## 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 Tuan Minh Ryan Pham Colton Harrison June 2017

#### Abstract

# Design of a decision-aiding model between subtractive manufacturing and 3Dprinting

### 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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Figure 1: Questions to	o determine f	easibility of 3D printing	9
Conventional vs Additive Manufacturing Is Intellectual Property protection significantly important to you?	No	You may want to consider using conventional manufacturing to enhance the security of your IP	
Is the area containing the 3D printer located/can be located in a high-airflow environment?	No	You should use conventional manufacturing as 3D printing will introduce particulates into the air, which is a health and safety hazard.	
Is material strength of significant importance for the given part?	Yes	You should consider sticking with conventional manufacturing as 3D printing yields lower material strengths than conventional practices.	
Figure 2: Completed f	easibility qu	estions	9
Conventional vs Additive Manufacturing Is Intellectual Property protection significantly in	mportant to you? No	~	

Is the area containing the 3D printer located/can be located in a high-airflow environment?	Yes	~
Is material strength of significant importance for the given part?	No	~

Continue

### Figure 3: Shared inputs

Number of Parts to be produced	
Select type of metal	~

### Figure 4:3D printing inputs

<u>3D Printing</u>		
What is the size of your part?	Number of Parts to be produced	· · · · ·
Largest Dimension (mm)	Colort tune of motol	
Second largest Dimension (mm)	Select type of metal	
Smallest dimension (mm)		
Smallest Thickness (mm)	7	
Weight of Part (grams)	Run Query	
Please select a 3D printer from the list. I	f none are listed, no 3D printers meet	your stated specs.

### Figure 5: Query results with selected printer/description

	Title •	Min_Thickness(mm)	٠	Price Min 🔹	Price Max •	Min_Dimens •	Mid_Dimens •	M
	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 too Food when the CLAD technology (Construction Laser Additive Directe). This technical process is capable of melting and projecting metal powder on a surface with a powerful baser 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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### Figure 6: Conventional manufacturing inputs/overall outputs

#### Conventional Manufacturing What is the standard per part Cost to produce using 3D printing cost? Cost per part using 3D printing $\sim$ Does it include depreciation? If not, please include it's Cost to produce using remaining depreciation/part conventional manufacturing Does this include setup cost? Lead time head start of 3D printing in days If so, what is the setup cost? (If negative, conventional is better) What is the lead time to make the specified # of parts? (days) Calculate

### Figure 7: Completed test case before edits

<u>D Printing</u>				Convent	tional Manufa	acturing		
/hat is the size of your i	part? N	umber of Parts to be produc	ced 200	What is the	e standard per part	\$1.00	Cost to produce using 3D printing	\$19.97
argest Dimension (mm)	400				cost?		Cost per part using 3D printing	\$0.05
Second largest	150	Select type of metal	Aluminum	<ul> <li>Does it inclu</li> </ul>	de depreciation?	No 💌	Cost per part using 5D printing	\$0.05
Dimension (mm)	150			If not, ple	ease include it's	\$0.00	Cost to produce using	\$300.00
				remaining	depreciation/part		conventional manufacturing	
nallest dimension (mm)	100			Does this i	nclude setup cost?	No 💌	Lond time band start of 2D evicting	1.0005040000
				If co. who	t is the esture cost?	¢100.00	Lead time nead start of 3D printing	1.9625046869
nallest Thickness (mm)	4			ir so, wha	t is the setup costr	\$100.00	(If negative, conventional is better)	
