Pens Up!
The Development of the Ole Miss Ballpoint Pen

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Thank you to the CME faculty and staff for always challenging our ideas and pushing us to try new and innovative ways to produce a pen.

Thank you to our family for always being there for us when we have lost all motivation and do not want to continue to produce. Thank you to all of the writers, Vera Gardner, Andrew Huff, and Charles McEuen for their help in writing this thesis and making sure that the CME senior design capstone is realized to its full potential.
Abstract

This thesis will document and analyze the ideation, research and design, production, and optimization processes for the Center for Manufacturing Excellence Senior Capstone design project. The Pens Up! team consisted of six team members- four mechanical engineering majors, one accounting major, and one business major- working together to continuously improve the Ole Miss ballpoint pen’s quality, design, and to standardize and eliminate wastes to its production process. After months of preparing and testing various ideas and ironing out kinks and mistakes, Pens Up! was able to produce a quality aluminum pen. This thesis will describe the various obstacles faced as well as the iterations taken in the optimization process of the Ole Miss Aluminum pen.
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List of Abbreviations:

ABS  Acrylonitrile Butadiene Styrene
CAD  Computer-Assisted Drafting
CEO  Chief Executive Officer
CFO  Chief Financial Officer
CME  Haley Barbour Center for Manufacturing Excellence
CNC  Computer Numeric Control
COO  Chief Operating Officer
CPI  Cost Performance Index
DFA  Design for Assembly
DFM  Design for Manufacturing
DFMA Design for Manufacturing and Assembly
ID   Inner Diameter
JIT  Just-in-Time
OD   Outer Diameter
OSHA Occupational Safety and Health Administration
PVC  Polyvinyl Chloride
SPI  Schedule Performance Index
TPI  Threads Per Inch
TPS  Toyota Production System
UNC  Unified National Coarse
1. Introduction

The Haley Barbour Center for Manufacturing Excellence (CME) Senior Capstone Design Project is developed to expose students to the entirety of the Toyota Production System (TPS) and the comprehensive scheme of the engineering design process and the product development process. Students realize an entire production process of a product from ideation to design to production to cost analysis to fulfilling customer orders. The CME is an interdisciplinary educational program that seeks to educate its students from the engineering and manufacturing side and the accounting and marketing/business side of the manufacturing process. The program includes students from three disciplines: engineering, business, and accounting. In addition to fulfilling degree requirements, students in the CME complete the requirements for the emphasis or minor in manufacturing through a set of three TPS classes at Parker-Racor Hannifin in Holly Springs, MS, and Viking Appliances in Greenwood, MS, or any other company willing to open its doors to students. These classes focus on takt time—the maximum amount of time that a product needs for production in order to satisfy the customer demand, practical problem solving, and continuous flow. Moreover, students take classes focusing on business law, strategic management, and manufacturing processes and the common processes behind manufacturing. The aim of the CME’s structure is to develop well-rounded students that can communicate outside of the disciplinary silos and better explain reasons behind a selection process or a manufacturing process. The CME Senior Design Capstone project aims to combine students from all three disciplines to work together to develop, produce, and market a product. This thesis will discuss the usage and effectiveness of the Toyota Production System (TPS) philosophy, lean manufacturing,
and design for manufacture and assembly (DFMA) principles in the development of a ballpoint pen from ideation to realization.

In August 2016, all of the senior students in the CME, 34 in total, were charged with developing and pitching a possible idea-shark tank style- to the CME faculty and staff. The product market was the Ole Miss community and the proposed product had to have the potential to be produced on the Dr. James Vaughan Factory Floor. The CME faculty and staff met to discuss and select six products to be produced. From these six chosen products, six teams were formed. The teams were comprised of at least one accountant and one business person, with the remainder engineers.

Throughout the rest of fall 2016, teams began to develop business plans, perform marketing research, and conduct research and development using various materials and production processes to further refine the product and market. In December 2016, the groups presented their initial prototypes to the CME faculty and staff to receive feedback on the functionality, manufacturability, marketability, and profitability of the product.

In the spring of 2017, teams continued to refine their manufacturing processes and design choices for materials. Through trial runs over the course of a week in February 2017, teams were given the opportunity to set up their machines in a proposed manufacturing cell and run through production. After each run, teams analyzed and subsequently optimized their production process, making changes to the setup of the manufacturing cell, and minor tweaks to the quality of the product’s material and design. In April 2017, teams ran a semi-final production run and a final production run. After having finished the semi-final production run, teams discussed various alternatives to the production process and enacted dry runs to improve their final production run two days
later. Thinking about the variety of solutions to improve the manufacturing process, such as a shorter takt time, a reduction in manpower, and balancing the workload, the teams continued to meet and produce various alternatives to reach a conclusion to present to the CME faculty and staff the first week of May 2017. The capstone project challenged the teams to work together in a real-world simulated environment, pulling from knowledge gained over the course of a four-year curriculum.

2. TPS and Lean Manufacturing

This thesis discusses the product development process, TPS, lean manufacturing, and design for manufacture and assembly (DFMA) principles in conjunction with their implementation in the Senior Design Capstone project. Through CME classes, both interactive factory-based and traditional classroom lectures, as well as various internships in industry, students obtained the knowledge and skill set required to carry out the production of a product from its inception as a mere idea to the optimization of the production process. Concepts drilled into students’ heads over the course of three years were finally implemented. The concept of one-piece flow aims at eliminating the batching system of manufacturing by producing only one piece at a time. One-piece flow eliminates the pile up of errors during a production process, as the quality check is more frequent during the production instead of at the end of the manufacturing process. In this method, it is easier for operators to catch flaws in a product and more efficiently eliminate waste or correct a problem. Also known as continuous flow, one-piece flow minimizes the transition times between individual operations in the production of a product while also reducing the inventory at each station. There is a monetary cost to batch production, so the philosophy of a one-piece flow cutting down on inventory helps
the manufacturer save cost on the front end. In the development of the manufacturing process, the Just-in-Time (JIT) philosophy is also incorporated. The JIT strategy increases efficiency and decreases waste in that it aims at receiving goods only as needed in the production process. This reduces inventory storage costs; moreover, it removes clutter from the manufacturing facility, minimizing the probability of operator error by reducing the decisions the operator must make as the only material needed for manufacturing is conveniently at hand [1]. For right-handed people, it is more natural to move counterclockwise; thus, a U-shaped manufacturing cell is preferred. Other manufacturing processes utilized in the research and implementation of the production process include the standardization of operations to reduce error in the production process, and the minimization of the part count to lower inventory demands and reducing the incorrect placement of components during manufacturing.

The lean manufacturing philosophy was incorporated into optimizing the production process. Lean manufacturing is a philosophy used to eliminate defects in manufacturing and business/service. In lean manufacturing, there are eight major wastes: (1) defects, (2) overproduction, (3) waiting, (4) non-value adding processing, (5) transportation, (6) inventory, (7) motion, and (8) unused employee talent. Along with the eight wastes there are solutions proposed that help to save capital and resources. The proposed solutions aim to minimize employee and part movement, reduce a sitting inventory, eliminate bottlenecks, remove distractions and unnecessary steps, as well as improve communication. Lean manufacturing incorporates the JIT philosophy of reducing inventory during the manufacturing process.
3. Ideation

3.1 The Pitch

The Center for Manufacturing Excellence requires the senior classmen to pitch an initial design concept with market analysis and cost analysis. All members were required to use information from the past manufacturing classes taken throughout the four years in college to create their design. The requirements for the design were that the design had to be marketed to Ole Miss Alumni or for disabled persons. Though the scope of the market is limiting however, the scope for what could be created was extensive. Every person then presented a 3 minute pitch of their design to a panel of judges. The judges decided on six designs that would be the best to manufacture and create at the lowest cost.

After selection, each member of the senior class applied for a position on the manufacturing team of the products selected. The six designs selected were formed into companies consisting of a CEO, a Project Manager (COO), an Accountant (CFO), a Market Analyst, and engineers. The number of engineers was based on the difficulty of the design selected.

Andrew Huff pitched a design to manufacture an original machined aluminum pen. Vera Gardner, Charles McEuen, Austen Poynter, Robert Lapeyre, and Tanner West were selected to join the team to make the aluminum pen. Andrew Huff, the designer, applied to be CEO of the team. Vera Gardner and Austen Poynter were appointed as engineers, and Charles McEuen was appointed to be an engineer and Project Management lead, and Robert Lapeyre was appointed the business lead.

The idea for making a pen came from the concept that not many people have a pen that they want to use as a novelty item. People tend to use cheap, mass produced
pens instead of handmade pens. After buying an expensive pen, Huff thought it would be challenging to make one as a project. The market would be to alumni who would want a novelty pen item to use when showing support and enthusiasm for the university in a professional setting. The initial design was a pen with five pieces: a cap, nozzle, barrel, a plug for the end, and an ink cartridge. The nozzle would screw into the barrel, the plug would tight fit into the bottom of the barrel, and the cap would be a slide fit over the barrel.

3.2 Feasibility

When Huff began to think of a possible design pitch for the ballpoint pen, there were many major feasibility issues with the initial proposed design. An all metal pen for manufacturing would be extremely difficult to manufacture in an efficient manner for a profitable business. Huff spent a long time talking with James McPhail, the team’s appointed CME manufacturing technician, about the feasibility of making a pen. The design was reduced to the simplest form as shown in Figure 1. The design was to screw the nozzle into the tapped barrel, press fit the end plug into the back of the barrel, and pressure fit the cap onto the barrel. The nozzle would cause some issues due to its geometry. This was fixed by using the CNC lathe; however, there were more challenges in forming threads while testing materials of various stiffness.

Fig. 1: Initial 3D pen design from CREO.
4. Team Organization

4.1 Team Organizational Chart

Figure 2 illustrates the organization of the six team members for Pens Up!.

Andrew Huff, the CEO, was the head officer charged with making decisions and leading the overall operations of the company. Moreover, Huff was charged with overseeing the procurement of materials, the marketing, costing, design and manufacturing engineering as well as the research and development of the product. The CEO was responsible for making the ultimate macro-decisions that relate to both the technical operations and the business/financial side of the company. These macro-decisions were made based on input from each of the team members. The CEO was also tasked with maintaining project cohesiveness by assuring that the team members remained on task to provide deliverables by given deadlines.

