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Cost-effective manufacturing process for plastic components in automotive industry

Gustav Bergling Vishnu Nair

BACHELOR'S THESIS
Industrial Engineering and Management
Department of Engineering Science

Preface

This thesis was carried out at University West, Trollhättan, Sweden in the subject area Industrial Engineering. The thesis consists of 15 credits and is the culmination of the three-year Bachelor of Science in engineering programme of 180 credits, Industrial Engineering and Management. The authors take full responsibility for opinions and conclusions presented.

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We would like to express our utmost gratitude and sincere appreciation to the individuals and companies mentioned below for contributing to the realization of this work.

First and foremost, we're immensely grateful for Lear Corporation Gothenburg AB presenting us this opportunity and giving us a warm welcome during our first encounter at the head office. We'd like to give our heartfelt thanks to our company supervisor Tobias Drufva in particular, for being accessible and cooperative throughout this process by providing essential material and information which enabled us to understand and carry out the thesis. Additional thanks to Odd Jaegtnes and Martin Lorén who has also been involved in our thesis by attending our meetings with Lear and providing support when needed.

Sincere thanks to our university supervisor Mats Larsson for sharing his knowledge and advice, as well as our pleasant and informative weekly meetings. We would also like to give thanks to our examiner Joar Draxler who has provided valuable feedback and guidance for our work.

Furthermore, we'd like to thank all the manufacturing companies who provided us quotations and great service including:

Danke Mold Ltd.

Protolabs

Forerunner 3D Printing

Prototal AB

Xometry Europe

RYD Tooling

Gustav Bergling & Vishnu Nair
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BACHELOR'S THESIS

Cost-effective manufacturing process for manufacturing plastic components in automotive industry

Abstract

A seemingly increasing trend in the automotive industry is the prevalence of hybrid and electric vehicles. For Lear Corporation, a global automotive supplier of seating and electronic systems, this has caused a decrease in quantity of their products as these types of vehicles are manufactured at lower rates of volumes. An essential element of the electronic system provided by Lear is the wire harness. The wire harness is fastened and protected through plastic components called channels or brackets. These channels are fabricated through injection molding, one of the most common plastic manufacturing processes which offer many benefits. However, injection molding entails high upfront costs which are not suitable for the lower scales of production Lear expect. This prompted the company to seek other alternative processes and thus the idea of this thesis arose.

The purpose of the thesis was to identify, evaluate and present alternative manufacturing processes that could potentially replace the current process. Furthermore, the possibility of decreasing the costs of the current process and making it viable for low volume production was explored.

The study presented a total of nine common plastic manufacturing processes and subsequently performed a screening where processes deemed incompatible, in terms of aspects such as part complexity, size, volume and cost, were dismissed and processes deemed compatible in relation to the desired application were evaluated further. The processes kept for further examination were injection molding and additive manufacturing.

Injection molding and additive manufacturing were evaluated further and ultimately cost estimates for each process were requested to manufacturers in order to make a cost analysis and further study the feasibility of respective process.

The cost estimates and subsequent cost analysis indicated that the ideal and most cost-effective option for Lear would be changing the injection molding tool to MUD, aluminum or steel grade 738. This allows Lear to utilize the benefits of injection molding while decreasing the mold cost and upfront costs for the injection molding process substantially. Another proposal presented was to merge injection molding and additive manufacturing in a method called bridge production. This would allow Lear to increase flexibility and reduce lead time.

Date:	May 27, 2020
Author(s):	Gustav Bergling, Vishnu Nair
Examiner:	Joar Draxler
Advisor(s):	Mats Larsson (University West), Tobias Drufva (Lear Corporation Gothenburg AB)
Programme name:	Industrial Engineering and Management
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Publisher:	University West, Department of Engineering Science, S-461 86 Trollhättan, SWEDEN Phone: +46 520 22 30 00, E-mail: registrator@hv.se, Web: www.hv.se

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1 Introduction

The bachelor thesis aims to identify, evaluate and suggest a cost-effective manufacturing process for plastic components used as fasteners in the wiring harness of automobiles. This chapter aims to introduce the reader to this bachelor's thesis and give a brief introduction of the subject and the company where the thesis was carried out.

1.1 Company introduction

Lear is a leading global automotive supplier that provides seating systems and electronic systems, or E-systems, to major automakers all over the world. The company manages 261 facilities around the world and operates in 39 countries globally.

This thesis was done in cooperation with Lear Sweden, which mainly operates within the E-systems division, engineering and business. The head office is situated at Eriksberg, an area on Hisingen Island in Gothenburg, Sweden. The company has 53 employees and 40 contingent workers. Lear Sweden provides E-systems and components for automakers such as Volvo and Geely [1].

1.2 Background

As mentioned in the company introduction, Lear Corporation provides E-systems and components to automakers. A fundamental part of E-systems are wires and wire harnessing. While assembling and structuring a complex network such as the wire harness, components such as straps, clips, channels and brackets are essential in order to fasten and protect the wires. These components are currently made from plastic. The current manufacturing process used by the company to produce these plastic parts is injection molding [2].

Injection molding is considered to be the most common and widely used process for manufacturing plastic parts and offers several benefits such as high production rate, flexible selection of material, ability to produce complex shapes, little or almost no need for subsequent processing, low cost of labor and low wastage. Although injection molding is favorable in many ways it does have drawbacks, the one in particular being high investment costs for tooling. However, the high investment costs can be incentivized through mass production, as the cost per detail decreases with higher volumes [3].

In the case of Lear Corporation who operates in the automotive industry, electrical vehicles and hybrids are gaining popularity. The manufacturing volumes of these vehicles are lower, and according to Lear global component manager T.Drufva [4], the numbers for electrical and hybrid cars are 5000 – 20 000 vehicles a year, in comparison to 100 000 – 300 000 a year. The lower volume of vehicles entails a lower volume of plastic parts which makes injection molding a less profitable option as the low volumes don't justify the high investment costs. Therefore, the company is pursuing a manufacturing process that is more suitable for the newer volumes.

1.3 Purpose

The purpose of the thesis is to identify, evaluate and present various cost-effective plastic manufacturing processes that could potentially replace the current process. This is done to provide Lear Corporation Gothenburg AB a foundation for future decisions concerning manufacturing of plastic parts for fastening and protection in wire harness of automobiles.

1.4 Problem

The project will analyze the possibilities of identifying a manufacturing process that is compatible with the lower and decreased volumes of plastic parts, as opposed to the current one. However, the possibility of making the current process itself more cost-effective will also be analyzed. The alternative manufacturing processes presented should be able to deliver parts with the same or similar properties, just like the traditional injection molding, as well as meeting the requirements and technical standards of automobile manufacturers.

Manufacturing processes must be evaluated in regard to all influencing aspects such as form of detail, annual volume, lead time, cycle time, set up cost, cost per detail and material.

The project aims to answer the following questions:

Is there a suitable and cost-effective manufacturing process that can replace the current one?

Can the new manufacturing process produce parts with the same, or similar, properties as the current one and thereby meet the technical standards of the automobile industry?

Is it possible to make the current process more cost-effective?

1.5 Limitations

Several limitations have been set. There is a time limitation as the thesis work will be done over the course of a 10-week period. The thesis will not present more than ten plastic manufacturing processes. Technical regulation and standards from automakers will be used as reference while choosing a manufacturing process. The components that will be analyzed include wiring plastic channels and exclude straps, clips and metal bushings. The thesis will focus on identifying plastic manufacturing processes suitable for existing parts and therefore, exploring the possibility of altering the design or changing the material of the parts will not be done.

2 Method

This section aims to guide the reader through the methods used in order to fulfill the purpose of the thesis and answer the questions raised in the problem section. It presents research design, the chronological steps of the thesis and the process of searching, retrieving, choosing and evaluating adequate and credible sources.

2.1 Research design

This thesis is a qualitative study and an investigative research where possible solutions to a problem are identified through interpretation of various texts, documents and conversations. However, the study also uses numeric data in order to present cost analysis. The object of the study is to gather information, understand and analyze different processes and concepts within a certain field in order to present proposals that could benefit Lear Corporation [5].

2.2 Information retrieval

With guidance from tutor, examiner and other university representatives, information was searched and retrieved through various search engines, databases and portals including the University West library, DiVA, Chalmers Open Digital Repository, LIBRIS, Google Scholar, Google and Amazon. Information about Lear Corporation was retrieved through oral communication with company advisor and representatives as well as documents provided by the company upon request. The data retrieved by company X was through direct contact.

2.3 Chosen sources

Oral communication, documents and material provided by Lear were valuable and necessary sources in order to build a foundation for the thesis and formulate the subsections in section 1 “Introduction”, such as company introduction, background, purpose, problem and limitation as well as section 3 “Overview of current situation” and its subsections “Current manufacturing process” and “Wire channels or brackets”.

The project used predominantly literature, scientific articles and web sources in order to write section 4.1 “Plastic Manufacturing Processes”. The data collected were used to obtain a fundamental understanding of how all the manufacturing processes operate as well as identifying their characteristics and most favourable application. The knowledge acquired from previous steps was used in subsection 4.2 “Screening of Manufacturing Processes”, where a screening was performed in order to eliminate and filter out inapplicable processes with regard to a number of factors derived from Lear Corporations requirements and prerequisites. The processes deemed plausible were kept and evaluated further.

The following step of the project was to collect more data regarding the remaining processes from the screening. The collection of information was through literature, scientific articles and direct contact with various manufacturing. The reason behind using manufacturing companies as a source was mainly to obtain data about the investment costs for manufacturing processes in the form of quotations, as well as getting feedback on our study.

This in return was done in order to evaluate the feasibility of implementing a certain process to desired application and ultimately answering the questions raised in the problem.

The remaining sections of the thesis (Discussion and Conclusions) include an analysis of the outcome and results presented in section 4, a summary of the study and conclusions drawn.

2.4 Source evaluation

The literature used in the study was deemed credible as the preface/introduction/foreword and overall content of each book provide sufficient evidence that validate the author/authors as scholars with the suitable expertise, qualifications and credibility. However, some of the literature was released more than ten years ago, which is a factor that must be taken into consideration when evaluating adequacy of a source. Due to changes and advancements being made in the manufacturing industry, information provided in the literature may be outdated or even invalid. In the case of literature that hasn’t been released within the last ten year, the source was either fact-checked or complemented by a newer or updated source. However, in this study the information provided in the older literature was generally accurate and valid.

The decision to use information from manufacturing companies was to complement the literature which, although it provided detailed and thorough description regarding the methodology and theoretical concepts behind different processes, it couldn’t give us accurate information regarding the feasibility and cost for our custom part. As more accurate and realistic numbers were needed in order to ultimately present a proper and realistic investment case for a manufacturing process, various manufacturing companies and institutions were contacted.

It's understood that every company will have a bias towards their own product or service, and therefore making them less reliable as a source. However, the decision to keep the companies as a source was made in compliance with our tutor as the companies still could provide useful and authentic information, in particular cost-related information, which will be significant for the project end goal.

3 Overview of the current situation

The overview of the current situation aims to give the reader a brief description of the current situation which includes the current manufacturing process injection molding, as well as describing the function and demands of the injection molded component which is the plastic channel or bracket for wire harness.

3.1 Current manufacturing process

The current manufacturing process applied when producing automotive plastic components is injection molding. As previously mentioned, it is one of the most widely used manufacturing processes for producing plastic parts and can create plastic parts into a variety of products for different end uses.

Briefly explained, plastic pellets or granules are fed into a barrel via a hopper. The pellets are pushed forward by a rotating reciprocating screw through a heated chamber, shearing and melting the material in the process. The molten is injected through the force of the screw into a mold cavity. The molten is then chilled down and solidified. Finally, the mold is opened and the part is removed [4]. A more in-depth description of injection molding will be presented in 4.1

3.2 Wire channels or brackets

Lear Corporation uses the aforementioned manufacturing process to produce plastic components used in the wire harness of automobiles as fasteners or protectors. In this thesis, plastic wire channels or bracket will be analyzed. According to the Technical Regulation from car makers [6], the objective of the wire channel or bracket is to protect the wire harness from mechanical, thermal and chemical influence. The task of the wire channel or bracket is to define and fix the location of the wire harness in the vehicle. The wire channel or bracket should also prevent any noise and rattle coming from the wire harness.

The car consists of eleven “zones” which include:

1. Engine
2. Engine-Subframe
3. Engine bay rear, left
4. Engine bay front
5. Engine bay, rear, right
6. Engine plenum
7. Wheel, Wheel suspension
8. Cabin

9. Cabin(leg room)
10. Luggage room
11. Luggage room(leg room)

The property requirements of the wire channel or bracket depend on what zone it's located in and where it shall be used.

According to V.Goodship et al [7], there are three distinct categories of raw plastic material:

- Thermoplastics: plastic materials which melt into liquid during heating and solidify during cooling. During heating the material becomes pliable and can be formed into another shape which it then retains during cooling and solidification. This process is reversible and can be repeated, meaning the material can be remelted and remolded. Examples of thermoplastics include Polypropylene (PP) and Nylon.
- Thermosets: materials that are initially in liquid or pliable state and then converted into a solid, stiff and brittle form. This conversion process is called curing and, in contrast to melting and solidification of thermoplastics, it is irreversible due to the cross linkage polymer network created. Examples of thermosets include epoxies and polyutherane.
- Elastomers: Furthermore, there are materials that could be either thermoplastic or thermosets that has the ability be repeatedly stretched and return to original shape. These are called elastomers and examples include rubber.

The raw materials used to produce these components are thermoplastics such as Polyamide 66(PA66, also known as Nylon 66), Polyamide 6(PA6, also known as Nylon 6) or Polypropylene (PP). In PA66 and PA6, 15 % or 30% glass fiber is sometimes applied to strengthen material and improve properties [6].

A prototype model of a plastic wire channel was provided by Lear, displayed in figure 1 below. This is an example of how the component can be constructed. However, it is important to note that channels and brackets differ in size, shape and has varying degree of complexity in its geometry depending on its location and use. According to T.Drufva [3], the current total annual volume for plastic articles are 150,000 parts with a program lifetime of 7 years, indicating that 150,000 plastic channels or brackets are fabricated annually over a seven-year time span. However, as earlier mentioned in the background section 2.1, these numbers are expected to decrease as the production of hybrids and electric cars are of lower volumes. The current tooling costs for producing plastic wire channels or brackets are in the price range of 93,000-130,000€ for an annual volume of 75,000-111,000 parts, with a program lifetime of 7 years. The costs per detail for these channels are 0.48-0.77€ per part.

Figure 1: Plastic wire channel prototype, Lear Corporation

4 Plastic manufacturing processes

This section aims to gain knowledge and an understanding of the most common plastic manufacturing processes in order to select an option that is adequate for the desired application. Firstly, an overview of each potential manufacturing option and its respective process, characteristics, applications, advantages and disadvantages will be presented. A total of nine manufacturing processes will be presented. In the following step a screening will be performed where the processes that are deemed inapplicable, in regard to aspects such as material; form; time; cost etc, will be eliminated and the processes that are considered to be a feasible and realistic option will be kept and assessed further.

4.1 Potential manufacturing processes

4.1.1 Injection Molding

Injection molding is one of the most widely used processes for mass production of plastic parts. Injection molding offers many benefits such as high precision, efficiency, ability to produce highly complex parts, flexible selection of material, low labor costs since it's an automated process requiring minimal supervision, low costs in mass production and little or almost no need for subsequent processing due to high pressures which ensures good surface finish. It is a fast process with a cycle time of approx 30 seconds, depending on complexity of mold.

The cons of injection molding are expensive equipment and tooling which amount to high upfront costs. Injection molding is a process that requires accurately engineered tools that can provide good surface finish and withstand the high pressure, temperature and forces at work during injection and clamping. Consequently, it is a process that becomes less cost-effective at a low volume as the high investment costs wouldn't be justified. Typical applications include a variety of objects, in particular automotive, industrial and household products [8].

It is defined as a method of producing parts with heat-meltable plastics material, according to the Injection Molding Division of the Society Plastics Engineers [9]. This method is done by the use of an injection molding machine. The machine consists of various key components:

The mold: The desired shape being produced is being controlled by a confined chamber called the mold.

The injection unit: The function of the injection unit is to feed, plasticize, melt, transport and dose material, to subsequently inject the material into the mold tool. The injection unit itself consists of several distinct features such as the hopper, the barrel, the screw and the nozzle.

The clamping unit: The purpose of the clamping unit is to hold the mold in a closed and rigid position during molding to resist the high pressure of the injection of material.

Tooling: The purpose of the tool is to form the mold cavity in which the material is injected into, remove heat from the surface of the cavity and sealing the mold halves during injection pressure

A basic injection molding process is initiated by closing the tool and shutting the clamp. Polymer material in the form of pellets or granules is fed from the hopper and into the barrel in the injection unit. The barrel is equipped with an auger, a rotating reciprocating screw, which has the function of conveying material through the barrel. The screw transports the pellets/granules forward towards the nozzle, shearing the material along the way. Heater bands wrapped around the barrel along with the screw-induced heat created from shearing friction warms up and eventually melts the material by the time it has reached the front of the barrel. The screw then injects a controlled dose of molten material through the nozzle of the injection unit into the mold cavity. When the mold cavity is filled, cooling of material is applied. The screw retracts and new melt is dosed in preparation for the next cycle. Once the material is cooled, the tool opens and the component is ejected. [7][10]

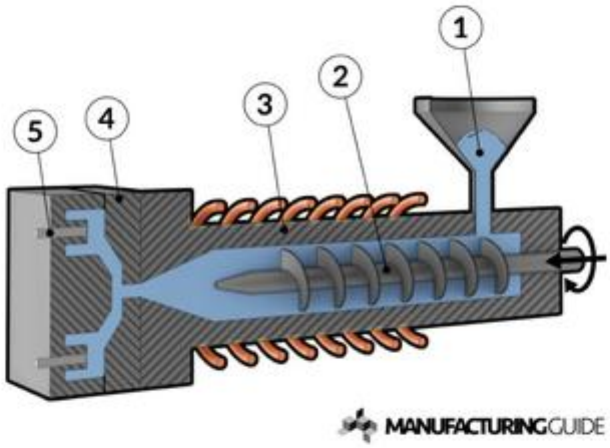

Figure 2 Injection molding process. From [11]. CC-BY.

(1) The hopper

(2) The rotating screw

(3) The heated barrel

(4) The mold

(5) Ejector pins

Table 1 Injection molding characteristics

Material	Thermoplastics, some thermosets
Upfront cost	High
Part cost	Low
Size	XS-L
Cycle time	Seconds
Quantity	10K-100M+
Complexity	High

[12]

4.1.2 Vacuum Forming

Vacuum forming is one of the subcategories of thermoforming, the others being pressure forming, plug-assisted forming and twin sheet thermoforming. It is a simple and inexpensive process. Due to low pressures and forces involved, tooling costs for vacuum forming are low compared to other techniques. Molds are made out of materials such as wood and plaster. This in return makes vacuum forming suitable for prototyping and low volume production. However, if higher quantities are needed it's possible to use more durable metal tooling. Vacuum forming offers flexibility in material selection as most thermoplastics can be used. The process has limited freedom in form as only thin walled parts can be produced. Typical applications include baths and shower trays, packaging, transportation and aerospace interiors [8].

The vacuum forming process:

A plastic sheet is clamped into a frame above the mold. The plastic sheet is heated to make it soft and ductile. The mold is moved upwards stretching the plastic sheet and vacuum is activated, which creates a vacuum in space between the sheet and the mold. The air trapped between the sheet and the mold escapes through vent ducts. This in return forces the sheet to adhere with the mold surface and thus forming the part. Once the part is cooled, the sheet is removed. Subsequent processing like trimming and cutting is often necessary to remove excess material [8][10].

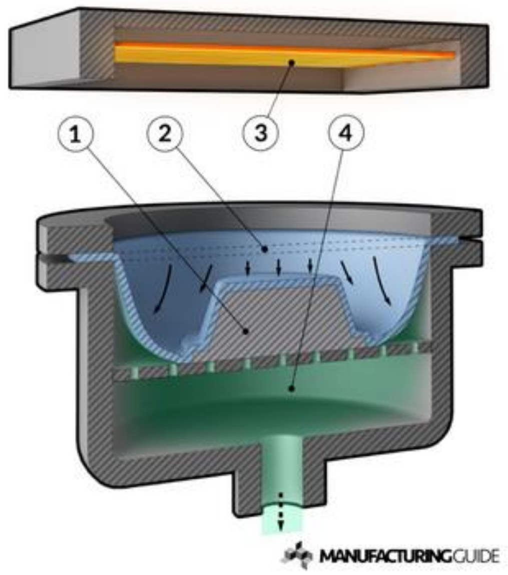

Figure 3 Vacuum forming process. From [13]. CC-BY.