eight of Part (grams)	200	Run Ouerv		What is the	lead time to make	2		
on Brit of L and (Branna)	200			the specifie	d # of parts? (days)	Calculate		
ease select a 3D printer from	the list. If no	ne are listed, no 3D printers	meet your state	ed specs.		()	Descripti	on
Title		Min Thicknoss(mm)	Drico Min -	Drico Max	Min Dimone - Mic	Dimons	The ReAM CLAD Unit is a professio	anal 2D printer made i
CLAD Unit	2	wini_friickness(iniff)	\$250,000,00	\$1,000,000,00	700	700	(Alsace) by BeAM. This 3D printer y	was design to repair o
EOS M 400	.09		\$1,000,000,00	\$2,000,000,00	400	400	new metal parts of great dimensio	ns. The BeAM CLAD U
Exerial	.28		\$1,000,000,00	\$2,000,000,00	700	1200	capable of operating on 3 up to 5 a	axis. The build volume
LASERTEC 4300 3D	.1016		\$250,000,00	\$1,000,000,00	660	660	industrial 3D printer is of 1000 x 70	00 x 700 mm.
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	The BeAM CLAD Unit is based on t	he CLAD technology
Magic	.2		\$1,000,000.00	\$2,000,000.00	800	800	Construction Laser Additive Direct	te). This technical proc metal powder on a su
M-Flox	.15		\$250,000,00	\$499,999,00	250	350	with a nowerful laser system. This	manufacturing techni
THE I WA			+	9.1001000100	2.50	250		
Mobile CLAD	.1		\$250,000.00	\$499,999.00	250	250	also called DED (Direct Energy Dep	osition) and offers se
Mobile CLAD M-Print	.1 .15		\$250,000.00 \$100,000.00	\$499,999.00 \$249,999.00	250 400	250 250 500	also called DED (Direct Energy Dep advantages compared to other 3D	osition) and offers sev metal printing technic
Mobile CLAD M-Print MYSINT300	.1 .15 .02		\$250,000.00 \$100,000.00 \$100,000.00	\$499,999.00 \$249,999.00 \$249,999.00	250 400 300	250 250 500 300	also called DED (Direct Energy Dep advantages compared to other 3D less raw materials are used, possib	osition) and offers se metal printing technic pility to quickly change
Mobile CLAD M-Print MYSINT300 ProX 400	.1 .15 .02 .01		\$250,000.00 \$100,000.00 \$100,000.00 \$250,000.00	\$499,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00	250 250 400 300 500	250 250 500 300 500	also called DED (Direct Energy Dep advantages compared to other 3D less raw materials are used, possib printing material and the ability to	oosition) and offers se metal printing techni pility to quickly change repair metal parts.
Mobile CLAD M-Print MYSINT300 ProX 400 ProX DMP 320	.1 .15 .02 .01 .03		\$250,000.00 \$100,000.00 \$100,000.00 \$250,000.00 \$250,000.00	\$499,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00	250 250 400 300 500 275	250 250 500 300 500 275	also called DED (Direct Energy Dep advantages compared to other 3D less raw materials are used, possib printing material and the ability to	position) and offers sev metal printing technic vility to quickly change repair metal parts.
Mobile CLAD M-Print MYSINT300 ProX 400 ProX DMP 320 SLM 500 HL	.1 .15 .02 .01 .03 .02		\$250,000.00 \$100,000.00 \$100,000.00 \$250,000.00 \$250,000.00 \$1,000,000.00	\$499,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$2,000,000.00	250 250 400 300 500 275 280	250 250 500 300 500 275 325	also called DED (Direct Energy Dep advantages compared to other 3D less raw materials are used, possib printing material and the ability to	osoition) and offers se metal printing technic pility to quickly change repair metal parts.
Mobile CLAD M-Print MYSINT300 ProX 400 ProX DMP 320 SLM 500 HL S-Max	.1 .15 .02 .01 .03 .02 .28		\$250,000.00 \$100,000.00 \$100,000.00 \$250,000.00 \$250,000.00 \$1,000,000.00 \$1,000,000.00	\$499,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$2,000,000.00 \$2,000,000.00	250 250 400 300 500 275 280 700	250 250 500 300 500 275 325 1000	also called DED (Direct Energy Dep advantages compared to other 3D less raw materials are used, possil printing material and the ability to	vosition) and offers see metal printing technic, ility to quickly change repair metal parts.

