DESIGN OF A DECISION-AIDING MODEL BETWEEN SUBTRACTIVE MANUFACTURING AND 3D-PRINTING

A Senior Project submitted to
The Faculty of California Polytechnic State University,
San Luis Obispo

In partial fulfillment
Of the Requirements for the Degree of
Bachelor of Science in Industrial Engineering

By
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Abstract

Design of a decision-aiding model between subtractive manufacturing and 3D-printing

Tuan Minh Ryan Pham and Colton Harrison

3D-printing is becoming more and more widely used in industry. As this happens, manufacturers are becoming unsure of when to use this new technology and when to trudge on with subtractive (conventional) manufacturing processes. Subtractive manufacturing processes are well-established within many manufacturing companies due to its high efficiencies and low costs. However, 3D-printing offers a greater level of customization, can be automated, and can easily have designs transferred via computer files. Each method has its respective advantages, however, each one also has its downfalls. Subtractive manufacturing produces unnecessary waste, is limited from creating certain geometries, and requires a skilled laborer to run the machines. 3D-printing can present a safety hazard due to its introduction of particles into the air, being slower at producing parts, and the design of a part being easily contained and compromised within a computer file.

Since there are so many different advantages and disadvantages to each method, it is very difficult for a business to decide which form of manufacturing to use for any part. To solve this problem, we developed a decision-aiding model that will ask key questions that will determine whether form of manufacturing to use, and to do an economic analysis comparing the two forms of manufacturing and the time to manufacture each.

Acknowledgements

I would like to acknowledge my friend Kim Hyun-Soo for his insightful philosophy that promoted the success of this design project.
In addition, I would like to acknowledge Lee Kyung-Hee for providing me the joy and support when I needed it the most.
- Ryan Pham

Dad, Mom, Jake, Allie, Tierney, and Russell; thank you for the continued support throughout every stage of my life.
- Colton Harrison

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Title	Min_Thickness(mm)	Price Min	Price Max	Min_Dimens	Mid_Dimens	Ma
CLAD Unit	.2	$250,000.00	$1,000,000.00	700	700	
EOS M 400	.09	$1,000,000.00	$2,000,000.00	400	400	
Exerial	.28	$1,000,000.00	$2,000,000.00	700	1200	
LASERTEC 4300 3D	.1016	$250,000.00	$1,000,000.00	660	660	
LASERTEC 65 3D	.1016	$250,000.00	$1,000,000.00	351	500	
LENS 850-R	.025	$500,000.00	$999,999.00	900	900	
Magic	.2	$1,000,000.00	$2,000,000.00	800	800	
M-Print	.15	$100,000.00	$249,999.00	400	500	
MYSINT300	.02	$100,000.00	$249,999.00	300	300	
ProX 400	.01	$250,000.00	$1,000,000.00	500	500	
SLM 500 HL	.02	$1,000,000.00	$2,000,000.00	280	325	
S-Max	.28	$1,000,000.00	$2,000,000.00	700	1000	
S-Print	.28	$500,000.00	$999,999.00	400	500	
*		$0.00	$0.00	0	0	

The BeAM CLAD Unit is a professional 3D printer made in France (Alsace) by BeAM. This 3D printer was design to repair or create new metal parts of great dimensions. The BeAM CLAD Unit is capable of operating on 3 up to 5 axis. The build volume of this industrial 3D printer is of 1000 x 700 x 700 mm.

The BeAM CLAD Unit is based on the CLAD technology (Construction Laser Additive Directe). This technical process is capable of melting and projecting metal powder on a surface with a powerful laser system. This manufacturing technique is also called DED (Direct Energy Deposition) and offers several advantages compared to other 3D metal printing techniques: less raw materials are used, possibility to quickly change the 3D printing material and the ability to repair metal parts.

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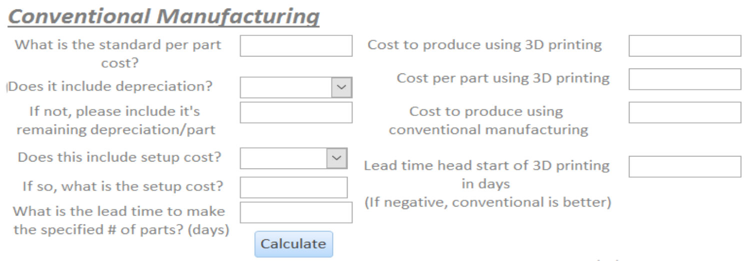

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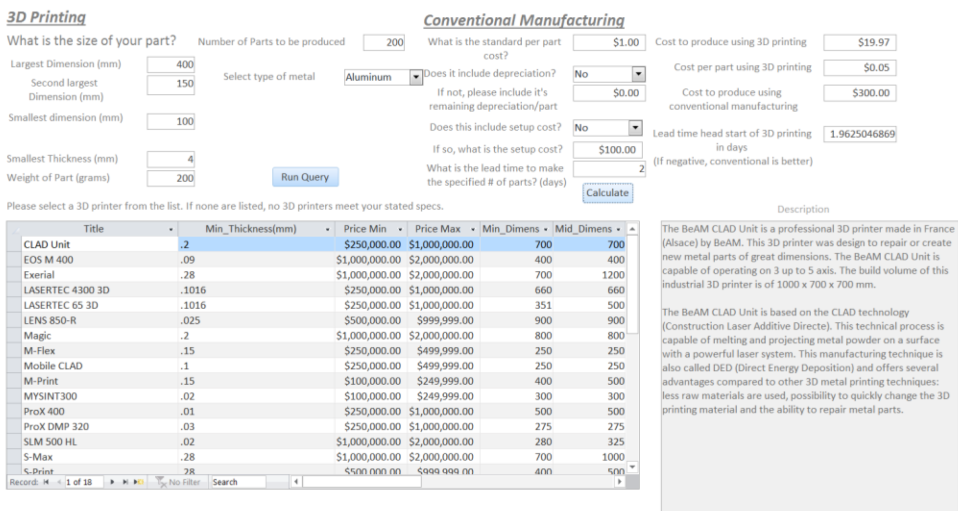