Fig. 2. Pens Up! organizational team structure
At an equal position underneath the CEO, were the CFO (Tanner West) and the Project Manager (Charles McEuen). West, the CFO, was the officer charged with handling all of the accounting and financial information, particularly as it related to costing for materials, labor, and the overhead. West was responsible for maintaining and analyzing financial information provided by the CEO, the business lead, and the technical team. Moreover, the CFO was responsible for providing and collecting any financial information necessary for future deadlines and deliverables as well as overseeing the overall success of the pen project. There were no team members underneath the CFO.

McEuen, the Project Manager, was also known as the Chief Operating Officer (COO), McEuen was tasked with scheduling through use of the Gantt chart, developing process timelines, and assisting the CEO in satisfying customer deadlines. As the Project Management Lead, McEuen was responsible for updating a Gantt chart, maintaining the status of the program as a whole. The COO was the liaison between the CEO and the manufacturing operations as well as the technical lead with the job of assuring that two technicals and the business lead were kept on track and were aware of their duties in regards to the project. McEuen additionally was in charge of checking that the engineering design goals were compatible with the business plan and costing.

Underneath the Project Manager were the two technical leads (Austen Poynter and Vera Gardner) as well as the business lead (Robert Lapeyre). The technical leads and the business lead were placed under McEuen, as the Project Manager was charged with assuring that these three positions understood their roles and their deadlines for completing tasks pertaining to the continuous development of the product and its production process. The technical team members were charged with the synthesis and
development of all technical aspects of the product. Technical team members were responsible for material selection, analysis of design, engineering drawings, and manufacturing synthesis. Poynter and Gardner produced fixtures used to aid in standardizing the manufacturing process as well as discussed and tested various process layouts. As the business lead, Lapeyre was charged with developing the project in all areas related to marketing, logistics, supply chain management, and procurement of materials. Lapeyre was responsible for the collection of marketing data and to have an overall understanding of all matters related to general business practices of Pens Up! as it related to marketing, sales, logistics, supply chain management, procurement, and business law. The business lead was also tasked with working with all team members, especially the CEO and CFO, to help in analyzing information for purposes of financial decision making in regards to the design of the pen product.

4.2 Marketing

Based on the initial market research, the team was able to gain a significant insight into what was desired in a pen. As can be seen in Fig. 3, through a survey taken by 43 participants, both students and faculty, it was deduced that having a laser etching of the Ole Miss logo on the pen would increase the value of the pen to the target market as can be seen from Fig. 4. This added selling point in combination with the want to add a powder blue color (Fig. 5) helped the team to refine the aesthetic of the aluminum ballpoint pen. From initial costing, the survey was taken at $40 per pen selling price; see section 4.3.

The Ole Miss aluminum ball point pen, from its very first concepts was designed to serve an individual who values the quality of a great pen. Not meant to be a
“disposable” pen, our Ole Miss themed ball point pen was designed with quality and durability in mind. With the pen constructed of 6061-T6 aluminum and durable high density PVC Type 1 plastic, it was built to last. When writing is an essential part of an individual’s day to day task, a quality pen is important. With this in mind, our team understood that our target market would range from high achieving Ole Miss students to Ole Miss alumni in a range of varying disciplines. Further, because writing is such an important aspect of these consumers lives, we anticipated they would be slightly less price sensitive in purchasing a pen, and ultimately value quality aesthetics and function over the cheaper alternative.

While we anticipated that our customers may be slightly less price sensitive than the market as a whole, we learned through an initial market research survey that students preferred a lower cost point and as a result made accommodations for this finding. A more important metric that was derived from our survey was that roughly 60% of our sample was classified as individuals who would buy our product if they had the opportunity. From this metric our team concluded that an estimate of our future demand would be roughly 12,600 units annually. This number was estimated by taking the percent of customers from our sample and finding that percent relative to the Ole Miss student population. While we do not expect 60% of students to purchase our product, the slight over estimate will help to account for the future alumni customers, of which we did not have an accurate metric for. The team decided to also apply the same metric to alumni who graduated from Ole Miss in a 2 year time period. The amount of students graduating in a two year span was 16,220 students [2]. Therefore the amount of recently graduated alumni in our market was 16,220 times 60% which was 9732. Adding student
plus alumni market sizes gave us an estimated market size of 22,332 people. This market will vary over time with the changing size of enrollment into Ole Miss.

Fig. 3: Survey results determining whether or not there is a market for the product.
Fig. 4: Survey results asking about engraving on the pen.
Fig. 5: Survey results determining color of the barrel.
4.3 Costing

4.3.1 Initial Costing

During the prototyping phase of the capstone project, Pens Up! collected and analyzed the initial costing of the pen. Table 1 included the initial cost per unit pen, and Table 2 showed the yearly project income statement. The cost per unit analysis included the cost for any direct materials, the cost for machining, and the cost for direct labor associated with each part of the pen. It also included the selling price ($40), the contribution margin ($25.24), and the total direct costs ($14.76). The project income statement included projected sales for 2016 ($400,000 from 10,000 units sold), total variable costs, contribution margin, total fixed costs, and profit margin ($42,400 or 10.6%).

The team adjusted the cost analysis of the pen during the production phase of the capstone project, because the team was able to physically realize how much more or less money the initial cost analysis budgeted for. After the production phase, the team began working on the final cost analysis of the pen. One of the main goals of the team’s project was to reduce the cost of the pen.
Table 1: Basic costing

<table>
<thead>
<tr>
<th>Per Unit</th>
<th>Total Direct Materials</th>
<th>Total Machining</th>
<th>Total Direct Labor- 7.25/hr.</th>
<th>Total Direct Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Selling Price</td>
<td>$ 40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Barrel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Materials</td>
<td>$ 1.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machining</td>
<td>$ 0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Labor- 7.25/hr.</td>
<td>$ 0.46</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pen Insert</td>
<td>$ 1.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Nozzle &amp; End-Cap</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Materials- Acrylic*</td>
<td>$ 0.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machining</td>
<td>$ 4.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Labor- 7.25/hr.</td>
<td>$ 0.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Assembly of Barrel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machining</td>
<td>$ 1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Labor- 7.25/hr.</td>
<td>$ 0.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cap Barrel</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Materials- Aluminum</td>
<td>$ 0.54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machining</td>
<td>$ 1.25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Labor- 7.25/hr.</td>
<td>$ 0.28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Endcap of Cap</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Materials</td>
<td>$ 0.07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machining</td>
<td>$ 2.49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct Labor- 7.25/hr.</td>
<td>$ 0.27</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Direct Costs</td>
<td>$14.76</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contribution Margin</td>
<td>$25.24</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*If Nozzle & End-Cap is made with Aluminum then DM costs will be- $0.29
4.3.2 Final Costing

The tables outline the initial cost vs. the final costs. Table 3 describes the project income statement, and Table 4 lists direct costs. Initially the teams’ direct costs were much lower due to the fact that no realized cap had been made yet. The direct materials cost reflects the addition of the cap in Table 5. Due to this cost, the team had to raise the price of the Pen from $40 to $45. The team saw that in order to meet market demand the team would need to produce 22,332 units yearly. If a 40 hour work week was the standard work week for production, 279 days of production would be required to meet the demand of 22,332 pens. With 279 days of perfect production required, this framework seemed problematic, so Pens Up! considered using a 24/7 work week with the hired employees changing shifts to meet the demand faster. Pens Up! also looked to buy 3D printers to make the cap “in-house” when manufacturing could be scaled, which

<table>
<thead>
<tr>
<th>Project Income Statement</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Sales for FY 2016</td>
<td>$ 400,000</td>
</tr>
<tr>
<td><strong>Variable Costs:</strong></td>
<td></td>
</tr>
<tr>
<td>Direct Materials</td>
<td>$ 32,200</td>
</tr>
<tr>
<td>Machining</td>
<td>$ 99,600</td>
</tr>
<tr>
<td>Direct Labor</td>
<td>$ 15,800</td>
</tr>
<tr>
<td>Contribution Margin</td>
<td>$ 252,400</td>
</tr>
<tr>
<td><strong>Fixed Costs:</strong></td>
<td></td>
</tr>
<tr>
<td>Salaries</td>
<td>$ 200,000</td>
</tr>
<tr>
<td>Marketing Costs</td>
<td>$ -</td>
</tr>
<tr>
<td>R&amp;D Costs</td>
<td>$ 10,000</td>
</tr>
<tr>
<td>Profit Margin</td>
<td>$ 42,400</td>
</tr>
</tbody>
</table>

Units Sold= 10,000
Selling Price= $ 40
Profit Margin= 10.6%
would drastically drive down the cost of the cap and the entire direct materials cost of making the pen.
Table 3: Final Project Income Statement

<table>
<thead>
<tr>
<th>Project Income Statement</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Sales for FY 2017</td>
<td>$ 1,004,940</td>
</tr>
<tr>
<td><strong>Sales</strong></td>
<td>$ 1,004,940</td>
</tr>
<tr>
<td><strong>Variable Costs:</strong></td>
<td></td>
</tr>
<tr>
<td>Direct Materials</td>
<td>$ 330,126</td>
</tr>
<tr>
<td>Machining</td>
<td>$ 289,326</td>
</tr>
<tr>
<td>Direct Labor</td>
<td>$ 16,191</td>
</tr>
<tr>
<td>Contribution Margin</td>
<td>$ 369,297</td>
</tr>
<tr>
<td><strong>Fixed Costs:</strong></td>
<td></td>
</tr>
<tr>
<td>Salaries</td>
<td>$ 225,000</td>
</tr>
<tr>
<td>Marketing Costs</td>
<td>$ -</td>
</tr>
<tr>
<td>R&amp;D Costs</td>
<td>$ 1,500</td>
</tr>
<tr>
<td>Purchased Asset Costs</td>
<td>$ 1,704</td>
</tr>
<tr>
<td>Total Fixed Costs</td>
<td>$ 228,204</td>
</tr>
<tr>
<td><strong>Profit Margin</strong></td>
<td>$ 141,093</td>
</tr>
<tr>
<td>Units Sold</td>
<td>22,332</td>
</tr>
<tr>
<td>Selling Price</td>
<td>$ 45</td>
</tr>
<tr>
<td>Profit Margin</td>
<td>14.0%</td>
</tr>
</tbody>
</table>