(1) The mold

(2) The plastic sheet

(3) The heater

(4) The vacuum in space created when activating the vacuum pump

Table 2 Vacuum forming characteristics

Material	Thermoplastics
Upfront cost	Low
Part cost	Low-moderate
Size	S – L
Cycle time	Minutes
Quantity	100 - 10K
Complexity	Low

[12]

4.1.3 Reaction Injection Molding (RIM)

The process characteristics of RIM are similar to injection molding, with the exception that RIM processes thermosetting materials and not thermoplastics. This means that material is cured, as opposed to thermoplastics where only cooling takes place. Another distinction between the two processes is that injection molding uses one single material (molten plastic) during injection whereas RIM uses two materials that are mixed and injected into the mold where they undergo a chemical reaction. The overall cycle is slower compared to injection molding and the raw materials used in RIM are more expensive. However, due to no heating of plastic, the lower injection pressure and lower material viscosity, the product equipment is significantly less expensive than injection molding and also makes it ideal for larger parts.

The process can be used to produce low or high quantities of thermosetting foams. It is commonly used to produce prototypes that will be injection molded because of low tooling costs, while repeatability, part consistency, complexity and accuracy are high. The most common RIM material is PUR (polyurethane) which offers a high level of dynamic properties, heat resistance and dimensional stability. Typical applications include automotive bumpers and car interiors, domestic and commercial furniture such as chairs and seats, and also sporting goods and toys.

The RIM process:

The process begins with two polymer liquids, usually isocyanate and polyol, being poured into separate containers. These containers are equipped with temperature and feed-controlling mechanisms where the material is properly conditioned. The materials are transported to the mixing head and then recirculated back to the containers in a continuous loop. The purpose of recirculation is to maintain temperature and nucleation. When the machine decides to switch from recirculation mode to dispense mode, the pumps transports the two liquids to the mixing head at required ratio, volume, temperature and flow rate. When the reactants are mixed together they undergo a chemical reaction, creating polyurethane which is injected into the mold cavity. After the mold is filled, the part must be cured, cooled and finally ejected [8].

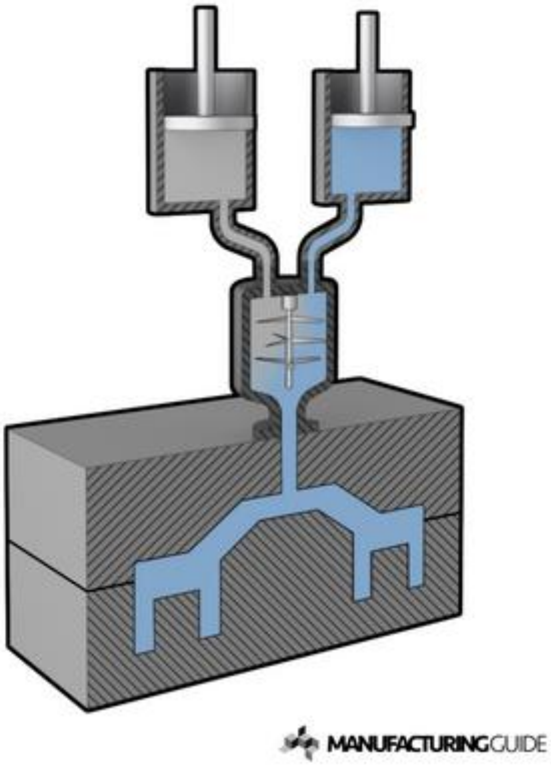

Figure 4 Reaction Injection Molding process. From [14]. CC-BY.

Table 3 Reaction Injection Molding characteristics

Material	Thermosets
Upfront cost	Moderate
Part cost	Low
Size	S-XL
Cycle time	Minutes
Quantity	<100K
Complexity	High

[12]

4.1.4 Compression Molding

Compression molding is a manufacturing process most commonly used to produce thermosetting polymers (such as rubber, polyester or phenolic), although it is applicable to some thermoplastic parts as well. It's also used to manufacture composite parts like bulk and sheet molding compounds (BMC and SMC). The process involves molding of molten plastic through compression. It is suitable for medium to high volume production and tooling costs are moderate. Compression molding produce small or large parts with high quality surface finish.

Although more time consuming than injection molding, it is a relatively fast process depending on material and size, but for plastic the cycle time is approx two minutes. Compression molding and injection molding share a lot of similarities as the both use matched tooling (although tooling for compression is cheaper) and both processes are done under heat. The main difference is that injection molding is predominantly used for thermoplastics and compression molding for thermosetting polymers. Compression molding also has limitations in form freedom and is not as suitable for complex designs in comparison to injection molding. Typical applications include electrical housing and kitchen equipment, buckles, rubber boots, buttons, knobs, device cases and appliance housing [8].

The compression molding process:

Compression molding consists of an open mold with two halves, the upper part of the die and the lower part of die. The lower part of the die is fixed and static while the upper part is movable through guide pins. The lower part is equipped with heating and cooling-mechanisms. A predetermined quantity of plastic material is placed in the mold cavity of the lower part. The two mold halves are then closed through applied hydraulic pressure and heat, which forces the material to fill up the mold cavity. After the material goes through a curing process, the mold halves separate and the part is ejected [15].

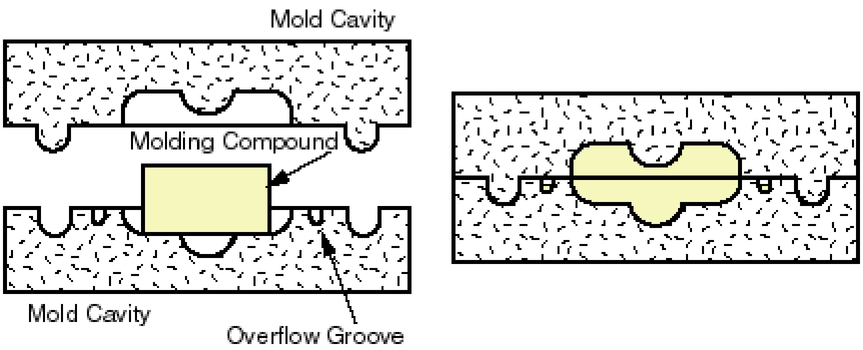

Figure 5 Compression Molding. From [16]. CC-BY.

Table 4 Compression molding characteristics

Material	Thermosets, some thermoplastics
Upfront cost	Low to moderate
Part cost	Moderate
Size	S-L
Cycle time	Minutes
Quantity	<100K
Complexity	Medium

[12]

4.1.5 Extrusion

Extrusion is one of most common manufacturing processes across many industries. It is a process used to produce small or large parts with a uniform cross section such as rods, tubes, films and sheets. In this process, raw plastic is melted and formed into a continuous profile. Most thermoplastics are compatible with extrusion. Cost for extrusion machinery is relatively cheap as it is less complex and doesn't require high levels of machine accuracy. Tooling costs are also inexpensive in comparison to injection molding. Similar to injection molding, it is a continuous and fast process, suitable for high volume and mass production. Typical applications include straws, pipes, tubes, window frames, fences, weather stripping and wire insulations [17].

The extrusion process:

The process begins by loading plastic material in the form of pellets or granules into a hopper and then delivered into a cylindrical barrel with a rotating screw. The screw pushes the material forward in a heated chamber and when it reaches the end of the barrel it is forced through a die. The process can be likened to squeezing toothpaste of the tube. The shape of the die is a cross-section of the final part and thus the workpiece is formed. The extruded part is cooled and later cut or spooled into lengths. The extrusion process is similar to injection molding, with the exception that molten material is being forced into a die instead of a mold cavity [18].

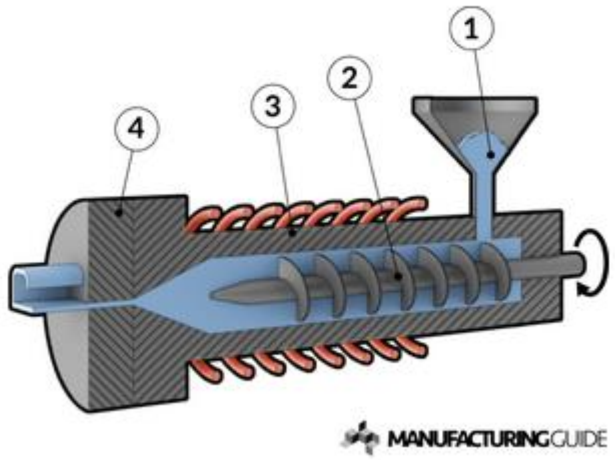

Figure 6 Extrusion process. From [19]. CC-BY.

(1) The hopper

(2) The rotating screw

(3) The heated barrel

(4) The die

Table 5 Extrusion characteristics

Material	Thermoplastics
Upfront cost	Low to moderate
Part cost	Low
Size	S-L
Cycle time	Seconds
Quantity	1K-100M+
Complexity	Low

[12]

4.1.6 Blow Molding

Blow molding is a group of processes including extrusion blow molding, injection blow molding and stretch molding, used to mass produce hollow containers. Extrusion blow molding will be the focal point in this section as it is the oldest, simplest and most common type of blow molding. It is a favorable process due to its versatility and can be used to process a variety of container shapes and an extensive choice of material. It enables the production of considerably large hollow products. The size is only limited by the size of machine as well as the mechanics of the molten material that forms the parison. The most compatible materials are thermoplastics such as PP, PE, PVC and PET. It operates at lower pressures than injection molding, which makes the tooling less expensive. Although slower than its relative process injection blow molding, it's a relatively fast process with a cycle time of 1-2 minutes. Typical applications are mainly in the medical, veterinary, chemical and consumer industries to produce bottles, containers and consumer packaging [8].

The extrusion blow molding process:

Plastic pellets or granules are melted and extruded into a hollow tube, called the parison. The parison is dropped in between two halves of a mold, one end of the parison is sealed and the other end is open. The mold halves are then clamped together and air is blown into the open end of the parison which inflates and expands it. The parison is forced against the internal surface of the mold cavity, thus taking the shape of the mold. The plastic part stays in the mold until it cools and hardens. The part is then ejected and often requires subsequent processing such as rimming and trimming to remove excess material [10].

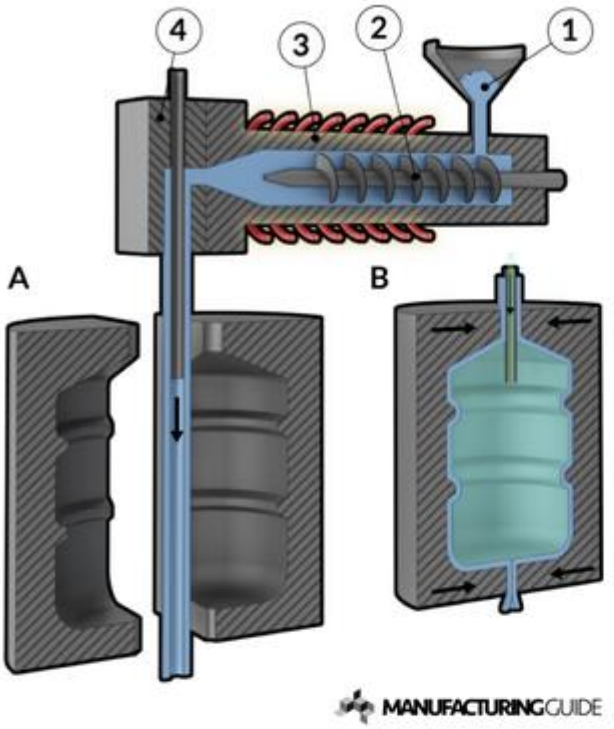

Figure 7 Extrusion Blow Molding process. From [20]. CC-BY.

(1) The hopper

(2) The rotating screw

(3) The heated barrel

(4) The die which extrudes the parison

Table 6 Blow Molding characteristics

Material	Thermoplastics
Upfront cost	Moderate
Part cost	Moderate-High
Size	M-XL
Cycle time	Minutes
Quantity	< 100K
Complexity	Medium

[12]

4.1.7 Rotational Molding

Rotational molding is a process used to produce large parts of hollow and complex forms with uniform wall thickness. It is cost-effective as the process uses centrifugal force, instead of pressure, to fill the mold, making tooling less inexpensive than most other plastic manufacturing processes. Although no pressures are involved, good quality and surface finish can be obtained. The molds are usually fabricated or cast, and typically manufactured from stainless steel or aluminum. These factors make rotational molding suitable for low to medium volumes. It is a slow and long process with cycle time between 30 and 60 minutes. Due to material demands of rotational molding it is restricted in material choices. The most commonly used material is PE, as it can be ground into powder at room temperature. Typical applications include tanks, large containers, furniture and toys [8].

The rotational molding process:

A predetermined amount of plastic material, in the form of pellets, granules or powder, is loaded into an open mold that is mounted on the arm of the molding machine. The mold is then closed and clamped. The mold starts to rotate around its horizontal and vertical axes while being moved into a furnace where heat is being applied. This causes the material to melt and subsequently adhere to the inner surfaces of the mold, which forms the part. The mold continues to rotate during cooling and solidification to ensure that even distribution and wall thickness. Finally, the mold is unloaded and the part is ejected [10].

Figure 8 Rotational Molding. From [21]. CC-BY.

(1) The polymer material

(2) The mold

Table 7 Rotational molding characteristics

Material	Some thermoplastics
Upfront cost	Moderate
Part cost	Moderate
Size	L – XL
Cycle time	Minutes
Quantity	<10K
Complexity	Medium

[12]

4.1.8 CNC Machining

CNC (Computer Numerical Control) machining includes a multiple of processes and operations such as milling, drilling, lathe turning, routing and grinding. The starting workpiece in a CNC machining process is usually a solid block, rod or bar of plastic, or metal, which is then shaped by lather or milling machine through removal of material, it is therefore defined as a subtractive process. Because it is a subtractive process it generates considerable excess waste in form of chips. However, modern CNC processes have efficient waste collecting and recycling systems.

Its applications are diverse and it is used for both prototyping and mass production in a variety of industries for shaping metal, plastic, wood, ceramic, composites and other materials. Most hard plastics can be machined with varying degree of difficulty and softer thermoset material requires specialized tooling. It is most often used as a post-processing operation for removing excess material or boring holes. It is also used as primary operation in production, for example low volume plastic parts that require preciseness, tight tolerances and geometries that are difficult to obtain through molding.

The set up costs for CNC machining are low to moderate and once the machines are set up, the process will repeat a sequence with high accuracy and speed. Due to the process being almost fully automated, little operator involvement is needed which results in low labor costs. Time and money is saved by the ability to directly create the part on the CNC machine, as opposed to creating a mold. However, factors such as time and cost are highly dependent on part size, complexity and design. Cycle time and part per cost increase with part complexity. The process has limitations in design as features such as undercuts or curved internal channels would require a cutting cool with a certain geometry that's also able to access all surfaces, which would, either increase cost significantly, or not be possible at all [8].

The CNC machining process:

The process begins by creating 2D or 3D CAD-design. The part geometry and technical information of the CAD file is extracted by CAM (Computer-aided manufacturing) software which generates the CNC-code. The code contains toolpath data, the toolpath can be seen as instructions which control and dictate movement of cutting tools, speed and tool changeovers. The toolpath data is sent to the machine, and once the machine is prepared the operation can be executed. Material is removed from the workpiece through suitable CNC-operation, for example drilling, milling or turning. After manufacturing the part is cleaned, trimmed or polished if needed [22].

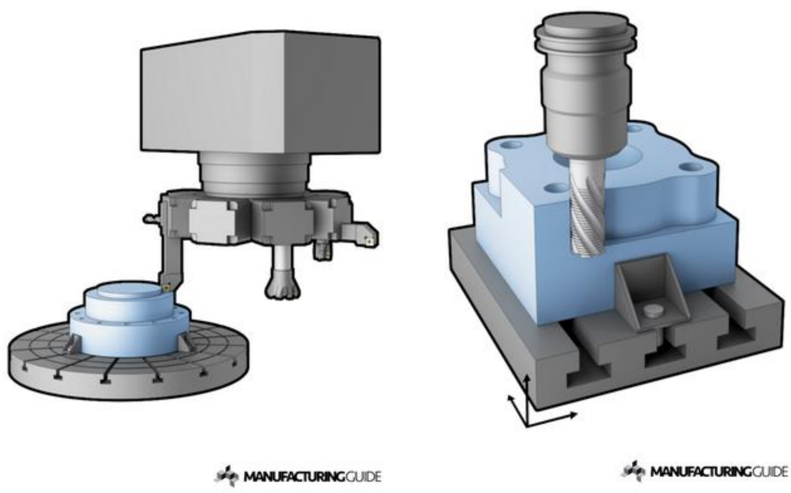

Figure 9 CNC-machining processes. From [23]. CC-BY.

Table 8 CNC Machining characteristics

Material	Thermoplastics
Upfront cost	Low to moderate
Part cost	Moderate to high
Size	XS-L
Cycle time	Minutes(depending on size)
Quantity	Low to mid volume
Complexity	Medium

[24]

4.1.9 Additive manufacturing

3D printing is a process where a 3D object is built by depositing layers of material successively, hence it is named additive manufacturing (AM). Note that the terms 3D printing and additive manufacturing can and will be used interchangeably in this study. Any AM process begins by design through computer-aided design software (CAD). The CAD model is exported to a file format called STL. STL-files stores information about the 3D model and describe only the surface geometry of the solid object, it contains no information about texture, color or other model attributes. The STL-file is then imported into another piece of software called "slicer" which converts the 3D model into a G-code. The G-code contains tailor made building instructions of the model which control the 3D printer.

A favorable aspect of additive manufacturing is that it doesn't require any tooling or tool changeover as opposed to the traditional manufacturing techniques, thus making the beneficial from a cost efficiency standpoint. The CAD model enables the possibility to create inventive and imaginative objects with a high degree of freedom in form. Depending on desired material and shape, there are different types of 3D printing that can suit your application. The technology of additive manufacturing is divided into two categories: Rapid Manufacturing (RM) and Rapid Prototyping (RP). Rapid Manufacturing is the additive manufacturing process used to produce final parts or products, while Rapid Prototyping is used to produce prototypes, models and mock-ups.

This study will focus on three 3D printing techniques in particular, that are suitable for additive manufacturing of plastic material: FDM, SLA and SLS [7][25].

4.1.9.1 Fused Deposition Molding

Fused Deposition Molding (FDM) is the most widely used additive manufacturing technology. The process involves a polymer filament, which is loaded into the 3D Printer and fed through rollers into one or more nozzles where it melts. The material is then extruded and deposited at the bottom of the printer where it solidifies, the next layer is then extruded and fuses with the bottom layer. This sequence is repeated, layer by layer, until the desired object is built and complete. It is then solidified and cooled. The nozzles are controlled by a three-axis system which enables it to move in X, Y and Z directions in order to create the object. Similar to CNC-machining, a G-code is used to control the movement of the axis.

FDM is generally used for final products and prototypes but also to manufacture molds or molding tools. FDM can process a wide range of material, mostly thermoplastics such as ABS, PLA and PA. It is the most cost-effective method for producing thermoplastic parts. However, FDM provides the lowest dimensional accuracy in comparison to other 3D printing techniques and consequently it is not suitable for intricate parts [25].

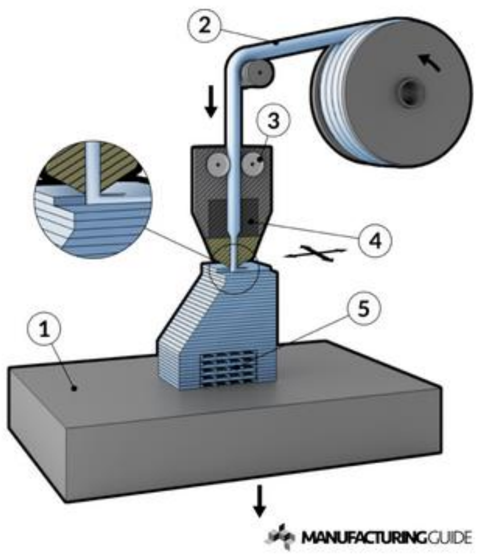

Figure 10 Fused Deposit Modeling process. From [26]. CC-BY.

(1) The building platform

(2) The polymer filament

(3) The rollers

(4) The heated nozzle

(5) Supporting structure

4.1.9.2 Stereolithography

Stereolithography (SLA) is known for being the pioneer of 3D printing technology SLA involves a UV laser (most commonly) and a light-reactive thermosetting polymer called "resin". The resin is stored in a tank where the object is created and an adjustable building platform is positioned slightly below a layer of the resin. The laser unit directs a UV beam to a reflective, computer-controlled mirror which steer the beam to the surface of the resin, where it draws or scan a cross-section of the 3D-model. The resin is cured and solidified in a process called photopolymerization when exposed to the UV laser. When a layer is complete, the building platform is lowered and the previous layer is coated by a new layer. This process of scanning and recoating is repeated layer by layer until the object is complete.

