PROCESS TESTING AND IMPROVEMENT OF TAPPING MACHINERY

AT LISI AEROSPACE

A Senior Project submitted

As part of the Requirements for the Degree

Of Bachelor of Science in Industrial Engineering

By:

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Introduction

This report documents my senior project for California Polytechnic State University San Luis Obispo. I have chosen to do a senior project with Lisi Aerospace. Lisi is a French corporate group that has roots in many industries. The group started in 1777 as a family factory in Montbéliard, France. Two other family owned firms joined the previous one to form GFD in 1968. Through the combined assets of the three firms, GFD vaulted to the top position in the manufacture of nuts, pins and bolts in the fledgling auto industry. Through strategic acquisition and maneuvering, GFD expanded to own over 15 different firms across France and the US by 2000 (8). The group now has holdings in the automotive, aero, and medical sectors. Lisi Aerospace was born of this conglomerate when the group reorganized by business sector in 2002. Lisi aerospace brings 230 years of experience in the production of the highest quality aircraft fasteners.

I found myself in a summer internship at Lisi after cold calling engineering firms in the Torrance area. I was placed into the purchasing department as a short term replacement of a senior buyer who had decided to leave the company. This position allowed me to obtain a sweeping overview of the company in Torrance. The purchasing department is involved in every part of the fastener production business. The process starts with an order coming in to our sales engineers. Purchasing is then informed to buy the required materials. Receiving gets the material and places it in inventory until the machines are ready to process it. The material makes the journey to the production floor and is refined into useable parts. It is in this area that my research takes place. At the end of the manufacturing cycle is tapping, where circular threads are added to the finished nut, bolt, or pin. Lisi would like to compare the manufacturer rated cycle count of taps versus an experimental one based on our machines in house. My goal for this project would be to run an experiment on one tapping machine and report on the achievable cycle count for the taps. I plan to do this in several ways including:

- Running extra cycle counts above tap manufacturer recommendations
- Documenting machine failure modes
- Create a process document to be repeated on other parts

My solution approach shall be based on these objectives. I have determined a process to work with machinist staffing to run cycle count experiments without affecting production. The machine is reset without changing the tap and I test parts every 50 cycles. I reduce the interval of testing when the tap nears extended life limits. When the tap finally fails pictures are taken of both the tap and part that indicated failure. These annotations and photos will be complied for management to review and make a decision on how far to extend the use of the taps.

A document detailing this experimental process will be created. This will include documentation of part/tap failures, machine failures and any other data that needs to be recorded about the production run. Many different aspects of the batch will be covered such as: material, tap material, tap maker, part produced, and tooling setup used.

A literature review shall be conducted to gain insight into the problem and factors involved. I will be reviewing literature on the history of tapping, current tap machinery, and materials engineering. These topics will give the necessary knowledge to complete the above objective for Lisi. Both print and electronic sources will be consulted. My deliverables to Lisi include:

- Documentation of experiment
- Documentation of machine/part/tap failures
- Recommendation for extension of tap life

Background

The following summarizes the tapping processes, as well as current systems used by Lisi.

Tapping

The specific process I am working with is how and when the taps are replaced. Taps are kept on the machine that is running them and are replaced on a cycle count. The tapping machines use numeric control system; a system to both control the machines and gather data about production. Each machine is set up differently depending on what type of nut is being manufactured. I chose to gather data on a specific Boeing part to minimize variation in recording the data. Three out of the six tapping machines in the area were set up to cover a blanket order of this part, so it was one of the better options for process improvement. The data acquired on this part and machine would then be replicated and applied to other areas to reap cost savings across the entire production line.

One of the key aspects of this experiment is that it does not require the base procedures of running the tapping machines to be changed. By experimentally determining when the tap fails on a per product basis, resources get more tap use with the same unit cost. Reading the personal account of Goldratt in "The Goal" which details his company's process improvement efforts gave me an idea on how to run the experiment (5). Lisi has been thinking about making these changes, but has not been able to test this improvement due to constant shifts in staff.

Processes

Experiment

1. Run the tap for 200 cycles; make sure no errors occur
2. Reset the cycle count on the machine
3. Run the machine over the 200 cycle count on the tap
4. Test the parts every 50-100 cycles
5. When an error occurs document it and take pictures
6. Record data for management review

Figure 1: A broken tap due to incorrect tap replacement

The photo above in Figure 1 is one of the end results of the experiment; both pictures and an explanation of what went wrong. This data will be complied so that management can decide if extending tap life is feasible.