Table 4: Direct Costs

| Total Direct Materials  | $ 14.79  |
| Total Machining         | $ 12.96  |
| Total Direct Labor- $7.25/hr. | $ 0.73 |
| Total Direct Costs      | $ 28.48  |

Table 5: Direct Materials Cost

<table>
<thead>
<tr>
<th>Direct Materials</th>
<th>Cost per UM</th>
<th>UM per pen</th>
<th>Unit of Measure</th>
<th>Cost per pen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray PVC Tubing</td>
<td>$ 0.13</td>
<td>1.14 in.</td>
<td></td>
<td>$ 0.15</td>
</tr>
<tr>
<td>Aluminum Tubing</td>
<td>$ 0.22</td>
<td>4.89 in.</td>
<td></td>
<td>$ 1.10</td>
</tr>
<tr>
<td>Powder Coat Paint</td>
<td>$ 0.03</td>
<td>1 g</td>
<td></td>
<td>$ 0.03</td>
</tr>
<tr>
<td>3D Printed Cap</td>
<td>$ 11.22</td>
<td>1 unit</td>
<td></td>
<td>$ 11.22</td>
</tr>
<tr>
<td>Uniball pen ink refill</td>
<td>$ 1.33</td>
<td>1 unit</td>
<td></td>
<td>$ 1.33</td>
</tr>
<tr>
<td>Scrap Costs</td>
<td>$ 0.96</td>
<td></td>
<td></td>
<td>$ 14.79</td>
</tr>
</tbody>
</table>
4.4 Project Management

Charles McEuen, the project manager, incorporated project management principles from a project management class, ENGR 497, taught by Dr. Jack McClurg. The class enlightened the student project manager to the 10 knowledge areas of project management and the 5 process groups of project management. The 10 knowledge areas and 5 process groups of project management all were able to be applied to the manufacturing of the ballpoint pen [3]:

10 Knowledge Areas
1. Integration Management
2. Scope Management
3. Time Management
4. Cost Management
5. Quality Management
6. Human Resource Management
7. Communications Management
8. Risk Management
9. Procurement Management
10. Stakeholder Management

5 Process Groups
1. Initiating
2. Planning
3. Executing
4. Monitoring and Controlling
5. Closing

The integration management knowledge area included weighing the different factors that were associated with the production of the pen in terms of stakeholder interests, manufacturing time, perceived quality, and cost. An instance of integration management was put to use when weighing each team member’s suggestion for the pen’s cap. Some team members suggested a wooden block to serve as the pen’s cap. Some
team members wanted to make a cap from the gray PVC Type 1 plastic that was purchased from OnlineMetals.com that was also used to make the nozzle and end plug. Some other team members wanted to 3D print a cap in the CME Maker-Space area using ABS plastic. Scope management was used when identifying what the team’s tasks were for the large prototyping and production stages, as well as the method of knowing what was needed to be done week-to-week. The project manager’s challenge in regards to scope management was controlling the team’s work progress on a weekly basis. The project manager monitored if the team was doing only the work required for the week, no more or no less. The project manager had to sometimes motivate team members to do the work necessary for the week, and sometimes tell team members to stop doing extra work (“gold plating”) or work that was intended to be done the next week. Time management pairs similarly with scope management in terms of knowing what needs to be done when and making sure the tasks were completed in a timely manner. Cost management was used when selecting and purchasing material, managing the amount and wages of labor used, and accounting for the cost of machining of all the equipment used in production of the pen. An example of cost management was when the team searched vigorously for quality material that could be purchased cheaply and in large quantities, so that the price point of the pen did not have to change. Quality management occurred when deciding on if design changes at least maintained quality or improved quality of the pen. Another area for quality management was during production runs. The team checked for quality pens produced during production runs, and identified problem areas/steps in the production process that harmed quality. Examples of pens that exhibited poor quality were ones with burrs on the nozzle and/or end plug, barrels that...
were too long or too short, laser etching that appeared weak, green, and blurry, and finally pens that still showed black numbering on the barrel through the paint and laser etching. The correction of these quality issues is discussed in more detail in Section 11.2. Human resources management involved making sure team members were pleased with each other, the work being done, needing any additional help, and finally “hiring” only the right amount of workers to be used on the production runs. Communications management was an extremely crucial knowledge area throughout the course of the capstone project. Any task changes, additional tasks, scheduled meetings, etc. needed to be communicated to the team quickly and in a way that ensured the team members received the message. Communications management also included making sure that all team members were using the same method of sending and receiving messages so that everyone was on the same page for the current design iteration. These platforms included text messaging, email, and the GroupMe phone app. Risk management dealt with any potential problems that could harm the progress of the production of the aluminum pen. The risk management included identifying any potential risks beforehand, labeling the severity of the risks, organizing the risks involved in the various areas of the project, and forming several possible solutions to those risks. As always with any project, there were some risks that were not foreseen and had to be dealt with on the fly or either endured until the risk/problem was fixed or no longer remained a risk. Some of these risks can be seen in Section 4.5 with a more complete version attached in the appendix. Procurement management involved searching and ordering materials for the best price, quality, and amount, planning/scheduling for the materials’ shipment arrivals, and also taking inventory of the materials after any days of prototyping or production to see if more
material needed to be ordered. Stakeholder management involved any person associated with the pen, whether it was a team member, instructor, advisor, or potential customer. The team had to consider each stakeholders’ opinion to an issue with the capstone project, weight of that opinion, and the overall importance of the stakeholders themselves to the project.

The initiating process group took place when the team was formed, the aluminum pen product was discussed, and the initial steps forward as a team happened. The planning process group involved all 10 knowledge areas of project management. The team planned for ordering materials, days team members could work, self-enforcing deadlines for deliverables/milestones, alternative methods to reach goals in case of any potential problems/risks, etc. Planning for everything in our project occurred through either long team meetings, short and frequent team meetings, email chains, text, discussion, or simply individual thought. There was a lot of planning done for each knowledge area of the project, and still more could have been done. The executing process group took place when the team actually was working towards completing set tasks and goals. Executing plans, tasks, and goals involved working on creating the different components of the prototype, producing the pen product down on the shop floor, and creating any documentation needed for updates, reports, or presentations. The monitoring and controlling process group occurred closely in sync with the executing process group. Monitoring and controlling served the purpose of tracking the work that was being done, making sure it followed the plans set forth, and seeing what can be improved on the execution of the work. Monitoring and controlling involved quality assessments, getting coordinating times for all of the team members, tracking inventory
of materials, checking any machine maintenance, and prodding team members to keep up their work. The closing process group occurred when goals or tasks were achieved and/or finalized. Closing happened when the team finalized its design for the prototype, process flow, process layout, work steps, as well as other things. Closing did not all happen at the end of production. Certain goals/tasks were closed at different times even before production ended.

While the 10 knowledge areas and 5 process groups were all extremely important to the project management of this capstone project, the project manager primarily focused on the “Iron Triangle” of project management [3]. The iron triangle, as shown in Fig. 6, figuratively explains how balancing the project constraints of cost, time, and scope must be well managed in order to maintain a quality product and project. If not well managed, a project could be late, over budget, not meet the project scope, and have poor quality. To maintain good quality, the iron triangle shows how to balance the three constraints. For example, if the delivery time suddenly became earlier to complete a project, the cost of the project would need to increase, and/or the scope of the project would decrease. An increased scope could lead to increased time and increased cost, and a smaller project budget cost could mean a decreased scope and increased time.
Two metrics that the project manager used to track the team’s progress were Cost Performance Index (CPI) and Schedule Performance Index (SPI) [3]. The CPI obviously measured the financial success of the project. The CPI ratio was obtained by dividing the budgeted cost of work performed by the actual cost of work performed. The SPI measured if the project was on schedule. The SPI ratio was obtained by dividing the budgeted cost of work performed by the budgeted cost of work scheduled. If the CPI ratio was less than 1, it meant that the project was over budget. If the SPI ratio was less than 1, it meant that the project was behind schedule. Ratios greater than 1 meant under budget and ahead of schedule, and ratios equal to 1 meant on budget and on schedule.

For the sake of this capstone project, these ratios were obtained through an educated estimate. The project manager estimated that, at the end of production and prototyping, the SPI ratio was equal to 1, and the CPI ratio was slightly less than 1. In other words, the project was completed on time but was slightly over budget.
4.5 Gantt Chart, Risk Register

The Gantt chart was a tool that was used to illustrate the project schedule. The Gantt chart resembles a bar graph with a data grid attached. The software that the project manager used to create the Gantt chart was Microsoft Project 2016. The Gantt chart included tasks that were long term projects, sub-projects, project milestones, meetings, deliverables. Details that were attached to these items were the start date, end date, duration, human resources, and percentage of the task complete. A portion of the Gantt chart is seen in Fig. 7.

<table>
<thead>
<tr>
<th>Task Description</th>
<th>Start Date</th>
<th>End Date</th>
<th>Duration</th>
<th>Human Resources</th>
<th>Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering/Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>3D Model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Material Selection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Customization/Heaters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Manufacturing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Nodet, Gau, Flag</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Finishing, Customization, Aesthetics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Creative Processes,实业</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Design, Assembly Drawings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>List of Equipment use and processes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Working Proposal/Assembly Drawings</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Product Flow Diagram</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Identify &amp; Document Production, Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Throatwash meeting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Proposal/Report</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Business/Marketing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Market Research/Purchasing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Market/Customer Research</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Formulate PIPs, market Analysis, Presentation, Profit Analysis, Pricing, Marketing Analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Market Survey</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Research Results, Processed Sales</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Accounting/Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
<tr>
<td>Material Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>100%</td>
</tr>
</tbody>
</table>

Fig. 7: Snapshot of Gantt chart
The Risk Register was a tool that was used to list all of the potential project risks. Some other details that were included in the Risk Register was the risk title, a description of the risk, the impact of that risk, the date the risk was identified, the category and sub-category of that risk within the project, the status of the risk (whether the risk is still open or closed), the owner or person responsible for the risk, the rating of the risk (low, medium, high or critical), all of the possible solutions to the risk, and the date the risk was closed. A portion of the Risk Register can be seen in Fig. 8.