It's a fast process that provides good dimensional accuracy, smooth surface finish and intricate details. However, mechanical properties and aesthetics of SLA parts can degrade overtime when exposed to sunlight. The common SLA materials are photopolymer resins (thermoset). Thermosetting parts are more brittle than thermoplastics and not suitable for functional parts or prototypes [25][27].

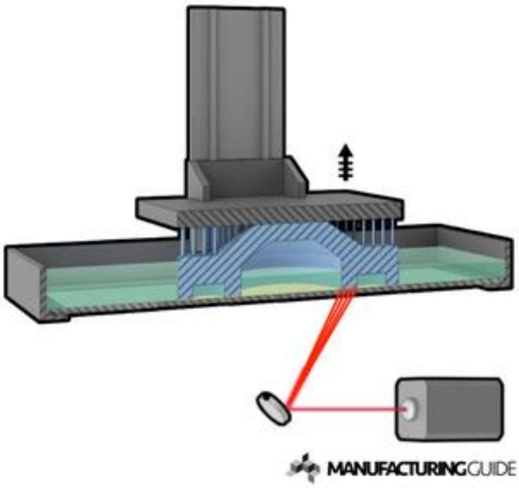

Figure 11 Stereolithography process. From [28]. CC-BY.

4.1.9.3 Selective Laser Sintering

Selective Laser Sintering is an additive manufacturing technique that uses a high powered laser to fuse powdered material, which then creates a solid 3D object. The powdered material is first heated just below its melting temperature and then dispersed in a thin layer over the building platform. The computer controlled laser unit directs a beam towards the powder surface, through reflective mirrors. The laser scans the cross-section of a CAD-model and selectively sinters the material which causes the particles in the powder to fuse together and solidify. When a layer is complete, the building platform is lowered and surface is recoated. The process is repeated until the object is complete.

The most commonly used material for SLS is PA12, also known as Nylon 12 due to ideal sintering behaviour and good mechanical properties. Other available materials include thermoplastics such as PEEK or PA11. A beneficial quality of SLS is that it needs no support structure as the unsintered powder provides all the support required, hence designs with complex geometries can be created. However, SLS parts often have rough surface finish which may require post-processing. SLS is suitable for low to medium batch production [27][29].

Note that aspects such as material, cost, surface finish, mechanical properties and geometric freedom vary depending on AM technology. Size is dependent on the build volume of the 3D printer.

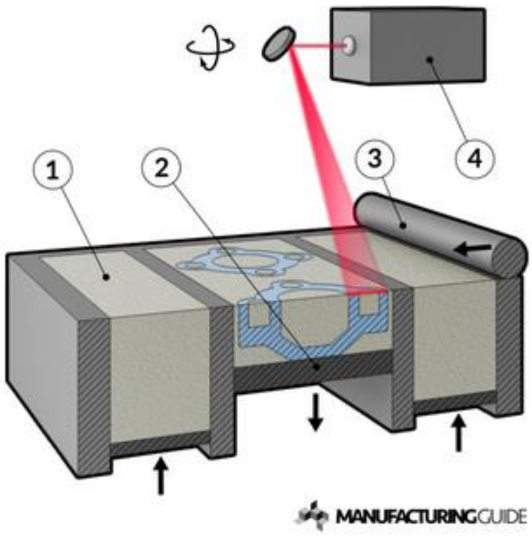

Figure 12 Selective Laser Sintering process. From [30]. CC-BY.

(1) Powdered material

(2) Building platform

(3) Recoating unit (rollers)

(4) Laser unit

Table 9 Additive Manufacturing characteristics

Material	Thermoplastics and thermosets
Upfront cost	Low to moderate
Part cost	Moderate
Size	XS-L(depending on build volume)
Cycle time	Minutes(depending on size and complexity)
Quantity	Low to mid-volume
Complexity	High

[24]

4.2 Screening of manufacturing processes

It is imperative to first establish a benchmark and describe what criteria the manufacturing processes must fulfill in order to produce desired parts and subsequently be considered applicable. Following influencing factors have been taken into consideration when performing the screening: material, upfront costs, part cost, size, cycle time, quantity and complexity.

Material

The problem section states that the manufacturing process should be able to produce parts with the same or similar properties as the current one. This doesn't necessarily indicate that the new part has to be a thermoplastic, or even a plastic for that matter. As it happens, Lear Corporation is deliberating replacing plastic parts with a more eco-friendly option. This subject is currently being studied in a separate bachelor thesis by two other students of University West, with the objective to identify cost-effective and environmentally sustainable alternatives to plastic parts in the wire harness of automobiles. Consequently, as stated in the limitations section, this study won't analyze the choice of material and therefore the premise is that the manufacturing process should be able to process thermoplastics, in particular material such as PA6, PA66 or PP. If a manufacturing process cannot process aforementioned materials or similar, then it is deemed inapplicable and screened out.

Upfront cost

Upfront costs include expenses that incur during the process of initiating a manufacturing process, such as tooling and equipment costs. The initial costs for injection molding are high due to expensive tooling and equipment. The upfront cost for the alternative manufacturing process should be lower than the current one in order to pose as a cost-effective option. If the manufacturing process has higher upfront cost than the current process it is deemed unprofitable and consequently inapplicable.

Part cost

The price per unit for injection molding decreases with increased volume of parts, which makes it a process suitable and cost-effective for mass production. However, Lear Corporation is seeking a process viable at lower volumes. This means that any manufacturing process that is more suited for mass production will presumably be deemed inapplicable, regardless of low price per unit costs, as the lower volumes doesn't incentivize the high upfront costs that a mass production process entails. However, it is possible to look at ways to modify a traditional mass manufacturing process to a process that suits lower volumes.

Size

A plastic wire channel or bracket can vary in size depending on its location and use in the automobile. However, most parts are in the range of small to medium. Manufacturing processes that have size constraints that don't conform to the desired size of the average wire channel or bracket are therefore deemed inapplicable.

Cycle time

Cycle time indicates the duration of an operation, in other words the time it takes to complete one production cycle from end to finish [8]. In the case of injection molding, the production cycle of one part can be completed within seconds. There are very few manufacturing processes that can match injection molding in terms of speed, therefore there will some degree of leniency towards processes that are slower (which most of them are) than injection molding and processes will not be dismissed solely on their speed, but it remains an essential factor when weighing and comparing processes.

Quantity

In this instance quantity is defined as the number of parts the manufacturing process can create in order to be profitable. As mentioned earlier in the part cost paragraph, injection molding is a process that is suitable for higher quantities and Lear Corporation is seeking a process that's favorable at lower volumes. It's established that the current annual volume of plastic channels or brackets are approx 150,000 parts and these numbers are expected to decrease. However, the new quantity cannot be valued with certainty and is thereby unidentified. This makes the screening somewhat difficult as there is no definite benchmark set for desired quantity, but through studying the manufacturing processes in section 4.1 it is known what volumes the different processes generally favor.

Complexity

The wire channel or bracket can have varying degree of complexity depending on its use and location, which means that manufacturing processes must have an ability to produce part of various shapes and have a high degree of freedom in form. Manufacturing processes with evident restraints in part complexity will be unable to produce desired parts and will therefore be deemed inapplicable. One could argue that part design can be adapted to the capacity of manufacturing process in regard to part complexity. However, as stated in the limitations section this thesis will not explore the possibility of altering the design of product.

A screening table will be presented below in regard to the aforementioned influencing factors. Injection molding has been set as the reference. Note that cost per part has been excluded from the screening table since it's an aspect dependent on volume which thereby makes it difficult to value or rate in a screening. For example, injection molding has a higher cost per part than vacuum forming under lower volumes but as the volume increases there is a break-even point where the cost per part for injection molding then becomes cheaper than vacuum forming. However, it is an important aspect that will be taken into consideration when reviewing each process post-screening.

Material: If the manufacturing process can process the same or similar material as injection molding (in particular thermoplastics such as PA66, PA6, PP) it is awarded a “0”. If it cannot process the same or similar material as injection molding it is awarded a “-“.

Set up cost: If the upfront costs of a manufacturing process is higher than injection molding it is awarded a “-“. If lower it’s awarded a “+” and if the upfront costs are the same or similar to that of injection molding it is awarded “0”.

Size: If the manufacturing has the ability, like injection molding, to produce the required size range of the wire channel or brackets (small to medium parts) it is awarded a “0”. If the manufacturing process has size limitations incompatible with the desired application it is awarded a “-“.

Cycle time: If the manufacturing process has a faster cycle time than injection molding it is awarded a “+”. If slower it is awarded a “-“, and if the process has the same or similar cycle times than that of the reference it is awarded a “0”.

Quantity: In this case, a process that produces lower quantities is considered a positive quality, with regards to the desire and preferences of Lear Corporation. Therefore, processes that produce lower quantities than injection molding are awarded a “+”. Processes that produce the same or similar quantities are awarded a “0”.

Complexity: If the manufacturing process can produce parts with higher complexity than injection molding it is awarded a “+”. If the manufacturing process can produce parts with the same or similar degree of part complexity it is awarded a “0” and if the process has limited degree of part complexity in comparison to injection molding it is awarded a “-“.

The “+”, “-“and “0” are indicators that display the compatibility of each respective process in regard to the desired application with the support of injection molding as a benchmark. These indicators are added and subtracted into a sum total which represents what processes are applicable or inapplicable.

Table 10 Screening of Manufacturing Processes

	Injection Molding	Vacuum Forming	RIM	Compression Molding	Extrusion	EBM	Rotational Molding	CNC Machining	3D Printing
Material	0	0	-	-	0	0	0	0	0
Set up cost	0	+	+	+	+	+	+	+	+
Size	0	0	0	0	0	-	-	0	0
Cycle time	0	-	-	-	0	-	-	-	-
Quantity	0	+	+	+	0	+	+	+	+
Complexity	0	-	0	-	-	-	-	0	+
Total	0	0	0	-1	0	-1	-1	1	2

Injection molding

One of the questions raised in the problem section was: Is it possible to make the current process more cost-effective? Injection molding is the current process and it has an excellent track record of delivering these parts with success, which is natural due to it being a highly compatible process for the desired application. It ticks almost every box regarding the aforementioned criteria, such as material, complexity and time. The issue with the current process is the high upfront costs which motivate high volume production rather than the lower volume production Lear Corporation expect in the future. However, can the process potentially be modified? Can the tooling costs be decreased to a point where injection molding is a feasible option for Lear Corporations preferences and circumstances? If so, what are the possible solutions? These questions are worth exploring and the process will be evaluated further.

Vacuum forming

It is a process with low tooling costs, reasonably fast and suitable for low volume production as well as offering flexibility in material selection. However, due to its limitations in part complexity, inability to form parts with uniform wall thickness and intricate parts it is deemed inapplicable and thereby dismissed from further evaluation. It can pose as a competitive option for visual prototypes but would not be the most suitable option for the desired application in comparison to injection molding or additive manufacturing.

Reaction Injection Molding

This process offer traits that comply well with the desired application in regard to several important aspects such as design freedom, quantity (low to medium volume), properties of part (depending on material) and cost (although costly it is less expensive than injection molding). The major drawback however is that RIM only processes thermosetting polymers. This aspect makes RIM inapplicable as it does not produce thermoplastic parts.

Compression molding

The process is a good choice for low volume production and upfront costs are lower than injection molding. Although compression molding can process materials such as advanced composite thermoplastic, it is similarly to RIM mainly suited for thermosetting polymers such as rubber which, along with limitations in part complexity, makes it inapplicable for the desired application.

Extrusion

Extrusion is one of few plastic processes that can match injection molding in terms of cycle time and similarly to injection molding it's a continuous process. However, the disadvantage of extrusion in this particular case is its restrictions in part complexity as it only produces parts with uniform cross section such as rods, tubes, films and sheets. This conflicts with the requirements of desired application and thereby it is dismissed from further evaluation.

Extrusion blow molding

Similarly to extrusion, EBM is limited to a certain type of shape (hollow and thin-walled parts such as bottles or containers). It is also restricted in terms of size (usually large parts) and speed (relatively fast but slower than its counterpart injection blow molding). Consequently, it is not suitable for the desired application and therefore eliminated.

Rotational molding

Although rotational molding offer several benefits on a general level such as producing parts with uniform wall thickness and low tooling costs, the process is evidently not intended for desired application due to limitations in material, shape(hollow parts) and speed.

CNC machining

The process presents many favorable characteristics such as material, size and design flexibility as well as its suitability for low to medium volumes and low to moderate tooling costs. Although it can create parts with tight tolerances and geometries that are difficult to mold, CNC-machining have some limitations in part complexity. For example, features such as undercuts or curved internal channels would either be impossible to create or require tool access that would raise part cost significantly. For this reason CNC-machining is, albeit by a small margin, deemed inapplicable as there are other processes (such as 3D printing) that are more appropriate for desired application.

Additive manufacturing

3D printing is an emerging manufacturing technology that provides high degree of freedom regarding form and part complexity which makes it a plausible option for the desired application. Moreover, it is a process suited for low to medium volume and upfront costs, although they vary, are low in comparison to injection molding. On the surface, 3D printing is an option that seems capable to produce desired parts and is deemed an applicable manufacturing option. The only drawback is the speed which is slower and more labor-intensive than injection molding. However, in this case the advantages, such as geometric freedom, outweigh the disadvantages and 3D printing is definitely a process worth evaluating further.

4.3 Remaining manufacturing processes

This subsections aims to provide further data and details regarding the remaining manufacturing processes that were deemed applicable during screening, in order to determine the most feasible option with regard to the desired application.

The screening resulted in two manufacturing process, injection molding and additive manufacturing, being kept for further evaluation. This section will delve into each manufacturing process and further study its advantages and disadvantages as well as analyze the feasibility of each process in relation to the application. Cost estimates from various manufacturers will also be presented in order to gain an understanding of the manufacturing processes through a cost perspective as well as enabling cost comparisons.

4.3.1 Injection molding

Injection molding was deemed an applicable process as it is Lear Corporation's current choice of manufacturing process and offer many favorable benefits which suit the desired application. Following questions were raised in the screening section in regard to injection molding and decreasing upfront costs:

What factors constitute the high upfront costs?

Can the process potentially be modified in order to decrease upfront costs?

If so, what would be the following consequences?

This section will attempt to answer these questions and identify solutions to minimize injection molding costs.

4.3.1.1 Molding Tool

The most important investment of any injection molding project is the design, build and purchase of the molding tool. The cost of tools varies greatly based on size and complexity with cost ranging from a few thousand dollars to millions.

The three primary cost drivers for injection molded components are: mold cost, material cost, processing cost. The proportion of costs between these three cost drivers can vary depending on the application. A commodity application has a different cost breakdown structure than a custom part, although the parts may be of same weight. The quantity and part complexity are deciding factors regarding magnitude and proportion of costs. The commodity application might be designed for mass production of 1,000,000 pieces while the custom application has a production volume of 100,000. Due to the economy of scale the overall costs would be lower for the commodity application. The material costs would constitute the majority of the part of cost of the commodity application and mold cost would account for a minor part of the cost due to simple part geometry. However, in the case of custom application the mold cost would be the most significant cost by far, as the mold requires more intricacy. The more complex the desired part, the more complicated and expensive the mold.

Furthermore, molds are divided into two main categories: cold runner and hot runner systems. The objective of the runner is to direct the material flow from the sprue to mold cavities.

Cold runners usually consist of two or three plate molds which are clutched in the mold base. Molten plastic is injected to the mold via the sprue and feeds the runners where the molten is then distributed to the mold cavities. Subsequently, the cold runner system cools the gate, sprue along with the molded part. An ejection system ultimately separates the runner and the part from the mold.

The advantages of cold runners are inexpensive production and maintenance costs, making it more cost-effective than its hot runner counterpart. It has high material flexibility and is suitable for a wide range of polymers. It's quick and easy to modify colors and can be rapid if system is robotic. The disadvantages of cold runners include the need to manually separate runner after each run, plastic material waste if the runners are not recycled, secondary operations needed trimming and longer cycle times in comparison to hot runner systems due to removal of sprues and runners.

A hot runner system consists of two plates heated through a manifold system which distributes the molten material to various nozzles that fill the mold cavity. The system is therefore called a runnerless system. The systems may be either externally or internally heated. Internal systems offer better flow control while externally heated systems are suitable for thermally sensitive polymers.

Due to the elimination of runners the system has leverage over cold runners in terms of cycle time as there are post-production activities and reduction of potential waste and increased efficiency. Further benefits of hot runner systems are improvement of part quality and consistency, design flexibility and ideal for fabricating larger parts. However, hot runner systems are more expensive as the production, maintenance and tooling costs are higher than that of cold runners.

Injection molds are expected to enable mass production and endure high pressure and temperatures during the molding process. Hence the mold material must be very rigid and durable, therefore steel is often the suitable choice of material. Note that there are several steel types and grades of steel available and costs vary depending on selected type. P20 is a steel grade that is widely used for plastic injection molding tools due to its versatility and characteristics such as hardness, corrosion resistance and good wear and tear resistance.

Steel is a difficult material to machine, thus requiring high precision CNC machining (or Electrical discharge machining) and polishing for the mold cavities, which is a considerable cost. The production of the mold also causes lengthy lead times. However, with steel tooling part complexity can be increased, the part cost becomes lower with increased quantity and millions of parts can be produced [7][10][31].

4.3.1.2 Aluminum Tooling

It is established that various steel grades are predominantly used for injection molding tools, as they possess properties that can satisfy the high demands of the molding process. For use in longer production runs, the properties of steel such as strength and durability are unparalleled. However, supposing the production runs are shorter and the quantities are smaller, the steel mold would become less cost-effective as the high upfront costs can't be justified by the low quantity. In those scenarios, aluminum tooling would be an ideal option. Just as steel, it is important to note that aluminum alloys have different grades with varying properties. Examples of aluminum alloys that are designed for injection molding are QC-10[32] or Alumec 89[33]. Along with reducing upfront costs, aluminum tooling can reduce cycle times due to better thermal conductivity and heat dissipation than steel, which in return leads to quicker cooling and heating times. Aluminum is also easier to machine. However, the lifespan of an aluminum tool is shorter than steel as it is not as robust. Furthermore, aluminum doesn't have the same part consistency as steel.

In conclusion, aluminum tooling can be a competitive and cost-effective alternative to steel depending on the application. If the demands from production are shorter runs and low-medium quantities, then aluminum tooling could definitely be a feasible option [34]. Aside from aluminum tooling, there are further solutions to adapt the injection molding process to low volume production such as rapid tooling, which will be covered in 4.3.2.2.

4.3.2 Additive manufacturing

Due to the design flexibility and geometric freedom of additive manufacturing processes as well as lower upfront costs in comparison to injection molding, it was deemed applicable and kept for further evaluation. This subsection will introduce another additive manufacturing process that wasn't presented in the earlier section, Multi Jet Fusion, a new emerging technology developed by HP (Hewlett-Packard) that displays faster production speed than other 3D printing processes and can produce functional, complex, lower cost parts. It is also said to enable mass production of parts [35]. This subsection will provide information regarding the advancements and benefits of additive manufacturing in the automotive industry, and also the cost mechanisms of additive manufacturing. Furthermore, this subsection will present a process called rapid tooling. 3D printed injection molding tools can be created in short time through rapid tooling, thus enabling the two processes injection molding and additive manufacturing to combine for low-volume production.

4.3.2.1 HP Multi Jet Fusion

Multi Jet Fusion is an additive manufacturing technique developed by HP. It creates parts layer by layer through a multi-agent printing process. It belongs to the powder bed fusion family, along with SLS. The two processes are closely related and share many similarities, for example no support structures are needed in either processes. However, the main difference is the heat source, as SLS uses laser to sinter powder while MJF uses a fusing agent.

First, nylon powder is loaded into the 3D printer and applied in a thin layer over the building platform. Powder is evenly distributed through a recoating unit, such as a scraper. The powder is then heated slightly below its melting temperature. Next, a print head moves across the platform, selectively discharging droplets of fusing and detailing agents onto the powder bed. An infrared light is activated through flash lamps, heating up areas where fusing agents have been applied. The thermal energy causes the material to melt and fuse together. Detailing agent dispersed around the edge of the part prevents sintering, create smooth surfaces and support cooling. Once a layer is completed, powder is distributed on top of the previous layer by the recoating unit. This process is repeated until the detail is built [36].

