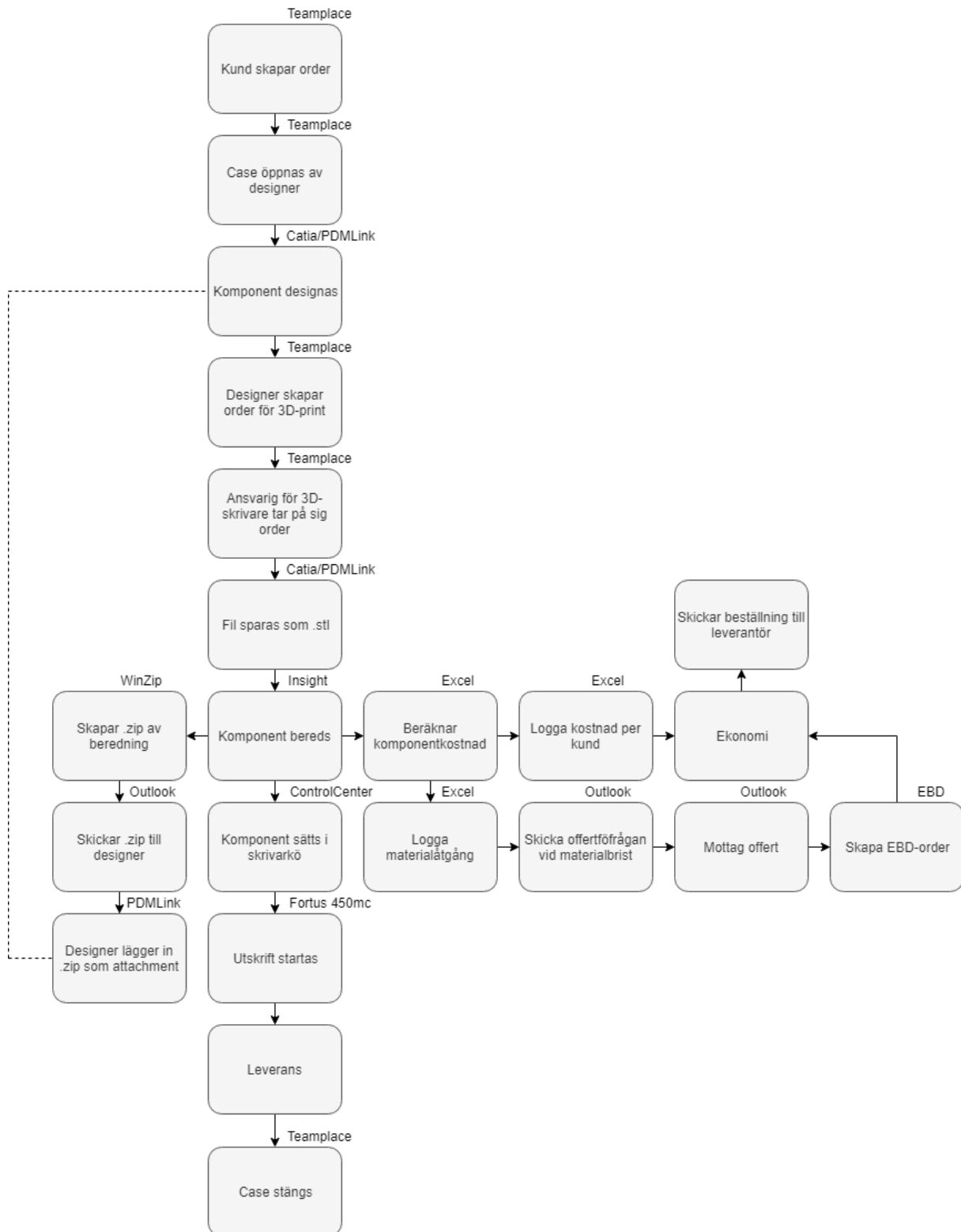
## Appendix F

### Arbetsflöde vid additiv tillverkning

#### 1 Background

The workflow that exists during additive manufacturing today is very laborious and takes a long time. There is a desire to find a faster process that fits with existing printer. Ideally, it should be integrated with the PDM system. With the number of components that is printed today, it takes about a week from the designer creates the order for a print until the component is delivered.

In figure 55 the existing workflow can be seen.



**Figure 55:** The existing workflow.

## 2 Requirements

See table 20 for the requirements of the case.

