Utilizing the Product Development Process to Bring an Idea from Concept to Production

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UTILIZING THE PRODUCT DEVELOPMENT PROCESS TO BRING AN IDEA FROM CONCEPT TO PRODUCTION

Sydney Ferguson & Jackson Sneed

A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

Oxford
May 2020

Approved by

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Reader: Professor Eddie Carr
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We would first like to thank our fellow team members Christian Niehoff, Cooper Hoskins, and Henry Jefferies. Their collaboration was integral to the successful design and manufacture of the portable firepit. Next, we would like to recognize James McPhail. James was constantly offering his time to give us advice, help us brainstorm solutions to problems, and safely manufacture the product. We also greatly appreciate the feedback and constant support of our advisor, Dr. Jeremy Griffin, and our readers, Mr. Michael Gill and Mr. Eddie Carr. Finally, we would like to acknowledge Miss Rochelle, Miss Ronica, and all other Center for Manufacturing Excellence faculty for their encouragement and assistance throughout our four years at The University of Mississippi, especially during our Capstone project.
ABSTRACT

The purpose of this thesis is to document and discuss the five-stage product development process starting with defining a problem and resulting in manufacturing a final product for sale as it was implemented in the Portable Fire Pit Center for Manufacturing Excellence Senior Capstone Project. This project was carried out over the course of the Fall 2019 and Spring 2020 semesters by a team consisting of three Undergraduate Mechanical Engineering majors and two Undergraduate Accountancy majors. The ultimate goal of the project was to carry out a full production run of the Portable Fire Pit outputting fifteen units meeting retail quality standards. At the onset of the project, a project management plan and product development schedule were created to sequence tasks and proportionally distribute labor and resources over the course of the project. The first step of the project plan was to begin the prototyping phase of the product development cycle. This involved creating an initial product design that included the features required to solve the initial problem and also implement principles of Design for Manufacturing and Assembly (DFMA). The second state of the development process was to create a final product design by carrying out market research, making iterative prototypes, and improving the original design. The third stage of development involved making preliminary plans for a full production run, estimating production cost and budget based off of this plan, and developing a mock business plan for our product. The fourth stage of the process involved setting up the process layout and testing a full production run, applying Lean manufacturing principles to increase optimization. The fifth and final stage consisted of ramping up to full production and doing an hour-long production run. The author of this thesis will carry out an analysis of
the product development process and discuss the effectiveness of DFMA and Lean manufacturing principles as they were carried out in this project.
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1 INTRODUCTION

Is there such a thing as a perfect product? While this may seem like a strange question, knowing the answer is crucial to understanding the driving forces behind the modern consumer economy and the creation of the products that are bought and sold within it. The question itself is phrased to elicit a simple yes or no response, but this is misleading as neither ‘Yes’ or ‘No’ is completely correct. In reality, the correct answer depends entirely on who you ask. This is because, like all things, products are not universally perceived the same way, but are instead viewed totally different by every individual. One product or product feature that a particular person finds value in and has a positive opinion of may be found by another person to be unnecessary and evoke an overall negative response.

Consequently, it would seem that there is no such thing as a perfect product, as there is no object or idea that is universally loved by everyone. This means that whenever a company is determining the design of a product, every choice they make will result in a product that will appeal to some potential customers, but also turn others away. Since it is impossible to appeal to every customer, it is not practical for companies to attempt to monitor the effect of design changes on each potential customer’s opinion. This is why companies choose to focus on a select group of people to sell their product to, referred to as a target market. The product is intended to solve a
problem or fill a need of the target market. Once a business has identified their target market and a shared problem to solve has been found within that market, the business has begun the first phase of the product development cycle. The product development cycle is a procedure followed by businesses all over the world to successfully bring an idea from generation to sale. The product development process utilizes cross-departmental communication and teamwork to translate what marketing discovers the targeted customer base values into final product design features through engineering. This same product development cycle was followed in this project for the creation of the Portable Fire Pit as a product intended for sale. This project therefore stands as a case study for the implementation of the product development cycle and a testament to the pros and cons of its implementation.

1.1 Center for Manufacturing Excellence

The Center for Manufacturing Excellence (CME) was founded in 2010 to provide students with academic and real world experience to thrive in the world of modern manufacturing. Admission to the Center for Manufacturing Excellence is very competitive, limited to 60 students per class. Traditionally the CME accepted students majoring in the disciplines of engineering, accountancy, and business, but has recently expanded to be open to accepting students of all majors. Regardless of the area of discipline, a proficiency in problem-solving techniques and continuous improvement is useful to the success of all students.