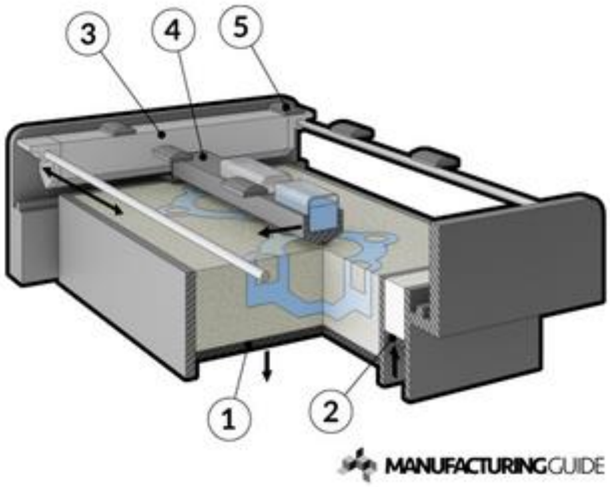

Figure 13 HP Multi Fusion Jet process. From [37]. CC-BY.

(1) Platform

(2) Powdered material

(3) Scraper

(4) Print head

(5) Flash lamps

HP Jet Fusion 5200 Series 3D Printing Solutions is HP's newly released 3D printing system. It is the upgraded version of HP Jet Fusion 4200 3D Printing Solutions and is ideal for mid-volume production of functional prototypes and end-use parts. It is able to produce parts with high accuracy and repeatability, similar to injection molding. Produced parts possess strong and isotropic material properties. Moreover, it's cost-effective and one of the fastest 3D printing technologies compared to other additive manufacturing processes such as FDM or SLS. Although it has a limited range of materials, the technology has expanded its material portfolio in relation to its predecessor which was limited only to Polyamide 12 (PA12). Apart from PA12, the new version can be used to manufacture

Polyamide 11 (PA11), PA 12 Glass Beads. Here follows a short summary of the materials compatible with the HP Jet Fusion 5200.

HP 3D High Reusability PA 11: PA11 provides ideal mechanical properties with chemical and impact resistance. Functional, quality and ductile parts can be created. It is suited for sports equipment, connectors, electrical, textiles and tubing, amongst other applications.

HP 3D High Reusability PA12: Produces strong, complex, low-cost and functional parts. PA12 provides high mechanical properties as well as chemical and thermal resistance. It's ideal for a vast array of applications such as connectors, panels, enclosures and gears.

HP 3D High Reusability PA12 Glass Beads: 40 % glass filled thermoplastic which produces stiff, dimensional and functional parts. It's ideal for applications requiring high stiffness and dimensional stability, such as housing, tooling and fixtures.

These are technical specifications of the printer performance:
Effective building volume: 380 x 284 x 380 mm
Building speed: Up to 5058 cm^3/hr
Layer thickness: 0.08 mm
Print resolutions(x,y): 1200 dpi
Job processions solutions(x,y): 1200 dpi
[35]

4.3.2.2 3D Printing in the automobile industry

M.Delic et al[38] explains and describes, in a scientific article called "*Additive Manufacturing: empirical evidence for supply chain integration and performance from the automotive industry"*, how additive manufacturing (AM) can be used to make the supply chain more effective, mostly regarding the common areas of a supply chain; cost, reliability and lead time. AM can generally reduce lead times, reduce cost with higher complexity and enable a production that can easily change to produce other products.

The authors have chosen to focus on how an integration of AM can be favourable for the automobile industry. Besides the aforementioned benefits such as time efficiency and the enabling of production variability, the impact of AM from a cost perspective, will reduce tool cost, less waste, lower transport and storage cost and will reduce the tied up capital in stocks etc. The authors state that these advantages are possible in low volume manufacturing and that manufacturing starts when an order is filled.

Therefore, the conclusion is that companies applying AM into their supply chain will have great leverage over their competitors. Through AM, you are given the possibility to easily respond to a dynamic market and still be able to offer a fast delivery time, which grants more satisfied customers and creates higher profits. Ford is an example of an automaker who has introduced AM into its supply chain, mainly into prototypes. This resulted in time for prototype design going from four months to four days.

4.3.2.3 The economics of 3D Printing

As previously stated, AM enables geometric freedom and can completely eliminate time spent for tool change, thus reducing time to market. AM will be able to reduce material waste from production, which will render in a reduction of total costs for production. The limitations for AM are mainly the inability to mirror their counterparts in traditional processes, in areas such as surface finish. However, N. Hopkinson and P. Dickens [39] believe the problem itself is not connected directly to AM, but lies in the knowledge on how to process various materials with AM. Since remarkable improvements in both cost and an increase in properties has been made in recent years, most likely the knowledge around AM will keep advancing and therefore cheaper and better quality parts will be produced.

N. Hopkinson and P. Dickens performed a study based on comparing Injection molding with different sub-processes of AM. The purpose of the study was to compare AM and Injection molding in terms of production cost per detail. The AM processes evaluated were; Sterolithography (SLA), Fused Deposition Modeling (FDM) and Selective Laser Sintering (SLS). The cost estimates were based on machine cost, labour cost and material cost which were used to get a understanding of the required volume that AM need to produce in order to be more favourable than Injection molding. Note that the study was based on the assumption that AM and injection molding will produce the same amount of parts for a year.

The result of Hopkinson and Dickens study showed that all AM methods have a static cost per detail, meaning the AM cost per detail remains the same irrespective of volume produced. Injection molding however, showed an exponential decay in cost per detail with higher and increased volumes. This clarifies that AM cost per detail is not dependent on the production volume, which could be useful for further cost analysis and comparisons.
Furthermore, Hopkinson and Dickens study also showcased that SLS will be cheaper to produce compared to SLA and FDM.

4.3.2.4 Rapid Tooling

Rapid Tooling is a method used to create tools for traditional manufacturing processes using additive manufacturing. Furthermore, this means that the purpose is to combine rapid tooling with a manufacturing process, for example injection molding. Through rapid tooling, it's possible to reduce lead time for tool manufacturing and achieve lower cost compared with aluminium or steel tools. However, rapid tooling has its disadvantages compared to a traditional tool manufacturing. Rapid Tooling has shown to result in lower quality of the end product and is only suitable for lower quantity manufacturing.

J.R.C. Dizon et al [40] followed through a study with the purpose to compare traditional manufacturing tools, or in this case molds/tools made with AM. Firstly, the author establishes some tooling material properties that are important to consider, such as thermal stability, thermal conductivity, hardness, corrosion resistance, ability to obtain desired surface finish etc. Materials that are ideal in terms of the aforementioned mechanical properties are steel and aluminium, and are therefore the most common injection molding tools. Aluminium has a faster cycle time compared to steel tools, but steel tools are stronger, durable and have a longer life span.

J.R.C. Dizon et al further states that thermal conductivity from the melted plastic to cooling media through the mould has a direct connection to lead time and cost. Meaning, if the heat transfer is increased it leads to faster cooling, thus making the cycle time faster. Therefore, it is extremely important with an effective cooling system and a material that has the possibility to lower cycle time, which has the possibility to give a cost reduction. The choice of material for a tool should be based on the desired application and requirements, and therefore making it important to understand what the tool should be used for to gain minimum cost.

Rapid tooling can be divided into more subcategories, but this study will focus on direct rapid tooling. Direct rapid tooling means creating tools that mirror the properties of a tool made from a traditional manufacturing method. The authors state that direct rapid tooling is only used for prototyping and low quantity manufacturing.

Injection molding (IM) with traditional tools has lengthy manufacturing times and tooling is expensive. However, the high investment costs can be justified if the tool has a long lifetime and is used for high quantities, but should the quantity reduce to low volumes it will lead to a drastic increase in cost/detail. Therefore, fabricating IM tools with AM is more profitable in low quantity manufacturing. Rapid tooling can result in a more rapid tool making and a more cost effective manufacturing with lower volume. It also offers the normal AM benefits, like geometric freedom and easier adoption in manufacturing. Using AM for tools demands a material which can withstand; high temperature, tough, hard and probably most important a material that has a higher melting point than the material getting processed to the end product.

In conclusion, the authors state that AM tools are useable but it's a highly complex process. To elaborate further as to what the authors mean by this is that there are a lot of parameters that have to conform and be correct in order for the process to work successfully, but there is still use for rapid tooling, especially for prototyping and low volume production of simple parts. However, it needs further research and development before it could replace traditional manufactured tools.

4.3.3 Cost estimates

In order to estimate the cost and feasibility of each process, various manufacturing companies who provide services related to injection molding and 3D printing were approached. The companies were asked to give their assessment of the part and determine what process would be ideal for the application and thereafter provide a quote for ideal process.

The part displayed in figure 2 was shared with manufacturers. Due to confidentiality reasons, CAD-designs of Lear's existing plastic channels or brackets were not allowed to be disclosed with manufacturers, therefore a modified model of a plastic channel or bracket was designed. The object of the designing of new part was to resemble the existing parts in terms of complexity, size and shape in order to get a fair cost estimate and later make cost comparisons. As mentioned earlier, it is important to emphasize that plastic wire channels or brackets have varying shapes, complexity, sizes and volumes. However, in order to receive quotes, following sample part was designed and distributed in agreement with Lear Corporation.

Figure 14 Model of plastic wire channel

4.3.3.1 Danke Mold

Danke Mold is a manufacturing company based in south China who provides services such as plastic injection molding, CNC-machining, vacuum casting, 3D printing, rapid prototyping and rapid tooling.

Danke Mold was approached through e-mail to give their opinion on which of their services would be best suited for the desired application. A stp-file of the part displayed in figure 2 was attached along with the following information required in order to request for quote:
Material: Either PA66, PA6 or PP
Surface finish: Standard
Quantity: 75,000 parts per year

As earlier stated, the quantity is not definite, partly due to varying volumes of channels and bracket but also due to difficulty valuing the new and lower quantities expected with hybrid and electric cars. However, in order to receive a quote a rough estimate had to be set and in agreement with company supervisor, 75,000 parts per year was set as a reasonable estimation.

Danke Mold provided injection molding quotation (appendix A), injection molding tooling quotation (appendix B) and prototyping quotation (appendix C). Danke Mold assessed that injection molding was the most feasible and cost-effective process for this application due to volume and mechanical properties. According to T.Tan, project manager at Danke Mold [41], additive manufacturing, in this case the SLA technology, is not recommended due to the volume production and the material used for 3D printing does not have the same mechanical properties as the ones used for injection molding. It's fragile and much easier affected by high temperature, sunlight and idle time. However, Tan claims that 3D printing could be viable for 1 to 20 prototype parts in order to test and check features.

In the tables and charts below, a comparison in molding and tooling costs between Danke Mold and Lear Corporation are displayed. Note that the compared parts are different in terms of volume, geometry and size which skews the comparison as these are important influencing factors of costs. However, it is done to give context and an indication of Danke Molds cost in relation to Lear Corporations costs.

A refers the part displayed in figure 2. B, C and D refer to parts currently used by Lear Corporation as plastic wire channels or brackets. As earlier mentioned, due to confidentiality reasons part supplier is not allowed to be disclosed and these parts are not allowed to be visually displayed in the thesis. However, part and cost details shown below can be shared. The quantity is the annual volume of parts.

Table 11 Presentation of Danke Mold and Lear Corporation costs

Company	Process	Part	Material	Quantity	Part per cost (€)	Part Cost (€)
Danke Mold	Injection Molding	A	PA6	1,000	0.71	710
Danke Mold	Injection Molding	A	PA6	75,000	0.48	36,357
Danke Mold	Injection Molding	A	PP	1,000	0.46	460
Danke Mold	Injection Molding	A	PP	75,000	0.28	21,266
Danke Mold	SLA	A	ABS-Like	1	11.89	11.89
Danke Mold	SLA	A	PA 12	1	22.87	22.87
Lear Corporation	Injection Molding	B	PA6	111,111	0,48	53,333
Lear Corporation	Injection Molding	C	PA6	111,111	0,772	85,778
Lear Corporation	Injection Molding	D	PA6	75,556	0,6913	52,134

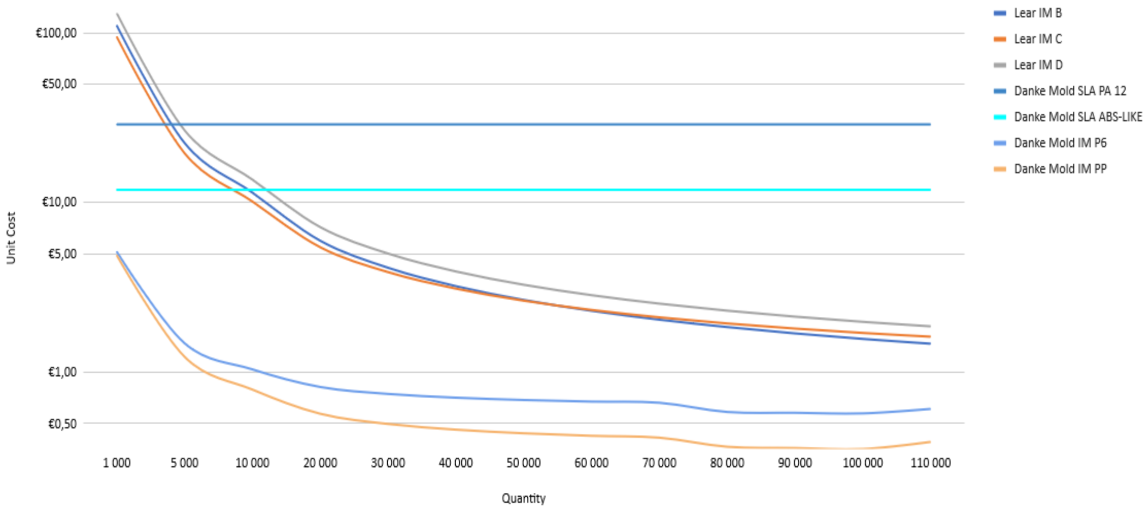

Figure 15 Cost comparison chart between Danke Mold and Lear Corporation

Table 12 and figure 16 presents and illustrates of the injection tooling costs between Danke Mold and Lear Corporation. Further information about Danke Mold and Lear Corpations tooling are presented in the table below.

Company	Part	Mold material	Lead time	Tooling Price (€)
Danke Mold	A	Steel	25 days	4427
Lear Corporation	B	Steel	16 weeks	109,600
Lear Corporation	C	Steel	16 weeks	93,700
Lear Corporation	D	Steel	16 weeks	129,550

Table 12 Presentation of the tooling costs of Danke Mold and Lear Corporation

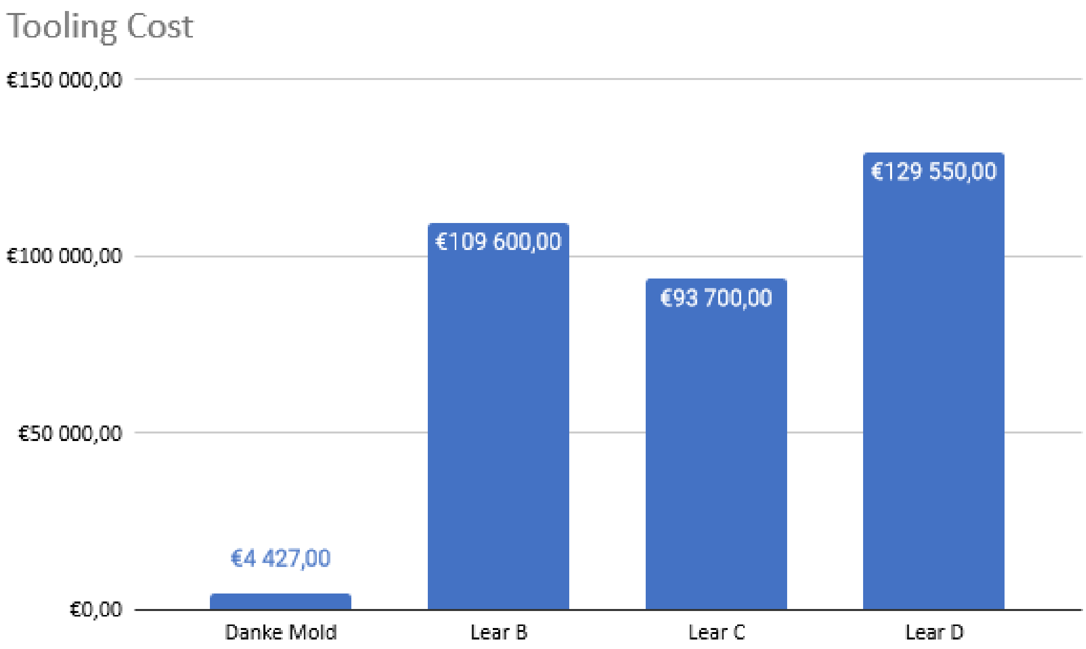

Figure 16 Cost comparison of the tooling costs between Danke Mold and Lear Corporation

Lear Corporation tooling information

The lifespan of part B, C and D production is 7 years. The annual volume for parts are 111,111 (part B), 111,111 (part C) and part D (75,556). In the case of part B and C, this means that 111,111 x 7 = 528,892 parts shall be produced. The tool has two cavities and thereby produces two parts per cycle, which means 528,892 parts are produced in 264,446 cycles in order to achieve lifetime production. Although steel grade of tooling is undisclosed, it can manufacture up to 1,000,000+ cycles.

Danke Mold tooling information

Life time: 50,000 cycles

Cavity number: 1 x 2

Mold base: MUD (Master Unit Die) base

Core/cavity steel: P20/P20

Tooling structure: Cold runner, edge gates; 4 sliders

What is a MUD mold?

A MUD (Master Unit Die) includes a typical injection molding frame coupled with several mold inserts in order to define the shape of the internal cavity, and thus the final part. The inserts are fabricated through CNC-machining or EDM, depending on material requirements for the inserts. There are different types of frames depending on size and number of units to be produced. The major benefits of MUD mold are the decreased upfront-costs, labor costs, setup time and lead time. It also creates a simpler and faster mold installation than a general mold [42].

4.3.3.2 Protolabs

Protolabs is a global manufacturer with headquarters in Minnesota, USA that provides 3D printing, CNC-machining and injection molding of parts for prototyping and short-run production. Protolabs were approached via e-mail, and request for quote was made. Unfortunately, Protolabs did not respond to the e-mail. However, there was a possibility to get an instant 3D printing quote through Protolabs web portal. Part requirements such as material, surface finish and quantity were filled in, and desired 3D printing process was chosen. This generated quotes for Selective Laser Sintering (appendix D) and Multi Jet Fusion (appendix E).

Table 13 presents a cost comparison between Protolabs 3D printing services and Lear Corporations current costs for various injection molded part. Estimated lead time for Protolabs 3D printing was unavailable and is therefore not included in the table.

Table 13 Presentation of Protolabs and Lear Corporation costs

Company	Process	Part	Material	Quantity	Part per cost (€)	Part Cost (€)	Tooling Cost (€)	Total Cost (€)
Protolabs	SLS	A	PP	1000	37.956	37,956	-	37,956
Protolabs	MJF	A	PA 12	1000	31.123	31,123	-	31,123
Lear Corporation	Injection Molding	B	PA6	111,111	0.48	53,333	109,600	162,933
Lear Corporation	Injection Molding	C	PA6	111,111	0.772	85,778	93,700	179,478
Lear Corporation	Injection Molding	D	PA6	75,556	0.6913	52,134	129,550	181,684

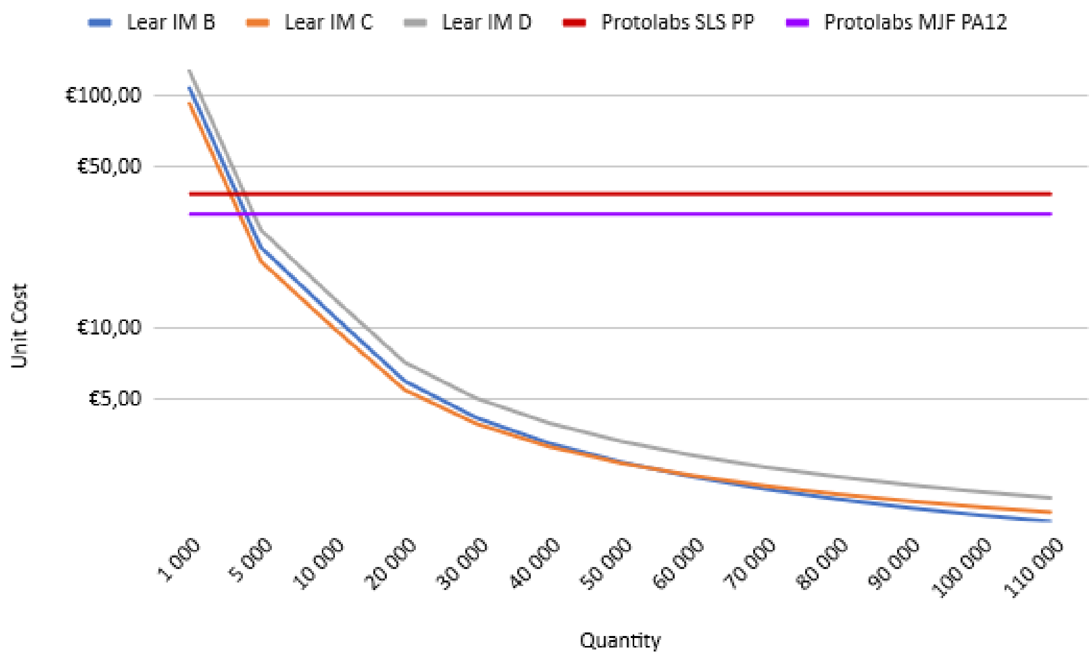

Figure 17 Cost comparison between Protolabs and Lear Corporation

4.3.3.3 Forerunner 3D Printing

Forerunner 3D Printing is a manufacturer based in Michigan, USA who provides 3D printed prototypes and low volume part manufacturing services. Their repertoire of additive manufacturing technologies includes SLS, FDM, PolyJet, HP Multi Jet Fusion and SLA. The company was approached via e-mail and requested to provide a quote for HP Multi Jet Fusion (appendix F). Forerunner 3D use the HP Multi-Jet Fusion 4200 3D Printer, a precursor to the 5200 3D printer which was presented earlier. The printer was able to accommodate 75 of the desired parts per build (the effective building volume is 380 x 284 x 380 mm).