<table>
<thead>
<tr>
<th>#</th>
<th>Risk Title</th>
<th>Risk Description / Impact</th>
<th>Identified Date</th>
<th>Risk Category</th>
<th>Risk Sub-Category</th>
<th>Status</th>
<th>Owner</th>
<th>Risk Rating</th>
<th>Possible Mitigations</th>
<th>Date Closed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Server issues</td>
<td>Server halts machine coding for CNC lathe</td>
<td>10/17/2016</td>
<td>Project</td>
<td>Faculty, Software</td>
<td>Closed</td>
<td>CEO</td>
<td>High</td>
<td>1. Meet with necessary faculty. 2. Confirm dates to fix or default</td>
<td>11/3/2016</td>
</tr>
<tr>
<td>2</td>
<td>FeatureCAM license expire</td>
<td>License expires, issues with server / can’t run CNC lathe</td>
<td>10/24/2016</td>
<td>Project</td>
<td>Faculty, Software</td>
<td>Closed</td>
<td>CEO, CTO</td>
<td>Critical</td>
<td>1. Meet with necessary faculty. 2. Confirm dates to fix or default</td>
<td>11/5/2016</td>
</tr>
<tr>
<td>3</td>
<td>Unplanned machining problems</td>
<td>Material expansion, drill bit breaking, tool fixtures, heating, material deformation</td>
<td>11/1/2016</td>
<td>Project</td>
<td>Engineering</td>
<td>Closed</td>
<td>CTO</td>
<td>Medium</td>
<td>1. Run more prototypes to mitigate risks</td>
<td>9/9/2017</td>
</tr>
<tr>
<td>4</td>
<td>Dimensioning</td>
<td>Barrel &amp; End Cap dimensions may vary with ink well</td>
<td>10/17/2016</td>
<td>Project</td>
<td>Engineering</td>
<td>Open</td>
<td>CTO</td>
<td>Medium</td>
<td>1. Run more prototypes to mitigate risks</td>
<td>11/1/2016</td>
</tr>
<tr>
<td>5</td>
<td>Communications Barrier</td>
<td>Accounting/Financial team member will be gone, interim half of the spring semester</td>
<td>11/9/2016</td>
<td>Project</td>
<td>Accounting/Finance</td>
<td>Closed</td>
<td>CFO</td>
<td>Medium</td>
<td>1. Set up a brief (30min) phone call once a week 2. Have a consistent email chain while CFO is gone</td>
<td>11/9/2016</td>
</tr>
</tbody>
</table>

These documents are too large to insert in this paper in this section. For a more detailed reading, the documents are attached in the appendix or separately with this thesis.

4.6 Safety During Production and Assembly

As with all projects in the manufacturing environment, safety precautions are necessary to protect the wellbeing of the operators and the employees. Occupational Safety and Health Administration (OSHA) outlines specific guidelines for operation with safety in mind for specific projects. Pens Up! researched OSHA standards that were
implemented during the trial and production runs to ensure safety of the team members. All team members were required to wear long pants, safety glasses, and closed-toed shoes while on the manufacturing floor, as per the CME shop floor safety agreement.

In lathe operation, the main hazards are at points of contact between the rotating components and contact at the point of operation. Operator’s hands, clothing, or jewelry has the potential of being caught in rotating parts and pulled into the machine. Flying chips are also a hazard on running lathes. At the point of operation, contact may occur with the tool or the cutter head. The cutter head was covered with a metal hood used to completely cover the tools and the raw material used, 29 CFR 1910.213(o)(3). Rotating components, i.e. the raw material stock, is a potential for getting clothing, hair, or hands caught into the rotating stock or cutter. Hair must be pulled back during operation. In order to reduce flying chips or kickbacks, the tools should be properly adjusted and used only as directed by the machine manual, stock that has cracks or knots should not be machined. A brake is incorporated into the lathe machine in order to bring the stock to an abrupt complete stop after power is shut off [4].

In operation of vertical band saws, a blade runs on two pulleys, a driver and idler, and through a work table where the raw material is manually fed through the blade. As the operator manually manages and feeds the raw stock into the blade in order to saw at a point, the operator must be aware of a few potential hazards. The raw material must be kept flush against the table at all times in order to ensure proper cutting. The most common injury associated with operating a vertical band saw is contact with the moving blade. As the band saw blade cannot be guarded, the operator must exercise extreme caution when hands near the blade. OSHA recommends to fully enclose the pulley
mechanism (23 CFR 1910.219(d), to guard the feed rolls (29 CFR 1910.213(i)(3), and to make sure that the band saw includes a tension control device that indicates when the blade is in proper tension (29 CFR 1910.213(i)(2). There are also some more common sense safety measures that OSHA recommends. The blades need to be sharpened, be of appropriate size and type for the material being cut, and to use a special fixture or jig when cutting smaller pieces of raw material [5].

In operation of drill presses, the rotating chuck and the swarf-fine chips produced during a machining process—produced by the drill bit during the drilling operation are the two potential hazards. The operator should not hold the stock in hand while drilling because hot chips are formed during the drilling process as well as chips and scraps from previous drilling jobs hold the potential to create a dangerous work area. In order to assure safety, the operator should check that the raw material is securely placed into the collet and that the drill bit is securely placed into the chuck before beginning operation. The operator should clean and remove residue on the work table between various operations to prevent damage to the drill bit and to the operator from flying chips [6].

For powder coating, a vacuum was attached to the powder coating tool in order to suck in excess powder during the operation. Moreover, it the operator should use a glove when touching the fixture used for powder coating as an electric charge is present.

5. Prototyping

Once the design was chosen for manufacturing and the team and business plan was developed, the prototyping of the pen began. There were four areas that were prototyped: the barrel, the nozzle and plug (together on the lathe), and the cap.
5.1 DFMA, DFA, DFM, etc.

Design for Manufacture (DFM) and Design for Assembly (DFA) are manufacturing philosophies incorporating specific design principles meant to aid the product designer in reducing the total cost in the manufacturing of a product while improving the product’s quality. In order to best achieve the goals presented in DFM/DFA, it is integral for a team to be present in each step of the design process, as the awareness of the DFM/DFA goals from the start of the design process require careful thought of the product’s production. In order for this to have been achieved, Pens Up! divided its six member team into roles, ensuring communication throughout.

Of the ten guidelines used in standard practice for DFM, Pens Up! utilized seven. (1) Minimizing the total number of parts allows the pen to be made at its minimum part count of five: barrel, ink refill, end plug, nozzle, and cap. By keeping the part count to a minimum eliminating a desk fixture wooden block or a clip, the company was able to save money from research and development, marketing surveys, and production time. (2) Standardizing components minimized costs and enhanced the overall quality of the product as commercial standard components were used in the design. Costs were saved from the discounts of the quantity produced and the elimination of varied design efforts. Once the product was designed and the manufacturing process was known to work efficiently, there was no reason to change it. This also lowered tooling costs in the long term. (3) Using common parts across product lines did not pertain to the Pens Up! pen as only one pen was produced at a time. (4) Standardizing design features such as the size of holes drilled, the screw thread types, or the finishing materials minimized the total number of tools maintained in the production cell. Moreover, the use of a standard size
ink refill was used as the basis to determine the required length to cut the barrel. (5) The reduction of inventory minimized overhead cost. Aiming to keep designs functional and simple assured that all materials and design characteristics of the component were crucial to its utility. A functional, quality product can be made from less costly materials such as 6061-T6 aluminum versus stainless steel for the barrels or plastic instead of aluminum for the nozzles and end plugs. For a pen, it was not feasible to design parts to be multifunctional; however, the design of parts for ease of fabrication was taken into account. Simple geometries, such as cylinders and tapered curves produced on a lathe allowed for minimal manufacturing as the components left their respective mini-cells at net shape. (6) By avoiding excessively tight tolerances, excessive costs were minimized. (7) By minimizing secondary finishing operations such as painting, heat treatment, and laser etching were ideal to avoid extra costs [7]. However, in the case of the pen, the finishing operations were pertinent to be able to increase the quality of the pen and to be able to sell it to the niche Ole Miss market. In creating a step drill block, the team utilized the special characteristics of processes to eliminate excess steps and tools needed to manufacture the components of the pen.

There are nine guidelines for DFA that can be grouped into three classes of general, handling, and insertion, Pens Up! utilized eight. The nine guidelines include: (1) minimize the total number of parts, (2) minimize the assembly surfaces, (3) use subassemblies, (4) mistake-proof the design and assembly, (5) avoid, separate fasteners/minimize fastener costs, (6) minimize handling in assembly, (7) minimize assembly directions, (8) provide unobstructed access for parts and tools, (9) maximize compliance in assembly [7]. As with DFM, DFA seeks to minimize the total number of
parts in order to reduce individual parts needed to be assembled. By minimizing the assembly surfaces, operators ensured that parts are assembled correctly without any confusion. In designing the pen, threads were placed on one end of the barrel and the other end of the barrel was not machined. This ensured that the nozzle and end plug were correctly installed during assembly. In order to prevent any mis-etched barrels, a weight was placed into the barrel after powder coating and curing and before the barrel is placed into the laser etcher. This aided in rotating the barrel properly during the etching process.

The assembly process was designed to be unambiguous so the operators could not make any mistakes in the assembly of the components. The Ole Miss logo and the three gripped lines to be laser etched onto the barrel are placed on the threaded end; the end plug should already be inserted into the barrel to foolproof the placement of the barrel into the laser etcher.

Mistake-proofing is a practice that introduces controls into the manufacturing process [7]. By mistake-proofing a manufacturing process, possible defects and errors in the components were able to be prevented from the start of the production, exponentially saving the company from having to do recalls on products already on the market. Checklists, guide pins, guideways, slots, specialized fixtures and jigs, limits switches, and counters were all ways to add operational controls that aim to prevent mistakes in the manufacturing of a product and encourage standardized work. In order to mistake-proof the production process of the pen, a few fixtures were made and steps added to the process. For cutting the barrel, an aluminum fixture was built to fit into the vertical band saw table with a screw used as a stopper, to ensure that the barrel be cut to 4.89 inches. In order to prevent mistakes during the laser etching process, the end plug is installed into
the barrel after the powder coating finishing process was complete but before being placed into the laser etcher. This subassembly measure ensures that the laser etching was engraved on the proper orientation of the barrel.

Machinability was also taken into account for the production of the pen. The final design was simple enough to allow for three processes of manufacturing - barrel cutting, end plug and nozzle lathe process, and outsourcing the 3D printed caps-and two finishing processes-powder coating and curing and laser etching.