**Table 20:** Requirements specification.

Nr	Requirements
1	The new workflow shall not have more steps than the existing

## 3 Possible solutions

### 3.1 GrabCad Print

GrabCAD Print is Stratasys new software for preparing 3D prints, the software can be downloaded from Stratasys for free. The new software is easier than Insight which could mean that the designer could prepare his prints himself and then put the component in the print queue. This means that the designer must learn how to use GrabCAD Print, but since this program seems to be user-friendly, I do not think that is a problem. If there are parts that need special settings, you can open the component in the old software Insight which is currently used, from GrabCAD Print. Insight is a powerful program with more setting, but it is not as often as these special settings need to be used.

If someone is to print that is not a designer at Virtual manufacturing, an order can be created as usual on the teamplace and the designer who has time can prepare the file. However, the responsible person still has to log material consumption and time spent in the existing excellence document as before.

The person in charge then only has to collect the components that are to be printed in the same material and then put these components together on the same build tray. This allows the person responsible to spend more time on other tasks that need to be performed.

This solution cannot be directly integrated with the PDM system, so a .cmb file must be saved and then entered manually in the PDM system.

After meeting with Protech AB, stratasys has begun the development of a module that will be called GrabCad Shop which will have most of Volvo's requests. But that module will not be ready until this project is finished so it will not be investigated further.

After meeting with Protech AB, stratasys has begun the development of a module that will be called GrabCad Shop which will have most of Volvo's wishes. But that module will not be ready until this project is finished so it will not be investigated further in this project.

### 3.1.1 Proposed workflow

After a meeting with Jimmy at Protech AB the following workflow has been compiled [24].



**Figure 56:** Proposed workflow when using GrabCad Print.

### 3.1.2 Pros/cons

See table 21 for pros and cons for the software.

**Table 21:** Pros/cons GrabCad Print

Pros	Cons
Reduced workload on the person in charge	Designers must be trained
Constructors gain an increased understanding of additive manufacturing	Can't integrate directly with the PDM system
The program is free	

## 3.2 3Dexperience CATIA 3D-printing

After meeting with Hans Eriksson and Jimmy Cresson from Dassault Systemes, it turned out that 3Dexperience was more targeted at metal printing and not for plastic. There might be some license that would suit the factory but it would have to be investigated more [25].