Dylan Fritz, company representative [43], further commented that a principle they go by with a customer deciding between injection molding and additive manufacturing is, if the part is bigger than one to two cubic inches in size (such as ours) and the desired quantity is above 2,000 parts, then injection molding is the favored option. However, if the desired quantity is less than 2,000 parts then MJF would be a more cost-effective and faster option than injection molding. Moreover, if the part is around 1 cubic inch, it's feasible to produce volumes up to 5000 parts a year due to the amount of parts being able to fit in one build.

D.Fritz also suggests another solution called bridge production. Tooling for injection molding causes lengthy lead times, and customers who are waiting for their tool to be manufactured can use the idle time to fill orders of 3D printed parts. This allows the customer to begin production earlier, and once the tooling is done the customer transfers over to launch injection molding process, with parts already available. This defines bridge production.

Table 14 presents a cost comparison between Forerunner 3D's HP MJF technology and Lear Corporations current costs.

Table 14 Presentation of Forerunner 3DP and Lear Corporations costs

Company	Process	Part	Material	Quantity	Part per cost (€)	Part Cost (€)	Tooling Cost (€)	Total Cost (€)	Lead Time
Forerunner 3D	HP MJF	A	PA12	75	27.6	2068	-	2068	3-4 days
Forerunner 3D	HP MJF	A	PA12	1000	27.6	27,573	-	27,573	-
Forerunner 3D	HP MJF	A	PA12	2000	27.6	55,147	-	55,147	-
Lear Corporation	Injection Molding	B	PA6	111,111	0.48	53,333	109,600	162,933	16 weeks
Lear Corporation	Injection Molding	C	PA6	111,111	0.772	85,778	93,700	179,478	16 weeks
Lear Corporation	Injection Molding	D	PA6	75,556	0.6913	52,134	129,550	181,684	16 weeks

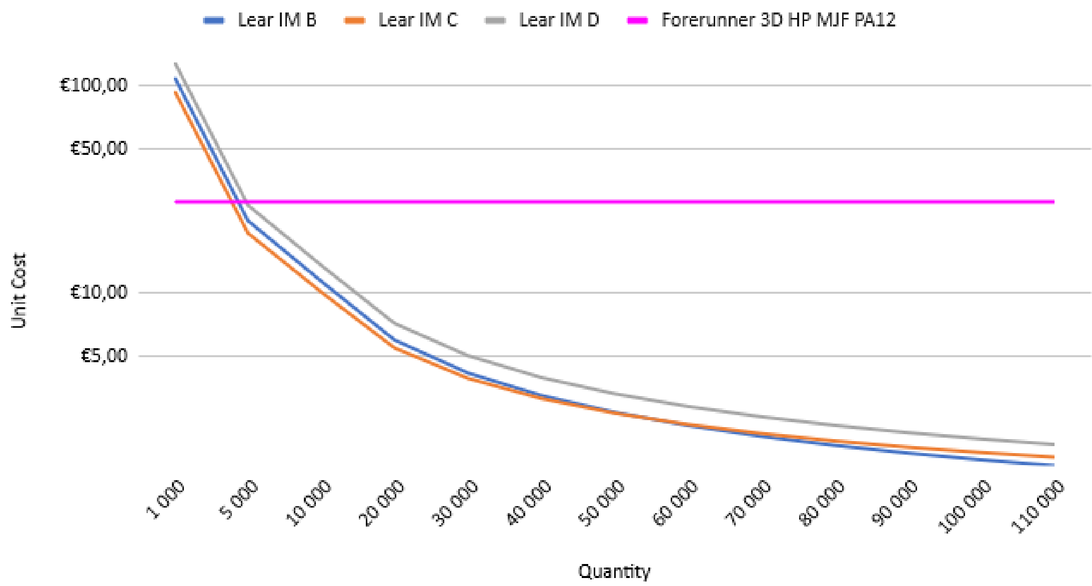

Figure 18 Cost comparison Forerunner 3DP and Lear Corporation

4.3.3.4 Prototal

Prototal is a manufacturer based in Jönköping, Sweden who specialize in 3D printing, PU-casting and injection molding and tooling. Prototal were approached via e-mail and asked to assess what process would be most suitable for our application, and subsequently provide a quote for said process.

J.Haskovec, key account manager [44], made the assessment that injection molding with aluminum tooling would be the most adequate option for this application. Although the detail can be 3D printed, Prototal wouldn't be able to fit an ideal amount of parts into the printer due to part size and shape, thus making 3D printing a less suitable option.

As per Prototal recommendations, a quote for injection molding was requested and subsequently provided (appendix G).

Cost details of Prototal's injection molding

The tooling material is aluminum. The lifespan of the aluminum tool is approx 20,000 cycles and it has two cavities, meaning the maximum capacity of details the tool can produce is 40,000. The cost for the aluminum tool is 13,900€.

A batch size of 5,000 parts results in a cost of 2491€, with an additional set up cost per order of 171€. In other words, the total investment cost of the injection molding, excluding shipping and packing is:
13,900 + 2491 + 171 = 16,562€

Suppose a quantity of 40,000 parts is needed, which is the maximum capacity of the tool, the cost would be as follows:

40,000 / 5000 = 8 batches

8 x 2491 = 19,928€ (the cost for 8 batches of 5000 parts each)

8 x 171 = 1368 € (total set up costs)

The total investment cost of the injection molding, excluding shipping and packing would be:

13,900 + 19,928 + 1368 = 35,196€

However, note that this cost is assuming the batch order is limited to 5000 parts. According to J. Haskovec, the batch sizes can be increased if requested, for example a batch size of 10,000 parts or even 20,000 parts can be delivered at once. A bigger batch size would reduce set up costs and thus the total investment cost.

Table 15 Presention of Prototal and Lear Corporation costs

Company	Process	Part	Material	Quantity	Part per cost (€)	Part Cost (€)	Tooling Cost (€)	Total Cost (€)	Lead Time
Prototal	Injection Molding	A	PA6	5,000	0.5	2662	13,900	16,562	4 weeks
Prototal	Injection Molding	A	PA6	40,000	0.4982	19,928	13,900	35,196	-
Lear Corporation	Injection Molding	B	PA6	111,111	0.48	53,333	109,600	162,933	16 weeks
Lear Corporation	Injection Molding	C	PA6	111,111	0.772	85,778	93,700	179,478	16 weeks
Lear Corporation	Injection Molding	D	PA6	75,556	0.6913	52,134	129,550	181,684	16 weeks

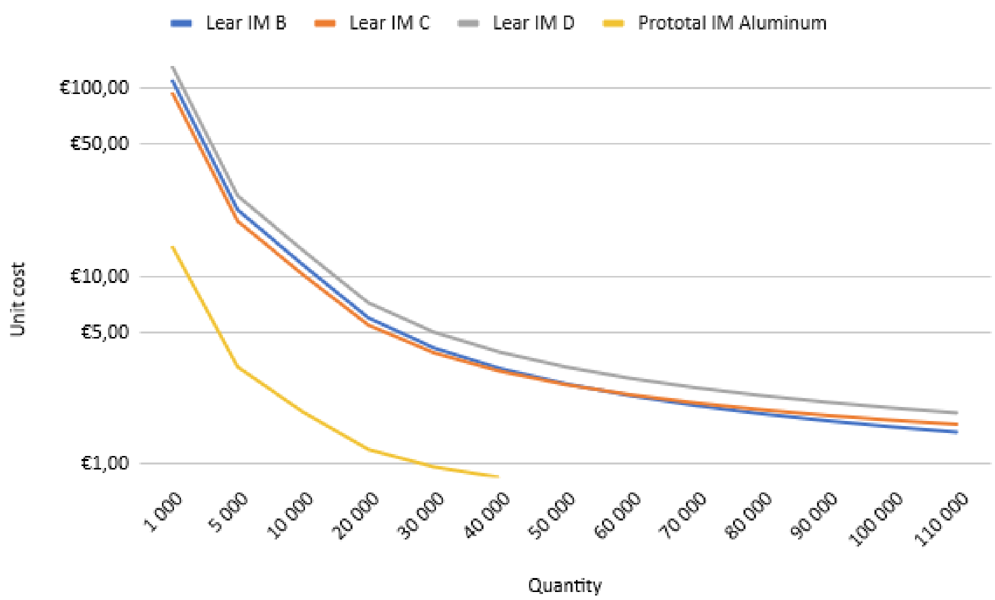

Figure 19 Cost comparison between Prototal and Lear Corporation

Figure 20 Cost comparison of tooling costs between Prototal and Lear Corporation

4.3.3.5 Xometry

Xometry is a global manufacturing company based in Gaithersburg, Maryland, USA. The services provided by Xometry include CNC-machining, Sheet Metal, 3D Printing and Injection Molding. Xometry were requested to provide a quote for HP Multi Jet Fusion (appendix H). Xometry uses several different models of HP 3D printers, including the HP Jet Fusion 5210, according to Xometry Business Development Manager L. Guedes [45]. The material requested was Nylon PA 12 Grey/White. The part will need color finishing if black color is desired. Guedes further commented that prices provided are approximate and depends on the type and quantity of items or part requested.

Table 16 Presentation of Xometry and Lear Corporation costs

Company	Process	Part	Material	Quantity	Part per cost (€)	Part Cost (€)	Tooling Cost (€)	Total Cost (€)
Xometry	HP MJF	A	PA 12	1	21.91	21.91	-	21.91
Xometry	HP MJF	A	PA 12	1000	21.91	21,910	-	21,910
Lear Corporation	Injection Molding	B	PA6	111,111	0.48	53,333	109,600	162,933
Lear Corporation	Injection Molding	C	PA6	111,111	0.772	85,778	93,700	179,478
Lear Corporation	Injection Molding	D	PA6	75,556	0.6913	52,134	129,550	181,684

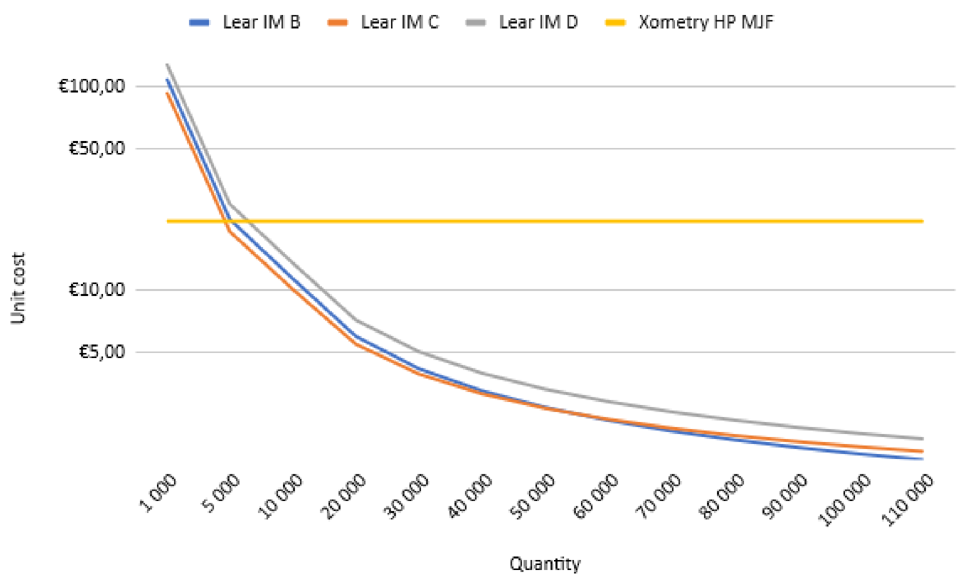

Figure 21 Cost comparison between Xometry and Lear Corporation

4.3.3.6 RYD Tooling

RYD Tooling is a manufacturer based in Shenzhen, China who specializes in plastic injection molding. Capabilities include design, prototyping, mold making and injection molding, from low volume production to large volume production. A quote was requested and provided by RYD Tooling for injection molding (appendix I), with PP as part material and steel type 738, which is a pre-hardened steel similar to P20, as tooling material. The tool life is 300,000 cycles and the number of tool cavity is two. The lead time for the tool is 35 days, while the lead times for the purchased parts only are presented in the table below.

Furthermore, marketing director K.Wu [46], explained that RYD Tooling have experience of fabricating similar type of molds for European customers in the automotive industry, such as BMW.

Table 17 Presentation of RYD Tooling and Lear Corporation costs

Company	Process	Part	Material	Quantity	Part per cost (€)	Part Cost (€)	Tooling Cost (€)	Total Cost (€)	Lead Time
RYD Tooling	Injection Molding	A	PP	5,000	0.26	1,300	8939	10,239	5 days
RYD Tooling	Injection Molding	A	PP	10,000	0.24	2,417	8939	11,356	6 days
RYD Tooling	Injection Molding	A	PP	75,000	0.21	16,077	8939	25,016	20 days
Lear Corporation	Injection Molding	B	PA6	111,111	0.48	53,333	109,600	162,933	16 weeks
Lear Corporation	Injection Molding	C	PA6	111,111	0.772	85,778	93,700	179,478	16 weeks
Lear Corporation	Injection Molding	D	PA6	75,556	0.6913	52,134	129,550	181,684	16 weeks

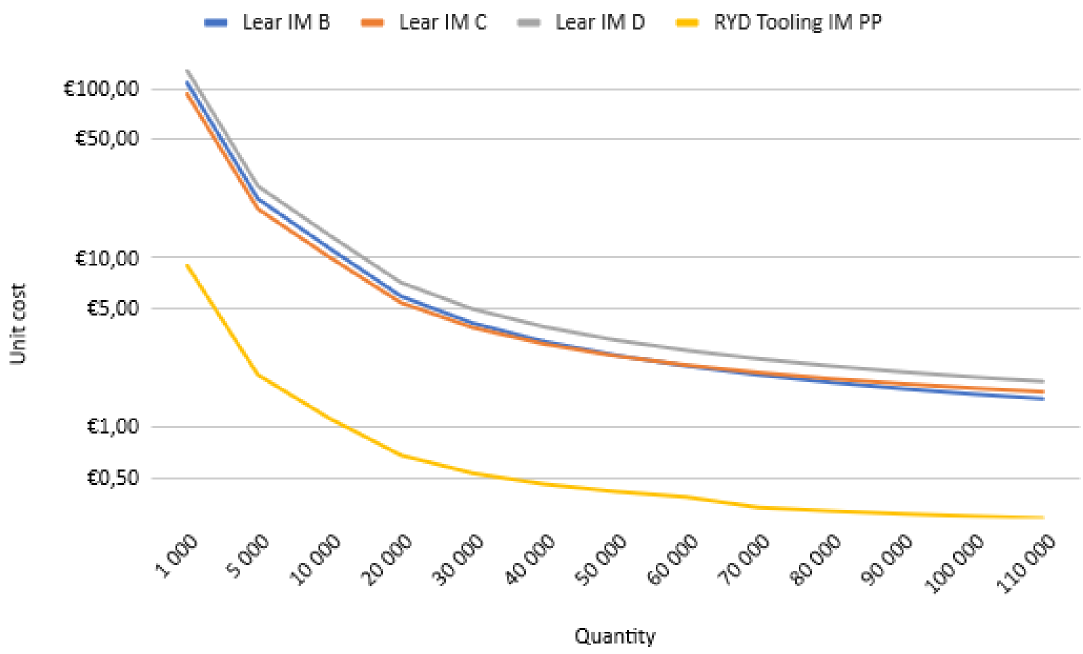

Figure 22 Cost comparison between RYD Tooling and Lear Corporation

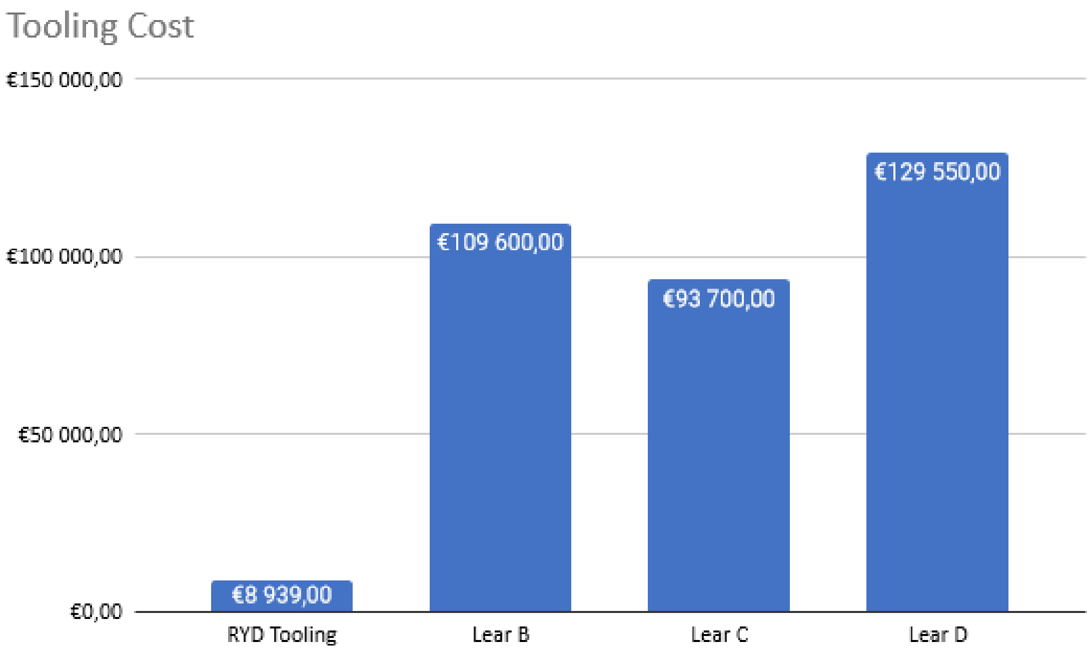

Figure 23 Cost comparison of the tooling costs between RYD Tooling and Lear Corporation

5 Discussion

This section aims to analyze, examine and explain the concepts and results presented in section 4, including potential manufacturing processes, screening of manufacturing processes and remaining manufacturing processes, with focus on the cost estimates provided by manufacturers. The analysis of the gathered data will yield proposed solutions and provide answers to the thesis problem.

5.1 Potential manufacturing processes

The purpose of this subsection was to gain an understanding of the most common plastic manufacturing processes. The knowledge was obtained through various sources, predominantly literature. A total of nine manufacturing processes were presented: injection molding, vacuum forming, reaction injection molding, compression molding, blow molding, rotational molding, CNC-machining and additive manufacturing.

A brief recap of each manufacturing process will be done, beginning with Lear Corporations current process injection molding.

Injection Molding

Injection molding is one of the most common plastic manufacturing processes used for a wide range of applications, in particular automotive, industrial and household products.

The process begins by feeding plastic pellets or granules into a barrel via a hopper. The pellets are pushed forward by a rotating reciprocating screw through a heated chamber, shearing and melting the material in the process. The molten is injected through the force of the screw into a mold cavity. The molten is then chilled down and solidified. Finally, the mold is opened and the part is removed.

Injection molding offers many benefits such as high precision, efficiency, ability to produce highly complex parts, flexible selection of material, low labor costs since it's an automated process requiring minimal supervision, cost-effective for mass production and little or almost no need for subsequent processing due to high pressures which ensures good surface finish. It is a fast process with a cycle time of approx 30 seconds, depending on complexity of mold.

The drawbacks of injection molding are mainly price-related, as expensive equipment and tooling for injection molding amount to high upfront costs. Due to the high pressures, temperatures and forces at work during injection and clamping, injection molding is a process that requires accurately engineered tools that are strong, durable and can provide good surface finish. Consequently, this means that injection molding requires high volume production to justify the upfront costs. At low volumes however, it would not be a suitable or cost-effective option.