5.2 3D CAD CREO Drawings

One of the initial steps in bringing an idea from just an idea to the realization of a possible product is through the design process. Using CREO, 3D CAD drawings were produced to be presented to James McPhail, Pens Up!’s assigned CME staff technician. Fig. 9 and Fig. 10 show the initial engineering drawings used during the prototyping phase of the capstone project. Fig. 11 is a 3D mockup of the desired look for the Ole Miss engineering pen.
Fig. 9: Initial CREO drawing of the pen nozzle.
Fig. 10: Initial CREO drawing of barrel with laser etched engraving

Fig. 11: 3D CREO mockup of pen.

5.2.1 Dimensions, Materials, and Cost of the Prototype

Table 6 lists the initial dimensions used in the design of the prototype by component, dimension, feature, and the units used. These initial dimensions for the prototype were based off of the Uni-ball Jetsream 101 Rollerball pen.
Table 6: Initial dimensions for the pen

<table>
<thead>
<tr>
<th>Component</th>
<th>Feature</th>
<th>Dimension</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrel</td>
<td>Tapped Hole</td>
<td>5/16-18 UNC</td>
<td>Inches</td>
</tr>
<tr>
<td>Barrel</td>
<td>Length</td>
<td>5.1</td>
<td>Inches</td>
</tr>
<tr>
<td>Nozzle</td>
<td>OD</td>
<td>0.4</td>
<td>Inches</td>
</tr>
<tr>
<td>Nozzle</td>
<td>Length</td>
<td>0.77</td>
<td>Inches</td>
</tr>
<tr>
<td>Nozzle</td>
<td>OD x Length</td>
<td>0.25 x 0.52</td>
<td>Inches</td>
</tr>
<tr>
<td>Nozzle</td>
<td>ID x Length</td>
<td>0.09 x 0.19</td>
<td>Inches</td>
</tr>
<tr>
<td>Nozzle</td>
<td>ID x Length</td>
<td>0.12 x 0.58</td>
<td>Inches</td>
</tr>
<tr>
<td>Nozzle</td>
<td>Profile</td>
<td>70</td>
<td>Degrees</td>
</tr>
<tr>
<td>End Plug</td>
<td>ID</td>
<td>0.255</td>
<td>Inches</td>
</tr>
<tr>
<td>End Plug</td>
<td>OD</td>
<td>0.375</td>
<td>Inches</td>
</tr>
</tbody>
</table>

5.3 Making the Prototype

5.3.1 Barrel

The barrel was the easiest part of the pen to tackle. Initially there were two possibilities of stock material to be chosen for the barrel: aluminum or stainless steel. 6061-T6 aluminum was chosen as the raw stock material to be used for the barrels in order to minimize the machining needed in forming the appropriate size and its cost effectiveness in comparison with that of the stainless steel. The barrel required two processes: to be cut to length and one end tapped for the nozzle to screw into. With the help of James McPhail, Pens Up!’s technical support, it was decided that the most efficient way to cut and tap the barrel would be to use a fixture to cut the barrel on a vertical band saw and then to use a collet chuck and tapping head to thread the barrel.

The design for the pen barrel needed to fall within usual, human, ergonomic dimensions. After observing several higher quality pens, the team’s decision for the range of the pen barrel’s length was between 4.8” - 5.2”. The decision was based on
how well the pen felt in an average human hand, and observations of various other currently mass-manufactured pens. The material selected for the pen barrel was 6061-T6 aluminum. The aluminum tube stock was originally cut into barrels on the horizontal band saw and then later eventually cut on the vertical band saw. The barrel was then taken to a drill press with the tapping head and the tap was used to thread the barrel for nozzle installation.

A collet chuck was used to hold a cylinder tightly with little to no movement vertically. For tapping a hand tapping machine was used, however this would break a good many tapping bits since aluminum was being tapped. Again with the help of McPhail, it was decided that an automated tapping head would be the best for making our threads. The tapping head consists of a planetary gear train that fits onto any drill press and can detect whether the drill in going down or up and will match the spin direction of the tapping head with the vertical motion of the drill press. The tapping head also supplied a constant torque which would allow smoother use on the tapping bit to ensure not as many breaks in the tooling. Fig. 12 illustrates a raw, cut barrel.

![Fig. 12: Picture depicting the cut, uncoated barrel.](image)

5.3.2 Nozzle and End plug

Referencing Fig. 9, the pen “nozzle,” as the team called it, was the part of the pen that held the ink refill cartridge and threaded into the top of the pen barrel. The “end plug” was the part of the pen that inserted into the bottom of the pen barrel and served as
a backstop and support, so that the ink cartridge would maintain solid contact with its writing surface. The team chose to use 6061-T6 aluminum and blue translucent acrylic as the materials for the nozzle and the end plug in the prototyping stage. Sets of nozzles and end plugs were manufactured together in aluminum and in the blue translucent acrylic. These parts were created on the lathe in the CME manufacturing facility.

McPhail programmed the G-code for the lathe from the provided 3D models. Together, the team and McPhail manufactured aluminum and acrylic sets of nozzles and end plugs. The lathe process included three different tooling methods: turning, threading, and drilling. The process began with turning the desired outer diameter in the material. Then the process changed to the threading tool and the threading process took place. The threading was a 5/16-18 UNC thread. The drilling process followed the threading and included a block of three different sized drills for a step drill process. The first drill was called the 5/32” “step” and only slightly drilled into the material to make it easier for the 1/8” drill to get started. Then the 1/8” drill drilled a 1/8” size hole 0.58” deep into the nozzle material. Then the 3/32” size drill drilled a 3/32” size hole 0.19” past the end of the 1/8 drill’s hole and drilled all the way out through the top end of the nozzle. Finally, the lathe returned to its turning tool and created the rounded curvature seen on the nozzle. The turning process was implemented last so more material could be left to handle the stresses involved during the drilling process.

The manufacturing process for the pen’s “end plug” also occurred on the lathe. The process was initially its own program on the lathe, but McPhail and the team merged the program for the nozzle and the end plug into one entire program to consolidate the programs, eliminate multiple set-ups, and save some time during manufacturing. The
lathe process for the end plug simply consisted of the turning tool. The tool turned an outer diameter into the end plug and cut the part off from the remaining stock material to begin a new program for a new nozzle and end plug. The outer diameter of the end plug was 0.4” and the inner diameter of the end plug was 0.262” diameter and 0.212” height.

5.3.3 Cap

The cap was the most daunting task that the team had to undertake to prototype. At first the team put off prototyping the cap until the last minute due to the strenuous task of prototyping the other aspects of the pen. When thinking about the cap, the most difficult aspect was that the cost for making the pen was already high, the production time was running high, and there were already too many processes in the manufacturing setup. Adding another process into the production cycle would be costly in terms of money, time, resources, and workers. By the time the team had finally finished prototyping all of the other aspects of the pen, it was time to run a production trial. Frantically the team put together a crude “pen holder” that would serve as a cap. The pen holder was a block of wood with a hole drilled into it the diameter of the pen barrel. The block of wood was a 2x4 board cut to 2” length. The pen holder was then stained a dark color to make it look more appealing. After the trial run, the team knew that this pen holder would not work. Pens Up! already had the business plan at this point and were pitching the pen as a quality novelty item; the pen holder was certainly not quality.

Here the team had an idea; since a cylindrical piece of barrel was already held in a collet, another collet could be utilized in a similar manner to make the cap. A collet could hold a cylindrical piece of plastic to be drilled out to have a tight fit over the barrel. The team then ordered 0.375” diameter PVC plastic tubing and a 4” 5C collet. The collet
would fit into the same fixture as used for the barrel. Cutting the tubing to 2” lengths, the team drilled the cap 1.75” deep with a V size drill bit (0.377in). The cap looked crude and fit tightly, almost so tight that it could not be pulled off once it had been put on. They then tried to step drill the piece of plastic with a W size drill bit (0.386in) for a depth of 1” and the V size drill bit for 0.75” depth. The step drilled cap worked well and was a smooth sliding fit over the barrel. After looking at the cap fit onto the pen, a new issue arose. The cap was not aesthetically compliant with Pens Up!’s initial vision for quality; it was a blocky cylinder that did not match the sleekness of the pen barrel. The team knew that it would not work as the final product.

The team talked a lot more with technicians about operations on the lathe that would be able to profile down the cylinder cap to make it look more appealing. No solutions were reached; the lathe could not be used again in the process since it was already being used for the nozzle and end plug. Any more lathe process would add a tremendous amount of work, time, and cost. After much discussion, 3D printing was discussed. At the very beginning the team suggested that 3D printing the cap would be the best and easiest way to make it. The idea was rejected early on because it was thought to be crude and the texture would clash with the barrel. However, the team turned to 3D printing again and after a quick prototype of a 3D printed pen cap (on the strong suggestion of Andy Gossett, one of the CME staff technicians), it was seen that the 3D printed cap looked aesthetically pleasing, worked well with fit and was easy to make without adding too much cost and process time.
5.3.4 Powder Coating

The team wanted to paint the barrel of the pen a color that maintained an Ole Miss theme. The color chosen to paint the pen was powder blue, very similar to the color on the football team’s helmets. The method that the team chose to paint the pen was through powder coating. Initially, when coating the pens individually and by hand, the task of keeping an even coat of powder on the barrel was difficult. The team concluded that a fixture was necessary to help the operator keep an even coat of powder on each pen. One team member welded aluminum square bars together and welded 10, 5/16-18 UNC bolts to the square bar for the pen barrel to thread into. This fixture allowed for ten pens to be coated at the same time and for an electric charge to be run through the fixture to help the powder coat stick to the pens.