The Center for Manufacturing Excellence teaches principles of engineering, accountancy, and business with respect to manufacturing. Specifically, the CME offers
classes specializing in manufacturing processes, materials, continuous improvement, the product development process, team-building, and lean manufacturing. Students have the opportunity to participate in hands-on learning at various manufacturing facilities across Mississippi. Students have collaborated to solve real-world problems at Toyota, Ingalls Shipyard, Viking Range, and VIP Cinema Seating, to name a few. The diverse industries and production capacities of these companies provide students with a wide range of learning opportunities.

All of these classes culminate in the senior Capstone project. In the Capstone project, teams design and manufacture a product and prepare a plan for full-scale production including financial information and a marketing plan. Students utilize their knowledge of product design and development, teamwork, manufacturing processes, and problem-solving techniques to successfully take an idea from a concept to production to market. Although there are class meetings and deadlines to ensure progress on the project, each Capstone Team relatively regulates itself. Each team appoints a team leader to be the point of contact between CME faculty and the team. The Capstone Team schedules time on the factory floor with a technician and creates a timeline to monitor the progress of the project. Students have the responsibility to be a valuable member of their team and to act professionally in regards to deadlines and meetings.
1.2 The Product Development Process

![Phase Diagram]

**Figure #1**

The product development cycle is typically broken up into six stages. The product development process is in a stage-gate process, as shown above in Figure #1. A stage-gate process is a conceptual and operational guideline for transitioning a new product project from idea to launch. A stage-gate process is used so that the producers of physical products are able to reach desired results quickly. In a stage-gate process, each phase is cross-functional. Every stage consists of a set of concurrent activities performed by personnel from different functional areas of the company. Activities within a stage are intended to collect information to reduce the uncertainties of the project.

Moving forward in the product development process, each stage costs more than the previous. However, the increase in cost is accompanied by a decrease in uncertainties.

Phase zero is the planning stage. This is the first step of the product development process. Phase zero encompasses the planning that should be performed prior to the approval of the project. In this phase a preliminary engineering evaluation is performed to determine technical and manufacturing feasibility. If this assessment deems the project feasible, the planning phase moves on to building the business support for the project. Important business research is performed, including patent searches and financial analysis. The patent search ensures that the proposed project will not infringe on any protected inventions and is able to move forward in the product
development process. The financial analysis typically utilizes sales and cost estimates to project the profitability of the proposed project. This is a crucial step, since a project that is not profitable is not worth moving forward with.

Once the planning stage is complete, the project team moves on to phase one, conceptual design. The conceptual design phase begins with the defined problem or product idea and uses it to create general design concepts and product requirements. The project team will use these product requirements and the information gathered during the planning stage to brainstorm and develop multiple product design concepts. Once multiple feasible concepts are generated, the team uses tools such as Pugh Charts to compare and rank the concepts according to their ability to meet the customer’s requirements. This process should result in the team choosing the best overall design concept and derived product design specifications for further development and design.

After choosing product design specification to build for, the project team moves onto phase two of the project development process, embodiment design. Embodiment design consists of product architecture, configuration design, and parametric design. Product architecture is the arrangement of physical elements of the product. Configuration design includes the selection of materials and manufacturing processes. Parametric design considers design for manufacturing (DFM), design for assembly (DFA), and design for environment (DFE). Although these design processes are typically seen as primarily engineering, cross-functionality of phases is easily visible in the embodiment phase. For example, the selection of materials involves both engineering and accounting departments. Engineers provide the expertise needed on
material specifications, while accountants evaluate the materials in terms of cost. The cost of direct materials, in combination with labor and variable overhead constitute the variable costs of the product. The sales price less these variable costs represent the amount available to cover the fixed costs of the operation. The accountant in this situation must consider these other costs while offering an opinion on the material choice.

Phase three of the product development cycle is detail design. In this phase, the engineering description is completed. Information is added on the arrangement, form, dimensions, tolerances, materials, and manufacturing of each part in the product. Also during this phase, manufacturing decisions are made. This includes whether the product will be outsourced or be produced in-house, the quality assurance process, and the design of the tooling necessary to produce the parts. Phase four is testing and refinement. As its name suggests, phase four is focused on producing and testing pre-production prototypes. Also during this phase, marketing personnel develop promotional materials and the sales team refines the sales plan. At the end of phase four, the project is reviewed to determine if the product is still consistent with the original problem definition.