### Figure 8: Completed test case after edits

Mainform ComparisonForm

				conventio	onur munuj	accurring		
What is the size of your	part? No	imber of Parts to be produce	d 200	What is the st	tandard per part	\$1.00	Cost to produce using 3D printing	\$1,686.34
Largest Dimension (mm)	400			0	ost?		Cost per part using 3D printing	\$8.43
Second largest	150	Select type of metal	Aluminum	<ul> <li>Does it include</li> </ul>	e depreciation?	Yes		
Dimension (mm)				If not, pleas	se include it's	\$0.00	Cost to produce using	\$300.00
Smallest dimension (mm)	100			remaining ue	preciation/part		convencional manufacturing	
	100			Does this incl	lude setup cost?	No	Lead time head start of 3D printing	0.2554386699
Construction and the second				If so, what is	s the setup cost?	\$100.00	in days	
Smallest Thickness (mm)	0.4			What is the le	ad time to make	2	(If negative, conventional is better)	
Weight of Part (grams)	200	Run Query		the specified	# of parts? (days)	Calculate		
ma	1. 1. 1.	CONTRACTOR AND A CONTRACTOR OF A CONTRACT OF		od space		L		
Please select a 3D printer from	n the list. If nor	ne are listed, no 3D printers n	leet your stat	eu specs.			Descripti	
Please select a 3D printer from Title	n the list. If nor	ne are listed, no 3D printers n Min_Thickness(mm) •	Price Min +	Price Max • N	Min_Dimens • Mi	d_Dimens • 🔺	Descripti The BeAM CLAD Unit is a professio	on onal 3D printer ma
Title S-Titanium	n the list. If nor • N .03	ne are listed, no 3D printers n Min_Thickness(mm) •	Price Min + \$0.00	Price Max • N \$49,999.00	Min_Dimens • Mi 150	d_Dimens • * 150	Descripti The BeAM CLAD Unit is a professio (Alsace) by BeAM. This 3D printer of	on mal 3D printer ma was design to repa
Title S-Titanium S-Titanium Pro	• 10 100 100 100 100 100 100 100 100 100	ne are listed, no 3D printers n Min_Thickness(mm) •	Price Min + \$0.00 \$0.00	Price Max • N \$49,999.00 \$49,999.00	Ain_Dimens • Mi 150 200	d_Dimens • • 150 200	Descripti The BeAM CLAD Unit is a professio (Alsace) by BeAM. This 3D printer y new metal parts of great dimensio	on anal 3D printer ma was design to repa ns. The BeAM CLJ
Title S-Titanium S-Titanium Pro M-Print	• 10 IIST. If nor .03 .03 .15	ne are listed, no 3D printers n Vlin_Thickness(mm) •	Price Min + \$0.00 \$0.00 \$100,000.00	Price Max • N \$49,999.00 \$49,999.00 \$249,999.00	Min_Dimens • Mi 150 200 400	d_Dimens • • 150 200 500	Descripti The BeAM CLAD Unit is a professio (Alsace) by BeAM. This 3D printer of new metal parts of great dimensio capable of operating on 3 up to 5	on anal 3D printer ma was design to repa ns. The BeAM CL axis. The build vol axis. The build vol
Please select a 3D printer from Title S-Titanium S-Titanium Pro M-Print MYSINT300	• 03 .03 .15 .02	ne are listed, no 3D printers n	Price Min + \$0.00 \$0.00 \$100,000.00 \$100,000.00	Price Max • N \$49,999.00 \$49,999.00 \$249,999.00 \$249,999.00	Ain_Dimens • Mi 150 200 400 300	d_Dimens • * 150 200 500 300	Descripti The BeAM CLAD Unit is a professio (Alsace) by BeAM. This 3D printer so new metal parts of great dimensio capable of operating on 3 up to 5 industrial 3D printer is of 1000 x 70	on anal 3D printer ma was design to repa ns. The BeAM CLJ axis. The build vol 30 x 700 mm.
Please select a 3D printer from Title S-Titanium S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D	* M .03 .03 .15 .02 .1016	e are listed, no 3D printers n Vlin_Thickness(mm) •	Price Min + \$0.00 \$100,000.00 \$100,000.00 \$250,000.00	Price Max • N \$49,999.00 \$49,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00	Min_Dimens • Mi 150 200 400 300 660	d_Dimens • * 150 200 500 300 660	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer new metal parts of great dimension capable of operating on 3 up to 5 industrial 3D printer is of 1000 x 70 The BeAM CLAD Unit is been on the	on anal 3D printer ma was design to repa ns. The BeAM CL axis. The build vol 00 x 700 mm.
Please select a 3D printer from S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D	• M .03 .03 .03 .15 .02 .1016 .1016	e are listed, no 3D printers n Min_Thickness(mm) •	Price Min +1 \$0.00 \$100,000.00 \$100,000.00 \$250,000.00 \$250,000.00	Price Max • N \$49,999.00 \$49,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00	Min_Dimens • Mi 150 200 400 300 660 351	d_Dimens • • 150 200 500 300 660 500	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer new metal parts of great dimension capable of operating on 3 up to 5. industrial 3D printer is of 1000 x 70. The BeAM CLAD Unit is based on the Construction Laure Addition Disco	on anal 3D printer ma was design to repa ns. The BeAM CL axis. The build vol 00 x 700 mm. he CLAD technolo ta). This tachnical
Please select a 3D printer from Title S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit	• N .03 .03 .03 .15 .02 .1016 .1016 .2	ne are listed, no 3D printers m	Price Min +r \$0.00 \$100,000.00 \$100,000.00 \$250,000.00 \$250,000.00 \$250,000.00	Price Max • N \$49,999.00 \$49,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00	Ain_Dimens • Mi 150 200 400 300 660 351 700	d_Dimens • * 150 200 500 300 660 500 700	Descripti The BeAM CLAD Unit is a professio (Alsace) by BeAM. This 3D printer 1 new metal parts of great dimensio capable of operating on 3 up to 5. industrial 3D printer is of 1000 x 70 The BeAM CLAD Unit is based on 1 (Construction Laser Additive Direc capable of meltine and projecting	on anal 3D printer ma was design to repi ns. The BeAM CLJ axis. The build vol 20 x 700 mm. he CLAD technoloc te). This technolocal metal powder on