The coating process for the pen took place at the CME’s powder coating station. The station included a perforated platform for excess powder to fall through, a fan to intake any powder floating in the air, the team’s coating fixture, an electric power source with two cables to conduct an electric charge through the aluminum fixture, containers of powder blue powder coat, the powder coating gun, and an air pressure source to be connected to the powder coat gun. The operator threaded ten pen barrels to the fixture and coated them liberally until they were heavily and evenly covered with powder blue powder coat. When the coating process ended, the operator set the coated barrels in an oven at 385 degrees Fahrenheit to heat the powder finish for 20 minutes. The oven heating process allowed the powder coat to bond and harden to give the pen a painted, finished look. Once the heating process finished, the pens cooled for about 5 minutes. After cooling, the pen barrel was ready to be laser etched and assembled.
5.3.5 Laser Etching

Laser etching included some issues that needed to be addressed due to the circular piece and the rotary etching job. First the circumference of the pen barrel and the length of the barrel were measured in order to make a project size in the 3D laser etching software. The project size is considered the surface on which the laser etching is etched on. Just as a printer for paper has a “project size” of 8 ½ x 11, so the project size of the etcher is the area of the surface that is etched. Once the project size was measured, an Ole Miss image, with licensing rights awarded to the CME, was imported from the internet into the 3D laser etching software. The laser etcher already came with a rotary fixture that could hold a cylindrical form and would rotate the piece automatically while etching to maintain a constant etch surface. The team tried etching the Ole Miss logo onto the pen barrel just by putting the barrel at an arbitrary zero point on the rotary fixture. The resulting etch was one that overlapped and was not clean or consistent. After etching a few more barrels it was seen that the rotary fixture would not turn the barrel consistently throughout the etching process. The reason identified was that the barrel did not have enough weight for the fixture to properly grab the barrel and turn it in constant time with the etching head. A metal punch, which had considerable weight for its size, was added inside the barrel. Using this extra weight in the barrel significantly reduced the inconsistency of the rotary fixture and the etching head alignment. The team decided to use this process in the initial trial run of production, because it improved the accuracy and preciseness of the laser etch.
6. Optimization for Design and Manufacturability

Whether it be the design of the product, the improvement of the production process, or changes to the process flow layout, team members should always have the concept of continuous improvement on the forefront. In order to ensure a culture of continuous improvement, Pens Up! held meetings three to four times a week to discuss changes and improvements to the product. The manufacturing process of the pen up to this point was very elementary and was not proven to be able to work in a full scale manufacturing environment. The optimization for the design was to try to minimize as many areas for mistake in manufacturing as we could through optimizing the design. This section will discuss how and why each of the components of the pen were changed.

6.1 Optimization Reflected in Design Changes:

6.1.1 Barrel

The barrel still used the tapping head to tap threads to the outside of the nozzle; however, the team saw that in order to hold the pen in place there would need to be an easy close to automatic fixture to hold the barrel while the tapping head tapped. A pneumatic collet fixture was decided upon. This fixture connected to an air source through hoses and would close and open through pneumatic operation of a pedal. The collet chuck optimized the ability to precisely and accurately tap the barrel every run. The tapping head reduced the failure of the tapping tool drastically while also insuring that each tap was uniform. In Fig. 13, the collet chuck used for tapping is shown.
The next optimization was to make a fixture to use on the band saw to cut the barrel at the same length every time. The fixture was modeled off of a preexisting fixture used in CME labs. The fixture would hold the pen in a single place while the operator cut the barrel at the same length every time. The fixture was made out of aluminum and was milled on the Bridgeport Vertical Mill. The fixture uses the standard slots that come on most machine table work spaces. The fixture was also equipped with a screw that would allow the operator the ability to adjust the length of the barrel to be cut. In Fig. 14, the fixture used for cutting the barrel is shown.
6.1.2 End plug and Nozzle

The end plug and the nozzle were one of the more challenging tasks to optimize. The issues that the team ran into with prototyping were dimensional tolerances, machine speed (rpms), design of the shape, material selection, consistency in production, tooling, and tool failure. First using a profile tool, the nozzle was reduced in diameter for about half of the nozzle length to make the threads with a profiling tool. The lathe then switched tools to a threading tool to make the threads on reduced diameter section. The threading tool needed to match its feed rate with the rpm rate of the stock material held in the chuck. Next the lathe switched tools to a drilling block containing three drill bits. Multiple diameters were drilled into the nozzle: first a 5/32 in. bit was used to start the hole then a 1/8 in. bit was used to drill a hole for 0.77 in. depth then lastly a 3/32 in. bit drilled a 0.19 in deep hole. These holes were used to hold the ink refill snuggly in the nozzle. Finally the lathe returned to the profiling tool to taper the nozzle to its desired final shape and to cut off the nozzle from the stock material.

When using acrylic, the first issues encountered were that at too high of an rpm the acrylic would melt and not maintain dimensional accuracy on the threads. Then it was seen that at a reduced rpm the acrylic would splinter or chip when the profiling tool was applied. The issues were mitigated to some extent through experimental changes in rpm and feed rates of the tools; however, the team could never quite fully make the nozzle where there were no quality issues. Even with the most optimized process the acrylic would still fail a quality test with various deformities on the finished product.

Pens Up! then decided to return to using aluminum and mitigate the issues associated with that material. The hardest part of using aluminum for the nozzle material was that the threads were never quite accurate, as aluminum is a soft material and has
some deflection associated with its machining. It was difficult to pinpoint exactly what was causing the threads to have dimensional issues. Through experimenting with the material, the team finally found a set of rpm and feed rates that would produce accurate dimensions as specified by the initial design. After this problem was solved, a new one immediately arose; the team had no way to prevent drill bits from the potential of breaking. The holes drilled were very small in diameter and long comparison to the specified diameter. The aforementioned proportion of dimensions put a lot of stress on the drill bits. Moreover, this in combination with the heat generated in the drilling process of aluminum also added more stresses to the drill bits, causing them to break randomly. The broken drill bit would remain stuck in the nozzle, becoming almost impossible to remove; ruining both the drill bit and the nozzle in production. The team then thought to make the drill bit move in and out of the hole in a pecking motion and combine that motion with an aerated coolant mist that the drill bits would not break. Even with the solution implemented, drill bits would still break after approximately every three nozzles. The team needed to rely on the machine to produce a quality part every time the program was run and could not waste time and money randomly ruining parts.

After many meetings with McPhail, the team decided to try to alter the plastic stock material. The down side to plastics was the cheap appearance which would detract from the initial business plan to create a novel, quality pen. The team nevertheless gave the plastics a try and ran through many different types of plastics. The plastics had so much variance in them, some chipped, some melted, some deflected making it impossible to maintain tolerances, while others failed in the aesthetics department after machining. The only plastic that seemed to work was PVC. This plastic deflected some, but only to a
point where the material would not chip or melt. Every time that the lathe was run with PVC stock, a quality part was formed with the specified dimensional requirements. By this time there were only two weeks left until the production trials. The issues with the nozzle were mitigated and after observing how the plastic nozzle and end plug looked with a blue barrel, the team decided upon gray PVC nozzles. Fig. 15 shows the different stages of nozzle optimization, and Fig. 16 shows the different stages of end plug optimization.

Fig. 15: The development of nozzles from initial prototype to final product (left to right).

Fig. 16: The development of end plugs from initial prototype to final product (left to right).
6.1.3 Cap

As discussed in prototyping, an initial need was not seen to design a cap or cap until the last minute leading up to the trial run for production. During the trial production run the team used the wooden block as the cap, or in this case a pen holder. That design not only needed optimization but needed to be redone completely. When the team decided to 3D print, there were still issues to work through with the cap. Initial issues with cap was that during the 3D printing process with the nylon, the prototype shrunk from the initial design by about 0.05” which made the cap not fit over the pen. The team then tried two different solutions; we tried using a different material and tried scaling the model up by 0.05”. Using a different material of ABS plastic worked well and maintained the initial dimensions of the design. Scaling the 3D model up 0.05” also worked as well but made the cap more oblong and not look as good. In light of those results, the team decided to stay with using ABS plastic to make the cap. The multiple “evolutions” of the pen cap were represented in Figure 17.

Fig. 17: The development of the caps from initial prototype to final product (left to right).
6.1.4 Finishing: Etching and Painting

The finishing of the barrel was done through powder coating and laser etching. When making prototypes, the team noticed a gray, streaked look on the barrel after it was laser etched. The team also noticed that sometimes the powder coat would not stick to the barrel or would create a very thin paint layer, which would allow the manufacturer’s prior coding for the raw material to show through. After investigating the quality defects, the team then found that the raw aluminum stock had residues of oils and paints left on it from the manufacturer. A simple solution was reached in cleaning the barrels by rubbing each raw barrel down with denatured alcohol before being powder coated. The denatured alcohol removed any foreign substance and made a clean material for the paint to stick on. The result was a clean paint application and nothing showing through the coating. Another issue was that the powder coating system that had been used was very expensive to operate and took a long time to prepare and clean. The team found a smaller painting system that we could use that would be much easier and began to use it instead.

Finally the laser etcher was having problems with creating a clear and consistent etch through the paint. The problem was that the powder coat was so durable that at the highest power setting on the laser etcher, the laser etcher charred the paint, and at low power, the laser would not even penetrate the coating. After experimenting with the power and speed settings, it was found that putting the etcher on 50% power and 100% speed was the most efficient way to go. Any etch that was not clear and had some coat residue left on it was wiped again with denatured alcohol, leaving a cleaner finished product.
6.2 Final Dimensions

Upon design optimization, the final dimensions were determined for the barrel, the cap, the nozzle, and the end plug. The dimensions listed in Table 7 are shown to 0.1” tolerances.
Table 7: Pen dimensions used for the final product.

