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Improving Rapid Prototyping Through the Installment of 3D Printers in Automotive Companies

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IMPROVING RAPID PROTOTYPING
THROUGH THE INSTALLMENT OF 3D PRINTERS
IN AUTOMOTIVE COMPANIES

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ABSTRACT

Three-dimensional (3D) printing is a relatively new form of additive manufacturing that has the potential to induce a second industrial revolution. This technology utilizes a print head to lay down raw materials in successive layers to fabricate a three dimensional object. There are several techniques in 3D printing, two of which will be discussed in this proposal: fused deposition modeling (FDM), and inkjet/polyjet matrix 3D printing.

Although this technology has been around since the 1980s, it is constantly evolving and new materials, uses, and objects are created daily. This technology presents the potential to manufacture a variety of objects across numerous fields such as automotive, aerospace, dental, medical, consumer electronics, fashion, art and more. With decreasing prices and homemade 3D printer options, one day consumers could simply download their needs and print them in their homes.

This proposal will determine which printer is best suited for rapid prototyping in the automotive industry. Consideration will be given to materials, functionality, and strength of the prototypes. Also, the potential to utilize the printer in rapid manufacturing will be considered. Testing of the printed automotive prototypes will be executed using the different technologies offered by Stratasys and Objet, two 3D printing manufacturers. Each of these companies utilizes a different 3D printing technology (FDM and inkjet 3D printing, respectively).

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INTRODUCTION

Three dimensional (3D) printers are considered an additive manufacturing process because they use raw materials to build an object layer by layer rather than a subtractive process which would carve away to form the object. It is also known as "rapid or instant manufacturing."[1] In 1986, Charles Hull received a patent for the first commercial 3D printer. His invention was based on a stereolithographic process (also known as SLA).[2] Stereolithography uses a thin layer of thermoplastic which is hardened by exposure to a UV light source such as a laser.[1]

3D printers use Computer-Aided Design (CAD) software to draw the 3D object digitally. Then, the information is sent to the printer using an STL file format.[3]The printer then lays down consecutive layers of the raw material to build the object.

As time has gone on, several methods of printing have been developed, including fused deposition modeling and 3D inkjet printing. These methods can be used for rapid prototyping. Rapid prototyping (RP) is not a new phenomenon in the manufacturing industry, but 3D printing has brought a new way to rapidly prototype objects. Rapid prototyping is vital in concept design in order to finalize the design of a new product. There are several reasons that companies use rapid prototyping. First of all, the new design can be held or seen as it would appear on a shelf. Secondly, the form, function, and appearance of an object can be tested and viewed. Also, if there are any flaws in the CAD file, they can be caught in the rapid-prototyped piece. Looking at the big picture, if a product flaw is not caught prior to mass producing the part, it could cost the company hundreds of thousands of dollars. [4] 3D Printing has introduced a new, faster, more efficient way of producing prototypes. Two of the main systems for doing this are offered by Stratasys and Objet.

Fused deposition modeling (FDM) is a patented 3D technology developed in 1988 by Scott Crump, CEO and founder of Stratasys. Stratasys offers two options with this technology: Dimension 3D Printers and Fortus 3D Production Systems.[5] These printers have cartridges that contain spools of ABS (acrylonitrile butadiene styrene) plastic and feature either breakaway supports or soluble supports. The plastic is heated within 3 degrees of its melting point and is known for its strength properties. This enables functional products to be made as rapid prototypes.[3] The material and water-dissolvable supports are extruded layer by layer from the bottom up.[6] FDM can produce parts that have high strength properties, allowing the object to function. Figure 1 shows the technology behind FDM printing.