Tap Replacement

1. Machine stops and informs tech of tap expiration
2. Spindle is raised
3. Last part is checked
4. Chuck loosened
5. Tap is taken out and replaced with new tap
6. Spindle is lowered
7. First 5 new parts tested to insure quality

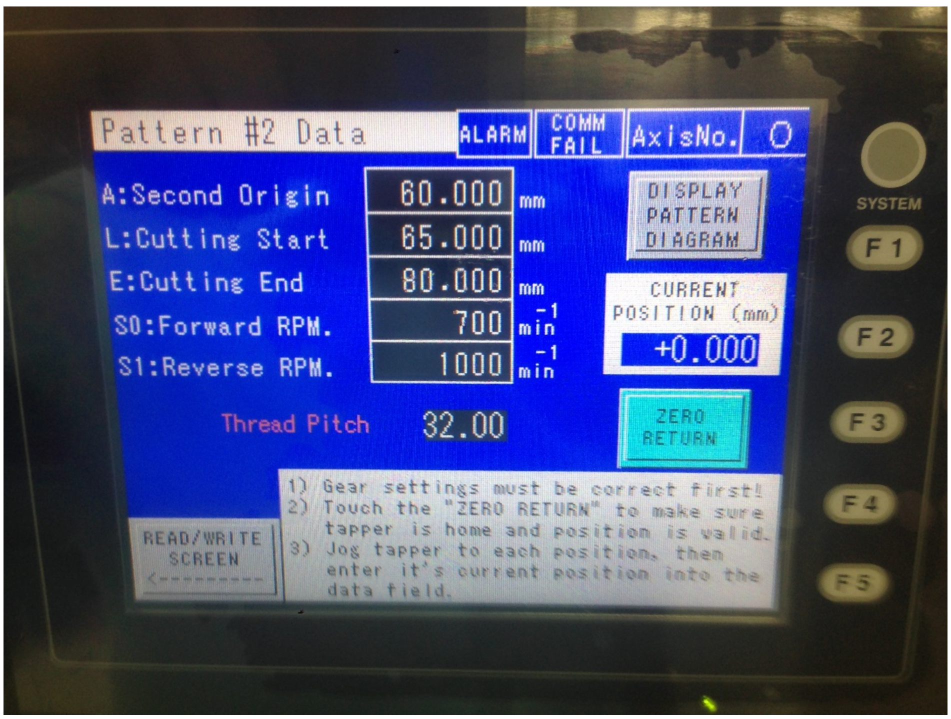

Figure 2: Control software detailing tap cutting information

Literature Review

Tapping Machine

This source concerns the tapping machine itself. It is concerned with the change over from manual tapping in machining centers to automated tapping. Before automated machinery could tap reliably most machine tapping was done by hand. The machinists would get a product that had been partially started by the production floor and finish the tapping on the holes in the product. This was achieved by turret drills and hand loading. This process was time consuming and required a large number of turret drills to have the proper production scale. The solution to this issue was automation of the process (4). Numeric control machines (N/C) were created to speed up the process and reduce the number of machines needed to do the same task. The new machines came with several issues however. The same technique of tapping was being used to run the new N/C machines. This method involved reversing the spindle that held the tap to get the tap out of the part. Stresses within the part and the materials limited the speed at which the spindle could spin to operate safely on the part. This is where the articles' research comes in. To solve the speed problem imposed by reversing back and forth the new N/C machines were fitted with a gear train that could flip the direction of the tap assembly without reversing the spindle of the machine. This technology brought the tapping speed from 200 up to 5000 rpm for 17-4 PH stainless steel, 300 series stainless steel, and 6061 T6 aluminum(3). This new speed allowed for increased productivity, reduced flow time, and reduced rework and scrap parts.

The tapping process I am currently studying makes use of this type of set up. This gave me additional insight into how the speeds are chosen by tap manufacturers. This research also noted a range of speeds that could be tested with the parts being made at Lisi. This information will allow me to work with engineers at Lisi to better determine the best operating procedures for the part under study.

Set Up

For this project I observed a Sugino ST3 servo tap head. The machine outside the tapping head, however, only siphons the parts into the chamber to be tapped. Then tapping mechanism takes over. This particular part has a +/- 0.03 mm tolerance. The rotation speed could be set up to 4000 rotations per minute (12). This tolerance and speed allows for parts to be tapped at 9-14 parts per minute.