### Aluminum Pen (PENS UP!)

Pen Dimensions (All units in Inches unless specified otherwise)

<table>
<thead>
<tr>
<th>Component</th>
<th>Measured</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Barrel</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length</td>
<td>4.8</td>
<td>4.9</td>
</tr>
<tr>
<td>Outer Diameter</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Inner Diameter</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Thread</td>
<td>5/16 - 18 UNC</td>
<td>5/16 - 18 UNC = .3125</td>
</tr>
<tr>
<td><strong>Ink Cartridge</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total length</td>
<td>5.4</td>
<td>N/A</td>
</tr>
<tr>
<td>Plastic sleeve length</td>
<td>5.0</td>
<td>N/A</td>
</tr>
<tr>
<td>Ink writing diameter</td>
<td>0.1</td>
<td>N/A</td>
</tr>
<tr>
<td>Sleeve diameter</td>
<td>0.1</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Top</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OD Bottom</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>OD top</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Round on Top</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Radius of Curvature from bottom to top</td>
<td>25.0</td>
<td>25.0</td>
</tr>
<tr>
<td>Length</td>
<td>2.1</td>
<td>2.0</td>
</tr>
<tr>
<td>ID 1 - for .5 in depth</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>ID 2 - for .75 in depth</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>ID 3 - for .2 in depth</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Nozzle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total length</td>
<td>0.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Threaded section length</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Profile length</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>Threaded inner diameter</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Threaded outer diameter</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td>First Hole Length</td>
<td>N/A</td>
<td>0.6</td>
</tr>
<tr>
<td>First Hole Diameter</td>
<td>N/A</td>
<td>0.1</td>
</tr>
<tr>
<td>Second Hole Length</td>
<td>N/A</td>
<td>0.2</td>
</tr>
<tr>
<td>Second Hole Diameter</td>
<td>N/A</td>
<td>0.1</td>
</tr>
<tr>
<td>Distance From top of nozzle to Base that touches barrel</td>
<td>N/A</td>
<td>0.6</td>
</tr>
<tr>
<td>Non Profiled Section to change in Diameter</td>
<td>N/A</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>End Plug</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total length</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Outer lip length</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Inner section length</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>Larger Diameter</td>
<td>0.4</td>
<td>0.4</td>
</tr>
<tr>
<td>Smaller Diameter</td>
<td>0.3</td>
<td>0.3</td>
</tr>
</tbody>
</table>
6.3 Discussion for design changes

Overall the optimization of the design for the pen improved the quality and manufacturability. The use of a fixture for the barrel allowed the team to produce the same length barrel every time quickly without error, the PVC on the lathe allowed us to reduce the number of rejects to zero per hour, the cleaning of the pen barrels using denatured alcohol created quality etches and paint finishes. The 3D printed caps created quality and consistency. The main goal of all the optimization was to build in as much quality as we possibly could into the pen without increases in the price. The team’s optimization practices achieved that goal, and, in fact, lowered our cost through the use of cheaper material. Design changes and updates are shown in Figure 18 and Figure 19 and Figure 20.
Fig. 18: Updated CREO nozzle drawing
Fig. 19: Updated End plug drawing
6.4 Manufacturing Bill of Materials

Listed in Table 8, the manufacturing bill of materials is the entire list of what materials the team would need for the manufacturing of one individual pen. Given a certain demand, the team would be able to rapidly order all of the materials needed for manufacturing.
Table 8: Bill of Materials per pen

<table>
<thead>
<tr>
<th>Component</th>
<th>Amount Used</th>
<th>Stock</th>
<th>Supplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barrel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum Tube</td>
<td>4.89 in</td>
<td>0.10 rods</td>
<td>Online Metals</td>
</tr>
<tr>
<td>Nozzle</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic Nozzle</td>
<td>1.05 in</td>
<td>0.02 rods</td>
<td>Online Metals</td>
</tr>
<tr>
<td>Plastic Plug</td>
<td>0.09 in</td>
<td>0.002 rods</td>
<td>Online Metals</td>
</tr>
<tr>
<td>Ink Refill</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>1/12 boxes</td>
<td>Office Depot</td>
<td></td>
</tr>
<tr>
<td>Cap</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Outsourced</td>
<td>CME Makerspace</td>
<td></td>
</tr>
</tbody>
</table>

7. Initial Layout for Trial Runs

The product, the aluminum ballpoint pen, and the manufacturing processes to make the aluminum ballpoint pen were both analyzed by the team after the end of the first semester of prototyping. Some issues that were discussed leading into the second semester, manufacturing, included: how to speed up manufacturing, any possible fixtures/jigs that could be made to improve speed and quality, material selection, aesthetic changes, product additions/compliments, cost strategy, etc. The layout shown in Figure 21 was the first layout created by the team. In developing the initial process layout, Pens Up! was constrained by the need to have sufficient electrical outlets and air supply. As a result, the decision to develop the layout around the assembly table was thought to be the easiest way to ensure usability of the machines. The team chose this initial layout because they felt the layout was a “start-to-finish,” chronological layout for the production trials. This initial layout provided adequate workspace for 5 team members, where the assembly/checkpoint table was located in the center of the production flow. Each team member produced his component of the pen and placed it on the table to be assembled.
Fig. 21: Initial process layout for Pens Up! process layout for aluminum pen production. Estimated process times and proposed operators are listed.

7.1 Method of Assembly

No extra safety precautions were required during the assembly of the pen components. The following list describes the standardized list of assembling a Pens Up! aluminum ballpoint pen after each of the components, nozzle, end plug, cap, and barrel, has been fully finished. This list is important for any future operator going through the pen manufacturing process and any customer or user that may be dis-assembling or re-assembling their Ole Miss aluminum ballpoint pen.

1. Insert the end plug into the barrel. Use the rubber hammer to aid in securing the end plug flush into the barrel.
2. Insert a Uni-Ball Jetstream 101 Rollerball Pen cartridge, Medium Point, 1.0 mm, Black Ink pen refill completely into the barrel.
3. Screw the nozzle firmly into the barrel. The ink refill should not move when the ballpoint is gently pressed onto a flat surface.
4. Secure the cap onto the pen.

8. Production Trials

The manufacturing cell was initially run by five operators: operator 1 in charge of barrels (vertical band saw, drill press, bench grinder), operator 2 running the lathe, operator 3 in charge of the wooden block caps (radial arm saw, drill press, hand drill, sander), operator 4 in charge of powder coating (powder coat paint gun, and oven), and operator 5 in charge of the etching (laser etcher). After each of the first three stations, the completed components would be delivered to quality control before proceeding to stations 4 and 5 for finishing. The assembly station was manned predominantly by operators 4 and 5.

The customer pace, also known as takt time, was not established at the time the production trials began. The manufacturing pace that the team had during production trials was said to be different than this customer pace. As the customer pace was not set at the time of the production trials, the team operated under production for 15 minute intervals.

The idle places in production, or “bottlenecks,” that the team identified during the production trials were the three automatic machines in the manufacturing process: the laser etcher, the oven, and the lathe. The laser etcher had to conduct two separate etching runs to obtain a clean etch, which took 3 minutes. The oven proved to be a bottleneck for multiple reasons. The oven needed to be preheated, had a cure time of up to 20 minutes, and a cooling time of up to 5 minutes. The team thought that a “one-at-a-time” product
flow was not the ideal manufacturing process as a result of the trial runs in regards to the
oven. The lathe was a slight bottleneck as well during the production process, lasting
about 6 minutes. The lathe had a pause in the program which the operator found to be a
nuisance. The operator’s desire for the lathe was to have one continuous program that
would produce both the nozzle and the end plug.

The flow of production began with the aluminum barrel at the vertical band saw, drill press and tap, and the bench grinder. This process for producing the barrel took a
time of 60 seconds. The operator then handed the produced barrel to the powder coat
operator, who then powder coated the barrel to go into the oven. The powder coating
process had a time of 70 seconds. At the same time during these two processes, the lathe
operator was running the programs to produce the nozzle and the end plug. This lathe
process took approximately 6 minutes, including the pause in the program. Another
process that was conducted was the process for the wooden block cap. The wooden
block cap production process took 65 seconds. After the painted barrel came out of the
oven and cooled, the product was passed to the laser etcher operator. The laser etching
operation took a time of 3 minutes 20 seconds.

One common and significant mistake that occurred that was found through quality
assessment was that the pen was put in the laser etcher the wrong way. The pen was
sometimes incorrectly inserted into the laser etcher, which would cause the laser etcher to
etch the Ole Miss logo onto the pen upside down and from the back to the front of the
pen. With the poka-yoke philosophy in mind, the team cautioned the laser etcher
operator to be more deliberate when inserting the pen into the laser etcher by placing the
weight in the threaded end first. Another mistake that occurred was the variance in the
length of the pen barrel. The stop screw in the barrel fixture would sometimes slip forwards or backwards, thus changing the length of the cut barrels. By tightening the screw on the barrel fixture, it was easier to ensure that the barrel length did not vary. The team looked forward to taking these observed and identified problems and improve them for the final production runs.

8.1 Optimization for Semi-Final Production Run

The layout shown in Fig. 22 was formed by the team to become more consolidated, reduce the number of workers, help to exactly meet our customer pace 10 pens per hour, reduce workers waiting around to do work, and to not overproduce or under produce. The layout did a better job of directing the production of the pen to move towards the final assembly stage. The layout also naturally became more consolidated due to fewer machines required in the layout. With a takt time (customer pace) set, the team set out to design a process that would produce exactly 10 pens per hour (1 pen every 6 minutes). Based off of the team’s production trial runs, the process had a much higher capability of production than the customer pace. The whole point of the process changes to meet customer time was not to reduce production but to reduce waste and “extras” in the process which would lead to a costly product. The takt time was a time based strictly off of the market and in the real world a company would only produce as much goods as the market demands. Even though the team had capabilities to produce over the customer pace, the team could not, because there would be no market to buy every pen the team produced over the customer pace, and therefore the team would lose money. That was why an optimization for the team’s initial process was so needed; if the team did not change the process, the team would beat the customer pace and not make profit as a
business. The largest issue with the process was that the team was using a batch system for the painted barrels to cure in the oven. On every other process the team used a “one in, one out” process. However, because the oven had such a long wait time, there was really no way to do a “one in, one out” process. What happened was that the process for making the barrel was “one in, one out” for a certain number of products. Then the products would be batched-painted and put in the oven. Because this seemed to be a fact that could not be mitigated, the team took the oven as the constraint for which all other processes were centered around to meet takt time when optimizing the process.

In Figure 22, the team decided to change the process from five operators to 2 operators. The layout in the figure shows the product flow and the given operator's movement related to the product flow given a blue and red line. The dotted line was a “plan B” in case there was a bottleneck on the etcher (as had been a problem before). Comparing Figure 21 to Figure 22, the first notable difference between the initial layout and the semi-final layout was the cap station. The wooden block cap was scrapped, thus eliminating three machines (the miter/radial arm saw, the drill press, and the sander) and one operator. Moreover, the initial process utilized five operators, whereas the semi-final process utilized two operators to meet the customer demand. The process was optimized in order to eliminate batching before the powder coat station and to eliminate downtime for various operators. In the initial process layout, there was downtime for the vertical band saw operator, the drill press operator for the barrel, and the etcher operator waiting for the powdered coated barrels to be cured. The second operator at the lathe produced one end plug and nozzle at a time and took them to the assembly table to assemble
completed barrels. If needed, as shown from the dotted line in Fig. 22, the lathe operator could also aid in the powder coating and oven processes to reduce his downtime.