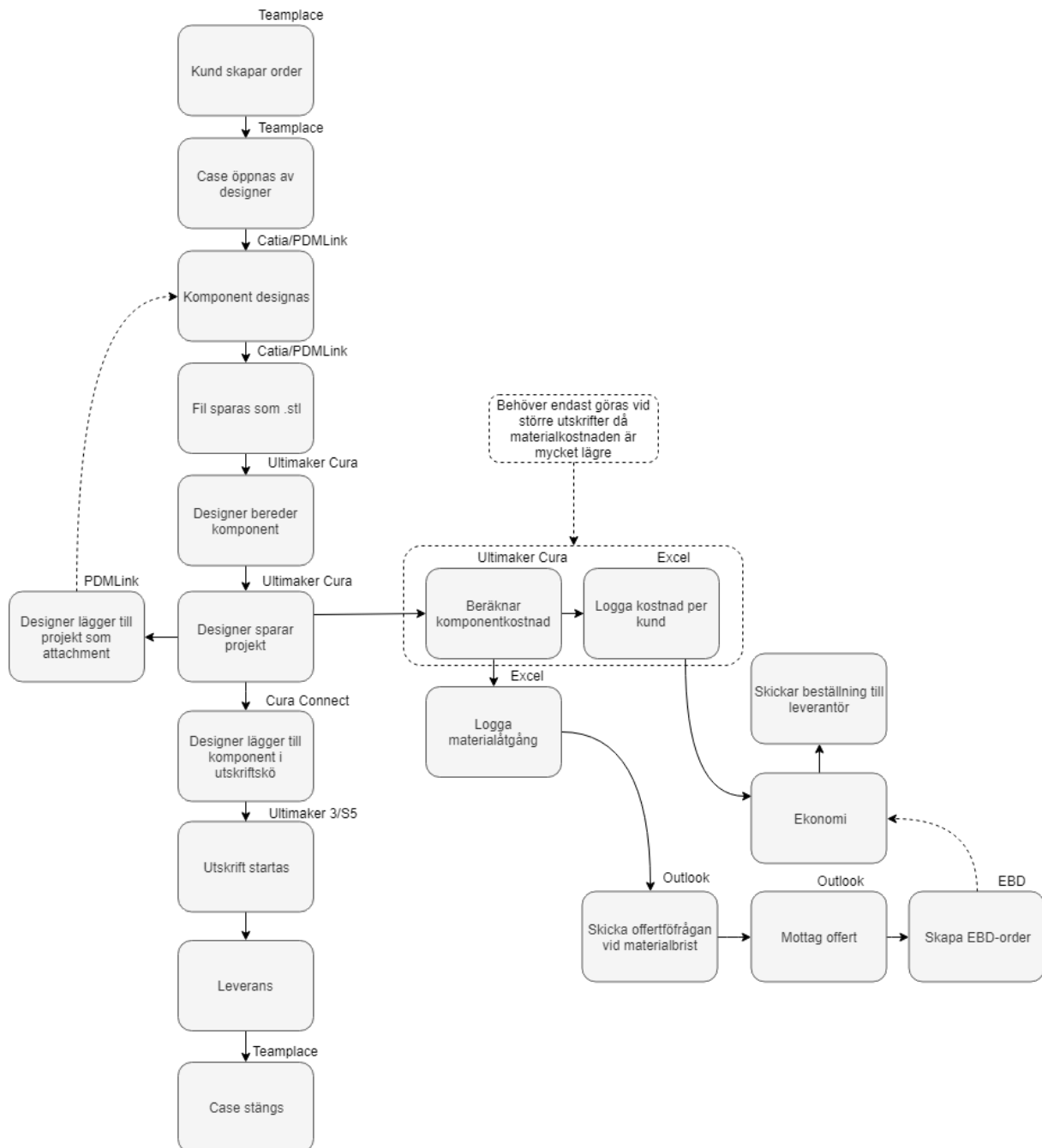
## 3.3 Cura With Ultimaker 3/S5

One possible solution could be to buy one or more Ultimaker 3 / S5 which can use the function Cura Connect, which means that prints can be prepared and then put into print queue directly in the same program. This solution is not free as it requires the use of Ultimaker's printer. However, these are cheap if you compare with the printer available today. This solution must be combined with the existing system as Cura can not be used together with Stratasys printers.

This workflow works in the same way as GRABCAD Print in that the designer would be responsible for the preparation of the component.

### 3.3.1 Proposed workflow

After a meeting with Patrik from 3DVerkstan, the workflow that can be seen in figure 57 has been compiled [26].



**Figure 57:** Proposed workflow when using Ultimaker Cura.

### 3.3.2 Pros/cons

See table 22 for pros and cons with Cura.