The tapping mechanism was the piece of machinery that I spent the most time with. The tap had to be aligned, locked in and tested before the parts could be run on the machine. These steps were normally taken by the production staff in the morning. I observed the set up process over 4 weeks and saw varying results. Most of the time the tap setup would go smoothly and production would resume from the night shift. But I found that three things could go wrong with the setup. The first error was the height that the tapping head had to move between to hit the parts at the right point (11). This resulted in parts with unfinished threads or parts being knocked out of the tapping tooling. The solution was to observe the readings on the machine relative to its defined zero origin and adjust the height settings.

The second error that could occur was with the alignment of the tap head (11). The head had to align with the part and face straight down in 3D space. This problem was harder to diagnose and fix. The parts would come out of the machine and not pass the thread and thickness pass/fail tests. The solution was to measure the tiny gap distances from the connection of the tap head to the rest of the mechanism. Next, if the measurements came back and showed errors the head would be loosened, adjusted and re-tested.

The third error that could occur with the tap head was the tooling (11). There were two types of tooling used in the machines' setup. One was circular that restrained the part vertically but not rotationally. The other was hexagonal tooling that restrained the part rotationally and vertically. The project was started using the circular tooling, but Lisi acquired the shipment of hexagonal tooling several days after I started observing the process. The two were tested against each other on the same machine and the hexagonal tooling setup yielded more parts that were within tolerance, fit and caused less tap breakages.

If all three of these errors are mitigated, the production process will yield the most parts per tap use. To account for all of these errors in the experiment the same machine was used with the same operator and set up. The setup of the machine was also checked every time that I ran the tap experiment. All of these factors were considered in determining if the baseline manufacturer recommendation of 200 cycles per tap was reasonable.

Quality

After testing the parts in the physical setup and coming to the conclusion that tap life could not be increased due to non-conforming parts, I decided to look into what quality applications were being used by this part of the process. I traveled back to Lisi to talk with Eric Cohen, the engineer I worked with to run the tap study. Since so many of the parts were produced and tapped in this part of the factory, the majority of quality control checkpoints were after completing this stage of the production process. I then toured sections of the production line that were focused on quality control (QC). I visited the both the QC center and machine visual inspection area. Both of these sections played a part in quality of the parts coming into the tapping process.

Quality Control Center

The quality control center is located in the middle of the Lisi production facility and is busting with people in white lab coats, safety glasses, and measuring devices. The quality control center is Lisi's response to the emergence of lean systems in their industry and is the hub of efforts to increase end part quality across all production lines (9). All of the quality inspection of tools and parts goes on in this small area. Final inspection is one of the last and most important steps before shipping the parts to the customer. Around 16 quality engineers are employed do this task. In the specific case of the Boeing part in the tap study the shape, diameters, length, and coating was checked by the engineer. However, this is part of the problem mentioned above, this stage comes after tapping. If part of inspection could occur directly after the parts were produced but before reaching the tapping process quality of the parts could be improved, thus making it easier to increase tap life. Also related to the inspection of parts is the tooling to do so. This came in the form of Go/No-go gauges that would be inserted or screwed into the parts after tapping. This tooling was important to judge the results of the tap experiment because it determined if the threads on the part were of the correct pitch and count, and also determined if the diameter was correct of the hole the threads resided in. The quality control center played the part of making sure that the tooling had the correct tolerances. To ensure that I was using accurate tooling, I took my devices to the QC center several times throughout the study. The QC center measures tooling with a laser super micrometer. This device has resolution down to the millionths of inches. All tooling used in my study was validated by this machine and within tolerance.

Visual inspection machine

After visiting the QC center I looked for a mechanism that could be used to improve the quality of parts that came to the tapping area. One solution that I found onsite was a visual inspection machine. This machine takes a number of photos of a part at once from different angles then compares it to a standard in tolerance picture and determines if the part is good or not. The abilities of this machine are briefly reviewed in the photo below (14).