Title S-Titanium Pro S-Titanium Pro M-S-Titanium Pro M-YSINT300 LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit Mobile CLAD	• N .03 .03 .03 .15 .02 .1016 .1016 .2 .1	e are listed, no 3D printers n Vin_Thickness(mm) •	Price Min +r \$0.00 \$100,000.00 \$100,000.00 \$250,000.00 \$250,000.00 \$250,000.00 \$250,000.00	Price Max • N \$49,999.00 \$249,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$499,999.00	Min_Dimens • Mi 150 200 400 300 660 351 700 250	d_Dimens • ▲ 150 200 500 300 660 500 <b>700</b> 250	The BeAM CLAD Unit is a professio (Alsace) by BeAM. This 3D printer v new metal parts of great dimensio capable of operating on 3 up to 5 , industrial 3D printer is of 1000 x 70 The BeAM CLAD Unit is based on th (Construction Laser Additive Direc capable of melting and projecting; with a goverful laser system. This	on anal 3D printer ma was design to rep ns. The BeAM CLJ axis. The build vol 00 x 700 mm. he CLAD technolol metal powder on manufacturing te
Please select a 30 printer from Title 5-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit Mobile CLAD ProX 400	<ul> <li>n the list. If nor</li> <li>.03</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.2</li> <li>.1</li> <li>.01</li> </ul>	ne are listed, no 3D printers n Min_Thickness(mm) •	Price Min +r \$0.00 \$0.00 \$100,000.00 \$100,000.00 \$250,000.00 \$250,000.00 \$250,000.00 \$250,000.00	Price Max • N \$49,999.00 \$49,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$499,999.00 \$1,000,000.00	Ain_Dimens • Mi 150 200 400 300 660 351 <b>700</b> 250 500	d_Dimens • * 150 200 500 300 660 500 700 250 500 500	The BeAM CLAD Unit is a professi (Asace) by BeAM. This 30 printer- new metal parts of great dimensio capable of operating on 3 up to 3. industrial 3D printer is of 1000 x 70. The BeAM CLAD Unit is based on t (Construction Laser Additive Direc capable of melting and projecting with a powerful laser system. This also called DED (Direct Energy Dep	on anal 3D printer ma vas design to repi ns. The BeAM CL axis. The build vol 00 x 700 mm. he CLAD technolo te). This technical metal powder on manufacturing te osition) and offer
Prease select a 30 printer from Title 5-Titanium 0-Print M*Print M*SINT300 LASERTEC 4300 30 LASERTEC 65 30 CLAD Unit Mobile CLAD ProX 400 ProX 0MP 320	<ul> <li>n the list. If nor</li> <li>.03</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.1016</li> <li>.2</li> <li>.1</li> <li>.01</li> <li>.03</li> </ul>	ne are listed, no 3D printers n Min_Thickness(mm) •	Price Min +r \$0.00 \$100,000.00 \$100,000.00 \$250,000.00 \$250,000.00 \$250,000.00 \$250,000.00 \$250,000.00	Price Max • N \$49,999.00 \$49,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$499,999.00 \$1,000,000.00 \$1,000,000.00	Atin_Dimens • Mi 150 200 400 300 660 351 <b>700</b> 250 500 275	d_Dimens	The BeAM CLAD Unit is a profession (Alace) by BeAM. This 3D printer newr metal parts of great direction capable of operating on 3 up to 5 is industrial 3D printer is of 1000 × 7C The BeAM CLAD Unit is based on t (Construction Laser Additive Direc capable of melting and projecting, with a powerful laser system. This also called DED (Direct Energy Dep advantages compared to Other 3D support	on anal 3D printer ma vas design to repira site. The BeAM CLI axis. The build vol axis. The build vol axis. The build vol axis. This technical metal powder on manufacturing te metal printing ter
Please select a 3D printer from Title 5-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit Mobile CLAD ProX 400 ProX 400 ProX 0MP 320 M-Flex	<ul> <li>n the list. If nor</li> <li>.03</li> <li>.03</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.2</li> <li>.1</li> <li>.01</li> <li>.03</li> <li>.15</li> </ul>	ne are lated, no 3D printers m	Price Min + \$0.00 \$0.00 \$100,000.00 \$100,000.00 \$250,000.00 \$250,000.00 \$250,000.00 \$250,000.00 \$250,000.00 \$250,000.00	Price Max         N           \$49,999.00         \$49,999.00           \$249,999.00         \$249,999.00           \$1,000,000.00         \$1,000,000.00           \$1,000,000.00         \$1,000,000.00           \$1,000,000.00         \$1,000,000.00           \$1,000,000.00         \$1,000,000.00           \$1,000,000.00         \$1,000,000.00           \$1,000,000.00         \$1,000,000.00	din_Dimens +  Mi 150 200 400 300 660 351 700 250 500 275 250	d_Dimens * * 150 200 500 500 500 700 250 500 250 500 250	The BeAM CLAD Unit is a profession (Alsoc) by BeAM. This 30 printer: new metal parts of great dimension capable of operating on 3 up to 5. industrial 30 printer is of 1000 x 70. The BeAM CLAD Unit is based on to (Construction Laser Additive Direct capable of meting and projecting) with a powerful laser system. This also called DBD (Direct Energy De advantages compared to other 30 less raw materias are used, positi	on onal 3D printer ma was design to repu- ns. The BeAM CLJ axis. The build vol 10 x 700 mm. he CLAD technolo te). This technical metal powder on manufacturing te iosition) and offet metal printing te- ility to quickly chi
Title Title S-Titanium Pro M-Print M-Print M-SINT300 LASERTEC 4300 3D LASERTEC 4300 3D LASERTEC 4300 3D LASERTEC 4300 ProX MMP 320 M-Flex LENS 850-R	- N .03 .03 .15 .02 .1016 .2 .1 .016 .2 .1 .01 .03 .03 .15 .025	ne are lated, no 30 printers m	Price Min +1 \$0.00 \$0.00 \$100,000.00 \$100,000.00 \$100,000.00 \$250,000.00 \$250,000.00 \$250,000.00 \$250,000.00 \$250,000.00 \$250,000.00	Price Max • N \$49,999.00 \$49,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$499,999.00 \$1,000,000.00 \$3999,999.00	Ain_Dimens • Mii 150 200 400 300 660 351 700 250 500 275 500 275 500 900	d_Dimens ► ▲ 150 200 500 660 500 700 - 250 500 275 500 225 900	The BeAM CLAD Unit is a profession (Alsco) by BeAM. This 3D printer: new metal parts of great direction capable of operating on 3 up to 5 industrial 3D printer is of 1000 x 77 The BeAM CLAD Unit is based on t (Construction Laser Additive Direc capable of melting and pojociting with a povertill are system. This also called DED (Direct Energy Dep davintages compared to Other 3D less raw materials are used, possib printing material and the ability of	on anal 3D printer ma was design to reps ns. The BeAM (L) sxis, The build vol sxis, The build vol axis, The build vol built vol built vol metal provider on metal printing te metal printing te repair metal printing te