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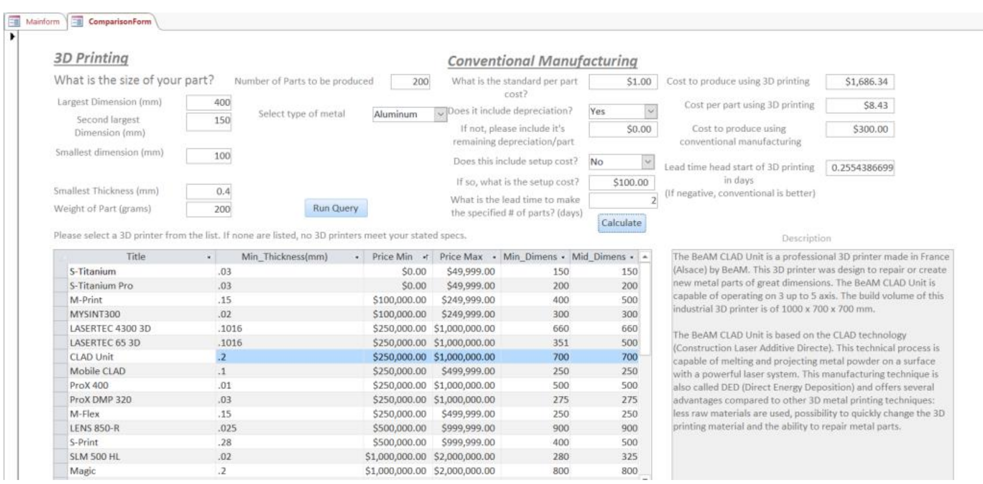
Magic	.2	$1,000,000.00	$2,000,000.00	800	800
M-Flex	.15	$250,000.00	$499,999.00	250	250
Mobile CLAD	.1	$250,000.00	$499,999.00	250	250
M-Print	.15	$100,000.00	$249,999.00	400	500
MYSINT300	.02	$100,000.00	$249,999.00	300	300
ProX 400	.01	$250,000.00	$1,000,000.00	500	500
ProX DMP 320	.03	$250,000.00	$1,000,000.00	275	275
SLM 500 HL	.02	$1,000,000.00	$2,000,000.00	280	325
S-Max	.28	$1,000,000.00	$2,000,000.00	700	1000
S-Print	.28	$500,000.00	$999,999.00	400	500

Figure 8: Completed test case after edits 14



Title	Min_Thickness(mm)	Price Min	Price Max	Min_Dimens	Mid_Dimens
S-Titanium	.03	$0.00	$49,999.00	150	150
S-Titanium Pro	.03	$0.00	$49,999.00	200	200
M-Print	.15	$100,000.00	$249,999.00	400	500
MYSINT300	.02	$100,000.00	$249,999.00	300	300
LASERTEC 4300 3D	.1016	$250,000.00	$1,000,000.00	660	660
LASERTEC 65 3D	.1016	$250,000.00	$1,000,000.00	351	500
CLAD Unit	.2	$250,000.00	$1,000,000.00	700	700
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ProX 400	.01	$250,000.00	$1,000,000.00	500	500
ProX DMP 320	.03	$250,000.00	$1,000,000.00	275	275
M-Flex	.15	$250,000.00	$499,999.00	250	250
LENS 850-R	.025	$500,000.00	$999,999.00	900	900
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SLM 500 HL	.02	$1,000,000.00	$2,000,000.00	280	325
Magic	.2	$1,000,000.00	$2,000,000.00	800	800

I. Introduction

With the recent advances in technology, there has been a rise in additive manufacturing, most commonly known as "3-D Printing." 3-D printing is a manufacturing technique where a printer "prints" parts, typically by using a molten metal or plastic and printing it using a computer file 3-D model. The opposite of additive manufacturing is subtractive manufacturing. Subtractive manufacturing is a form of manufacturing where material is removed to form a part. A prime example of this is the laser removal of aluminum to form the body of an iPhone from a single block. Because of the recent rise of 3D printing, companies lack a definitive way to compare 3D-printing and subtractive manufacturing to determine which is better for their need. Because of this, companies must resort to using common knowledge or source knowledge within their company, costing time and resources. In addition, this form of decision-making can result in inconsistent results and may have not all factors considered in determining whether to use 3D printing or subtractive manufacturing.

For our project, we decided to address this problem by creating a decision-aiding model to ensure that all necessary factors are considered and that 3D printing and subtractive manufacturing are compared at an equal level. For 3D printing, there are certain criteria that can determine whether a company could consider 3D printing, in which these questions will be included in the decision-aiding model. In addition, we will incorporate a financial aspect to our decision-aiding model to ensure that the costs associated with each form of manufacturing are compared equally.

To achieve our objective of providing a solution to this problem, we will research the limitations associated with 3D printing, the speeds associated with each major type of printing technology, and the 3D printers available on the market. From this research, we will create a decision model, and then test the veracity of this decision model by surveying results from professionals within the manufacturing industry familiar with 3D printing and subtractive manufacturing. In our report, we will detail the results of our research that is applicable to our design, the design of our decision model, and the results of our testing and conclusion.

II. Background and Literature Review

Background

With the recent rise of additive manufacturing, more colloquially known as 3D printing, many manufacturing businesses are faced with the decision on whether to manufacture a part using subtractive (conventional) manufacturing, or to use the relatively new additive manufacturing (3D printing). With 3D printing being so new, there is a relatively small knowledge base to pull from, whereas subtractive manufacturing has been around for centuries. Besides this, 3D printing has gained a stigma of being only suited for rapid prototyping, whereas with recent technological advances it is becoming more and more suited for the manufacturing needs of today. However, if a business decides to form a decision-making team, it can be lacking in many ways. An example of such is failing to account whether their facility is capable of safely locating a 3D printer, due to it introducing particulates in the air. Besides such factors, the major factor behind decisions are the monetary reasons. When doing economic comparisons, there are many factors to account for, and can only be compared on an equal basis. However, achieving this is difficult as decision teams change due to turnover and due to technological advances. This problem led to our decision of creating a decision-aiding model. We are not the first team to attempt to achieve a comparison of the two forms of manufacturing, but we are the first to attempt to address this by designing a decision-aiding model that can compare the two forms at a high-level.