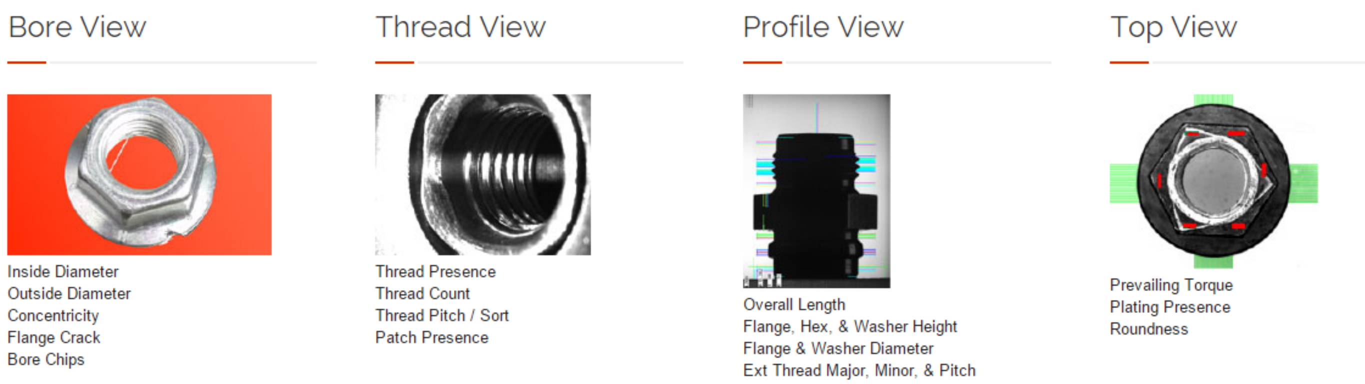

Figure 3: Visual inspection machine capabilities

The machine used at Lisi is a Retina Systems Inc. model 32x turnkey visual inspection system (14). Lisi incorporated this machine into its production line because it can do 100% visual inspection on parts and can do so very quickly. Since this machine can view the thread and top areas of a part, which is where most of the errors occurred in my study, this machine could be leveraged both after and before the parts are tapped. An example of this would can be seen from the error data I took during the study. Below is a picture of a defective part and the screen of the top view of a good part.

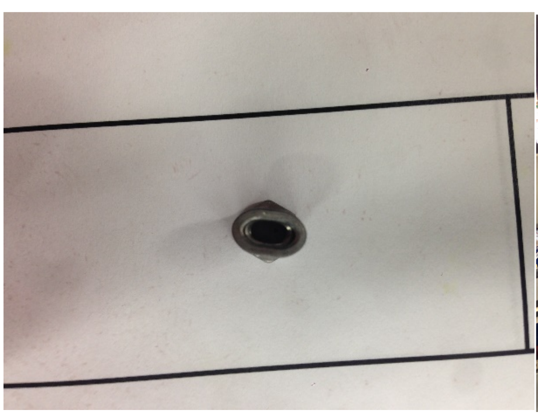

Figure 4: Broken part

Figure 5: Visual inspection machine display

100% visual inspection would have caught this error and insured that only good parts are coming into the tapping area to be processed.

Cost Analysis

Even though the initial project study did not yield successful results, a cost and benefit analysis would still be prudent for future project opportunities. This analysis compares several different things including the costs of the tap purchasing, the depreciation on the machine to be purchased, and employee wages. I will go through several interlocking calculations to determine the total cost of the savings of tapping process studied and compare it to the cost of implementing new quality control measures to enhance the process. The numbers used in the following calculations were obtained by personal interview with Eric. First, and foremost, is the cost of buying the taps themselves. Taps generally cost from $10-$15. In the chart below tap costs are calculated with a high and a low value ($10 or $15). The cumulative number of taps purchased is also show for perspective.