Fig. 22: The final process layout for Pens Up! Aluminum pen production

9. Semi-Final Production: April 4th

On April 4, the semi-final production trial was implemented with two operators. As can be seen in Fig. 22, two operators were needed to implement the manufacturing process: one person monitoring the lathe and another person in charge of cutting and tapping barrels, painting and etching barrels, and assembling the pens.

The process was set up with the main operator as represented by the blue line working in a one-piece flow. The main operator cut, sanded, and tapped the barrel, moved it to be screwed onto the powder-coating fixture, and repeated the process until five barrels were ready to be powder coated. Then the five barrels were powder coated...
and placed into the oven. After 20 minutes, the five barrels were removed and etched one at a time. While one barrel was being etched, a completed barrel would be assembled. The secondary operator represented by red in Fig. 22 was solely in charge of running the lathe. As there was a stop built into the program, the secondary operator was needed to push the button in between the production of the endcap and the nozzle. In between the lathe’s production of the nozzle and the endcap, the secondary operator would recover the endcap from the chute in the lathe before producing the nozzle and clean off the completed part, walking it to the assembly table. Although this operator included waste from extra walking steps, walking to and from the assembly table aided in ensuring that the takt time of 6 minutes per pen was closely met. The challenge sought to be met from this semi-final production run was to meet the given takt time while maximizing the capacity of the oven without overproducing.

The semi-final process included both realized and unrealized elements of TPS. The realized elements of TPS in the semi-final production process were: (1) the production process met the customer pace of 1 pen per 6 minutes, (2) 100% of the produced pens met quality requirements, and were able to be sold, and (3) the production process maintained a “one in, one out” flow, except for the oven process. The unrealized elements of TPS in the semi-final production process were: (1) all processes were organized to match the machine time of the oven, (2) the operators moved and walked around the layout excessively, and (3) the secondary operator “babysat” or idly watched the lathe machine.

The team’s takeaways from the semi-final production run in regards to TPS were: (1) the one-piece flow needed to be utilized throughout the whole process or operation,
and not centered around the machine time of the oven, (2) one operator needed to be eliminated because the operator was idly watching the lathe and wasted work talent, (3) “alarms” needed to be set in place on the machines to signal the primary operator that the machine’s operation was completed, and (4) the layout needed to optimized to reduce excess movement and any potential user error for the primary operator.

10. Optimization for Final Production Run

The team hosted a meeting in one of the CME conference rooms after the semi-final production to discuss optimization for the final production run. Four ideas were proposed, each with a unique layout and production process. Two of these ideas were chosen from the meeting on April 4th to be fully explained in two back-to-back dry runs on the CME factory floor. Fig. 23 pertains to the first layout and process, and Fig. 24 pertains to the second layout and process. Each of the process flows allowed for a one-man flow, with a one-piece flow implemented as much as possible. The first one-piece flow did not meet the takt time of 6 minutes per pen (10 pens per hour), resulting in one pen shy at 9 pens per hour. On the other hand, the second layout and process concluded with 11 pens total produced in an hour.

Changes were made to the semi-final process flow and manufacturing layout in order to better optimize the manufacturing process, improve takt time to meet the customer pace, and to reduce the overall cost of producing the product. The final process layout allowed for more of a one piece flow. The team conducted two dry runs: one dry run of the first layout and process shown in Fig 23, and one dry run of the second layout and process shown in Fig 24. After performing the two dry runs, the team elected to use the second layout and process for the final production run, because the team observed
that this layout and process contained fewer process steps, made a “U-shape” layout to
better reduce walking steps, and drastically reduced operator waiting time on machine
processes to almost no time at all during production. These factors led to a better
standardization of the production process for the operator.
Fig. 23: The first process flow for the dry run along with the process flow steps pertaining to it.

1) Powder coat barrels
2) Place powder coated barrels in oven
   - Oven process time = 20 minutes
3) Take cooked barrels and place to cool
   *Quality Control Station – Reject barrels that do not meet quality standards
4) Start laser etch
5) Start lathe
6) Cut 1 barrel
7) Tap 1 barrel
8) Wire brush 1 barrel
   - Place barrel in WIP on assembly table
9) Assemble 1 pen
   *Quality Control Station – Reject Nozzle, End Caps, and non-functioning pens.
10) Retrieve end cap, nozzle and etched barrel and place in WIP on assembly table
11) Repeat steps 4-11 until oven time of 15min of baking and 5min of cooling is complete
12) Repeat entire process starting at step 1.

= Standardized work instructions and reminders for team member for each process.
11. Final Production Run

In order to properly implement the chosen one-piece, one-operator manufacturing process and meet the takt time of 6 minutes per pen produced, two human alarms were necessary. In an actual factory manufacturing setting, machines would have installed alarms to let the operator know when the set time ends. However, as alarms were not installed in the machines, one person was used as an alarm for the oven and the laser etcher; the second person was used as an alarm at the CNC lathe, in order to alert the operator if anything went awry with the machine. The usage of human alarms played two roles in the one-man process flow. It put the operator at ease during production and alerted the operator if an issue arose with the machine. In being a timekeeper for the operator, the human alarm at the lathe would set a timer for 17 minutes and also notify the operator of any problems with the lathe. There was one instance of human error in
regards to the lathe. The operator pressed the green start button on the CNC lathe twice, accidentally resetting the program and jamming the raw stock in the collet. The alarm went off and the technician had to readjust the stock and properly restart the program. The usage of the alarm, kept the process running although there was a hiccup with the CNC lathe. The alarm at the oven would begin alerting the operator of time left on the oven in two minute intervals, starting with 5 minutes left on the oven time, in order to pace the operator as he passed by the alarm.

The team noted realized and unrealized TPS elements in the one-person final production process. The realized TPS values of the production process were: (1) the use of one operator, (2) a better one-piece flow than any previous production run, and (3) a better layout that conserved space, reduced walking, felt more chronological than any other previous layout. The unrealized elements of TPS values that the team saw during the final production were: (1) no standardization in the length and assembly of the ink cartridge, (2) no accounting for machine downtime, (3) mistake proofing against operator error during production, (4) the final production actually overproduced pens, and (5) the final production did not meet quality requirements. The operator would sometimes cut the ink cartridge in length with pliers during assembly into the barrel, which would create a non-ideal situation. This observation in the process was not a standard procedure. The operator also committed an error when using the lathe that caused the lathe to have significant downtime, and the team did not make a process adjustment for the operator. Finally, the final production overproduced by 2 pens, and 5 pens did not meet quality requirements.
Through the implementation of the chosen process, the theory of a one-man, one-person flow was proven; however, there were certain aspects of the hour run where Pens Up! realized it needed further improvements in order to better standardize the process. From this production run, it was noted that although one operator was capable, adding at least a second operator would have aided in eliminating some of the mistakes and relieved some of pressures/stresses visible in accomplishing a production run with a takt time of 6 minutes per pen in a one-person flow.

The usage, or lack of usage of denatured alcohol was an issue that was not caught until the production had already started. There was only one container of denatured alcohol that was left at the assembly station and there was not any at the powder coating station. As a result, there was a batch of 5 pens that were not cleaned with denatured alcohol before being painted (Fig. 25) resulting in wasted barrels—barrels still with the aluminum rod manufacturing numbers printed on. Fig. 26 illustrates the difference between cleaned and uncleaned barrels.

Fig. 25: Non-denatured barrels before paint. Notice the numbers from the manufacturer still on the pen even after powder coating.
Fig. 26: Non-denatured barrel vs. denatured barrel after etching. Notice the color difference in the etched portion.

11.1 Improvements: Problem Solving and Future Resolutions

The team worked with the designated TPS mentor for the CME to analyze what needed to be changed and how to continuously improve the process in order to make it better. As a result of 5 rejects produced in the final trial run, the team saw the need to produce standardized work documents for the manufacturing process. The rejects that were made were produced as a result of forgetting certain processes because the team did not have any set documentation or standardized form of work. Moreover, each team member had a different understanding of standardized work.

In order to identify and truly solve a problem, the problem must first be narrowed down to a specific point of cause. Secondly, the point of cause must be addressed. In order to maintain standard work, written documentation of the work steps to be accomplished was added to the process flow.

These hiccups were immediately addressed in order to improve any future production runs. The aspects of the production flow that were immediately addressed to improve the one-operator, one-piece flow were: (1) standardize a set barrel length and ink cartridge length for assembly purposes, (2) give the operator more practice and time to become comfortable with his workflow and the steps involved (this can be done, after all, the operator only worked for one hour, so longer works shifts could solve this
problem), and (3) solve the quality requirement issue through knowing how to run the lathe, and (4) provide enough denatured alcohol at the necessary places in the manufacturing process. A final, more consolidated U-shaped layout proposal (Fig 27) was suggested by the TPS mentor and implemented by the team in the April 6th production run. Moreover, quality checks would need to be added before the powder coating process and before the laser etching process to eliminate any potential defects of barrel length and of leaving the manufacturer’s numbers on the barrel.

Fig. 27: The suggested improved process layout.

12. Conclusion

Pens Up! arrived at the conclusion after the final production run that a one-operator, one-piece flow was possible. The capstone project was designed for the team to learn about lean manufacturing specific to a process. This capstone process gave the team
a chance to evaluate and analyze problems given a unique situation of manufacturing. In
the real world manufacturing will be full of unique products with sets of unique
problems. The goal of learning lean manufacturing is not to follow a procedure and
checklist that is a fix all solution to every problem; rather, lean manufacturing is about
giving you the tools to apply in any situation needed. In the case of this thesis, the
manufacturing of the pen is the unique situation in which the team solved problems. In
conclusion the team saw unique problems related to the product being: 1.) One in one out
flow, 2.) Reduction of cost through waste elimination: specifically, overproduction,
movement, processes, inventory, and quality. The team observed and solved these
problems throughout the life of the project.

If the poor instances of TPS manufacturing were addressed and another
production run occurred in the future, the one-operator, one-piece work flow would be
able to meet the customer pace. The goal of a one-operator, one-piece flow was the most
TPS satisfying manufacturing run, and during the final production run Pens Up! achieved
that goal.
13. References

14. Appendix

Gantt chart, Risk Register, and electronic links to videos are attached in the final submission online.