Literature Review

With our literature review, we first tried to find the current state that 3D printing has had with the manufacturing industry. Additive manufacturing has seen a surge in popularity and usage over the past several years, but is actually an old technology. Additive manufacturing was first created in the 1980s, but has only surged due to the patents of additive manufacturing filed in the 1980s expiring, allowing for companies of all sorts to build on top of the innovation of these patents. (Caffrey & Wohlers 2015)

Besides finding the current state, we wanted to also find out where the industry is heading towards, as it would affect how long the veracity is held in the creation of our decision-aiding model. Additive manufacturing is heading towards using liquid phase metals, rather than the current usage of powder/filaments as the material to print. This usage of liquid phase printing would allow for 3D printers to print faster, and exhibit better physical properties as it would inhibit oxidation of the metals, allowing for a strong bond between particles. (Wang & Liu 2014) Given that this was published in 2014, and with research on the current market offerings of metal 3D printers, we can determine whether that technology has entered the market and make a conclusion on how long we believe the veracity of our decision-aiding model will hold. Besides how the material is handled while being printed, we also learned that how the printer process is conducted could be accelerated. An advancement in this is the tilting of the 3D printer's printing area and placing the part on a conveyor belt, accelerating its printing speed. (Günther et. al. 2014) This advancement achieved a threefold increase in printing speed, and we plan to use this knowledge to compare to the current offerings on the market if any 3D printers offer this to determine if the model we create would still hold true in a certain time span. The technology growing is not the only future effect moving to 3D printing would have. A company that moves to 3D printing will have to change aspects of management and operations to cope with the change. These changes are further discussed in the conclusion. (Nakamura, Yoshiki, Chihiro Hayashi, Masaaki Ohba, and Satoshi Kumagai)

In addition to finding the current and future state of additive manufacturing, we want to know how subtractive (conventional) manufacturing will change, as it could possibly affect how we would design our model. From our reading, it was surveyed that amongst manufacturers that there was a desire to move towards hybrid manufacturing, a form of manufacturing that incorporates additive and subtractive manufacturing techniques to form a particular output. (Strong et. al. 2017) From their work, we believe that our model will continue to be used, albeit with some updates, as there will be a gradual transition between the two forms of manufacturing, rather than a business choosing 100% between one or the other.

After determining the state, we did some research on whether our model could be built to model the geometries of a given part. Particularly, we researched the geometrical and assembly based limitations of 3D printing. (Adam & Zimmer 2015 & Jacques, Dan A. Calian, Cristina Amati, Rebecca Kleinberger, Anthony Steed, Jan Kautz, and Tim Weyrich) From this source, we concluded that the limitations associated with 3D printing were too technical to be able to model it in our design, so we decided to orient this project more towards whether 3D printing can be used for a business, and the economic justification associated with the decision.

Since geometries was out of the scope of our project, as per our review above, we decided to focus on the properties of the part being printed. We discovered that 3D printed parts using Fused Deposition Modelling lack the material strength compared to parts manufactured using subtractive engineering. This is due to constantly heating and cooling cycles as the part is being printed, resulting in varying levels of stress in the part that reduce the ability of the part to resist outside forces. (Casavola et. al. 2017) In addition, we also learned that with extrusion as a 3D printing technology also has the issue that its surface finish is less than desired and has poor material strength qualities. (Jin et. al. 2017)) From this reading, we determined that such is a strong enough factor in deciding between 3D printing or subtractive manufacturing that we will incorporate this into our decision-aiding model.

With this decision, we moved our research towards the limitations of 3D printing at the printer technology level, rather than at the part level. From this, we discovered that there is a safety hazard when handling 3D printers. 3D printers move small amounts of metal through the air, which can result in nano-sized particulates aerosolizing into the air. This can accumulate in the bodies of workers working near the 3D printer, and poses a health hazard. (Ryan and Hubbard 2016) This health hazard can be avoided through the placement of the 3D printer in a high airflow environment that utilizes an air filter. We used this knowledge as a key factor to include in our model, as we believe it to be a determining factor whether a company uses 3D printing in their facility.

In addition to the particulates being a determining factor, we also discovered in our literature review that intellectual property is another determining factor. According to Kurfess and Cass, they note that the 3D printing's advantage of providing a quicker time to design and market can be viewed as a negative. The reason for this is because that 3D printing relies on computer file, which can easily be transferred to other entities and produced. There is little to no protection a company can engage in to protect the file from being used after it lives their control as the file contains everything that is needed to produce the part. One related article suggested using watermarks as a solution to IP protection but it is still in an infant stage and will develop with the technology. (Macq, Benoat, Patrice Rondao Alface, and Mireia Montanola) Besides this reason that Kurfess and Cass mention, they also note that alongside the rise of 3D printing is the rise of a lesser-known technology as 3D laser scanning. This, as it would suggest, scans a part using a laser to form a basic computer-aided design (CAD) file. This inhibits the intellectual protection of a part, applying to both 3D printing and subtractive manufacturing, but is more applicable to 3D printing as the basic CAD file can be processed into a file that can be used to 3D print a part. Besides the technicalities regarding intellectual property protection, companies have to operate in within the legal confines they reside in. We decided to pick the US, since it is our area of expertise and because it is where a lot of research is conducted. In the US legal system, the time to achieve a patent can take up to five years, which is far too long for a subtractive manufacturing system, but is much more so when dealing with 3D printing and its instantaneous changeover between parts.

With these issues in mind, we decided to include this in our model as a determining factor; to pose the question whether intellectual property protection is significant to the company. According to Thomas, additive manufacturing is most suited for small batches, matching what is common knowledge and stigma for usage for prototyping. He expands more on this by mentioning the cost breakdown of 3D-printed parts, in which the machine cost and the material cost formulates almost 99% percent of a part cost, with all other costs consisting of the rest. Another source expounds on the material advantages with 3D printing. Due to the significant reduction in material needs to manufacture a part with 3D printing as opposed to conventional practices the company would create a far smaller carbon footprint as well as attain a much more sustainable supply chain. (Le, L., and R. Chudasama) In relation to the benefits of 3D printing, Thomas also mentions that parts can be printed at a moments notice, allowing for a lead-time advantage over subtractive manufacturing. With this, we decided to have our economic portion of our decision-aiding model revolve around the two major cost drivers of 3D printing, machine cost and material cost. In addition, we decided that having a lead-time comparison between the two forms of manufacturing to be an important comparison as companies would like to know the point where a batch/order size is too large for 3D printing to be timely.

To confirm whether our determining questions are sufficient to model the situation a business, we looked for a previous team that did research on the limitations of 3D printing and where it is beneficial, and we discovered that their discoveries to match ours just as well. (Chen & Lin 2017)

III. Design

In designing our decision-aiding model, we had to narrow the scope of our project to ensure that we could accomplish what we set out to do at a high quality. A major constraint that employed in our design is that it will only support the consideration of metal parts. We decided on this constraint because of the strong market presence of 3D printers regarding other materials, such as plastics. This strong market presence has resulted in 3D printers (non-metal) being very affordable and would not require a comprehensive decision-making process to determine whether such a printer would be of use to a business to be worth the time.