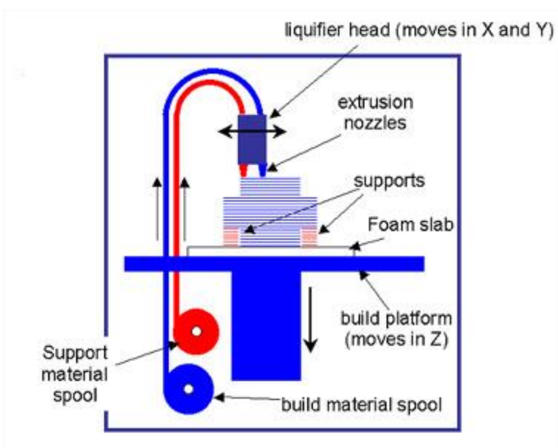

Figure 1: FDM Technology

Inkjet 3D printing was first introduced by Objet Geometries Ltd. in April 2000. Their inkjet technology is a Polyjet Matrix technology, and currently the only additive manufacturing device that can produce 3D printed objects consisting of different 3D printing materials in a single print run.[7] Inkjet is a great option for 3D printing because of its compatibility with other growing technologies such as printed electronics.[2] Their printers can use 2 materials at once and can print 16 micron layers. Prototypes produced from these can mimic the look, feel, and function of objects. [3]

Inkjet RP uses a Polyjet piezoelectric head[7], which uses thousands of nozzles to jet photopolymer materials in layers as thin as 16 micron onto a build tray. The print head jets build and support material simultaneously. After a layer is built, a UV light cures the material to solidfy it before the next layer is printed. The build tray moves down as the building progresses. Inkjet 3D printing is similar to 2D inkjet printing in that the printer uses multiple nozzles to jet the layers of material. Quality, speed, and functionality of finished pieces are just a few of the pros of using this type of technology.[8] Figure 2 below shows this PolyJet technology.

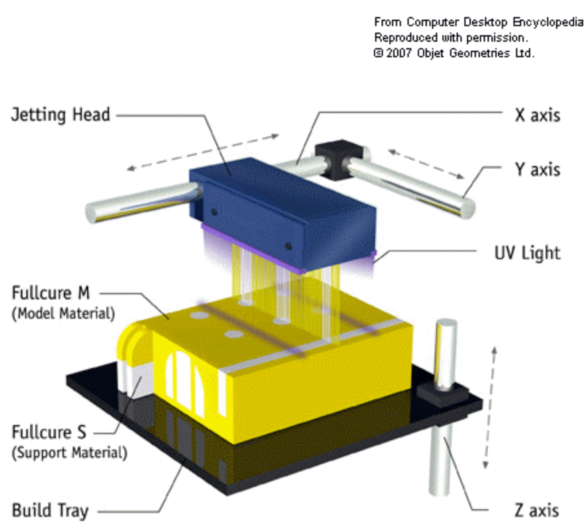

Figure 2: Objet PolyJet 3D Technology

These two 3D printing technologies were chosen because they provide viable options for producing rapid prototypes. Each has its pros and cons and the processes are under constant research and development. For rapid prototyping, the main purpose is to produce a model to test the design concept, appearance, ergonomics, strength, and functionality of a product. In the automotive industry, this could be utilized to test vents, tires, wheels, dashboards, keys, engines, and much more. Current concerns that may be holding companies back from buying a 3D printer compared to using traditional prototyping methods are costs, materials available, functionality, and overall change to the industry. These automotive companies must look at the bigger picture, seeing that an industrial revolution is in its midst, and by jumping on board, 3D printing can have a very positive influence on their companies.

LITERATURE REVIEW AND ANALYSIS

Three dimensional printing has been seen as a new and exciting opportunity and usage and knowledge in this field is increasing rapidly. It has presented opportunities to companies that have never existed before, having the ability to spark an industrial revolution. There is an abundance of literature available regarding the technologies behind 3D printing and the potential implications it will have on the manufacturing industry.