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#### **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 decisionaiding 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 decisionaiding 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<sup>1</sup>, 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.

<sup>1</sup> 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.

Conventional vs Additive Manufacturing			
Is Intellectual Property protection significantly important to you?	No	~	You may want to consider using conventional manufacturing to enhance the security of your IP
Is the area containing the 3D printer located/can be located in a high-airflow environment?	No	~	You should use conventional manufacturing as 3D printing will introduce particulates into the air, which is a health and safety hazard.
Is material strength of significant importance for the given part?	Yes	~	You should consider sticking with conventional manufacturing as 3D printing yields lower material strengths than conventional practices.

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.

Conventional vs Additive Manufacturing		
Is Intellectual Property protection significantly important to you?	No	~
Is the area containing the 3D printer located/can be located in a high-airflow environment?	Yes	~
Is material strength of significant importance for the given part?	No	~
	Continue	

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.

Page	10	
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Number of Parts to be produce	d
Select type of metal	~

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.

### **3D Printing**



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

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.

	The	Adia Thislanses(assa)	Datas Ada	Datas Mass	Mda Diarra	Add Discours Ad	,
1	litle	viin_Thickness(mm)	<ul> <li>Price Min</li> </ul>	<ul> <li>Price Max</li> </ul>	win_Dimens +	wiid_Dimens + Ma	The BeAM CLAD Unit is a professional 3D printer made in Fra
	CLAD Unit	.2	\$250,000.	00 \$1,000,000.00	700	700	(Alsace) by BeAM. This 3D printer was design to repair or crea
	EOS M 400	.09	\$1,000,000.	0 \$2,000,000.00	400	400	new metal parts of great dimensions. The BeAM CLAD Unit is
	Exerial	.28	\$1,000,000.	00 \$2,000,000.00	700	1200	capable of operating on 3 up to 5 axis. The build volume of the
	LASERTEC 4300 3D	.1016	\$250,000.	00 \$1,000,000.00	660	660	industrial 3D printer is of 1000 x 700 x 700 mm.
	LASERTEC 65 3D	.1016	\$250,000.	00 \$1,000,000.00	351	. 500	
	LENS 850-R	.025	\$500,000.	\$999,999.00	900	900	The BeAM CLAD Unit is based on the CLAD technology
	Magic	.2	\$1,000,000.	00 \$2,000,000.00	800	800	(Construction Laser Additive Directe). This technical process
	M-Print	.15	\$100,000.	\$249,999.00	400	500	with a powerful laser system. This manufacturing technique i
	MYSINT300	.02	\$100,000.	\$249,999.00	300	300	also called DED (Direct Energy Denosition) and offers several
	ProX 400	.01	\$250,000.	00 \$1,000,000.00	500	500	advantages compared to other 3D metal printing techniques:
	SLM 500 HL	.02	\$1,000,000.	00 \$2,000,000.00	280	325	less raw materials are used, possibility to quickly change the
	S-Max	.28	\$1,000,000.	\$2,000,000.00	700	1000	printing material and the ability to repair metal parts.
	S-Print	.28	\$500,000.	\$999,999.00	400	500	
*			\$0.	00 \$0.00	0	0	

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.

Conventional Manufo	acturing		
What is the standard per part cost?		Cost to produce using 3D printing	
Does it include depreciation?	~	Cost per part using 3D printing	
If not, please include it's remaining depreciation/part		Cost to produce using conventional manufacturing	
Does this include setup cost?	~	Lead time head start of 3D printing	
If so, what is the setup cost?		in days	
What is the lead time to make the specified # of parts? (days)	Calculate	(If negative, conventional is better)	

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 (mm<sup>3</sup>/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 22hour 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

<sup>1</sup>this multiplier is to account for overhead costs <sup>2</sup>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.

3D Printing		Convent	ional Manufa	acturing		
What is the size of your part?	Number of Parts to be produced	200 What is the	standard per part	\$1.00	Cost to produce using 3D printing	\$19.97
Largest Dimension (mm) 400 Second largest 150	Select type of metal Alun	minum 💌 Does it inclu	de depreciation?	No	Cost per part using 3D printing	\$0.05
Dimension (mm)		If not, ple remaining (	ase include it's lepreciation/part	\$0.00	Cost to produce using conventional manufacturing	\$300.00
Smallest dimension (mm) 100		Does this ir	nclude setup cost?	No 🔻	Lead time head start of 3D printing	1.9625046869
Smallest Thickness (mm) 4		If so, what	is the setup cost?	\$100.00	in days (If negative, conventional is better)	
Weight of Part (grams) 200	Run Query	the specifie	d # of parts? (days)	Calculate		
Please select a 3D printer from the list. If	none are listed, no 3D printers meet y	your stated specs.		·	Descriptio	on
Z Title -	Min_Thickness(mm) - Price	e Min 👻 Price Max 👻	Min_Dimens - Mid	l_Dimens ▼ 🔺	The BeAM CLAD Unit is a professio	nal 3D printer made in France
CLAD Unit .2	\$250	0,000.00 \$1,000,000.00	/00	/00	(Alsace) by BeAW. This 3D printer v	The BeaM CLAD Unit is
EOS M 400 .09	\$1,000	0,000.00 \$2,000,000.00	400	400	capable of operating on 3 up to 5 a	vis. The build volume of this
Exerial .28	\$1,000	0,000.00 \$2,000,000.00	/00	1200	industrial 3D printer is of 1000 x 70	0 x 700 mm.
LASERTEC 4300 3D .10	16 \$250	0,000.00 \$1,000,000.00	660	660		
LASERTEC 65 3D .10	5250	0,000.00 \$1,000,000.00	351	500	The BeAM CLAD Unit is based on the	ne CLAD technology
LEINS 850-R .02	5 5500	0,000.00 \$999,999.00	900	900	(Construction Laser Additive Direct	e). This technical process is
Magic .2	51,000	0,000.00 \$2,000,000.00	250	250	capable of melting and projecting r	netal powder on a surface
Markila CLAD	3250	0,000.00 \$499,999.00	250	250	with a powerful laser system. This	manufacturing technique is
MODIle CLAD .1	\$250	0,000.00 \$499,999.00	250	250	also called DED (Direct Energy Dep	osition) and offers several
	\$100	0,000,00 \$249,999,00	400	300	less raw materials are used possib	ility to quickly change the 2D
Drox 400	\$100	0,000.00 \$249,999.00	500	500	printing material and the ability to	renair metal parts
ProX DMP 320	\$250	0,000,00 \$1,000,000.00	275	300	printing indicenting and the dointy to	opan metar partsi
SLM 500 HI 02	\$1.000	0,000,00 \$1,000,000,00	275	325		
S-May 29	\$1,000	0,000,00 \$2,000,000.00	280	1000		
C-Drint 29	\$1,000	0,000,00 \$2,000,000.00	100	500 -		
Record: H 4 1 of 18 + H +KI T No Filt	er Search 4	1999 999 (8)	44117	Þ		

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.