An assumption we made is the printing speed of the 3D printers. Printers can vary wildly between one another, even within the same form of printing technology, whether it be jetting, extrusion, or powder deposition (listed in our decision-model as just "powder"). However, in the formation of our database of metal 3D printers on the market, we discovered that not all printers specified their printing speed. To obtain such specifications, we would have to inquire each business on the printer, which was infeasible as no business would consider releasing such information to non-buyers. Therefore, we made the decision of taking the average of the printing speed of the printers within a specific printing technology of those whose printing speeds are published, with jetting have a specific speed, and extrusion having another etc. In addition, the printing speeds for jetting and powder deposition are a function of the material being used. The code for this can be found in the appendix.

Another design decision was to have the method of depreciation used in our model be the MACRS depreciation system. This decision was to reflect the fact that all the 3D printers are priced in USD. Within the MACRS depreciation system, we decided to depreciate the cost of the 3D printers using a 7-year class, as 3D printers are not a defined depreciation class at the time of writing. We used 14.29%, which is the percent depreciation for year one, and divided it over the standard number of working hours within a year, which is 2,087 hours per year[1], and multiplied that by the time to produce the amount of parts to be printed to determine the amount of depreciation per part.

An additional assumption we made with our model was that the 3D printer would be able to be operational for 22 hours within a day, whereas in a subtractive manufacturing sense, it would only be operational 8 hours a day. The reason for the 22 hours instead of 24 hours is to leave two hours for setup and maintenance, which would occur at the start and the end of the normal work day.

We decided to use different total hours for depreciation and how long the machine can be operated for to ensure that the depreciation between the subtractive and additive manufacturing are comparable.

With these constraints and assumptions in mind, we decided to create our decision model using Microsoft Access. The alternatives we considered were creating a Microsoft Excel spreadsheet or creating a form of web application. We decided to use Microsoft Access due to the ease of designing an interface for the user to interact with compared to a Microsoft Excel spreadsheet; and we decided against creating a web application as it was not in our expertise to be able to create, update, and design one and because products that exist on the market (Microsoft Access) are readily available for an affordable price.

With our decision to use Microsoft Access as our solution, we formed a database table containing all the 3D printers that can print metal, with the associated price ranges, name of the printer, printing technology, maximum printable dimensions, minimum printable thickness, and a short description of the 3D printer. We included the material category, which is only metal in this project to allow for future expansion of our decision-aiding model to support other materials.

[1] 5 U.S. Code § 5504

Upon opening the database as an end-user, the first page that appears is a basic form that contains three questions: whether the 3D printer can be in a high-airflow environment, whether IP protection is significant to the company, and if material strength is significant for the given part. We formulated these questions from our literature review, which we deemed to be significant enough to determine if a part should be manufactured using 3D printing.

Figure 1: Questions to determine feasibility of 3D printing

If 3D printing is suitable to the end-user according to our questions page, the user then continues to the main page that contains the various inputs for the decision model to work.

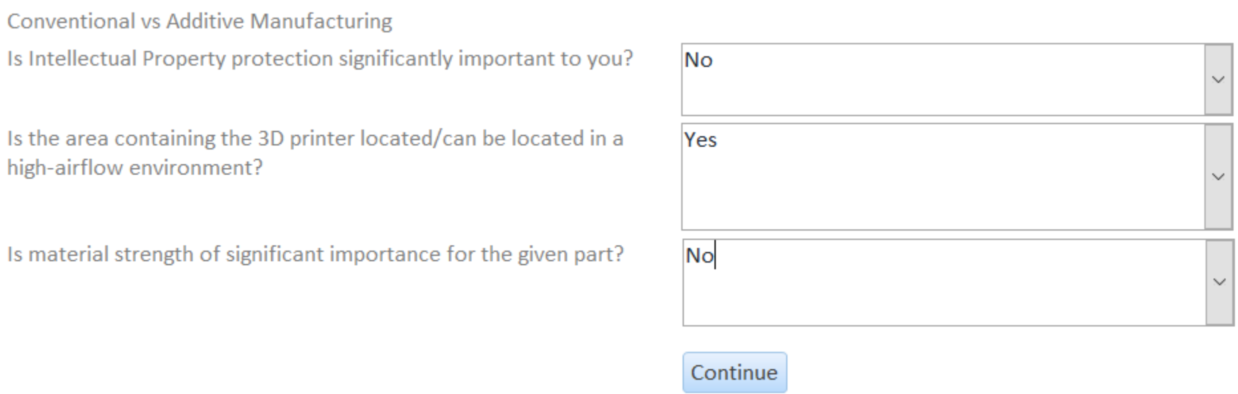

Figure 2: Completed feasibility questions

The inputs shared between 3D printing and subtractive manufacturing is the number of parts to be manufactured and the metal that forms the majority of the part.

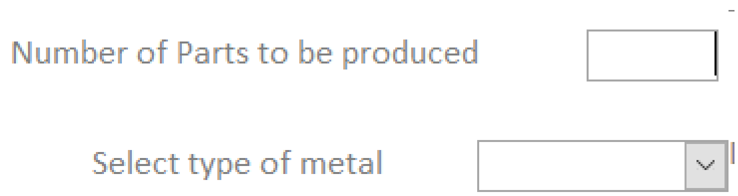

Figure 3: Shared inputs

On the 3D printing side of inputs, it is a two-step process. The first step is to enter the dimensions of the part (to help us determine which printers are capable of that size part), the minimum thickness required for the part, and the volume of the part (for us to determine material costs and printing time, one of the advantages to 3D printing is that there is very little material waste so just the weight of the part is needed). Then, the user is to execute a query of our database to determine if there is a 3D printer on the market that can print the part.