Vacuum forming

Vacuum forming is a subcategory of thermoforming where first, a plastic sheet is clamped into a frame above an adjustable mold and then heated. Upon heating the sheet becomes pliable. The mold is moved upwards, stretching the mold and vacuum is activated which causes the sheet to adhere with the mold surface, thus forming the part.

It is a simple and inexpensive process due to low pressures and forces involved, therefore expensive tooling is not required. Molds are usually made out of wood and plaster. Consequently, vacuum forming is economical for prototyping and low volume production. Vacuum forming also offers material flexibility as most thermoplastics can be used. However, the process has limited freedom in form, as only thin walled parts can be produced. Post-production processing such as trimming is often needed which causes expenses, waste and longer production time. Typical applications include baths and shower trays, packaging, transportation and aerospace interiors.

Reaction Injection Molding

The RIM process is similar to injection molding but with a few exceptions such as processing material, where thermosets are used in RIM and not thermoplastics. This means that material is cured, rather than only cooled as is the case with thermoplastics. Another distinction is that injection molding uses one single material, molten plastic, during injection whereas RIM uses two polymer liquids or reactants. These two reactants, usually isocyanate and polyol, are poured into separate containers equipped with temperature and feed-controlling mechanisms where the material is properly conditioned. Pumps transport the two liquids to the mixing head where they are mixed together and undergo a chemical reaction, creating polyurethane which is then injected into the mold cavity.

The overall cycle is slower compared to injection molding and the raw materials used in RIM are more expensive. However due to no heating of plastic, the lower injection pressure and lower material viscosity, the product equipment is significantly less expensive than injection molding and also makes it ideal for larger parts.

The process can be used to produce low or high quantities of thermosetting foams. It is commonly used to produce prototypes that will be injection molded because of low tooling costs, while repeatability, part consistency, complexity and accuracy are high. The most common RIM material is PUR (polyurethane) which offers a high level of dynamic properties, heat resistance and dimensional stability. Typical applications include automotive bumpers and car interiors, domestic and commercial furniture such as chairs and seats, and also sporting goods and toys.

Compression molding

Compression molding is a manufacturing process most commonly used to produce thermosetting polymers (such as rubber, polyester or phenolic), although it is applicable to some thermoplastic parts as well. A predetermined quantity of plastic material is placed in an open mold with two halves. The mold closes through applied hydraulic pressure and heat, which forces the material to fill up the mold cavity.

It is suitable for medium to high volume production and tooling costs are moderate. Compression molding can produce small or large parts with high quality surface finish. Compared to injection molding it is less efficient and the cycle times are longer. Compression molding and injection molding share a lot of similarities as the both use matched tooling (although tooling for compression is cheaper) and both processes are done under heat. The main difference is that injection molding is predominantly used for thermoplastics and compression molding for thermosetting polymers. Compression molding also has limitations in form freedom and is not as suitable for complex designs. Typical applications include electrical housing and kitchen equipment, buckles, rubber boots, buttons, knobs, device cases and appliance housing.

Blow molding

Blow molding is a group of processes including extrusion blow molding, injection blow molding and stretch molding, used to mass produce hollow containers. Extrusion blow molding (EBM) is the oldest, simplest and most common type of blow molding. During EBM, plastic pellets or granules are melted and extruded into a hollow tube, called the parison. The parison is dropped in between two halves of a mold, one end of the parison is sealed and the other end is open. The mold halves are then clamped together and air is blown into the open end of the parison which inflates and expands it. The parison is forced against the internal surface of the mold cavity, thus taking the shape of the mold.

It is a favorable process due to its versatility and can be used to process a variety of container shapes and an extensive choice of material. It enables the production of considerably large hollow products. The most compatible materials are thermoplastics such as PP, PE, PVC and PET. It operates at lower pressures than injection molding, which makes the tooling less expensive. Although relatively fast it is slower than its blow molding counterpart injection blow molding. Typical applications are mainly in the medical, veterinary, chemical and consumer industries to produce bottles, containers and consumer packaging.

Rotational molding

Rotational molding is a process used to produce large parts of hollow and complex forms with uniform wall thickness. The process involves an open mold mounted on the arm of the molding that rotates while being moved into a furnace where heat is applied which causes the content inside the mold, in the form plastic powder, to melt and adhere to the inner walls of the mold, thus forming the part.

It is cost-effective as the process uses centrifugal force, instead of pressure, to fill the mold, making tooling less inexpensive than most other plastic manufacturing processes. Although no pressures are involved, good quality and surface finish can be obtained. The molds are usually fabricated or cast, and typically manufactured from stainless steel or aluminum. These factors make rotational molding suitable for low to medium volumes. It is a slow and long process with cycle time between 30 and 60 minutes. The most commonly used material is PE, as it can be ground into powder at room temperature. Other thermoplastics such as PP, PVC and EVA can be used. Typical applications include tanks, large containers, furniture and toys.

CNC machining

CNC (Computer Numerical Control) machining is a subtractive proves which multiple processes and operations such as milling, drilling, lathe turning, routing and grinding. The process begins by creating 2D or 3D CAD-design. The CAD file is extracted by CAM (Computer-aided manufacturing) software which generates the CNC-code. The code can be seen as instructions which control and dictate movement of cutting tools, speed and tool changeovers. The code is sent to the machine, and once the machine is set up the operation can be executed. The workpiece in a CNC machining process is usually a solid block, rod or bar of plastic, or metal, which is shaped by lather, drilling or milling machine through removal of material, it is therefore defined as a subtractive process.

Its applications are diverse and it is used for both prototyping and mass production in a variety of industries for shaping metal, plastic, wood, ceramic, composites and other materials. It is most often used as a post-processing operation for removing excess material or boring holes. It is also used as primary operation in production, for example low volume plastic parts that require preciseness, tight tolerances and geometries that are difficult to obtain through molding.

The set up costs for CNC machining are low to moderate and once the machines are set up, the process will repeat a sequence with high accuracy and speed. Due to the process being almost fully automated, little operator involvement is needed which results in low labor costs. Time and money is saved by the ability to directly create the part on the CNC machine, as opposed to creating a mold. However, factors such as time and cost are highly dependent on part size, complexity and design. Cycle time and part per cost increase with part complexity. The process has limitations in design as features such as undercuts or curved internal channels would require a cutting cool with a certain geometry that's also able to access all surfaces, which would, either increase cost significantly, or not be possible at all.

Additive manufacturing

3D printing is a process where a 3D object is built by depositing layers of material successively, hence it is named additive manufacturing (AM), although 3D printing and additive manufacturing can be used interchangeably. Any AM process begins by design through computer-aided design software (CAD). The CAD model is exported to a file format called STL. The STL-file is then converted into a G-code. The G-code contains tailor made building instructions of the model which control the 3D printer.

A favorable aspect of additive manufacturing is that it doesn't require any tooling or tool changeover as opposed to the traditional manufacturing techniques, thus making the beneficial from a cost efficiency standpoint. The CAD model enables the possibility to create inventive and imaginative objects with a high degree of freedom in form. Factors such as material, cost, surface finish, mechanical properties and geometric freedom vary depending on AM technology. Size is dependent on the build volume of the 3D printer. Fused Deposit Modeling (FDM), Stereolithography (SLA) and Selective Laser Sintering (SLS) are examples of common additive manufacturing technologies, with each technology having their own unique process characteristics, applications, advantages and disadvantages.

Summary

Several processes were covered in this study, but there are even more established plastic manufacturing techniques available that could've been included. However, as the limitations state, no more than ten manufacturing processes will be presented. Moreover, for this particular application there are only a few realistic and feasible alternatives, therefore including more than ten processes, although fruitful from an educational standpoint, would be redundant and insignificant for the project goal.

The section gave us an understanding of the processes in terms of their methodology, characteristics, applications, advantages and disadvantages. The knowledge was obtained through various sources such as literature, science based articles and web sources. The sources were deemed reliable and the information obtained was considered sufficient in order to perform the next step, which was the screening. The sources were interpreted in relation to the desired application and thereafter the manufacturing processes were judged applicable or inapplicable.

5.2 Screening of manufacturing processes

The knowledge obtained about the potential manufacturing processes in the previous subsection was used as the foundation to perform the screening. The purpose of the screening was to eliminate and filter out inapplicable processes with regard to a number of factors derived from Lear Corporations requirements and prerequisites. The processes deemed plausible were kept and evaluated further. An eventual flaw with the screening is that the data used as grounds are solely interpretations of literature, science based articles and web sources in relation to the application, whereas one might suggest that an opinion of, for example a manufacturer that provides services related to aforementioned processes, would complement the sources in order to make a more legitimate and authentic judgement during the screening. However, the outcome of the screening was deemed reasonable according to our university supervisor and we chose to proceed without approaching any manufacturers during the screening. Moreover, contacting manufacturers for all nine manufacturing processes and awaiting feedback before proceeding might've resulted in idle time, which would be inconvenient due to our time constraints.

Table 10 illustrates the screening of manufacturing processes. Injection molding was set as the reference and was intended beforehand to be kept and evaluated further due to its compatibility with the desired application and the possibilities of optimizing the process in terms of cost. A "+" indicated that a process had a better and positive quality in a certain parameter than injection molding in relation to the application. A "0" indicated that a process had the same quality in a certain parameter as injection molding, and a "-" indicated that a process had a negative quality in a certain parameter in relation to injection molding. Results of the screening showed that the process considered most suitable for the application in relation to the reference was additive manufacturing. Additive manufacturing was found to offer many favourable benefits, the only issue was the slow production speed and longer cycle times in comparison to injection molding. However, the pros of additive manufacturing outweighed the cons and therefore it was kept for further evaluation.

The other manufacturing processes were screened out due to various reasons, such as limitations in complexity, size or material. A recap of the rationale behind deeming the processes inapplicable will be done below.

Vacuum forming

Due to its limitations in part complexity, inability to form intricate parts or parts with uniform wall thickness, it was deemed inapplicable and thereby dismissed from further evaluation. It could pose as a competitive option for visual prototypes but would not be a favorable option for this particular end use in comparison to injection molding or additive manufacturing.

Reaction Injection Molding

The disadvantage of RIM for this particular application is that it only processes thermosetting polymers. This aspect makes RIM inapplicable as it does not produce thermoplastic parts.

Compression Molding

Although compression molding can process materials such as advanced composite thermoplastic, it is similarly to RIM mainly suited for thermosetting polymers such as rubber which, along with limitations in part complexity, makes it inapplicable for the desired application.

Extrusion

Extrusion has restrictions in part complexity as it only produces parts with uniform cross section such as rods, tubes, films and sheets. This conflicts with the requirements of desired application and was thereby dismissed from further evaluation.

Blow molding

Similarly to extrusion, blow molding is limited to a certain type of shape (hollow and thin-walled parts such as bottles or containers). It is also restricted in terms of size (usually large parts) and was consequently deemed not suitable for the desired application and therefore eliminated.

Rotational molding

Rotational molding was deemed inapplicable due to restrictions in material, shape (hollow parts) and speed(slow process).

CNC machining

Although it can create parts with tight tolerances and geometries that are difficult to mold, CNC-machining has some limitations in part complexity. For example, features such as undercuts or curved internal channels would either be impossible to create or require tool access that would raise part cost significantly. For this reason CNC-machining is deemed inapplicable as additive manufacturing trumps CNC-machining in geometric freedom, cost-effectiveness and suitability for desired application.

In summary, processes were deemed inapplicable mainly due to limitations in part complexity, shape or material. Processes such as extrusion, rotational molding and blow molding were dismissed as they can only produce a certain type of part geometry such as long parts with uniform cross-section or hollow and thin-walled parts. Processes such as RIM and compression molding were dismissed mainly due to the fact that they only or predominantly process thermosetting polymers and not the desired thermoplastics. Vacuum forming and CNC-machining offer several traits that favour low volume production but have limitations in part complexity.

However, it is important to emphasize that plastic channels come in varying shapes, size, volumes and part complexity. Moreover, Lear Corporation is considering making alterations in design and material in the future. This opens up several opportunities and alternative ways to approach the study which may allow the processes eliminated in this screening as well as processes outside the domain of plastic manufacturing to possibly be applicable for the application.

However, exploring all potential outcomes and reviewing every single channel or bracket independently would be too extensive of a study for our time frame. Analyzing product design or choice of material, albeit closely related to manufacturing, is a separate field of study itself which would require a separate thesis or report in order to be examined properly. Consequently, we chose not to cover these areas in this study due to time constraints. In the screening, we looked at the channels as a whole, in relation to factors such as material, size, shape and complexity. In other words, a general approach was taken and the benchmark model was based on injection molding as the precedent, as well as on the premise that the ideal manufacturing process should be able to manufacture all types of channels regardless of complexity, size or shape.

5.3 Remaining manufacturing processes

The aftermath of the screening was to evaluate the remaining manufacturing processes further, partly through literature and science based articles. The subjects examined in this section were areas that could be potentially interesting or relevant for our application as well as future quote requests and analysis. These subjects include mold tooling for injection molding, aluminium tooling for injection molding, the HP Multi Fusion Jet technology, advantages of 3D printing in the automotive industry, cost mechanisms of additive manufacturing and rapid tooling. ¨

The approach towards injection molding in this subsection was to answer the questions raised in the screening:

What factors constitute the high upfront costs?

Can the process potentially be modified in order to decrease upfront costs?

If so, what would be the following consequences?

The answers to these questions were made based on the knowledge obtained through literature. According to D.Kazmer [31] there were three main parameters that affected part cost in injection molding: tooling cost, material cost and processing cost. The distribution of these costs varies depending on the part complexity, size and volume. However, in most cases the tooling constitutes a significant part of the total costs and is the single most important investment in an injection molding project. Moreover, factors that affect the costs of the mold itself is material, cold runner or hot runner systems, number of cavities, part complexity, size, volume and choice of thermoplastic.

Tool material is a factor that has a significant impact on cost. Steel is a strong and durable material that has a long lifetime, but is expensive. Note that there are various grades of steel which can fit different application. Aluminum would decrease the lifetime of the tool, but is cheaper than steel and could be cost-effective for lower volumes. This answers the question as to whether injection molding can be modified in order to decrease upfront costs, which is for example changing the material of tool. The repercussions of using the aluminum tool would be as mentioned a shorter tool lifespan and possible deterioration in part consistency. However aluminum would speed up cycle times due to abilities such as thermal conductivity and heat dissipation which in return leads to quicker cooling and heating times. Aluminum is an easier material to machine in comparison to steel, which would further decrease costs.

The approach towards additive manufacturing in this subsection was to further understand the technology and examine the feasibility of additive manufacturing in relation to the application, by studying science based articles on the costs mechanisms of additive manufacturing and integration in the automotive industry. Moreover another 3D printing technology, HP Multi Jet Fusion, was presented as well as the capabilities of Hewlett-Packards newly released "HP Jet Fusion 5200 Series 3D Printing Solutions". The HP MJF technology is able to print in much faster speeds than its 3D printing counterparts and also enables mid-volume production. Although there are restrictions in material, as the process currently only produces PA 11, PA 12 and glass filled PA 12, it will expand its material portfolio in the future. The qualities of HP MJF were interesting and potentially applicable for the desired application. Its feasibility was therefore further explored in the cost estimate section.

Rapid tooling was also presented as it was deemed relevant for this study due to its ability to combine injection molding and additive manufacturing. It is a method used to create tools for traditional manufacturing processes using additive manufacturing, for example 3D printed injection molds. Through rapid tooling, it's possible to reduce lead time for tool manufacturing and achieve lower cost compared with aluminium or steel tools. However, rapid tooling has its disadvantages compared to a traditional tool manufacturing, as it has shown to result in lower quality of the end product and is only suitable for prototyping and low quantity manufacturing. In this point in time it wouldn't be able to replace traditional molds for volume production, but it is an emerging process under progress which has potential to be competitive in the future.

Ultimately, cost estimates were requested from manufacturers in order to make cost comparisons with the current process and consequently identify the most-effective alternatives. We approached various manufacturers who specialize in injection molding for low to mid-volume applications and/or additive manufacturing processes (all AM technologies but HP Multi Jet Fusion was requested in particular).

Due to confidentiality reasons, the original parts were not allowed to be shared with manufacturers. In order to request for a quote, one of the current models was modified in agreement with Lear Corporation and distributed to various manufacturers, along with part requirements such as material, surface finish and quantity. This can be regarded as a flaw in the study, as the cost estimates provided are only valid and representative for a particular part and not all other plastic channels provided by Lear Corporation. However, it was not feasible to request a quote for every existing channel or bracket due to difficulty of accessing the complete set of channels, and even then it wouldn't be allowed to distribute them without altering the design of each part, and subsequently get approval from the company before presenting them to manufacturers. Thus, a modified sample part was sent to receive a rough cost estimate.

Let's examine each cost estimate respectively, beginning with Danke Mold.

Danke Mold

Danke Mold provided quotes for injection molding and tooling as well as a prototyping quotation. The costs were compared in table and figure. It should be noted that these comparisons are slightly skewed and inaccurate, due to different parts being produced and therefore different tools being used. These parts, although similar, vary in size, shape and complexity, which is a critical aspect of costs. Therefore comparing costs of different parts with different tooling might be inappropriate or vague. However, the reasoning behind comparing costs was to give the reader as well as Lear Corporation a context and a perception of Danke Molds (and the others manufacturers) costs in relation to Lear Corporations current costs.

As illustrated in figure 3, the initial cost for injection molding with Danke Molds process is significantly cheaper than Lear Corporation. A reason for this drastic difference in price is the tooling costs for each process, presented in table 11 and figure 4. Tooling price for part D with Lear Corporation is 25 times the price of part A with Danke Mold. There is a natural explanation for this, apart from the size/shape/complexity aspects mentioned earlier, the Lear Corporations tool is designed for a lifetime production of 7 years with an estimated annual volume of 75,556, which result in a total of 528,892 parts. Moreover, the tool has a lifespan of 1,000,000+ cycles. Danke Molds MUD tool, in contrast, has a lifespan of 50,000 cycles and is designed to produce 75,000 parts. If Danke Molds MUD tool was to deliver parts in a program lifetime of 7 years, it would be a total of 100,000 details with an annual volume of approximately 14,285 parts.

Nevertheless, Danke Molds injection molding process is seemingly a more cost-effective choice at lower volumes of production. Danke Molds prototyping options would, as per recommendations from company representative T. Tan not be suitable for this application due to the parts not being functional or possessing the mechanical properties required. Moreover, Danke Molds injection molding process is cheaper and more cost-effective as illustrated in figure. However, Tan suggest the Danke Molds additive manufacturing alternatives could be used as prototypes or testing.

In conclusion, provided the cost estimates from Danke Mold are authentic, their injection molding process with MUD tooling could pose as a competitive option for low to mid-volume production of plastic wire channels or brackets, as per Lear Corporations requests. It is a way of modifying the current process in order decrease upfront costs. A consequence would be the shorter lifespan of tool, which would compel Lear Corporation to change tools more frequently. Regarding the quality of parts, it is not clear whether as to the Danke Mold process can provide the same quality as current one, as there has been no testing. However, it does produce parts of the same material as the current process (PA6 and PP) which motivates the assumption that parts have the same, or similar, properties.

Protolabs

In contrast to the other manufacturers, there was no direct contact with the company, and therefore no feedback provided by company representatives regarding the parts or the chosen processes for this Protolabs quote. The quote was acquired through Protolabs self service web portal where the user choose desired process and provide the part requirements which generates an automated instant quote. However, this was only possible for additive manufacturing technologies and not injection molding, which had to be quoted manually.

The additive manufacturing technologies chosen were SLS with PP as part material and HP MJF with PA12 as part material. MJF was slightly cheaper than SLS, with a unit cost 31€ compared to SLS which has a unit cost of 38€. There was no estimated lead time. The cost estimates confirmed what Dickens and others sources established; that additive is manufacturing is viable and more cost-effective than injection molding at lower volumes. In the case of Protolabs costs for additive manufacturing technologies versus Lear Corporation injection molding costs the break-even point, as illustrated in figure 5, is around 5,000 details where injection molding thereafter becomes the cheaper option. As there was no assessment made by company representative regarding the parts in relation to the application, it is unconfirmed whether it is actually feasible to manufacture up to 5,000 details with said processes for this particular part.

In conclusion, provided the costs from the automated quote are accurate and assuming the technologies produce parts with the same quality and mechanical properties as the current process, Protolabs SLS or MJF technique could be viable for volumes of 5,000 parts or lower. Due to MJF being faster and cheaper than SLS it is the more cost-effective option of the two processes. However, further expertise from the company would've been needed to discuss the numbers presented in the quote as well as an assessment of the part in relation to the AM technologies.