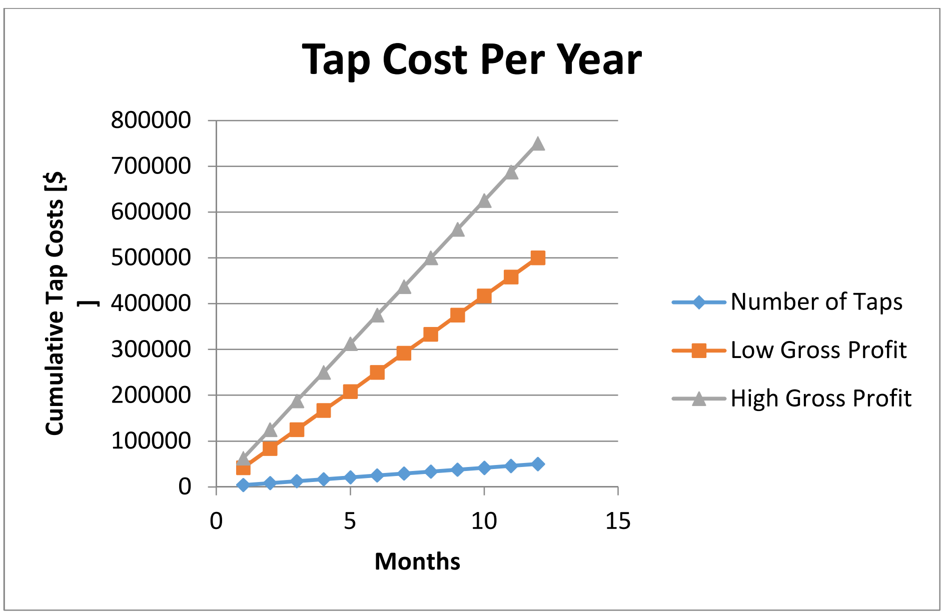

Figure 6 Cumulative tap costs based on 1 year

Next we can consider costs incurred by workers running the machines in the facility. Since the facility operates on a 24 seven basis we will use those hours for our calculations. Workers running the tapping machines and the photo quality machines both get $20 per hour as wages. The chart on the next page is an Excel calculation detailing the total cost of all workers working the process studied. The data is based on this formula:

$$\frac{24\ Hours}{Day} * \frac{7\ Days}{Week} * \frac{50\ Weeks}{Year} = 2{,}016{,}000$$

Worker Wages

Month	Hours	Wages
1	2016	40320
2	4032	80640
3	6048	120960
4	8064	161280
5	10080	201600
6	12096	241920
7	14112	282240
8	16128	322560
9	18144	362880
10	20160	403200
11	22176	443520
12	24192	483840

Depreciation	
Cost	110000
Salvage	10000
Life	10
Period	5

Table 1: Supporting cost calculations in Excel

Finally, the calculations for depreciation of the new photo quality machine to be purchased by Lisi. I made several assumptions in the calculation. I assumed that the life of the product would be 10 years and that the product will be depreciated over five years. The machine will depreciate around $9000 over a five-year period. All the different data can then be combined to find the cost of a tap cycle increase over five years.

$$Average\ Tap\ Savings\ (\$625{,}000 - \$178{,}571) * 5 - (Worker\ Wages\ \$483{,}840 * 5) - Machine\ investment\ 110{,}000 + Salvage\ Value\ \$10{,}000 + Depriciation\ \$9{,}000 = -\$278{,}044$$

Equation 1: Tap cost savings VS visual inspection machine & employee costs

The above calculation shows that the average tap savings of $446,429 per year does not directly cover the cost of hiring more employees to run the new photo quality machine. It would not be possible to justify the purchase of the new machine solely based on savings coming from running taps for more cycles.

Methods

The main method for determining tap life in the experiments was the creation of the document that would record all the information related to the experiment (7). This document would need to have input from both engineering and production line staff to encompass all aspects of the end result of the study. I divided the process of making the document into three stages:

- Rough draft
- Engineering Input
- Production Input

The first stage was the initial attempt to visualize a way to easily record and input various machine data related to the experiment. The production floor is a messy and dangerous place; also not computer friendly. The only computers present on the floor are those connected to the machines to run them. They did not have the capability to run a data input/collection program like Excel that I could manipulate. The reason Excel was to be used, rather than the central network that machines posted data to, was that much of the information posted on the network was not specific enough. The machines could tell how many cycles they went through at what power but could not show the parts made on each one. Also basic details like what kind of tap was used could not be determined. The first draft can be viewed in Figure 7.

Machine	7672
Tap	10-32 H6 Plug TiN

Vendor	
Dimensions	
Thread #	

Style	Hex	Cirular
Holder	Free	Solid

Condition

Error	
Notes	

Figure 7: First draft of data recording document for tap study

Second, the input from the engineering department of Lisi was taken into account. Many data columns were added to be more specific to each part and to account for possible factors affecting tap life. The MO column is the manufacturing order that the parts were being made on. This is important to be able to track order splits of parts, a very common and wasteful part of production. Matl was the specific metal that the parts were being made of. This was added because of the large number of alloys Lisi is forced to use to make the end products customers want. # of Cycles, Date and Time were added at the top of the document to simplify the Notes section and allow for easier viewing of critical data. Dimensions were taken off the chart due to displaying repetitive data. This version can be seen in Figure 8.