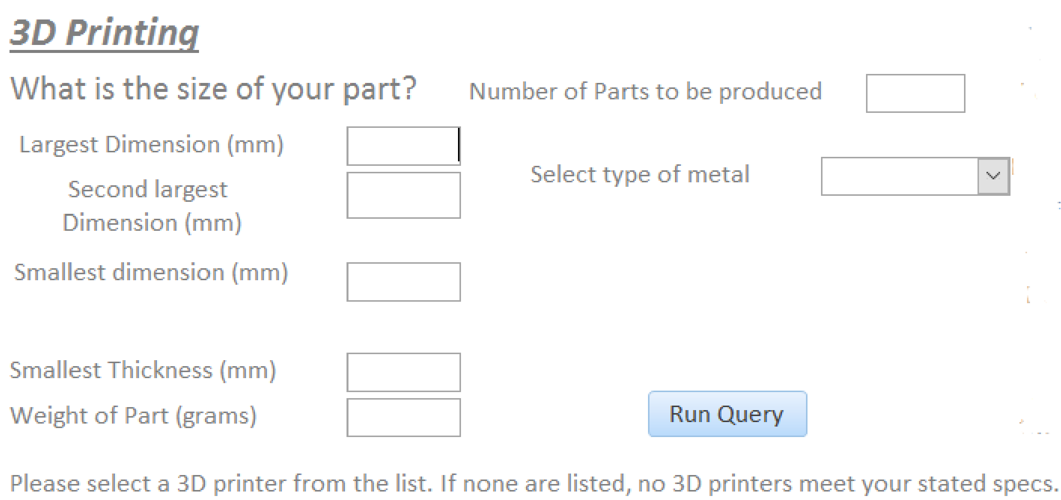

Figure 4: 3D printing inputs

For the second step, the user is to select a printer from the table. If no printers appear in the table, it means that there is no 3D printer in our database that supports the listed specifications. When they select the printer a description of the printer will show up on the right-hand side of the form.

Title	Min_Thickness(mm)	Price Min	Price Max	Min_Dimens	Mid_Dimens	Ma
CLAD Unit	.2	$250,000.00	$1,000,000.00	700	700	
EOS M 400	.09	$1,000,000.00	$2,000,000.00	400	400	
Exerial	.28	$1,000,000.00	$2,000,000.00	700	1200	
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Figure 5: Query results with selected printer/description

On the subtractive manufacturing side of inputs, there are several inputs required, with the number differing due to differences in how companies price their parts. The first input is for the user to input the standard cost per part, which would include various costs, such as material, labor, overhead, etc. To support differences in how companies define "standard cost per part", we included questions to ensure that the costs associated with subtractive manufacturing would be able to be compared to 3D printing, such as whether that standard cost per part includes depreciation and setup cost. Lastly, we asked for the lead time associated with fulfilling the entire order.

Upon entering all the required inputs, the end-user presses calculate and the outputs are displayed, with total cost to produce using 3D printing, total cost to produce using subtractive manufacturing, per part cost to produce using 3D printing, per part cost to produce using subtractive manufacturing, and the lead time difference between the two.

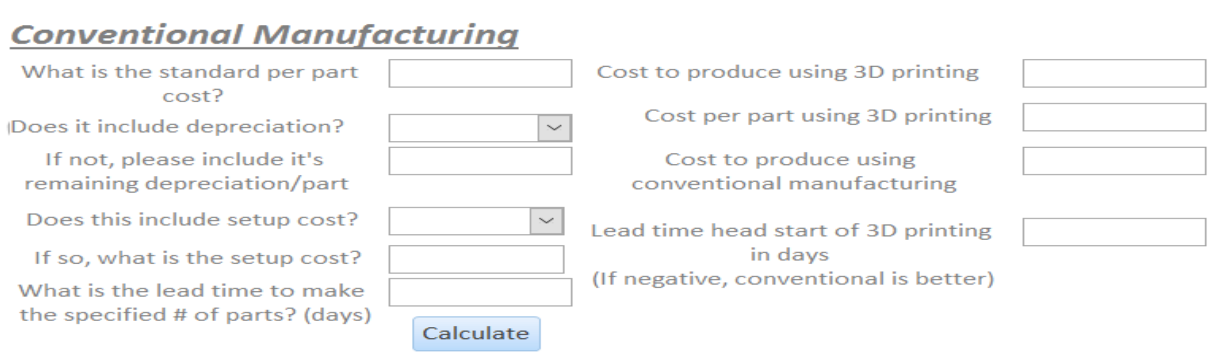


Figure 6: Conventional manufacturing inputs/overall outputs

To obtain the total cost of producing a part using 3D printing, we first determined the time to produce the part. Upon a user selecting a 3D printer, the model grabs the average printing speed of the selected printer's technology and uses that for calculations. We had originally utilized a multiplication of the three dimensions for the printer selection in our calculation for printing time but realized that using volume of the part would be more accurate. So, by using the weight of the part inputted by the user and the density associated with the chosen material, we calculate volume, and use that as well as prices for spools of 3D printable metal PLA from Amazon, we could determine the material costs. Executing this calculation correctly was important since a major advantage of 3D printing is the lack of material waste. Our printing time formula is as follows:

*time = (number of parts * weight of part (g) / density of selected material) * (1 / printing speed (mm³/hr))*

Our total cost of 3D printing formula is as follows (0.1429 is the MACRS of 7 years):

*Total cost =1.02 [1] *((time * 0.1429 * d / (2087[2])) + (weight of given part * material cost($/gram)))*

To obtain the difference of lead time of each, we took the time to print the entire order of parts, as calculated in the total cost portion of the calculation, utilized a 22-hour work day (an advantage of 3D printing), and took the difference of this value (days) against the lead time using subtractive manufacturing, utilizing an 8-hour work day.

IV. Experimentation

To test the veracity of our design, we decided to provide our model to people familiar with 3D printing and subtractive manufacturing and to ask whether they believe the outputs of the decision model to be accurate and enough to be used in lieu of

[1]this multiplier is to account for overhead costs

[2]this is a number from opm.gov for average working hours per year

bringing various people together to form a decision. In addition, we also asked whether there were enough factors considered to be able to draw a conclusion.

However, due limitations associated with the amount of people knowledgeable in both subtractive and additive manufacturing, we were only able to test our model with one professional, Professor Xuan Wang. He provided us a test case so we could ensure that all our outputs were appropriate for the inputs provided. The inputs as well as our original outputs are as shown below.