Forerunner 3D Printing

Forerunner 3D Printing provided a quote for HP MJF. The company uses the HP MJF 4200 printer which is a precursor to the newly released HP MJF 5200 Series. Similar to other additive manufacturing processes, it confirms what Dickens presented in his study; that the cost for AM processes are static and the slope is zero as illustrated in figure. The break-even point for Forerunner 3D's MJF costs in relation to Lear Corporation injection molding costs, similarly to Protolabs is approx. 5,000 details. The part material is PA12.

Company representative D.Fritz provided further information on their approach to customers deciding between AM and IM as well as guidance for the provided part in particular. Fritz stated that details bigger than two cubic inches, such as the provided part, would be applicable and cost-effective for volumes up to 2000 parts. However, if the part is around one cubic inch it's feasible to produce parts up to 5,000 parts. In other words, size of part is essential and can improve profitability. Furthermore, Fritz suggested a solution called bridge production that Forerunner 3D provides, which could be a favorable solution for Lear Corporation depending on situation. With bridge production, a company can use the idle time, waiting for their injection mold to be manufactured, to fill orders of 3D printed parts which allows production to begin earlier, and once the mold is ready the company can switch over to injection molding.

In conclusion, HP MJF would be a competitive option at low volumes. For plastic channels or brackets around one cubic inch, orders up to 5,000 parts could be a cost-effective alternative for Lear Corporation. However, with channels bigger than two cubic inches such as the sample part no more than 2,000 parts are feasible. Bridge production is a solution that would allow Lear Corporation to combine injection molding and HP MJF, increasing flexibility and reducing lead time while doing so. As is the case with all other manufacturers, it is uncertain whether the parts will be of the same quality as the current one, however according to HP their PA 12 parts are strong, functional with good mechanical properties such as mechanical and chemical resistance.

Prototal

Prototal evaluated the part and made the assessment that injection molding would be the most suitable process. Although their additive manufacturing processes could manufacture the part in theory, it wouldn't be practical for volume production due to part size. Prototal uses aluminum tooling for injection molding which decreases upfront costs significantly. Part material is PA6. The tool life is 20,000 cycles and has two cavities, meaning its maximum capacity would be 40,000 parts, which confirms the theory presented about aluminum tooling regarding the shorter lifespan in comparison to steel tooling. However, cycle times and machinability for material would improve. If the program lifetime was 7 years, like the current Lear Corporation tool, the annual volume of parts would be 5714. If Lear Corporation desires higher volumes, the tool would need to be changed.

In conclusion, changing to aluminum tooling would be a feasible option for Lear Corporation at low volume production. The aluminum tool would decrease upfront costs and speed up cycle time. The consequence is a less durable tool which would need to be changed more frequently. Aluminum is said to have less part consistency than steel, however it is unclear as to whether that's the case for Prototal's tool since it has not been tested.

Xometry

Xometry uses, amongst other HP MJF printers, the HP Jet Fusion 5210. The part material is PA12 and the break-even point between Xometry costs for HP MJF and Lear Corporations costs for injection molding are, again, approx around 5,000 parts. Although company representative Guedes state the prices estimate are approximate, the unit costs are the lowest of all the additive manufacturing quotes presented in this study(22 €/part). This is a further contribution to the notion that MJF is a cost-effective AM technology.

In conclusion, Xometry provides the cheapest AM and HP MJF alternative and could be viable for volumes up to 5,000 parts. However as company representative state, these costs are only approximate and could change depending on the type of part.

RYD Tooling

RYD Tooling assessed the part and provided a quote for injection molding. The tool is of steel grade 738 and has a lifetime of 300,000 cycles with two cavities. This means the tool could produce a maximum of 600,000 parts. If the tool had a program lifetime of 7 years, such as Lear Corporation, the annual volume would be 85,714 parts. The part material is PP. RYD Tooling would substantially lower the upfront costs in comparison to Lear Corporation as well as reducing lead time. RYD Tooling could be viewed as the middle-ground between Lear Corporations current process and the earlier presented MUD and aluminum tooling from Danke Mold and Prototal, as it decreases the high costs of Lear Corporations tool while offering a more durable and strong tool than Danke Mold or Prototal.

In conclusion, for mid-volume production of plastic channels or brackets where Lear's current tool would be too costly and the lifespan of the MUD or aluminum tool would be insufficient, RYD Toolings offer could prove to be an appropriate option and a good trade off due to decreased costs and lead time while simultaneously offering a solid tool.

Summary

Several manufacturers were approached and a total of five manufacturers responded and provided quotations for the sample part, while one quote was automated. Of course a wider range of data in terms of more quotes would've been favourable and yielded a more nuanced discussion and proposals. However, companies decision to engage in this matter or not are out of our control and therefore we can only examine the presented results.

Nonetheless, the quotes did give desired results that assisted in providing answers for the questions raised in the thesis problem, as it confirmed many of the theoretical concepts presented as well as our own presumptions. The diversity in the results also allows for different solutions, depending on Lear's prerequisites. Moreover, we are aware that injection molding and additive manufacturing are like any other service or product in the sense that price can heavily fluctuate from one manufacturer to the other due to a plethora of reasons affecting price, and therefore choosing one single manufacturer that represents a process as a whole from a cost perspective is obviously biased and invalid. However, the cost for a certain process should rather be viewed as a specimen that provides a rough estimate.

The cost estimates as a whole confirmed what Hopkinson and Dickens [37] established in their study, traditional injection molding has high upfront costs that exponentially decay with higher and increased volumes (such as Lear's injection molding costs) and additive manufacturing has a static cost with zero slope, meaning cost remains the same irrespective of volume. The break-even point between injection molding and additive manufacturing varies between different manufacturers and technologies, but a recurring theme was additive manufacturing shown to be a cost-effective option at volumes up to approx 5000 parts.

However, application suitability in terms of quality and mechanical properties differ between AM technologies, whereas Danke Molds SLA process was only suitable for prototyping, testing and checking features while HP MJF are able to produce functional parts for end-use applications. The size and shape of part is also an important aspect as our sample part was deemed too long and big in order to be feasible for volume production according to some AM manufacturers, due to the amount of parts being able to fit into a build.

As for additive manufacturing technologies, HP MJF definitely poses as the most interesting and suitable option for the desired application, and although it could already be implemented by Lear today for low volume production or bridge production, its abilities is said to improve through advancements in efficiency, printing speed and material portfolio, which will allow it to be even more applicable and relevant for Lear in the future.

Furthermore, the high upfront costs of Lear's injection molding process could be significantly decreased through changing tooling, for example to MUD tooling provided by Danke Mold, aluminium tooling provided by Prototal or RYD Tooling's steel mold 738. These alternative steel mold have a shorter life span and is less wear resistant than the current one, but considering Lear is expecting lower volumes of production which yielded them to pursue a cheaper option than the current one, this shouldn't be a concern. All three processes are compatible with the thermoplastics used in the current process (PA66, PA6 or PP).

Danke Mold was shown to be the cheapest option, thereafter RYD Tooling and then Prototal being the most expensive of the three in terms of tooling costs. RYD Tooling's 738 steel tool has the longest life span (300,000 cycles), Danke Mold's MUD tool has the second longest (50,000 cycles) and Prototals aluminum tool has the shortest life span (20,000 cycles). Each tool had a tool cavity number of two, meaning the maximum capacity of each tool is 600,000(RYD Tooling), 100,000 (Danke Mold) and 40,000(Prototal) parts before a tool change is necessary. The most suitable option depends on the quantities required; therefore several proposals will be presented.

Lastly, one of the questions raised in the problem section was: can the new manufacturing process produce parts with the same, or similar, properties as the current one and thereby meet the technical standards of the automobile industry?

This give rise to concerns as it is unproven whether the parts produced by any of the aforementioned companies and their processes can produce the same quality of parts as the current one. Obviously the companies themselves claim that the parts are fully functional and of great quality, but those statements can't be viewed as a reliable and unbiased. However, the material of parts produced by the processes (PA6, PA12 and PP) are same or similar to the current ones, which leads to the assumption that they eventually could have same or similar mechanical properties and quality. However, due to the fact that none of the parts have been tested as per automakers standards, the question raised in the problem section unfortunately remains unanswered. This might be a matter that Lear themselves would have to control or investigate assuming they're interested and choose to collaborate with any of the companies included in the cost estimates.

Figure 24 presents a summary chart comparing all provided cost estimates along with Lear's costs.

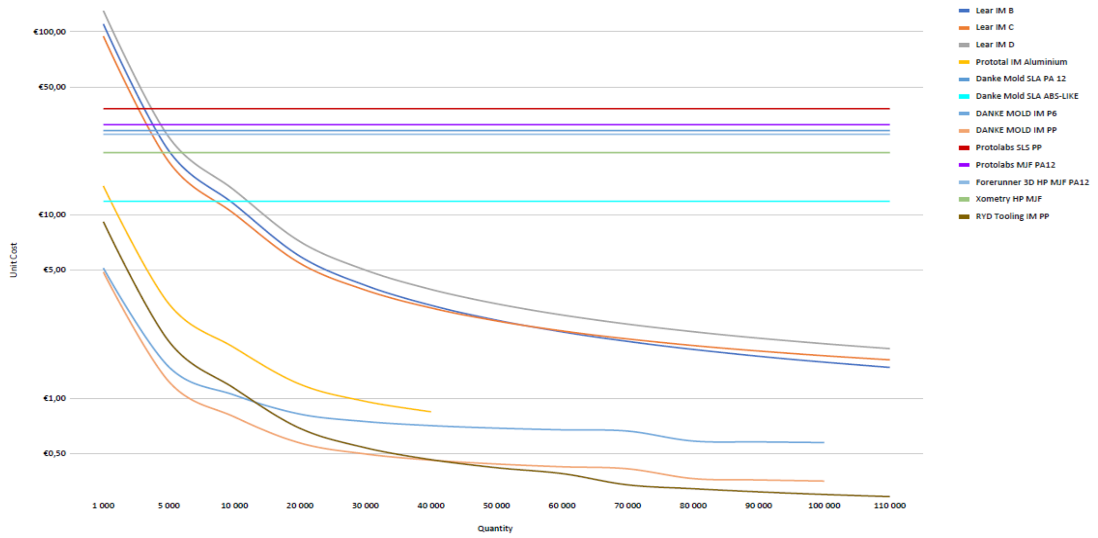

Figure 24 Summary of all cost estimates and Lear's costs

5.4 Proposals

The purpose of the thesis was to identify, evaluate and present various cost-effective plastic manufacturing processes that could eventually replace the current process, and the questions raised in the problem section was as follows:

Is there a suitable and cost-effective manufacturing process that can replace the current one?

Can the new manufacturing process produce parts with the same, or similar, properties as the current one and thereby meet the technical standards of the automobile industry?

Is it possible to make the current process more cost-effective?

This subsection strives to answer these questions in the form of presenting various solutions, and thus fulfilling the purpose of the thesis. As mentioned earlier, due to the varying quantities of plastic channels or brackets, it's not possible to present one superior option, but rather suggesting several proposals depending on required quantity.

5.4.1 Alternative tooling

The primary proposal presented to Lear is to choose an injection molding process with cheaper tooling. This allows Lear to keep utilizing the benefits of injection molding at lower volumes of production while simultaneously saving costs on tooling, and thus decreasing the upfront costs.

In this study three companies providing injection molding services were presented, each with different type of tooling: Danke Mold, Prototal or RYD Tooling. The cost estimates of each company showed a significant decrease in tooling costs. Due to differences in tooling material and lifespan of tooling of these three processes, proposals for each one respectively will be presented below in relation to Lear's current costs.

5.4.1.1 Danke Mold

Danke Molds injection molding offer is a viable and cost-effective option for low volume applications. As illustrated in figure 24, Danke Mold injection molding with MUD tooling displayed the cheapest upfront costs of all cost estimates provided in this study. In relation to Lear's costs, as displayed in figure 16, Danke Molds process would decrease tool costs by 105,173€ for part B, 89,273€ for part C and 125,123€ for part D. Danke Mold provided cost estimates for two injection molding options, one with PA6 as part material and one with PP as part material, with the latter one giving a cheaper unit cost. The tool could produce up to 100,000 details of the sample part provided. The proposal is as follows:

Choose Danke Molds injection molding offer for parts with material PA6 or PP and quantities of 100,000 parts or lower.

5.4.1.2 Prototal

As illustrated in figure 24, Prototal injection molding with aluminum tooling was shown to be the most expensive out of three injection molding processes presented in the cost estimates. Although Danke Mold and RYD Tooling are more cost-effective for the particular part provided, Prototal's offer is still a viable option in relation to Lear's current costs as it decreases tooling costs by 95,700€ for part B, 79,800€ for part C and 115,650€ for part D, as illustrated in figure 20. Moreover, the aluminum mold would offer further benefits such as faster cycle times and easier machining.

In conclusion, the Prototal injection molding is a suitable and cost-effective option for low volume production. It could produce up to 40,000 details of the sample part provided. If Lear desires more parts, a new tool would have to be procured. The proposal is as follows:

Choose Prototals injection molding offer for parts with material PA6 and quantities of 40,000 parts or lower.

5.4.1.3 RYD Tooling

The RYD Tooling mold is the most durable of the three injection molding offers with a lifespan of 300,000 cycles. It is the second most expensive out of three injection molding offers in terms of mold price. RYD Tooling becomes the most cost-effective option at 40,000 parts and above in relation to the other offers, as illustrated in figure 24.
In relation to Lear's costs RYD Tooling's offer would decrease tool cost by 100,661€ for part B, 84,761 for part C and 120,611€ for part D, as illustrated in figure 23. It could produce roughly 600,000 parts until the tool would need to be replaced. It's a competitive option for low to medium application. The proposal is as follows:

Choose RYD Tooling for parts with material PP and quantities of 600,000 or lower.

5.4.2 Bridge production with 3D Printing

As figure 24 illustrates, nearly none of the AM technologies were more cost-effective than the injection molding offers at quantities over 1,000 parts for provided sample part. The only exception was Danke Mold SLA ABS-like, which was less expensive than Prototal IM offer for volumes slightly above 1000 parts. These particular 3D printed parts would not be functional and only applicable for prototyping.

However, in relation to Lear's current costs, several additive manufacturing offers were cost-effective up to 5,000 parts. An essential part of 3D printing is part size, the smaller the parts the more parts can be fit into a build of production, and thus a higher volume can be fabricated. Due to the sample part being bigger than two cubic inches, it was recommended for production up to 2,000 parts. The additive manufacturing technologies presented were SLS, SLA and MJF. HP MJF was deemed to the most suitable technology for the application due to its capabilities and cost.

Although HP MJF is a competitive alternative for volumes ranging from 1-5000, injection molding would be a more suitable option if higher quantities were required. However, HP MJF could still be involved in the process through complementing the injection molding in bridge production. While waiting for their injection molding tool to be manufactured, Lear can use the idle time to fill orders of 3D printed parts or manufacture parts in-house by purchasing a printer, in order to begin production earlier and reduce lead time. Once the mold has arrived, switch over and proceed production with injection molding. The proposals are as follows:

Choose HP MJF with part material PA12 and quantities of 5,000 or lower.

Choose HP MJF for bridge production with injection molding.

5.4.3 Problem review

Once again, the questions raised in the problem section, as well as in the beginning of this subsection were as follows:

1. Is there a suitable and cost-effective manufacturing process that can replace the current one?
2. Can the new manufacturing process produce parts with the same, or similar, properties as the current one and thereby meet the technical standards of the automobile industry?
3. Is it possible to make the current process more cost-effective?

Let's review them respectively, beginning with question 1.

Is there a suitable and cost-effective manufacturing process that can replace the current one?

There were several suitable and cost-effective solutions that could potentially replace the current one for different prerequisites and provided the new volumes Lear expect materialize. They are deemed suitable and cost-effective as they are designed for lower volumes of production, decrease the upfront costs and fulfill the requirements of the application.

Can the new manufacturing process produce parts with the same, or similar, properties as the current one and thereby meet the technical standards of the automobile industry?

Due to the fact that none of the parts have been tested as per automakers standards, this question unfortunately remains unanswered as there are no ways to test and ensure the quality of the parts fabricated by the manufacturers who provided offers. The companies claim the parts are fully functional and of great quality, but those statements can't be judged as reliable or unbiased. However, the material of parts produced by the processes (PA6, PA12 and PP) are the same or similar to the current ones, which leads to the assumption that they eventually could have same or similar mechanical properties and quality.

Is it possible to make the current process more cost-effective?

There are possibilities of modifying the current process through changing the mold, for instance to a MUD, aluminum or steel grade 738, and thus decreasing upfront costs significantly and making the injection molding process suitable for low volume production.

6 Conclusion

Lear Corporation is a global automotive supplier that provides, amongst other services, E-systems to various auto manufacturers. An essential element of the E-systems is the wire harness. While assembling and structuring a complex network such as the wire harness, components such channels and brackets are essential in order to fasten and protect the wires. These components are currently made out of thermoplastic material. The current manufacturing process used by the company to produce these plastic parts is injection molding. Injection molding is one of the primary means of manufacturing plastic parts. It is used for a wide range of applications and offers several benefits such as high precision, efficiency, speed, ability to produce highly complex parts and flexible selection of material. Due to expensive tooling and equipment, injection molding implicates high upfront costs and is therefore used for mass production, where price per unit decreases and the initial investment can be justified.

However, the current trend in the automotive industry is hybrid and electric cars which are manufactured at lower volumes. This in return decreases the production of plastic channels or brackets. Consequently the current injection molding process becomes less cost-effective. This prompted Lear Corporation to pursue other alternatives for the lower volume of production which could replace the current process, and thus this thesis was carried out.

The purpose of the thesis was to identify, analyze and suggest alternative manufacturing processes that could potentially replace the current one. Furthermore, the substitute process should be able to deliver parts of the same or similar quality and properties as the current one. Another aspect which would be examined was whether the current process could be altered in order to decrease costs and be feasible at lower volumes of production.

Several limitations were set, mostly due to time constraints as the thesis was done over a 10-week period. Therefore, the approach for this thesis was to base the choice of manufacturing process on existing parts, and not exploring the possibility of altering part design or material. Furthermore, the analyzed components include wiring plastic channels and exclude other parts used in the wire harness such as straps, clips and metal bushings.

The objective of the plastic channel or bracket is to protect the wire harness from mechanical, thermal and chemical influence. The task of the wire channel or bracket is to define and fix the location of the wire harness in the vehicle. The wire channel or bracket should also prevent any noise and rattle coming from the wire harness. Plastic channels or brackets can vary in size, shape, complexity and volume depending on its use and location in the car. They are currently made out thermoplastics such as PA66, PA6 or PP.

The information and data presented in the thesis were based on literature sources, scientific articles, websites and direct communication with various manufacturing companies as well as our company advisors. The sources were retrieved through various search engines, databases and portals including the University West library, DiVA, Chalmers Open Digital Repository, LIBRIS, Google Scholar, Google and Amazon.

The study presented nine potential manufacturing processes including: injection molding, vacuum forming, reaction injection molding, compression molding, blow molding, rotational molding, CNC-machining and additive manufacturing. This was done to introduce the most common plastic manufacturing process and acquire an understanding of their respective characteristics, applications, advantages and disadvantages. The knowledge was obtained predominantly through literature, but also via web based sources.

The knowledge provided from the sources was interpreted in relation to the desired application, and thereupon a screening was performed. The purpose of the screening was to screen out processes deemed inadequate for the application. Table 10 present the screening, where injection molding was set as the precedent and additive manufacturing was shown to have positive qualities in relation to the reference and thus the application. Therefore, additive manufacturing was evaluated further along with injection molding, due to the question raised in the problem section regarding the possibility of adapting the current process to the new circumstances. The other manufacturing processes were deemed inapplicable due to various reasons, such as constraints in part complexity, shape and material.

Further areas were presented regarding injection molding and additive manufacturing that could eventually be relevant to the application such as injection molds, aluminium tooling for injection molding, the HP Multi Jet Fusion technology, economics behind 3D printing, the benefits of 3D printing in the automotive industry and rapid tooling.

Ultimately, quotations were requested to various manufacturers who provide services related to injection molding or additive manufacturing in order to get a cost estimate, and thus further analyzing the feasibility of the remaining processes. A reproduced sample part of Lear's plastic channel was distributed along with desired part requirements. A total of six quotations were provided, containing cost estimates for both injection molding and additive manufacturing.

These cost estimates were then each respectively presented along with Lear Corporations current costs, in order to make cost comparisons and give context to the numbers provided. The results of the cost estimates showed that there are multiple options for Lear to decrease the costs. The most viable option would be to change the injection mold to a cheaper one and thus substantially decreasing the upfront costs. The options presented in this study was MUD tool from Danke Mold, aluminium tool from Prototal and tool with steel grade 738 from RYD Tooling, with the MUD tool being the least inexpensive. The ramifications of changing tool would be a deterioration in tool strength and durability, as these tools have life spans of 20,000 (Prototal aluminium tool), 50,000 (Danke Mold MUD tool) and 300,000 (RYD Tooling) cycles respectively, in contrast to the current tool that has lifetime of 1,000,000 cycles.