Machine			MO	
Tap			Matl	
	Vendor		# Cycles	
			Date	
	Thread #		Time	
Tooling				
	Style	Hex Circular		
	Holder	Free Solid		
Condition				
	Error			
	Notes			

Figure 8: Second draft of data recording document for tap study

Finally the version used for the majority of the experiment was created with input from production staff. A large area to display the part being manufactured was added to clarify different parts being tapped with the same thickness taps. Dimensions were added back in to highlight the specific tolerances that the tap adhered to. It also was more readable because the long tap title did not have to be consulted every time to determine the tap measurements. The final version in Figure 9 is a sample from data taken during the experiment.

Machine	**7688**		**MO**	8118459
Tap	**11015 10-32 H6 3S/P Plug TiN**		**Matl**	1407253558
	Vendor	HY-Pro-Aero	**# Cycles**	725
	Dimensions	10-32 H6	**Date**	8/12/2014
	Thread #	1101501805	**Time**	4:00pm
Tooling	**Style**	**Hex** Circular	BACC30AB65	
	Holder	**Free** Solid		
	Vert Mvmnt	**Yes** No		
Condition	**Errors**			
	Notes	Tap wore out; parts out of tolerance produced, pictures not taken		

Figure 9: Final draft showing sample data taken during the experiment

Results and Discussion

Throughout the experiment the data was not as expected. The initial study of if the taps could be set to greater cycle counts resulted in more questions than answers. Data showed that bad parts, instead of vendor settings, were the main cause of tap failure. Out of 10 test runs taken, 8 taps failed due to part issues. There were many different types of part failures from small incomplete holes, to bent parts. Since the test data was so difficult to obtain with production going at full bore 24/7 there was no trend to the types of errors witnessed in the experiment. Upon examining quality measures in place to filter bad parts before reaching the tapping area, none were found. Most of the important quality checkpoints occurs after the tapping process.

The process can be changed to incorporate quality measures to insure that both the parts and taps are being used to the most potential at the least cost. The cost analysis showed that the purchase of one of these machines could not be justified. However, if the profit from the increase in quality is introduced into the calculation it might change the results. On average during a year, Lisi Corporation must reject one out of every 13 lots of parts due to quality concerns (9). This means that out of be 10 million parts sold, Lisi must produce an extra 769,230 parts to have the whole 10 million part order. The one dollar lost on each of the failed lots over 5 years can easily cover the costs incurred by implementing the new quality measures. This an excellent example of considering the interactions within the whole system as opposed to looking at micro view of one of its parts.

This is only one small piece to making a large system more efficient. There are some additional problems that should be considered if the visual inspection machine is to be implemented. The production floor is already a crowded place. It would be difficult to find a space where the machine could be within the flow of parts it needs to control, yet not get in the way of other jobs going on at the factory. Also the process flow would have to be optimized to account for the extra time of transporting the parts to the machine, the machine inspecting them, and the parts moving on to the next part of the process (13). The machine also runs the risk of being reassigned to other more important jobs than taking care of this part of the process. This happens because other machines break down, the expense of running the machine, and external job pressures. All of these issues can be mitigated by intelligent factory floor design and job scheduling.

Conclusion

This project has spanned over 300 hours of work time. It started on a sunny afternoon, cold calling companies in Torrance, California and has ended the cavernous labs of Cal Poly. The original question of if taps could be optimized resulted valuable tests and data being collected. Ten runs were conducted on Sugino ST3 heads. It was found that defects in the parts were the main cause of tap failure. Since few quality assurance measures were in place before this step in the manufacturing process, solutions were examined. The visual inspection machine was one option already present in the factory being used. Cost analysis showed that an extra machine could not be purchased on savings gained by purchasing fewer taps and using them at higher cycle counts. Fortunately, there were additional savings found in the increase in quality caused by the purchase and use of the visual inspection machine. Many lots that would be internally rejected would no longer have to be because the individual bad parts would be sorted out.

Personally, I have gained experience and learned many lessons in a real world setting. I learned not to make ungrounded assumptions in my first engineering class upon coming to Cal Poly. This project has refreshed this creed and put it into actual experience. There was no professor, theory, or textbook telling me the results before the experiment. I was forced to pivot mid-way and change the focus of the research. The second lesson taken away from this project is that of revision. There were so many rough drafts, revisions, corrections, and submittals during the time this project took place. Input from as many people as possible yields an acceptable (but not perfect) final result. Finally, I learned a lesson in project scope. I faced both scope creep and being too narrow in my senior project experience. I had to balance these effects to both solve a specific problem and solve it in a defined time frame. In completing a project of this scale I have demonstrated all the knowledge and skills Cal Poly has taught me over 6 years of engineering. I can now take these skills outside of the classroom to get the job of my dreams and confidently step into adulthood.