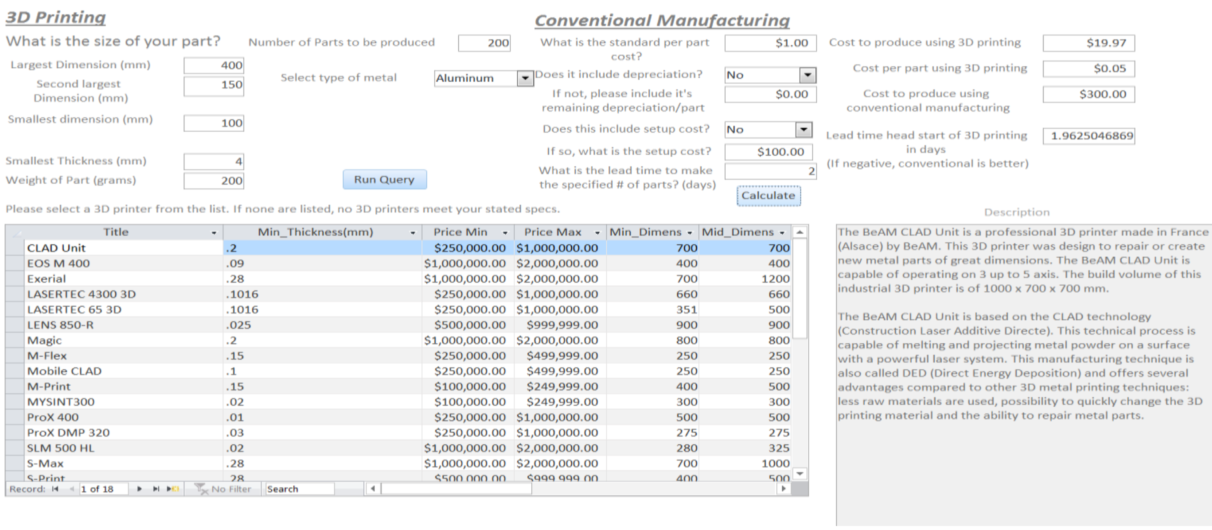
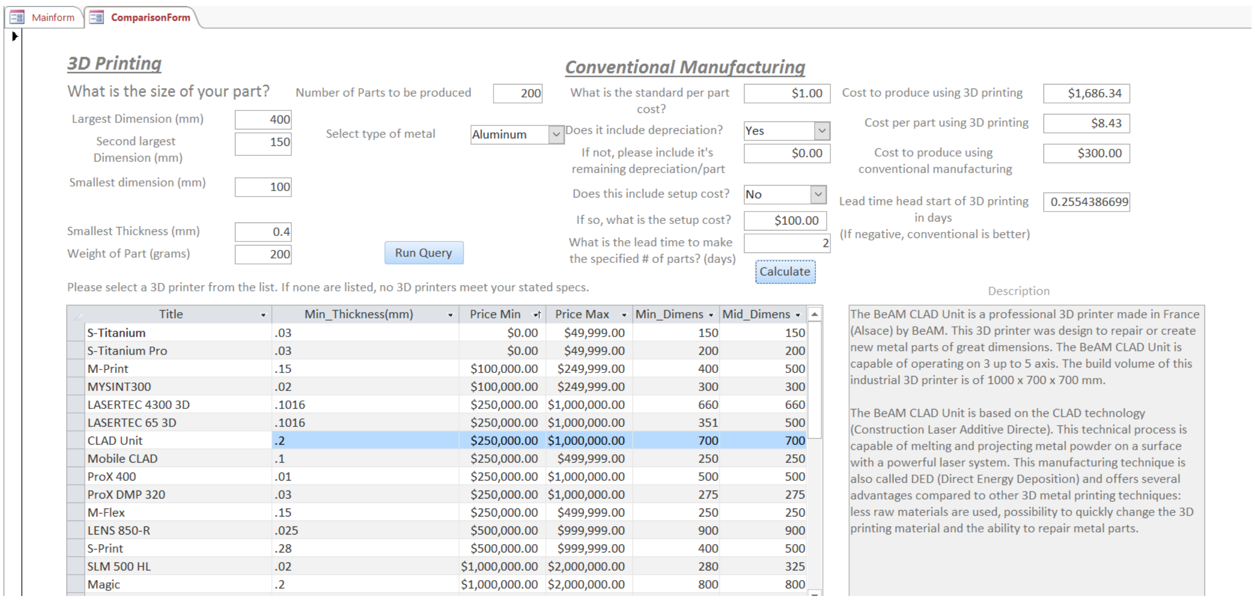


Figure 7: Completed test case before edits

V. Results and Discussion

From our test case and discussion with Professor Wang we determined there to be a few edits necessary to obtain outputs that were on par with what was expected from an expert in the field like Professor Wang. The depreciation figure was adjusted using a divisor of 2087, a government provided standard for work hours per year. Next, we added a 1.02 (2% increase) multiplier to our printing cost formula to account for overhead costs to purchasing and operating the printer. In addition, we altered the operating hours of the 3D printers for lead time to 22 hours a day rather than 24 hours a day to account for setup, maintenance, and changeover, which would normally occur during the beginning and end of the workday as the printer works overnight. Lastly, we eliminated an error that would occur when the user failed to input a number for setup or depreciation costs for conventional manufacturing when they chose “yes” in the combo boxes indicating that those costs were already factored into their per part cost. After doing this and retesting the model, our outputs are on par with what is expected. As expected, small runs typically are in favor of 3D printing and large runs are typically in favor of conventional practices. The updated outputs for the same inputs are shown below.



Mainform | ComparisonForm

3D Printing

What is the size of your part?

Largest Dimension (mm): 400

Second largest Dimension (mm): 150

Smallest dimension (mm): 100

Smallest Thickness (mm): 0.4

Weight of Part (grams): 200

Number of Parts to be produced: 200

Select type of metal: Aluminum

Run Query

Conventional Manufacturing

What is the standard per part cost?: $1.00

Does it include depreciation?: Yes

If not, please include it's remaining depreciation/part: $0.00

Does this include setup cost?: No

If so, what is the setup cost?: $100.00

What is the lead time to make the specified # of parts? (days): 2

Calculate

Cost to produce using 3D printing: $1,686.34

Cost per part using 3D printing: $8.43

Cost to produce using conventional manufacturing: $300.00

Lead time head start of 3D printing in days (If negative, conventional is better): 0.2554386699

Please select a 3D printer from the list. If none are listed, no 3D printers meet your stated specs.