3D Printing			<u>Convent</u>	ional Manuf	acturing		
What is the size of your pa	art? Number of Parts	to be produced 200	What is the	standard per part	\$1.00	Cost to produce using 3D printing	\$1,686.34
Largest Dimension (mm)	400			cost?		Cost por part using 2D printing	69.42
Second largest	Select type	of metal Aluminum	<ul> <li>Does it inclu</li> </ul>	de depreciation?	Yes 🗸	Cost per part using 50 printing	\$0.45
Dimension (mm)	150		If not, ple	ase include it's	\$0.00	Cost to produce using	\$300.00
Construction (construction)			remaining o	lepreciation/part		conventional manufacturing	
Smallest dimension (mm)	100		Does this ir	nclude setup cost?	No 🗸	Load time head start of 2D printing	0.3554386600
			If so what	t is the setup cost?	\$100.00	in days	0.2554380099
Smallest Thickness (mm)	0.4		11 30, What	is the setup cost:	\$100.00	(If negative, conventional is better)	
Weight of Part (grams)	200	Run Query	What is the	d # of parts2 (days)	2		
			the specifie	u # of parts: (uays)	Calculate		
Bloace coloct a 2D printer from th	and the second	a 2D printers maat upur statu	ad an and		ii		
Flease select a 5D printer from ti	he list. If none are listed, no	o op printers meet your state	su specs.			Description	n
Title	Min Thickness(	mm) • Price Min •	Price Max •	Min Dimens - Mic	d Dimens 🗸 🔺	Description The BeAM CLAD Unit is a profession	n al 3D printer made ir
Z Title S-Titanium	Min_Thickness(     .03	mm) • Price Min •t \$0.00	Price Max • \$49,999.00	Min_Dimens • Mic 150	d_Dimens • • 150	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer wa	n Ial 3D printer made ir as design to repair or
Title S-Titanium S-Titanium Pro	Min_Thickness(r .03 .03	mm)   Price Min	Price Max • \$49,999.00 \$49,999.00	Min_Dimens • Mid 150 200	d_Dimens ▼ ▲ 150 200	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer wa new metal parts of great dimension	n Ial 3D printer made ir as design to repair or s. The BeAM CLAD U
S-Titanium S-Titanium Pro M-Print	Min_Thickness(     .03     .03     .15	mm)   Price Min +t \$0.00 \$0.00 \$100,000.00	Price Max • \$49,999.00 \$49,999.00 \$249,999.00	Min_Dimens - Mid 150 200 400	4_Dimens ▼ ▲ 150 200 500	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer wu new metal parts of great dimension capable of operating on 3 up to 5 ax	n Ial 3D printer made ir as design to repair or s. The BeAM CLAD U ris. The build volume
Title S-Titanium S-Titanium Pro M-Print MYSINT300	Min_Thickness(     .03     .03     .15     .02	mm)   Price Min +t \$0.00 \$0.00 \$100,0000.00 \$100,000.00 \$100,000.00 \$100,000.00 \$100,000.00 \$100,000.00 \$100,0000.00 \$100,0000.00 \$100,0000.00 \$100,0000000 \$100,0000000 \$100,	Price Max • \$49,999.00 \$49,999.00 \$249,999.00 \$249,999.00	Min_Dimens • Mio 150 200 400 300	d_Dimens ▼ ▲ 150 200 500 300	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer w. new metal parts of great dimension: capable of operating on 3 up to 5 as industrial 3D printer is of 1000 x 700	n aal 3D printer made ir as design to repair or s. The BeAM CLAD U cis. The build volume 9 x 700 mm.
S-Titanium S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D	<ul> <li>Min_Thickness(r)</li> <li>.03</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> </ul>	mm)  Price Min + \$0.00 \$0.00 \$100,000.00 \$100,000.00 \$250,000 \$250,00	Price Max <ul> <li>\$49,999.00</li> <li>\$49,999.00</li> <li>\$249,999.00</li> <li>\$249,999.00</li> <li>\$1,000,000.00</li> </ul>	Min_Dimens • Mio 150 200 400 300 660	d_Dimens ▼ ▲ 150 200 500 300 660	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer w. new metal parts of great dimension capable of operating on 3 up to 5 as industrial 3D printer is of 1000 x 700 The BeAM CLAD Link is based on the	n al 3D printer made ir as design to repair or s. The BeAM CLAD U cis. The build volume x 700 mm.
Title S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D	<ul> <li>Min_Thickness(r .03</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.1016</li> </ul>	mm)      Price Min +t     S0.00     \$100,000.00     \$100,000.00     \$250,000.00	Price Max • \$49,999.00 \$49,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00	Min_Dimens • Mia 150 200 400 300 660 351	4_Dimens • 150 200 500 300 660 500	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer wi- new metal parts of great dimension capable of operating on 3 up to 5 as industrial 3D printer is of 1000 x 700 The BeAM CLAD Unit is based on the Construction Laser Additive Directo	n al 3D printer made in as design to repair or s. The BeAM CLAD U dis. The build volume ix 700 mm. e CLAD technology of This technology
Title S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit	<ul> <li>Min_Thickness(t)</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.2</li> </ul>	mm)      Price Min et Volt state mm)      Price Min et     S0.00     S0.00     S100,000.00     S100,000.00     S250,000.00     S250,000     S2	Price Max - \$49,999.00 \$49,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00	Min_Dimens - Mid 150 200 400 300 660 351 700	4_Dimens • 150 200 500 300 660 500 700	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer w. new metal parts of great dimension capable of operating on 3 up to 5 as industrial 3D printer is of 1000 x 700 The BeAM CLAD Unit is based on the (Construction Laser Additive Directe capable of melting and projecting m	n al 3D printer made in as design to repair or s. The BeAM CLAD U dis. The build volume ix 700 mm. e CLAD technology of LAD technology of this technical proc