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Appendix

Raw Data

Machine	**7688**		**MO**	8118459
Tap	**11015 10-32 H6 3S/P Plug TiN**		**Matl**	1407253558
	Vendor	HY-Pro-Aero	**# Cycles**	725
	Dimensions	10-32 H6	**Date**	8/12/2014
	Thread #	1101501805	**Time**	4:00pm
Tooling	**Style**	**Hex** Circular	BACC30AB65	
	Holder	**Free** Solid		
	Vert Mvmnt	**Yes** No		
Condition	**Errors**			
	Notes	Tap wore out; parts out of tolerance produced, pictures not taken		

Machine	**7688**		**MO**	8118626
Tap	**11015 10-32 H6 3S/P Plug TiN**		**Matl**	1407293587
	Vendor	HY-Pro-Aero	**# Cycles**	300
	Dimensions	10-32 H6	**Date**	8/20/2014
	Thread #	1101501805	**Time**	4:20
Tooling	**Style**	**Hex** Circular	BACC30AB65	
	Holder	**Free** Solid		
	Vert Mvmnt	**Yes** No		
Condition	**Errors**	Bad part caused tap failure		
	Notes	A part had a large bottom. This bottom caused the tap not to go through the part. This resulted in a chipped tap.		

Machine	**7688**		**MO**	8118459
Tap	**11015 10-32 H6 3S/P Plug TiN**		**Matl**	1407253558
	Vendor	HY-Pro-Aero	**# Cycles**	81

	Dimensions	10-32 H6	**Date**	8/12/2014
	Thread #	1101501805	**Time**	1:30
Tooling	**Style**	**Hex** Circular	BACC30AB65	
	Holder	**Free** Solid		
	Vert Mvmnt	**Yes** No		
Condition	**Errors**	Sensor alignment, bridge height		
	Notes			

The tap broke after skewring a part. Top part of the part was stripped bare; no hex

Machine	**7688**		**MO**	8118484
Tap	**11015 10-32 H6 3S/P Plug TiN**		**Matl**	1407293587
	Vendor	HY-Pro-Aero	**# Cycles**	500
	Dimensions	10-32 H6	**Date**	8/14/2014
	Thread #	1101501805	**Time**	4:15
Tooling	**Style**	**Hex** Circular	BACC30AB65	
	Holder	**Free** Solid		
	Vert Mvmnt	**Yes** No		
Condition	**Errors**	Tap was sheared off		
	Notes			

Tap was broken after a part was bent into the tooling. The next part then rammed into the tap.

Tap			Matl	1404012676
	Vendor	HY-Pro-Aero	# Cycles	200
			Date	8/7/2014
	Thread #	1101501805	Time	2:00
Tooling			Part	BACC30AB65
	Style	**Hex** Circular		
	Holder	**Free** Solid		
Condition				

	Error	
	Notes	

Machine	7688		MO	
Tap			Matl	
	Vendor	HY-Pro-Aero	# Cycles	200
			Date	
	Thread #	1101501805	Time	2:00
Tooling			Part	BACC30AB65
	Style Holder	**Hex** Circular **Free** Solid		
Condition				
	Error			
	Notes			

Machine	7687		MO	8117206
Tap			Matl	1404112747
	Vendor	Hy-Pro-Aero	# Cycles	256
			Date	
	Thread #		Time	2:00
Tooling			Part	BACC30DA8K
	Style Holder	**Hex** Circular **Free** Solid		
Condition				
	Error			
	Notes			

Machine	7670		MO	8117455
Tap			Matl	
	Vendor	Hy-Pro-Aero	# Cycles	220

			Date	
	Thread #	1101501805	Time	2:00
Tooling			Part	BACC30AB65
	Style Holder	**Hex** Circular **Free** Solid		

Condition

Error	
Notes	

Machine	7671		MO	8116833
Tap			Matl	1407033390
	Vendor		# Cycles	220
	~~Dimensions~~		Date	
	Thread #		Time	2:00
Tooling			Part	BACC30AB6A
	Style Holder	Hex Circular Free Solid		