Title	Min_Thickness(mm)	Price Min	Price Max	Min_Dimens	Mid_Dimens
S-Titanium	.03	$0.00	$49,999.00	150	150
S-Titanium Pro	.03	$0.00	$49,999.00	200	200
M-Print	.15	$100,000.00	$249,999.00	400	500
MYSINT300	.02	$100,000.00	$249,999.00	300	300
LASERTEC 4300 3D	.1016	$250,000.00	$1,000,000.00	660	660
LASERTEC 65 3D	.1016	$250,000.00	$1,000,000.00	351	500
CLAD Unit	.2	$250,000.00	$1,000,000.00	700	700
Mobile CLAD	.1	$250,000.00	$499,999.00	250	250
ProX 400	.01	$250,000.00	$1,000,000.00	500	500
ProX DMP 320	.03	$250,000.00	$1,000,000.00	275	275
M-Flex	.15	$250,000.00	$499,999.00	250	250
LENS 850-R	.025	$500,000.00	$999,999.00	900	900
S-Print	.28	$500,000.00	$999,999.00	400	500
SLM 500 HL	.02	$1,000,000.00	$2,000,000.00	280	325
Magic	.2	$1,000,000.00	$2,000,000.00	800	800

Description

The BeAM CLAD Unit is a professional 3D printer made in France (Alsace) by BeAM. This 3D printer was design to repair or create new metal parts of great dimensions. The BeAM CLAD Unit is capable of operating on 3 up to 5 axis. The build volume of this industrial 3D printer is of 1000 x 700 x 700 mm.

The BeAM CLAD Unit is based on the CLAD technology (Construction Laser Additive Directe). This technical process is capable of melting and projecting metal powder on a surface with a powerful laser system. This manufacturing technique is also called DED (Direct Energy Deposition) and offers several advantages compared to other 3D metal printing techniques: less raw materials are used, possibility to quickly change the 3D printing material and the ability to repair metal parts.

Figure 8: Completed test case after edits

VI. Summary and Conclusions

First, this model has a lot of potential for growth. As 3D printing grows the model must grow with it. This growth can be with additional printers entering the market, improvements to the speed of the technology, and changes in the likelihood that companies already own the printers and use them for other parts. Right now, the model assumed the printer would be used for this part alone. As the technology becomes more and more commonplace, that assumption will change. However, despite the ever-changing market, we believe that the veracity of our model can hold for up to 2-3 years, as it takes time for new technologies to be developed and be released into the market.

Second, the impacts of this model have potential to make large changes for a company. A company beginning to move from conventional manufacturing to 3D printing undergoes changes in their workforce needs, material needs, responsiveness, and design limitations. The skilled laborers needed for the conventional manufacturing lines will no longer be needed. This could be both a negative and a positive for a company. Massive layoffs are bad for company morale but also could save the company tons of money in the long run. By using 3D printers to produce a portion of their parts, the company can save in labor costs. Since 3D printing uses much less material than a conventional line would, the company will also be reducing its footprint on the environment as well as reduce their material needs. Although the material needs will be significantly less, they will also be significantly different. An aluminum bar that might be utilized by a conventional manufacturing line to produce a part might not be used by a 3D printer to produce the same part. Depending on the technology of the 3D printer you could be required to purchase the material in a filament, powder, or another form. This greatly alters the supply chain and should not go unnoticed. A company that uses 3D printers will be more responsive to demand. When an urgent order comes in the company will no longer need to wait for a current production run to end or halt that run, but rather simply change the file the printer is printing and keep going. In addition, it would make it much easier to perform smaller orders as the setup costs for conventionally manufacturing rarely allow justification of a small volume run. The responsiveness of a company can be integral to its success and proves to be a major advantage of 3D printing. In addition, this quick changeover allows a company to support a product for a longer period time, as it would not be as financially infeasible compared to conventional/subtractive manufacturing. Having products with a longer support lifetime will allow people to continue their products longer without having to dispose of the entire product, leading to less waste.

Lastly, the company will be significantly less limited by “design for manufacturing” limitations. A major advantage of 3D printing is the fact that they can produce complex, internal geometries at the press of a button. Allowing the engineers to be limited to their creativity rather than machining limitations could lead to some awesome designs.

Overall, the model is a decision-aiding tool. Although very important, cost and lead time are not the only factors to include in such a decision as this. The organizational impacts and factory floor impacts must be considered when making such a serious manufacturing change.

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Aluminum filament cost

https://www.amazon.com/SainSmart-Aluminum-1-75mm-Filament-Printing/dp/B017SGCX2G

Stainless steel filament cost

https://www.amazon.com/Proto-Pasta-Stainless-Steel-PLA-1-75mm/dp/B00VIW6OD6

Brass filament cost

https://www.amazon.com/SainSmart-1-75mm-Filament-Printing-1-1lbs/dp/B017SGCWYK

Bronze filament cost

https://www.amazon.com/Gizmo-Dorks-1-75mm-Filament-Printers/dp/B016996EEQ

Appendix

Item 1: Table Design

Printers

Field Name	Data Type
Title	Short Text
Manufacturer	Short Text
Technology	Short Text
Material	Short Text
Min_Thickness(mm)	Short Text
Price Min	Number
Price Max	Number
Availability	Short Text
Min_Dimension	Number
Mid_Dimension	Number
Max_Dimension	Number
Unbounded_Dimension	Yes/No
Description	Long Text