3D printing works by using CAD software to slice an object into digital layers as thin as 10 microns. The information is sent to the 3D printer, which sprays, extrudes, or spreads material onto a platform. After each layer, the material is cured, laser-sintered, fused, or cured with UV light, lasers, or electron beams.[9]

This proposal seeks to explore the usefulness of rapid prototyping in the automotive industry. The fastest growing segments of 3D printing have been in aerospace and medical. An important note in the automobile industry is that weight is directly related to costs. Using subtractive manufacturing methods, there is up to 90% waste of raw materials (titanium), which is not found with 3D printing. The parts can also be customized and manufactured faster with 3D printing. Impellers, fuel-injection nozzles, and door hinges can all be more cost effective to print via 3D methods. Another area of growth is foreseen for NASA. If printers can be incorporated onto flights, tools (such as wrenches) could be built as needed. This saves greatly on the weight, which if loaded before takeoff, must be heavy enough to withstand liftoff vibrations. [9]

There are many benefits to 3D printing as concept modeling. It can help sell ideas when a potential customer can physically touch, feel, and see the object. Proposals often have more of a success rate when a physical model is presented. Jim Wyman, an engineer, said that “a rendering of a solid model communicates information 10 times more easily than engineering drawings.” 3D printing reduces costly changes that may need to occur. The more changes or mistakes you can catch early on in a design, the more money you will save later. 3D printed prototypes allow you to see what you can’t see in a computer model. Ideally, catching 1 mistake will end up paying for the entire 3D printer alone. Printing can also reduce the cost of the quote for the entire project. Many times, when a model is presented, quotes are lowered by 10% because the buyer can visually see what the project is.[4] In the current market, 20% of 3D printers are now being used as a means of rapid manufacturing rather than just making prototypes. This is due to the lower costs and risks associated with it. Also, 3D printing essentially eliminates the problem of economies of scale, because the price will be a concrete number.[10]

In order to decide on which technologies to utilize, various companies offering solutions for 3D printing were researched. The main difference between 3D printing and other rapid prototyping methods is the choice of materials, how these materials are deposited, fused, and solidified. 3D printing also enables items to be produced on a smaller scale, faster speed, less costly, and at a greater convenience than other additive manufacturing methods. Prior to purchasing a 3D printer, one must determine what the printed prototype will be used for (appearance, functional testing, fit, or characteristics).[3]

Besides Objet and Stratasys printers discussed in the previous section, other 3D printers include 3D Systems, Mcor Technologies, and Z Corp. 3D Systems employs two types of technologies: multi-jet modeling and film transfer imaging technology. Mcor Technologies is one of the few companies to offer an eco-friendly 3D printer and primarily is used for woodcarvings. Z Corp offers a powder & binder process of inkjet printing. The powder is laid down, and the binder is applied to the areas of the model (and not to the supporting powder, which is then recycled). This printer has multiple print heads and the ability to print more than 1 color a time. [3]

The usefulness in printing prototypes lies in testing structural properties such as strength-to-mass ratios and surface-to-volume ratios. Even in the past 10 years, materials able to be printed have increased to glass, ceramics, and metal. Other advances in metal printing have led to the ability to print layers as thin as 1 micron. [9] Currently, utilizing 3D printing for electrically conductive prototypes is under extensive research and development. Rapid prototyping that uses 3D printing has several limitations when dealing with conductivity. First of all, there are few materials that can be utilized. If the model is not of the correct material, the extent of tests that can be performed on the model are limited. This affects medium and high voltage engineering products especially, because the shape and electric properties of the material will affect the distribution of electric fields which is critical for how the device will work.[4] As materials and printers develop, electronics look promising for 3D printing.