Condition

Error	
Notes	

Machine	7672		MO	8116834
Tap			Matl	1402103458
	Vendor		# Cycles	200
			Date	
	Thread #		Time	2:00
Tooling			Part	BACC30AB6A
	Style Holder	**Hex** Circular **Free** Solid		

Condition

Error	
Notes	

Cost Calculations

Tap Cost	
Low	High
10	15

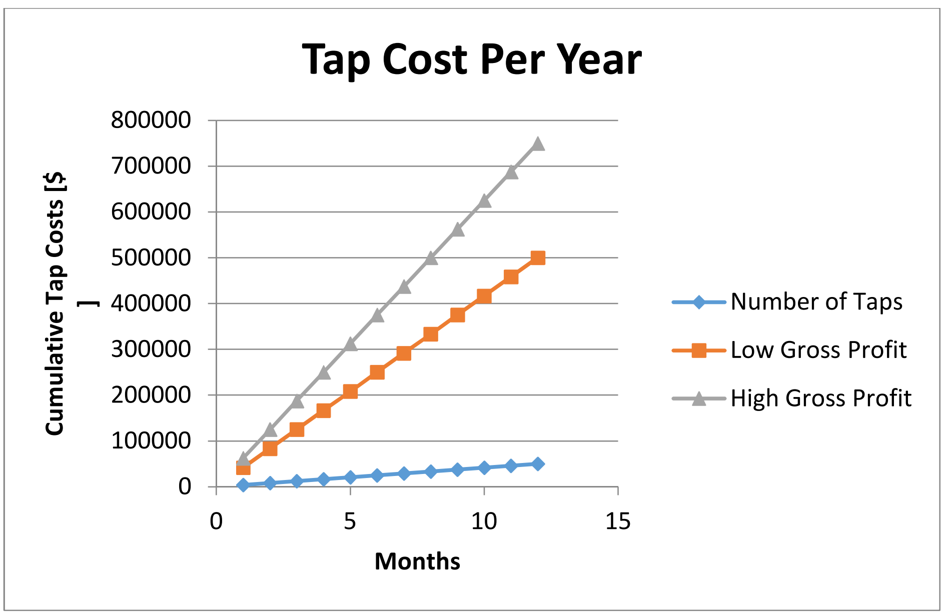
Table 2: Tap cost assumptions

Month	# of Taps	Low Cost	High Cost
1	4166.67	41666.7	62500.05
2	8333.34	83333.4	125000.1
3	12500.01	125000.1	187500.15
4	16666.68	166666.8	250000.2
5	20833.35	208333.5	312500.25
6	25000.02	250000.2	375000.3
7	29166.69	291666.9	437500.35
8	33333.36	333333.6	500000.4
9	37500.03	375000.3	562500.45
10	41666.7	416667	625000.5
11	45833.37	458333.7	687500.55
12	50000.04	500000.4	750000.6

Table 3: Tap Cost at 200 Cycles per Tap

Month	# of Taps	Low Cost	High Cost
1	1190.477	11904.77143	17857.15714
2	2380.954	23809.54286	35714.31429
3	3571.431	35714.31429	53571.47143
4	4761.909	47619.08571	71428.62857
5	5952.386	59523.85714	89285.78571
6	7142.863	71428.62857	107142.9429
7	8333.34	83333.4	125000.1
8	9523.817	95238.17143	142857.2571
9	10714.29	107142.9429	160714.4143
10	11904.77	119047.7143	178571.5714
11	13095.25	130952.4857	196428.7286
12	14285.73	142857.2571	214285.8857

Table 4: Tap Cost at 700 Cycles per Tap



Month	Hours	Wages
1	2016	40320
2	4032	80640
3	6048	120960
4	8064	161280
5	10080	201600
6	12096	241920
7	14112	282240
8	16128	322560
9	18144	362880
10	20160	403200
11	22176	443520
12	24192	483840

Table 5: Worker Wages

Depreciation	
Cost	110000
Salvage	10000
Life	10
Period	5

Table 6: Depreciation

Part Profit	Low Cycle Tap Cost Avg	High Cycle Tap Cost Avg	Depreciation	Tap Savings	Cost Comparison
$ 10,000,000.00	$ 625,000.50	$ 178,571.57	$ 9,011.20	$ 446,428.93	$ (278,044.16)

Table 7: Results