Title S-Titanium S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit Mobile CLAD	<ul> <li>Min_Thickness(t)</li> <li>.03</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.1016</li> <li>.2</li> <li>.1</li> </ul>	Sol printers inter your state           mm)         Price Min. +t           \$0.00         \$0.00           \$100,000.00         \$100,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00	Price Max  \$49,999.00 \$49,999.00 \$49,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$499,999.00	Min_Dimens • Mia 150 200 400 300 660 351 <b>700</b> 250	A_Dimens ▼ ▲ 150 200 500 300 660 500 700 250	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer w. new metal parts of great dimension: capable of operating on 3 up to 5 as industrial 3D printer is of 1000 x 700 The BeAM CLAD Unit is based on the (Construction Laser Additive Directer capable of meting and projecting m with a powerful laser system. This n	n ial 3D printer made ir as design to repair or s. The BeAM CLAD U dis. The build volume I x 700 mm. e CLAD technology c). This technical proc retal powder on a sur nanufacturine techni distance technical proc technical proc t
Title S-Titanium S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit Mobile CLAD ProX 400	<ul> <li>Min_Thickness( .03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.1016</li> <li>.2</li> <li>.1</li> <li>.01</li> </ul>	Stoppinters         Interviou         Status           mm)         Price Mini         +         \$0.00           \$0.00         \$0.00         \$0.00         \$20,000.00         \$250,0	Price Max • \$49,999.00 \$49,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$499,999.00 \$1,000,000.00	Min_Dimens • Mia 150 200 400 300 660 351 <b>700</b> 250 500	4_Dimens ▼ ▲ 150 200 500 300 660 500 700 250 500	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer w. new metal parts of great dimension: capable of operating on 3 up to 5 as industrial 3D printer is of 1000 x 700 The BeAM CLAD Unit is based on th (Construction Laser Additive Directe capable of melting and projecting m with a powerful laser system. This m also called DED (Direct Energy Depo	n al 3D printer made in as design to repair or s. The BeAM CLAD U dis. The build volume tx 700 mm. e CLAD technology child technology this technical proc retal powder on a sur nanufacturing technic sition) and offers sev
Title S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit Mobile CLAD ProX 400 ProX MDP 320	<ul> <li>Min_Thickness(i)</li> <li>.03</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.1016</li> <li>.201</li> <li>.01</li> <li>.03</li> </ul>	Stoppinters         Intervious Status           mm)         Price Min         +           \$0.00         \$0.00         \$0.00           \$100,000.00         \$100,000.00         \$250,000.00           \$250,000.00         \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00         \$250,000.00	Price Max • \$49,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00	Min_Dimens • Mia 150 200 400 300 660 351 <b>700</b> 250 500 275	4_Dimens	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer w. new metal parts of great dimension capable of operating on 3 up to 5 as industrial 3D printer is of 1000 x 700 The BeAM CLAD Unit is based on the (Construction Laser Additive Directe capable of melting and projecting m with a powerful laser system. This m also called DED (Direct Energy Depo advantages compared to other 3D n	n al 3D printer made in as design to repair or s. The BeAM CLAD U dis. The build volume l x 700 mm. e CLAD technology of LAD technology of this technical proce- cetal powder on a sur ananufacturing technic sition) and offers sev- netal printing technic
Title S-Titanium Pro S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit Mobile CLAD ProX 400 ProX 400 ProX DMP 320 M-Flex	<ul> <li>Min_Thickness(i)</li> <li>.03</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.1016</li> <li>.2</li> <li>.1</li> <li>.01</li> <li>.03</li> <li>.15</li> </ul>	Stoppinters         Intervious State           mm)         Price Min         +           \$0.00         \$0.00         \$0.00           \$100,000.00         \$100,000.00         \$250,000.00           \$250,000.00         \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00         \$250,000.00	Price Max • \$49,999.00 \$49,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00	Min_Dimens • Mia 150 200 400 300 660 351 700 250 500 275 250	▲ Dimens ▼ ▲ 150 200 500 500 500 700 250 500 250 500 275 250	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer w. new metal parts of great dimension. capable of operating on 3 up to 5 as industrial 3D printer is of 1000 x 700 The BeAM CLAD Unit is based on the (Construction Laser Additive Directe capable of melting and projecting m with a powerful laser system. This n also called DED (Direct Energy Depo advantages compared to other 3D n less raw materials are used, possibil	n al 3D printer made in as design to repair or s. The BeAM CLAD U dis. The build volume to X 700 mm. e CLAD technology ch. This technical proc etal powder on a sur anufacturing technic sition) and offers sev netal printing technic ty to quickly change
Title S-Titanium S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit Mobile CLAD ProX 400 ProX DMP 320 M-Flex LENS 850-R	<ul> <li>Min_Thickness(i)</li> <li>.03</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.1016</li> <li>.2</li> <li>.1</li> <li>.01</li> <li>.03</li> <li>.15</li> <li>.025</li> </ul>	SD printers inter your state           mm)         Price Min +t           \$0.00         \$0.00           \$100,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00	Price Max • \$49,999.00 \$49,999.00 \$249,999.00 \$1,000,000.000,000.000 \$1,000,000,000.000,000,000.000,000,000,00	Min_Dimens • Mii 150 200 400 660 351 <b>700</b> 250 500 275 250 900	4_Dimens       150     150     200     500     300     660     500     700     250     500     275     250     900	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer w. new metal parts of great dimension. capable of operating on 3 up to 5 as industrial 3D printer is of 1000 x 700 The BeAM CLAD Unit is based on th (Construction Laser Additive Directe capable of metting and projecting m with a powerful laser system. This m also called DED (Direct Energy Depo advantages compared to other 30 n less raw materials are used, possibili printing material and the ability to rr	n al 3D printer made ir as design to repair or s. The BeAM CLAD U sis. The build volume i. x 700 mm. e CLAD technology ). This technical proc etal powder on a su nanufacturing technic sition) and offers se netal printing technic ity to quickly change pair metal parts.