3D printing faces a few obstacles. First of all, factory workers are also fearful of losing jobs to these machines. Taxes used for public services may also see a decrease as a result of in-home printing capabilities. Another recent threat came with the passing of U.S. Patent #8,286,236. This patent holds the rights to a method for secure manufacturing to control object production rights. The largest roadblock for 3D printing lies in part 17: “The method of claim 1 further comprising: enabling the manufacturing machine to perform if the authorization code meets the one or more predetermined conditions, including manufacturing using one or more of skin, textiles, edible substances, paper, and silicon printing.”Based on this, the Digital Rights Management can prevent any person or company from printing any of the items mentioned above. [11]

Price also is an obstacle for 3D printing. Commercial 3D machines cost anywhere from $19,000 to $33,000, or as much as $300,000.[12] These prices have dropped, but large scale 3D printers can be quite costly. There are also components that can enhance the 3D printer, including 3D scanners and CAD software which can cost upwards of $4,000 depending on the amount of licenses needed. However, there are cheaper, do-it-yourself 3D printers available for low costs. This presents an interesting scenario because users will be able to print whatever they want. This could enhance the economic status of 3rd world countries. It could also be a threat if people begin to print weapons.

Based on these sources, it is clear that 3D printing has brought a new future to industrial manufacturing. 3D rapid prototyping can play an exceptional role in any of these industries, especially that of the automotive. It offers time, money, and convenience savings. The research and development of 3D printing is growing immensely. Overall, this is a worthwhile investment for any company where engineers and designers collaborate on new products on a regular basis.

PROBLEM STATEMENT

The objective of this proposal is to target the current capabilities for 3D printing in rapid prototyping and determine what the impediments to utilizing these capabilities are. The goal is to assess the success, financial, and time savings to automotive industries. Should they purchase and utilize 3D printers within their companies in order to save money on prototypes and join in on this manufacturing revolution. The more accepted usage and tests that are run on objects printed by these machines, the more likely the 3D technology is to grow and develop. If 3D rapid prototyping becomes a standard for industrial companies, there will be more time and money available to be allocated to further research and development in automotive and other industries.

EXPERIMENTAL PROCEDURE

The success of this objective depends upon the ability to 3D print testable prototypes. Both Objet and Stratasys offer consults for your needs. However, it would be most important to find test facilities for the printing of your test objects. As the automotive industry will typically use RP for strength, assembly, and function, these are 3 features that should be tested. There are several steps involved in this procedure:

1. Determining the test models and their requirements
    a. Consider uses in real-industry situations. Select three prototypes to be printed on each of four machines chosen for this experiment. These will include an interior part, exterior part, and mechanical part in order to test the useful features pertaining to the auto industry. An engine block interior, gearbox, or specific car customized fixtures should be considered.

    b. Contact auto manufacturers to determine what parts they would consider rapidly manufacturing, as well as their familiarity with the prototyping process. If 3D printing is something that they feel would benefit them, they may be willing to supply a design file for the experiment.

2. Creating 3D CAD files
    a. The CAD files should be identical in order to accurately compare the results of the printed prototypes.

b. The file type must correlate to the printer specifications. These may vary from printer to printer.

3. Investigate/assess materials to test

   a. **Objet:** A list of materials can be seen in Table 1. These materials can be separated into two families: those that simulate engineering plastics, and those that simulate standard plastics.[8]

      1. Simulate engineering plastics

         a) *High Temperature material (RGD525)* has a heat deflection temperature of 145-153°F upon removal from printer. Thermal post treatment in a programmable oven can increase this temperature. Can be used for form, fit, and thermal functional testing of static parts. Ideal for taps, pipes, household appliances, and hot air/water testing.

         b) *ABS (RGD 5160-DM)* is a fabricated plastic used for functional prototypes that require snap-fitting parts for high and low temperatures. Can be used for electrical parts, casings, mobile phone casings, engine parts, and covers. It has high impact resistance (1.22-1.5 ft lb/inch) and heat deflection temperature of 136-154°F upon removal.

      2. Simulate standard plastics

         a) *FullCure720* and *VeroClear* are two transparent materials used for form and fit testing of clear or see-through parts.