**Table 22:** Pros/cons Cura

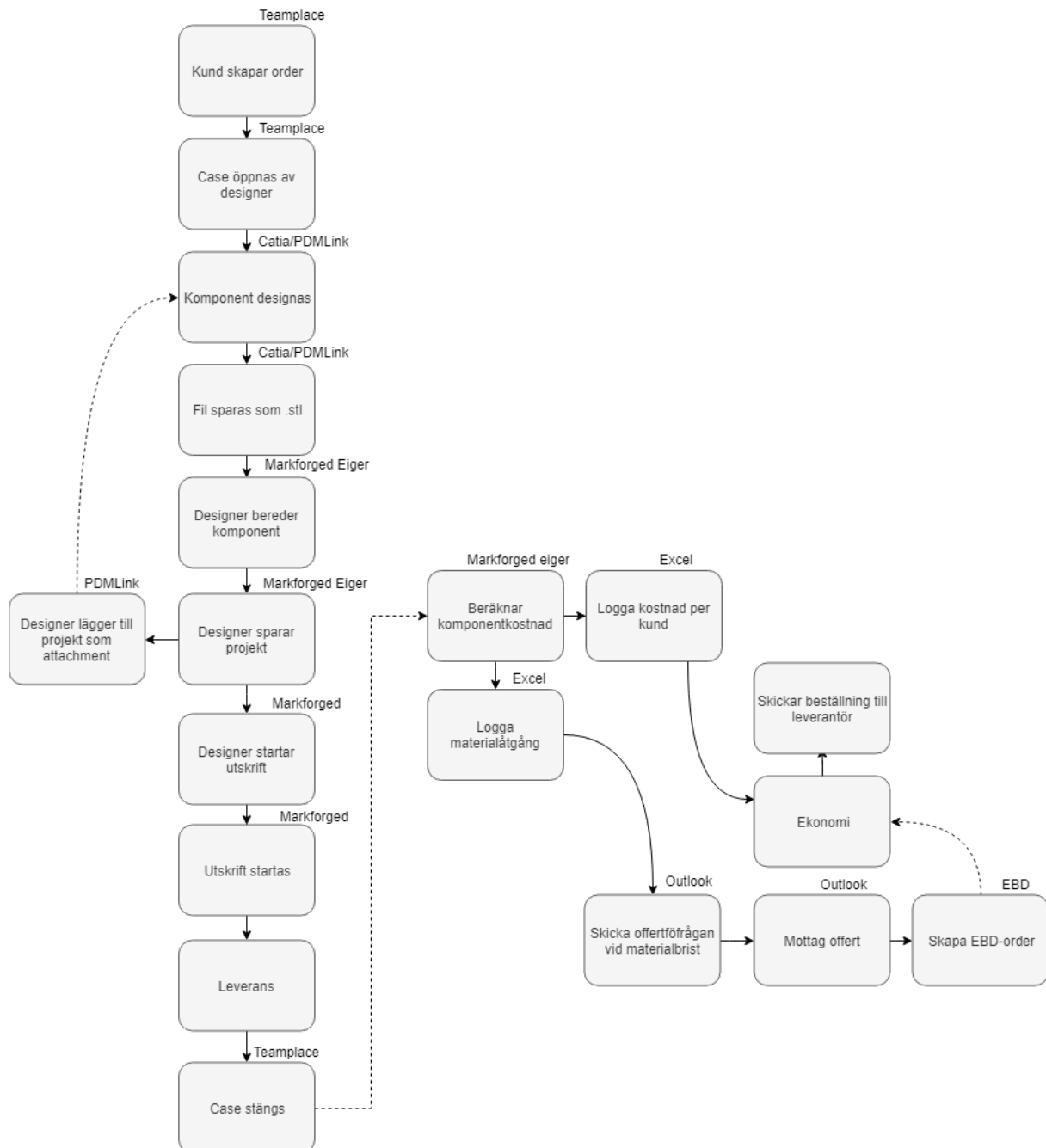
Pros	Cons
Reduced workload on the person in charge	Designers must be trained
Constructors gain an increased understanding of additive manufacturing	Can't integrate directly with the PDM system
The program is free	Printers must be purchased
Reduced prototype costs	

### 3.4 Eiger with Markforgeds printer

After the meeting with Patrik from 3Dverkstan, he suggested that one would use Markforgeds printers that uses Markforgeds print preparation program Eiger. This is because their software offers the possibility to download the print history. This file logs material consumption, which means that you could skip logging the material consumption and the cost of manufacturing, but you could do it for example every other month.

#### 3.4.1 Proposed workflow

After a meeting with Patrik from 3DVerkstan, the workflow that can be seen in figure 58 has been compiled [26].



**Figure 58:** Proposed workflow when using Eiger.

### 3.4.2 Pros/cons

See table 23 for pros and cons with Eiger.



**Table 23:** Pros/cons Eiger

Pros	Cons
Reduced workload on the person in charge	Designers must be trained
Constructors gain an increased understanding of additive manufacturing	Can't integrate directly with the PDM system
Stronger prints	Printers must be purchased
Can download file with print history	Locked material system

## 4 Conclusion

These proposed workflows are intended to reduce the workload of the person responsible for the 3D printer. This is done by making use of programs that are easier to learn than Insight that is used today, which means that the designers can prepare the components themselves. I believe that this deeper knowledge in how additive manufacturing works will help the designer to learn how to utilize additive manufacturing in a more efficient way. If one were to choose the solution by purchasing one or more cheaper printers using less expensive materials, one could also test more prototypes before making the real component. Which I think will promote the creativity of the designers.

In this case, Eiger's solution of downloading a file with print history has been the best solution, but their printers are expensive and have a locked material system. Their printers also use a special method that can add long fibres to enhance their parts. But during this project there has been no need for such strong prints. So at this time a markforged printer cannot be recommended.

So the recommended solution for this case is GrabCad Print as it is the only software that doesn't need an investment.