Title S-Titanium Pro S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit Mobile CLAD ProX 400 ProX 0MP 320 M-Flex LENS 850-R S-Print	<ul> <li>Min_Thickness(i)</li> <li>.03</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.1016</li> <li>.1015</li> <li>.2</li> <li>.1</li> <li>.01</li> <li>.03</li> <li>.15</li> <li>.025</li> <li>.28</li> </ul>	Sto printers inter your state           mm)         Price Min +1           \$0.00         \$0.00           \$100,000.00         \$100,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00           \$250,000.00         \$500,000.00	Price Max  - S49,999.00 S49,999.00 S49,999.00 S249,999.00 S1,000,000.00 S1,000,000.00 S1,000,000.00 S1,000,000.00 S1,000,000.00 S1,000,000.00 S1,000,000.00 S1,000,000.00 S499,999.00 S999,999.00	Min_Dimens • Mit 150 200 400 300 660 351 700 250 500 275 250 900 400	▲ Dimens ▼ ▲ 150 200 500 300 660 500 700 250 500 275 250 900 500	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer w. new metal parts of great dimension capable of operating on 3 up to 5 as industrial 3D printer is of 1000 x 700 The BeAM CLAD Unit is based on the (Construction Laser Additive Directe capable of melting and projecting m with a powerful laser system. This m also called DED (Direct Energy Depo advantages compared to other 3D n less raw materials are used, possibili printing material and the ability to re-	n al 3D printer made in as design to repair or s. The BeAM CLAD U dis, The build volume by 700 mm. e CLAD technical proc etal powder on a sur anrufacturing techni sition] and offers see netal printing techni tiy to quickly change epair metal parts.
Title S-Titanium Pro S-Titanium Pro M-Print MYSINT300 LASERTEC 4300 3D LASERTEC 65 3D CLAD Unit Mobile CLAD ProX 400 ProX 400 ProX 0MP 320 M-Flex LENS 850-R S-Print SLM 500 HL	<ul> <li>Min_Thickness(i)</li> <li>.03</li> <li>.03</li> <li>.15</li> <li>.02</li> <li>.1016</li> <li>.1016</li> <li>.2</li> <li>.1</li> <li>.01</li> <li>.03</li> <li>.15</li> <li>.025</li> <li>.28</li> <li>.02</li> </ul>	SD printers         Ineer Your State           mm)         Price Min         +           \$0.00         \$0.00         \$0.00           \$100,000.00         \$100,000.00         \$250,000.00           \$250,000.00         \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00         \$250,000.00           \$250,000.00         \$250,000.00         \$250,000.00           \$500,000.00         \$500,000.00         \$500,000.00           \$500,000.00         \$500,000.00         \$1,000,000.00	Price Max - \$49,999.00 \$49,999.00 \$249,999.00 \$249,999.00 \$1,000,000.00 \$1,000,000.00 \$1,000,000.00 \$499,999.00 \$1,000,000.00 \$1,000,000.00 \$249,999.00 \$299,999.00 \$29,000,000.00	Min_Dimens • Mii 150 200 400 300 660 351 700 250 500 275 275 275 250 900 400 280	4_Dimens × 150 200 500 300 660 500 250 250 500 275 250 900 500 325	Description The BeAM CLAD Unit is a profession (Alsace) by BeAM. This 3D printer w. new metal parts of great dimension capable of operating on 3 up to 5 as industrial 3D printer is of 1000 x 700 The BeAM CLAD Unit is based on the (Construction Laser Additive Directe capable of melting and projecting m with a powerful laser system. This m also called DED (Direct Energy Depo advantages compared to other 3D m less raw materials are used, possibili printing material and the ability to re-	n al 3D printer made in s design to repair or s. The BeAM CLAD U dis. The build volume to X 700 mm. e CLAD technology the technology the technology the technology and a differs see netal printing technic sition] and offers see netal printing technic sition and offers see netal printing technic ty to quickly change epair 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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- 75mm/dp/B00VIW6OD6
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- 1lbs/dp/B017SGCWYK
- Bronze filament cost
- https://www.amazon.com/Gizmo-Dorks-1-75mm-Filament-Printers/dp/B016996EEQ

## Appendix

### Item 1: Table Design

Printers	
Z 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	í.
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	6
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	1
ProX DMP 200	3D Systems	Powder	Metal	.005	\$250,000	\$1,000,000		125	140	140		The 3D Systems ProX DMP	1
ProX DMP 300	3D Systems	Powder	Metal	.005	\$250,000	\$1,000,000		250	250	330		The 3D Systems ProX DMP	4
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	Π	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	Π	The Concept Laser Mlab ci	
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 4	
LASERTEC 65 3D	DMG Mori	Extrusion	Metal	.1016	\$250,000	\$1,000,000		351	500	500		The DMG Mori LASERTEC (	i i
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	
Record: H < 1 of 73	No Filter	Search	Motal 4	1	\$500.000	\$000 000		250	250	225	Ē	The FOS M 200 is an indus	Ť

#### 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 1b As Double
    If Me.Combo66.Value = "Aluminum" Then
        v = 0.0027
        lb = (26.99 / 500)
    ElseIf Me.Combo66.Value = "Steel" Then
       y = 0.0079
        1b = (58 / 500)
    ElseIf Me.Combo66.Value = "Brass" Then
       y = 0.0084
        1b = (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
```