They have great dimensional stability and create fine detail models. These materials are ideal for glass, eye-wear, lighting covers, and light-cases, as well as visualization of liquid flow and color dying.

b) *VeroWhite, VeroGray, VeroBlue, VeroBlackPlus* are rigid opaque materials that combine dimensional stability and high detail visualization. These materials are used for testing fit and form and used for both moving and assembled parts. Ideal uses include assembly of electronic components, silicon molding (VeroBlue), and sales and marketing models.

c) *TangoFamily* rubber-like materials have various levels of elastomeric characteristics such as Shore scale A hardness, elongation at break, tear resistance and tensile strength. This is useful for non-slip or soft surfaces on automotive interiors. Commonly used for knobs, grips, pulls, handles, gaskets, seals, hoses, and footwear.

d) *DurusWhite* material is a polypropylene-like material that will print well in areas of appearance, flexibility, strength, and toughness. This material is used for reusable containers and packaging, flexible snap-fit applications, hinges, battery cases, lab equipment, loudspeakers, and automotive components.

b. **Stratasys**: A list of materials can be seen in Table 2. These production-grade thermoplastics print functional prototypes that have the strength and durability to be used as end-use parts. There are three main classes of materials offered by Stratasys: ABS (acrylonitrile butadiene styrene) based, and PC (polycarbonate) based, and others.[6]

1. ABS-based materials

    a) *ABS-M30* and *ABSplus-P430* have greater tensile, impact, and flexural strength than standard Stratasys ABS, as well as stronger layer bonding. Ideal for form, fit, and functional applications.

    b) *ABS-M30i* is a high strength, biocompatible material that is capable of being sterilized.

    c) *ABS-ESD7* has static dissipative characteristics, which is used for electronic and static sensitive assembly tools and products. Useful for functional prototypes of cases, enclosures, and packaging.

2. PC-based materials

    a) *PC-ABS* and *PC* materials are widely used industrial thermoplastics that have accurate, durable, and stable characteristics. These materials produce products with high impact strength, superior mechanical properties, and heat resistance capabilities. Surfaces have a smooth finish and high quality appearance.

3. Other materials

a) *ULTEM9085* is a polyetherimide material which is flame, smoke, and toxicity certified. It has high heat and chemical resistance, and the highest tensile and flexural strength. Ideal use is for commercial transportation applications (planes, trains, buses, and boats).

b) *PPSF/PPSU* are polyphenylsulfate materials that have the highest heat and chemical resistance of all Fortus materials, the greatest strength and mechanically superiority. These materials are best suited for caustic and high heat environments.

4. Send to printers

a. Turnaround time for the prototypes will be dependent upon the test printing facility. Prototypes should not take more than 1-2 weeks to print and ship once the files have been received. This is one of the many benefits of printing compared to traditional CNC manufacturing.

b. Success/Failure rate of prototypes should be examined on a pass/fail basis. Either the printer was successful in producing the prototype based on the file sent, or it was not. If the file was corrupt, the method would have failed.

5. Properties to test
    a. It will be vital that the prototypes function as they are intended to. If the prototype's primary purpose is for design and concept modeling, color accuracy, precision of detail, and surface smoothness must all be taken into consideration. If function is the primary role of the prototype, measurements such as strength, thickness, weight, conductivity, heat transfer, and corrosion tests should be considered. A combination of physical, mechanical, and thermo-mechanical tests should be considered depending on the prototypes produced.

6. Applications of the Rapid Prototypes
    a. These printers have the ability to print actual products to size (in most cases). Once prototypes have been created and tested, consider the possibilities for them. Will they used purely as prototypes (concept testing), or is there a future for producing these parts permanently via 3D printers (rapid manufacture)?

7. Assessment
    a. Minimizing costs is one of the primary goals for any business. The cost of the printer, the materials used, software needed, and time allocation must be considered.

       Overall impact of the prototypes must be considered as well. How will this affect your business growth? The nature of the economy, as well as the trends in the automotive field must be considered. 3D printing could be the competitive edge the company needs to promote internal and external growth.

Several case studies have been performed at both Objet and Stratasys. Jaguar Land Rover utilizes Objet's Connex500 printer and KOR EcoLogic utilized a combination of Dimension 3D printers and the Fortus 3D production system from Stratasys.