Item 2: A page of our table

Printers

Title	Manufacturer	Technology	Material	Min_Thickne	Price Min	Price Max	Availability	Min_Dimension	Mid_Dimension	Max_Dimension	Unbounded_Dimension	Description
Phenix PXL	3D Systems	Jetting	Metal	.01	$250,000	$499,999	Discontinued	250	250	300		The 3D Systems Phenix PXI
Phenix PXM	3D Systems	Jetting	Metal	.01	$250,000	$499,999	Discontinued	100	140	140		The 3D Systems Phenix PXI
Phenix PXS	3D Systems	Jetting	Metal	.01	$100,000	$249,999	Discontinued	80	100	100		The 3D Systems Phenix PX
ProX 100 Dental	3D Systems	Powder	Metal	.01	$100,000	$249,999		80	100	100		The 3D Systems ProX 100 I
ProX 200 Dental	3D Systems	Powder	Metal	.01	$250,000	$499,999		100	140	140		The 3D Systems ProX 200 I
ProX 400	3D Systems	Powder	Metal	.01	$250,000	$1,000,000		500	500	500		The 3D Systems ProX 400 i
ProX DMP 100	3D Systems	Powder	Metal	.005	$100,000	$250,000		100	100	100		The 3D Systems ProX DMP
ProX DMP 200	3D Systems	Powder	Metal	.005	$250,000	$1,000,000		125	140	140		The 3D Systems ProX DMP
ProX DMP 300	3D Systems	Powder	Metal	.005	$250,000	$1,000,000		250	250	330		The 3D Systems ProX DMP
ProX DMP 320	3D Systems	Powder	Metal	.03	$250,000	$1,000,000		275	275	420		The 3D Systems ProX DMP
MetalFAB1	Additive Industries	Extrusion	Metal		$1,000,000	$2,000,000		400	420	420		The Additive Industries Me
A2	Arcam	Powder	Metal	.13	$500,000	$999,999	Discontinued	200	200	350		The Arcam A2 is an industr
A2X	Arcam	Powder	Metal	.13	$500,000	$999,999		200	200	380		The Arcam A2X is an indus
A2XX	Arcam	Powder	Metal	.13	$500,000	$999,999	Discontinued	350	350	380		The Arcam A2XX is an indu
Q10	Arcam	Powder	Metal	.1	$500,000	$999,999	Discontinued	180	200	200		The Arcam Q10 is an indus
Q20	Arcam	Powder	Metal	.18	$500,000	$999,999	Discontinued	180	350	350		The Arcam Q20 is an indus
S-Titanium	Aurora Labs	Powder	Metal	.03	$0	$49,999		150	150	500		http://auroralabs3d.com/
S-Titanium Pro	Aurora Labs	Powder	Metal	.03	$0	$49,999		200	200	500		http://auroralabs3d.com/
CLAD Unit	BeAM	Jetting	Metal	.2	$250,000	$1,000,000	Discontinued	700	700	1000		The BeAM CLAD Unit is a p
Magic	BeAM	Jetting	Metal	.2	$1,000,000	$2,000,000	Discontinued	800	800	1500		The BeAM Magic is a profe
Mobile CLAD	BeAM	Jetting	Metal	.1	$250,000	$499,999	Discontinued	250	250	400		The BeAM Mobile CLAD is
M1 cusing	Concept Laser	Jetting	Metal	.02	$250,000	$499,999		250	250	250		The Concept Laser M1 cus
M2 cusing	Concept Laser	Jetting	Metal	.02	$250,000	$499,999		250	250	280		The Concept Laser M2 cus
M3 Linear	Concept Laser	Jetting	Metal	.02	$500,000	$999,999	Discontinued	300	300	350		The Concept Laser M3 line
Mlab cusing R	Concept Laser	Powder	Metal	.02	$100,000	$249,999		80	90	90		The Concept Laser Mlab c
Studio	Desktop Metal	Extrusion	Metal	.05	$100,000	$249,999		200	200	300		https://www.desktopmeta
LASERTEC 4300 3D	DMG Mori	Extrusion	Metal	.1016	$250,000	$1,000,000		660	660	150114		The DMG Mori LASERTEC
LASERTEC 65 3D	DMG Mori	Extrusion	Metal	.1016	$250,000	$1,000,000		351	500	500		The DMG Mori LASERTEC
millGrind	ELB-Schliff	Jetting	Metal		$250,000	$1,000,000		600	900	1500		The ELB-Schliff millGrind is
EOS M 100	EOS	Powder	Metal	.1	$100,000	$250,000		95	100	100		The EOS M 100 is an indus
EOS M 290	EOS	Powder	Metal	.1	$500,000	$999,999		250	250	325		The EOS M 290 is an indus

Record: 1 of 73 No Filter Search

Item 4: Code for our calculation button

```
Private Sub Command73_Click()
    'below is the code to determine time to print
    'y is density
    'lb price from amazon postings in $/gram
    Dim y As Double
    Dim lb As Double
    If Me.Combo66.Value = "Aluminum" Then
        y = 0.0027
        lb = (26.99 / 500)
    ElseIf Me.Combo66.Value = "Steel" Then
        y = 0.0079
        lb = (58 / 500)
    ElseIf Me.Combo66.Value = "Brass" Then
        y = 0.0084
        lb = (29.99 / 500)
    Else
        y = 0.007813
        lb = (29.95 / 1000)
    End If
    'x is speed listed in mm/hr
    Dim x As Double
    If Me.Text60.Value = "Jetting" Then
        x = ((1863 / y) + (82000)) / 2
    ElseIf Me.Text60.Value = "Powder" Then
        x = ((3083 * 9) + (500 / y)) / 10
    Else
        x = 6123
    End If
    'below is the code to determine cost to 3D print
    'a,b,c are dimensions
    'z is number of parts
    'r is weight of the part in grams
    Dim a, b, c, z, r As Double
    a = Me.Text24.Value
    b = Me.Text22.Value
    c = Me.Text19.Value
    z = Me.Text42.Value
    r = Me.Text82.Value

'time is time to print the given batch
Dim time As Double
time = ((z * r / y) * (1 / x))
'd is price of printer
'weight is the weight of the part in grams as inputted by the user
Dim d As Double
Dim weight As Double
weight = Me.Text82.Value
d = Me.Text52.Value
'.1429 is MACRS of 7 yr with it being the first year divided over 2087 as specified by opm.gov
'(weight * lb) is material cost
'1.02 multiplier is to account for overhead costs
Me.Text46.DefaultValue = 1.02 * ((time * 0.1429 * d / (2087)) + (weight * lb))
'j is per part cost for 3d
Dim j As Double
j = (1.02 * ((time * 0.1429 * d / (2087)) + (weight * lb))) / z
Me.Text74.DefaultValue = j
'below is the code to determine the cost to norm manufacture
'e is cost per part of norm manufacturing
'k is setup cost
'f is depreciation
Dim e As Double
Dim f As Double
Dim k As Double
```

```
e = Me.Text32.Value
k = Me.Text78.Value
f = Me.Text40.Value
If Me.Combo34.Value = "Yes" And Me.Combo76.Value = "Yes" Then
    Me.Text48.Value = z * e
ElseIf Me.Combo34.Value = "Yes" And Me.Combo76.Value = "No" Then
    Me.Text48.Value = (z * e) + k
ElseIf Me.Combo34.Value = "No" And Me.Combo76.Value = "No" Then
    Me.Text48.Value = (z * (e + f)) + k
ElseIf Me.Combo34.Value = "No" And Me.Combo76.Value = "Yes" Then
    Me.Text48.Value = z * (e + f)
End If

    'below is the code to determine the lead time difference between the two
    Dim g As Double
    Dim h As Double
    'h is lead time of conv manu
    'g is calculation of lead time difference
    h = Me.Text44.Value
    g = (h) - (time / 22)
    Me.Text50.DefaultValue = g
End Sub
```