As for additive manufacturing, HP MJF was deemed as the most interesting and applicable option due to its capabilities such as speed, cost, geometric freedom and fabrication of functional, end-use parts. It could be a cost-effective choice for volumes up to 5,000 parts, which was the approximate break-even point in the most cases for Lear's injection molding and the additive manufacturing presented. However the volume is depending on part size and shape, and it the case of the sample part delivered, it was seen as too big for production up to 5,000 parts and could be viable for 2,000 parts at most.

Furthermore, although HP MJF will not be able to fully replace or compete with injection molding at higher volumes than 5000 parts at this point in time, there is a way to combine the two processes and utilize the short lead times of HP MJF in so called bridge production. Manufacturing of tooling for injection molding can be a lengthy and slow process which causes idle time for customer. However through bridge production, customers can begin production earlier by filling orders of 3D printed parts, enabling flexibility and shorter lead times. Once the tool has arrived the customer can switch over and continue production through injection molding.

Due to the variety in volume of the plastic brackets or channels it wasn't feasible to formulate one exclusive proposal or suggestion. Therefore, several proposals were presented based on different prerequisite. The most cost-effective choice and thus the primary suggestion was to change the tooling used for injection molding, which would allow Lear to continue utilizing the benefits of injection molding while decreasing upfront costs substantially. Furthermore, complementing injection molding with additive manufacturing (HP MJF in particular) was presented as the second proposal.

The proposals answered the questions raised in the problem regarding if there was a suitable and cost-effective process that could replace the current one as well as if it was possible to make the current process more cost-effective. However, the question regarding if the new manufacturing process can produce parts with the same, or similar, properties as the current one and thereby meet the technical standards of the automobile industry remains unanswered. The answer couldn't be obtainable in this study as there was no testing done as per automakers standards to ensure that the parts have the satisfactory and suitable quality. However, the parts produced by the suggested processes are of the same or similar material as the current ones PA6, PP and PA12) which could indicate that the material properties would be same or similar. This might be a matter that Lear themselves would have to control or investigate assuming they're interested and choose to collaborate with any of the companies included in the cost estimates, or perhaps it might be further examined in another thesis or project.

7 References

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A: Danke Mold Molding Quotation

danke mold

Danke Mold Molding Quotation

Prepared for:
Address:
Contact: **Vishnu Nair**
Email: vishnupuchi@gmail.com

From: Danke Mold Limited
Address: Unit 5, 27/F.,Richmond Comm. Bldg., 109 Argyle Street, Mongkok, Kowloon, Hong Kong
Contact: Tabby Tan (Project Manager)
Email: tabby.tan@dankemold.com

Quote No. : **M202107** Quote Date: **May. 9th, 2020** Currency: **USD**

Pos.	Part Name	Process	Finish	Part Material	Color	Unit Price	Quantity	Part Price
1	ModifieradBLA	Injection Molding	Smooth (SPI-B1)	PA66 or PA6	Black	0.71	1,000	710.00
2	ModifieradBLA	Injection Molding	Smooth (SPI-B1)	PA66 or PA6	Black	0.60	5,000	3,000.00
3	ModifieradBLA	Injection Molding	Smooth (SPI-B1)	PA66 or PA6	Black	0.53	75,000	39,750.00
							Shipment Cost:	Not Included
							Total Amount:	N/A
1	ModifieradBLA	Injection Molding	Smooth (SPI-B1)	PP	Black	0.46	1,000	460.00
2	ModifieradBLA	Injection Molding	Smooth (SPI-B1)	PP	Black	0.35	5,000	1,750.00
3	ModifieradBLA	Injection Molding	Smooth (SPI-B1)	PP	Black	0.31	75,000	23,250.00
							Shipment Cost:	Not Included
							Total Amount:	N/A

General Notes:
Molding Quotation will normally start after sample approval.
The unit price does not include the shipment cost.

Payment Notes:
Payment before shipment.

File Code:	DM/RF-QP-10-09
Version:	A0

B: Danke Mold Tooling Quotation

danke mold

Danke Mold Tooling Quotation

Prepared for:	From: Danke Mold Limited
Address:	Addess: Unit 5, 27/F, Richmond Comm. Bldg., 109 Argyle Street, Mongkok, Kowloon, Hong Kong
Contact: **Vishnu Nair**	**Contact:** Tabby Tan (Project Manager)
Email: vishnupuchi@gmail.com	**Email:** tabby.tan@dankemold.com

Quote No. : **T202107** Quote Date: **May. 9th, 2020** Currency: **USD**

Pos.	Part Information		Tooling Informa		Lead Time(T1 sample)	Tooling Price
1	**Drawing Name:**	ModifieradBLA 	**Life Time:**	50,000 cycles	25 calendar days (DFM confirmed in advance)	4,840.00
			Cavity number:	1*2		
			Mold Base:	MUD mold base		
	Part Material:	PA66, PA6 or PP; Black	**Core/Cavity Steel:**	P20/P20		
	Surface Finish:	Smooth (SPI-B1)	**Tooling Structure:**	Cold runner, edge gates; 4 sliders		
					Total Amount:	4,840.00

Tooling Notes:
5 pcs/set of T1 samples with the shipment cost are included in the toolng prices.
Lead time (T1 samples) starts from DFM confirmation.
The tooling price may require an update if there is any change of the drawing.
Special tolerance should be informed before order confirmation.
Tooling prices include first inspection report-supplied upon request.

Payment Notes:
DFM starts upon receipt of customer PO.
Machining starts after receiving 50% upfront payment.
The balance 50% upon sample approval.
Prices exclude VAT.

File Code:	DM/RF-QP-10-08
Version:	A0

C: Danke Mold Prototyping Quotation

danke mold

Danke Mold Prototyping Quotation

To:		From:	Danke Mold Limited	Quote No.:	P202107
Address:		Address:	Unit 5, 27/F.,Richmond Comm. Bldg., 109 Argyle Street, Mongkok, Kowloon, Hong Kong	Date:	11-May-20
Contact:	Vishnu Nair	Contact:	Tabby Tan (Project Manager)	Currency:	USD
Email:	vishnupuchi@gmail.com	Email:	tabby.tan@dankemold.com	Quotation Validity:	30 Days

Pos.	Part Name/Drawing No.	Process	Material	Surface Finish	Surface Color	Lead Time	Quantity	Unit Price	Total Cost
1	ModifieradBLA	SLA	ABS-Like	Natural	Natural	2~3 Days	1	13.00	13.00
2	ModifieradBLA	SLA	ABS-Like	Natural	Natural	TBD	1,000	3.14	3,140.00
3	ModifieradBLA	SLA	ABS-Like	Natural	Natural	TBD	5,000	2.88	14,400.00
4	ModifieradBLA	SLA	ABS-Like	Natural	Natural	TBD	75,000	2.69	201,750.00
								Shipment Cost	Not Included
								Delivery time	3-4 days
								Total	N/A
1	ModifieradBLA	SLA	PA 12	Natural	Natural	2~3 Days	1	25.00	25.00
2	ModifieradBLA	SLA	PA 12	Natural	Natural	TBD	1,000	17.75	17,750.00
3	ModifieradBLA	SLA	PA 12	Natural	Natural	TBD	5,000	17.31	86,550.00
4	ModifieradBLA	SLA	PA 12	Natural	Natural	TBD	75,000	16.29	1,221,750.00
								Shipment Cost	Not Included
								Delivery time	3-4 days
								Total	N/A

General Notes:	Payment Notes:
• CNC (Metals): DINISO2768 (fine) | CNC (Plastics): DINISO2768 (medium) • Vacuum casting: between +/-0.2mm or +/-0.15mm (depend on part size) • SLA: +/-0.1mm (<100mm) or +/-0.2mm (100mm to 200mm)	Payment before shipment.

D: Protolabs 3D Printing Quote (SLS)

PROTOLABS

Proto Labs, Ltd.
Halesfield 8, Telford
Shropshire
TF7 4QN
United Kingdom

3D Printing Quote

Date	12-May-2020
Quote #	F484715

Customer Information
UNIVERSITY WEST

Estimated Lead Time
Unavailable

Description	**Qty**	**Rate**	**Total**
Build 2: PP natural, Selective Laser Sintering build in 100 micron layers **Part Name** / **Finish** / **Copies** ModifieradBLA.stp .... Standard 1000			€37,956.00
Standard Shipping Included			

For questions or inquiries, contact us:

Phone: +44 (0) 1952 683047
Email: customerservice@protolabs.co.uk

Sub Total	€37,956.00
VAT	**
Total	€37,956.00

*** Subject to Terms and Conditions*

E: Protolabs 3D Printing Quote (MJF)

PROTOLABS

Proto Labs, Ltd.
Halesfield 8, Telford
Shropshire
TF7 4QN
United Kingdom

3D Printing Quote

Date	12-May-2020
Quote #	F484715

Customer Information
UNIVERSITY WEST

Estimated Lead Time
Unavailable

Description	**Qty**	**Rate**	**Total**
Build 1: PA 12 Black Multi Jet Fusion build in 80 micron layers **Part Name** / **Finish** / **Copies** ModifieradBLA.stp .... Standard 1000			€31,123.00
Standard Shipping Included			

For questions or inquiries, contact us:

Phone: +44 (0) 1952 683047
Email: customerservice@protolabs.co.uk

Sub Total	€31,123.00
VAT	**
Total	€31,123.00

*** Subject to Terms and Conditions*

F: Forerunner 3D Printing Quote

DeWys Engineering FORERUNNER

PO Box 211

Estimate

Date	Estimate #
5/14/2020	Q4062

Name / Address	Ship To
Vishnu Nair vishnupuchi@gmail.com	

Terms	Lead Time
See Note in Red	3-4 Days

Material	File Name	Finish	Color	Shop	Qty	Amount
Jet Fusion-Nylon 12	ModifieradBLA	Bead Blast D...	Black	N/A	75	2,258.55

Please submit PO's for;
DeWys Engineering Business Unit to info@dewyseng.com
Forerunner 3D Printing Business Unit to sales@forerunner3d.com

Total $2,258.55

ALL 3D MODELS ASSUMED TO BE IN MM OR INCH UNITS, 3D MODELS SAVED WITH ANY OTHER UNITS CAUSE THIS QUOTE TO BE INVALID. ALL QUOTES ARE VALID FOR 30 DAYS UNLESS OTHERWISE STATED. LEAD TIMES TO BE RE-EVALUATED AFTER 3 DAYS FROM DAY OF QUOTE. STANDARD TERMS ARE CREDIT CARD DUE BEFORE SHIPPING UNLESS OTHERWISE STATED. ADDING OR SUBTRACTING PARTS TO THIS QUOTE WILL REQUIRE A REQUOTE. GROUND SHIPPING TO LOWER 48 USA IS INCLUDED IN PRICE.

G: Prototal Quote Injection Molding

PROTOTAL

Offert

Offertnummer	Kundkod	Sida
20202069 / 1	20149	1 / 2

Offertdatum	Utskriftsdatum
2020-05-19	2020-05-19

Ert momsreg.nr	Förfrågansnr	Vår referens	Er referens
	Verktygsoffert	Johan Haskovec	Vishnu Nair

Leveransadress	Postadress
Vishnu Nair Akkas Gata 4 422 48 Hisings Backa Sverige	Vishnu Nair Akkas Gata 4 422 48 Hisings Backa Sverige

Leveransvillkor FCA - Mottagarfrakt	**Betalningsvillkor** 30 dagar netto
Leveranssätt Schenker pallgods	**Leveranstid** Enligt nedan
Giltighetstid 30 dagar från offertdatum	**Godsmärkning**

Telefax

Pos	Artikelnr	Benämning	Antal	à-pris	%	Belopp
		Vi tackar för Er förfrågan och har nöjet att offerera enligt följande:				
		Tillverkning av formverktyg enlig fil:				
5	701647V	ModifieradBLA	1,00 ST	146 500,00		146 500,00
		Yta: fräst				
		Intag: tunnelintag				
		Backar: 2st underliggande backar för "julgran"				
		Info: 2 facksverktyg, livslängd på verktyg ca 20000 cykler.				
		Övrigt: inklusive 10 st utfallsprover exkl mätprotokoll (se anm)				
		Tillverkning av detaljer, pris/st vid denna volym				
6	701647-1	ModifieradBLA	5 000,00 ST	5,25		26 250,00
6		Ställkostnad / order	1,00 ST	1 800,00		1 800,00
		Material: PA6				
		Kulör: Svart				
57	320120	Recept ny masterbatch, pris per kulör	1,00 ST	5 000,00		5 000,00
		(utgår vid natur, svart eller kulör som vi lagerför)				

Anmärkningar:
Verktygen tillverkas i aluminium.

Minsta föreslagen fräsradie är 0,5 mm om annat ej avtalas.

Formfyllnadsanalys kan beställas mot tilläggskostnad. Resultatet är en teoretisk indikation på detaljens mått- och formriktighet.

Vid inköp av granulat som ej lagerförs av oss är minsta inköpskvantitet normalt 25 kg. Material som ej åtgår till ordern faktureras mot kund.

Vid framtagning av ny masterbatch som vi ej lagerför tillkommer receptkostnad.

Vi förbehåller oss rätten till prisjustering vid förändringar av råvarupris med mer än 3%.

Generella toleranser enligt DIN16742 - TG6*, på av oss mätbara dimensioner.

Postadress	Besöksadress				
Prototal AB		Telefon	036-38 72 00	Bankgiro	5520-2485
Instrumentvägen 6	Instrumentvägen 6	Telefax			
553 02 JÖNKÖPING	553 02 JÖNKÖPING	Org.nr.	556015-5532	SWIFT	NDEASESS
SWEDEN		VAT.nr.	SE556015553201	IBAN	SE9795000099602601220979
		Säte:	Jönköping		Nordea
info@prototal.se	www.prototal.se	F-skattsedel innehas			

PROTOTAL

Offert

Offertnummer	Kundkod	Sida
20202069 / 1	20149	2 / 2
Offertdatum	**Utskriftsdatum**	
2020-05-19	2020-05-19	

Ert momsreg.nr	Förfrågansnr	Vår referens	Er referens
	Verktygsoffert	Johan Haskovec	Vishnu Nair

Pos	Artikelnr	Benämning	Antal	à-pris	%	Belopp

* för shore A material TG7.
Andra toleranser enligt separat överenskommelse.

Eventuell formförändring eller detaljens funktion och hållfasthet som beror på materialval och/eller detaljens konstruktion kan vi ej ta ansvar för. Vid ojämn godstjocklek föreligger t ex risk för sjunkmärken.

Eventuellt mäprotokoll omfattar max 15 dimensioner på av er tillhandahållen ritning, om annat ej avtalas. Mätprotokoll, mer omfattande mätning och/eller dokumentation sker mot överenskommen tilläggskostnad.

PPAP ingår ej i verktygspris om detta inte tydligt framgår av er förfrågan och vår offert.

Lagring: verktyg lagras hos Prototal i 2 år efter den senaste ordern av detaljer, därefter sker utsortering i samråd med kund.

Ledtid:
För närvarande ca 4 arbetsveckor med reservation för mellanliggande order.
Ledtiden avser från det att Prototal mottagit slutgiltigt
underlag för verktygsframtagning. Leveranstid måste avtalas då nuvarande orderläge kan påverka tiden.

Vi delfakturerar efter utförda leveranser.

Priser exkl frakt och emballage.
Allmänna Leveransbestämmelser enligt NL09 och Incoterms 2010.

Vi hoppas ni finner offerten intressant och ser fram emot er beställning.

Summa Exkl. Moms (SEK) **179 550,00**

Med vänlig hälsning
Prototal AB
Johan Haskovec
johan.haskovec@prototal.se
036-387209

Postadress
Prototal AB
Instrumentvägen 6
553 02 JÖNKÖPING
SWEDEN
info@prototal.se

Besöksadress
Instrumentvägen 6
553 02 JÖNKÖPING
www.prototal.se

Telefon 036-38 72 00
Telefax
Org.nr. 556015-5532
VAT.nr. SE556015553201
Säte: Jönköping
F-skattsedel innehas

Bankgiro 5520-2485
SWIFT NDEASESS
IBAN
SE9795000099602601220979
Nordea

H: Xometry 3D Printing Quote

Xometry Europe GmbH
Ada-Lovelace-Str. 9,
85521 Ottobrunn
T: +49 32 22 109 8186
F: +49 32 22 641 3911
E: info@xometry.de
www.xometry.de

UST-id.Nr.: DE318027176
Steuer-Nr.: 161/118/12687
Amtsgericht: Amtsgericht Jena / HRB 514527
Sparkasse Altenburger Land
IBAN: DE89 8305 0200 1200 1345 71
BIC: HELADEF1ALT

Managing Directors: Albert Belousov Dmitry Kafidov

Vishnu Nair

Quotation: E-15212-6206
Date: 20.05.2020
Estimated delivery date: 04.06.2020
(if ordered by 21.05.2020)

Pos.		Description	Quantity	Unit price	Total
1		**Part name:** ModifieradBLA(1).stp **Bounding Box:** 202.53mm×65.07mm×62.23mm **Process:** 3D Printing MJF - HP Multi Jet Fusion **Material Type:** Nylon PA12 Gray / White **Material:** Nylon PA12 Grey / White (MJF) **Finish:** Standard	1000	21.91 €	21910.0 €
2		Shipping cost can not be calculated without address			—
			Order value:		21910.0 €
			Total order value, net:		**21910.0 €**

Quote status: Manually quoted

Confirm the order

We want to earn your business. If you get a lower quote, send it to us and we will try to beat it.

Please review this quote for accuracy prior to order

- We have priced and estimated a delivery window for your job based on the geometry in 3D model you have provided, along with the tolerances, features and secondary operations you have selected during the submission process and which are specifically confirmed by us in this Quote. We do not automatically extract features, tolerances or other non-geometric information from your submitted 3D model, even if represented there (e.g. threads, tapped holes, etc.). Even though our prices are dynamically generated in real time, we will honor the price in this Quote for thirty (30) days from generation (although the estimated delivery window will be re-calculated at time of actual order placement).

- While we may provide you with design for manufacturing assistance, you are ultimately responsible for the suitability of your design, and associated material selection, for any intended purpose. You may submit one or more engineered drawings and or specification sheets to us. While we will do our best to identify any inconsistencies or conflicts in your materials prior to manufacturing your part, you alone are responsible for any inconsistencies between the materials you provide to us and what is reflected in this Quote.

- Unless specified otherwise, Terms and Conditions of Xometry Europe GmbH apply

- Parts made of rust-prone materials may be coated with oil-based anti-corrosion agent at our discretion. Please inform us if you accept the risk of possible corrosion during transportation and want to receive your parts oil-free

Page 1 from 2

I: RYD Tooling Injection Molding Quote

RYD TOOLING® Realize Your Design

PRODUCTION AND MOLD QUOTATION

From: Kevin Wu   Email: marketing@rydtooling.com / kevin@rydtooling.com
Web: www.rydtooling.com;   Tel: 86-755-85241121
Address: Building D, BeiFangYongFa High-Tech Park,No. 615 ShaJing Road, ShaJing Town, ShenZhen,China. P.C 518104

Customer:
Attn: Vishnu Nair

RFQ No.: 20200521-R190-Q20-001

RYD Project NO.	Part Description			No. Of Cavity	Mold Steel Type	Mold Structure	Mold Size (mm)	Mold Life (shots)	Part Surface Finish	Injection System (Hot Runner or Cold Runner)	Lead Time (Days)	Mold Price (USD)	Note/Exceptions
	Part Name/No.	Part Picture	Part Material										
R190-Q20-001	ModifieradBLA		PP	2	738	3-Plates mold	450*550*505	300,000	SPI B2	Cold Runner System	35	US$9,800	

RYD Project NO.	Part Description				Batch Quantity (Piece)	Unit Price (USD)	Total Price (USD)	Lead Time (Days)	Trade Term	Note/Exceptions
	Part Name/No.	Part Picture	Part Material	Part Weigth (gram)						
R190-Q20-001	Modifierad BLA		PP	21	5,000	US$0.285	US$1,425	5	EXW	
					10,000	US$0.265	US$2,650	6		
					75,000	US$0.235	US$17,625	20		

First Shot Time: is calculated from mold design approval and deposit payment done.
Mold/Tooling Payment Term: T/T, 50% Deposit with P.O., Balance Term: 50% Upon samples received.
Production Payment Term: T/T, 50% Deposit with P.O., Balance Term: 50% Before parts shipping.
Shipping Price: Shipping cost is estimated on this quotation form and will be double checked based on the actual weight when molds completed.
Exceptions: RYD takes no responsibility for any patent or copyright infringements.
Quotation Valid: 60 days.