Jaguar Land Rover (JLR) purchased their Connex500 3D printer in 2008 because it allows for printing of multiple materials simultaneously. JLR has only 8 vehicles lines, and must maintain a premium position in the marketplace. In order to do this, 20% of their employees are in product development. They use CNC technologies, as well as SLA, laser sintering, and polymer jetting rapid prototyping machines. They proved the capabilities of their Connex500 by producing a complete facia air vent for a Range Rover Sport. This piece uses rigid materials for the housing and air-deflection blades, and rubber-like materials for control knobs and the air seals. This prototype not only worked, but also saved time and money. In a short time period, the Connex accumulated 5000 hours of operation, printed over 2500 parts, and went through just 5 print heads.[13]

Kor EcoLogic, a Winnipeg-based engineering group, took their chances with Stratasys 3D printers in 2010. In doing so, they produced the first car ever to have its entire body printed as opposed to traditional manufacturing processes. Project Urbee is one of the world's most fuel-efficient and environmentally friendly vehicles, capable of achieving 150 mpg combined highway and city driving, costing only 2 cents per mile. The FDM process allowed them to eliminate tooling, machining, and handwork in their project design, as well as shorten the period of time from 10 months to just a few weeks. All components, including the glass paneling, were created with a combination of Dimension and Fortus 3D printers of Stratasys' RedEye on

Demand. With the success of Urbee's first prototype, the Kor EcoLogic group has been able to proceed with a second prototype, tailored to the full capabilities of the 3D printers.[14] It has been saving their company money, time, and allowed them to do things not possible with traditional manufacturing techniques.

Tables 1 and 2 show the raw materials available for use from each company. The materials each have characteristics that could be beneficial to major automotive company prototypes.

Table 1: Objet 3D Printers

	OBJET[8]	
	Connex500	**Eden500V**
Size	500x400x200mm	500x400x200mm
Thickness	16 micron	16 micron
Resolution	600x600x1600	600x600x1600
Achievable Accuracy	NA	NA
Technology	PolyJet Matrix	Ultra-thin-layer PolyJet
Special Features	Up to 200 micron accuracy full model size Print models made of 14 materials in 1 job	Up to 200 micron accuracy full model size 72 hours of continuous unattended printing
List of Materials	100+Materials available, including: FullCure720 General Purpose (Transparent) Vero Family (Opaque) Durus White (Polypropylene-like) Tango Family (rubber-like flexible)	FullCure720 General Purpose (Transparent) Vero Family (Opaque) VeroClear (Transparent Clear) Durus White (Polypropylene-like) Tango Family (rubber-like flexible) RGD525 (High temp. resistant)

Table 2: Stratasys 3D Printers

	STRATASYS	
	Dimension 1200ES[5]	**Fortus 900mc[6]**
Size	254x254x305mm (10"x10"x12")	914.4x609.6x914.4mm (36"x24"x36")
Thickness	NA	NA
Achievable Accuracy	+/- .010" or +/- .013" (geometry dependent)	+/- .0035" or +/- .0015" (geometry dependent)
Technology	FDM	FDM
Special Features	Higher level of detail than wax Office space friendly	2.1x Throughput 300% stronger parts than Dimension
List of Materials	P430 ABSplus (model material) SR-30 SST or BST (support material) Colors: white, ivory, blue, fluorescent yellow, black, red, olive green, nectarine, gray	ABS-M30 (strength, function) ABS-M30i (biocompatible, strength, sterilization) ABS-ESD7 (static dissipative) PC-ABS (highest impact strength, heat resistant) PC (Most widely used, strength, mechanical) ULTEM 9085 (flame, smoke, toxicity certified) PPSF (Highest heat and chemical resistant)

For this experiment, it will be important to note the features seen in the case studies discussed above. These relate to size of the objects, functionality, temperature conditions, strength characteristics, and lifespan of the objects. The following charts were created to record data retrieved from the testing of the printed test objects. This will be recorded for each of the 3 prototypes (all of which have been printed 3 times). Furthermore, the repeat prints of the prototypes can be compared to each other. Upon the conclusion of data testing, analysis of the properties will be compared.

Table 3: Potential Data Measurements of Prototypes

PROTOTYPE 1A	**Objet**		**Stratasys**	
	Connex500	Eden500V	Fortus900mc	Dimension 1200ES
Time				
Amount of material				
Cost of material				
Accuracy (microns)				
Functional? (yes/no)				
Strength (MPa)				
Heat resistance (temp)				
Design Flaws				

Based on the information presented in the data analysis section, costs must be available for the testing for a minimum of 25 prototypes from each distributor (Objet and Stratasys). Costs will reflect the material chosen, the printer chosen, the company fee for either producing the prototypes or allowing trial runs, and testing equipment.

Upon completion of testing, the cost of the machine can be calculated by factoring the printer cost, average amount of material to be used (per year). Consideration must also be given to depreciation of the printer. However, it is important to note that many times, these printers can even produce parts to make new printers. It is also important to consider that many industries will buy not only one of these printers, but several. For example, VistaTek, a rapid prototype service bureau, recently acquired 14 three-dimensional printers from 3D Systems, as well as 1 Stratasys 3D production system. This enables them to produce a greater quantity of prototypes for their customers faster and more cost effectively. [15]

Looking at the stock market, the economic situation for 3D companies is growing. This is due to the increase in awareness of the technology, as well as expansion of the 3D industry. Stratasys, Inc. is currently in the process of acquiring Objet Ltd. in order to rival the market leader, 3D Systems.[16] Figure 3 below shows the stock trends over the past 6 months for Stratasys. Although short term the stock could see some weak points, if the merger goes through, stocks will likely rise.

Figure 3: Stratasys SSYS Past 6 months

Cost savings because of in-house rapid prototyping as a result of time savings, and overall cost savings must be examined. In several instances, one design flaw found in a prototype prior to mass production can save a company thousands of dollars. Overall, this purchase will be seen as an investment, and recovery costs can occur within the first several months of the purchase.

Task Description	**Timeline**			
	Nov-Dec 2012	Nov-Feb 2013	Feb-March 2013	Feb-April 2013
-Contact /acquire printer to run tests with distributors				
-Identification of materials and process requirements -Determination of 3D models -Creation of CAD files -Send to printers				
-Run tests on prototypes				
-Assess results/future -Decide best purchase option -Make presentation to automotive company				

FINAL COMMENTS/OBSERVATIONS

The benefits that could potentially be seen by the installation of 3D printers in an automotive company are numerous. They may enable the ability to rapid prototype in-house items. This may not only speed up concept development, but also enable the manufacture to catch any design flaws. It could allow for testing of parts for fit, form, and function, as well as strength and thermo-mechanical properties.

During the planning, I chose 4 separate printers based on size, resolution, and capabilities to prototype functional models. There are however, several other companies as noted in the literature review that may also be explored.

Also, as technology is rapidly evolving in 3D printers, there is a possibility that a newer and more capable printer may come out in the timeline allocated (6 months). Consideration must also be given to the possibility of these 3D printers being able to rapidly manufacture parts, rather than just prototype. This may influence greater cost savings or offer an option for customizable parts in automotives, creating a competitive edge for consumers.

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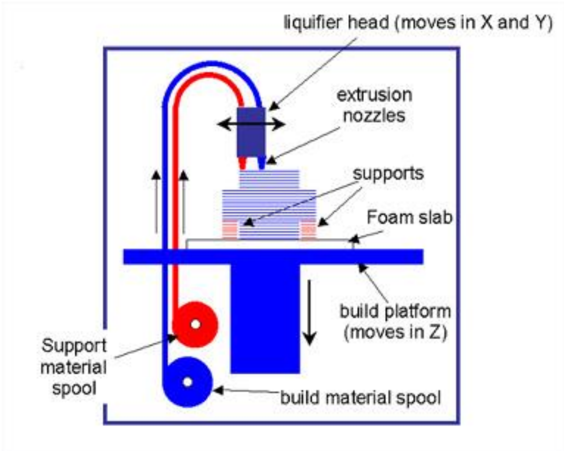

Figure 4: FDM Technology

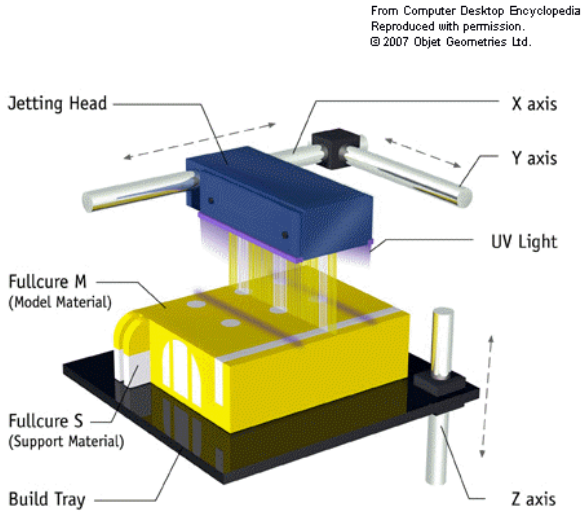

Figure 5: Objet PolyJet 3D Technology

Table 4: Objet 3D Printers

	OBJET[8]	
	Connex500	Eden500V
Size	500x400x200mm	500x400x200mm
Thickness	16 micron	16 micron
Resolution	600x600x1600	600x600x1600
Achievable Accuracy	NA	NA
Technology	PolyJet Matrix	Ultra-thin-layer PolyJet
Special Features	Up to 200 micron accuracy full model size Print models made of 14 materials in 1 job	Up to 200 micron accuracy full model size 72 hours of continuous unattended printing
List of Materials	100+Materials available, including: FullCure720 General Purpose (Transparent) Vero Family (Opaque) Durus White (Polypropylene-like) Tango Family (rubber-like flexible)	FullCure720 General Purpose (Transparent) Vero Family (Opaque) VeroClear (Transparent Clear) Durus White (Polypropylene-like) Tango Family (rubber-like flexible) RGD525 (High temp. resistant)

Table 5: Stratasys 3D Printers

	STRATASYS	
	Dimension 1200ES[5]	Fortus 900mc[6]
Size	254x254x305mm (10"x10"x12")	914.4x609.6x914.4mm (36"x24"x36")
Thickness	NA	NA
Achievable Accuracy	+/- .010" or +/- .013" (geometry dependent)	+/- .0035" or +/- .0015" (geometry dependent)
Technology	FDM	FDM
Special Features	Higher level of detail than wax Office space friendly	2.1x Throughput 300% stronger parts than Dimension
List of Materials	P430 ABSplus (model material) SR-30 SST or BST (support material) Colors: white, ivory, blue, fluorescent yellow, black, red, olive green, nectarine, gray	ABS-M30 (strength, function) ABS-M30i (biocompatible, strength, sterilization) ABS-ESD7 (static dissipative) PC-ABS (highest impact strength, heat resistant) PC (Most widely used, strength, mechanical) ULTEM 9085 (flame, smoke, toxicity certified) PPSF (Highest heat and chemical resistant)

Table 6: Potential Data Measurements of Prototypes

PROTOTYPE 1A	Objet		Stratasys	
	Connex500	Eden500V	Fortus900mc	Dimension 1200ES
Time				
Amount of material				
Cost of material				
Accuracy (microns)				
Functional? (yes/no)				
Strength (MPa)				
Heat resistance (temp)				
Design Flaws				

Figure 6: Stratasys SSYS Past 6 months