The fifth phase of the product development cycle is production ramp up. In this phase, the product is manufactured and assembled using the final production system. During phase five, employees will likely experience a learning curve as they work through initial production process and quality issues. Figure #2 below shows how production speed per unit increases as the personnel becomes more familiar with the
process and gains experience. Moving along this curve, production typically increases gradually until full production is reached.

![Learning Curve Diagram](image)

**Figure #2**

While in phase five, the product is launched and made available for general distribution. After the product is launched, the product goes through a final review. The primary purpose of this review is to determine the strengths and weaknesses of the product development process. This analysis is completed so that the next project team can learn from the successes and failures of this one.

### 1.3 Essential Manufacturing Principles

In addition to the product development cycle, this project was also heavily influenced by the teachings of Lean Manufacturing, Design for Manufacturing and Assembly, and Total Quality Management. All of these are examples of the
The CME program focuses heavily on teaching practices and techniques commonly used in the manufacturing industry. The major guiding manufacturing philosophy for the program is Lean Manufacturing, a philosophy developed by Taiichi Ohno while he worked as an engineer for Toyota in Japan during the Mid-20th century. Lean manufacturing focuses on eliminating waste through continuous improvement, also known as kaizen. According to Ohno, the seven kinds of waste are overproduction, waiting, conveyance, over-processing, inventory, motion, and defects.

Overproduction is when a part is manufactured before it is actually required. Overproduction can result in excessive lead times or high storage costs. Waiting refers to the idle time when goods are not moving or being processed. Conveyance or transportation is the unnecessary movement between or during processes. Excess conveyance can be caused by poor layouts or complex material handling systems. Over-processing results from the production steps that do not add value to the customer. For example, painting unseen areas or using unnecessarily tight tolerances would be considered over-processing. Inventory waste refers to the retention of excess inventory. Excess inventory increases lead times and costs of storage facilities. Ideally, inventory would be received at exactly the time it is needed, so that there is a continuous process and limited storage needs. This inventory strategy is referred to as “just-in-time,” and is intended to increase efficiency. The waste of motion is any movement of the employee or equipment. Excess motion decreases efficiency and also can be a safety hazard to employees. Defects encompass the typical idea of waste. Defects cause the product to either be reworked or scrapped, which affects the bottom
line. The elimination or minimization of these wastes will increase efficiency of the production process and increase profitability.

One of the most common practices found in engineering design today is Design for Manufacturing and Assembly (DFMA). DFMA is a series of principles that help govern the design of a product to make it easier to both produce and assemble. Some of the key principles of DFMA are standardizing parts, reducing the design to as few parts required for the product to function, and diminishing all sources of impedance for workers in assembly and manufacturing. Implementing DFMA principles into the product development process is believed to increase quality, decrease cost, and decrease overall production times. These improvements are attributed to a variety of the outcomes of implementing DFMA like decreasing the variety and size of part inventory. DFMA is a popular philosophy to implement because it takes place primarily in the design stage of product development where the decisions made directly affect 70-80% of the manufacturing cost of the product (Dieter, 4).

Total Quality Management is a management system that focuses on customer satisfaction across all departments. Total Quality Management (TQM) emphasizes the connection between design and the desires of the consumer. TQM includes processes for making design choices that will result in the highest level of satisfaction for the target consumer. An integral aspect of TQM is understanding what the customer finds valuable. Understanding of the customer can be derived from market research or past experience. TQM, DFMA, and Lean Manufacturing are not mutually exclusive philosophies. These strategies build on one another and their combined usage makes the business more efficient and profitable as could be demonstrated by this case study.
2 The Team

In Industry, one of the first things that comes to a project manager’s mind when they are assigned a new project is team formation. Project managers ponder how they can use the human resources available to build a team that is best suited to accomplish the goals of the project in question. For the CME Capstone project that is serving as the case study this thesis is based on, the project team was assigned to the project rather than chosen by a project leader. While this may seem like an academic practice rather than the process representative of industry, this isn’t necessarily the case. Many companies have limited human resources with only a small group of people who are available to work on a project. Therefore, it is important for a project manager to be able to develop a team to successfully complete a project even if the team members themselves may not seem ideal to the project. Team composition is arguably the most important aspect of a project, as it can aid or hinder the success of a project.

2.1 Team Development

The Center for Manufacturing Excellence teaches students to achieve team synergy through the five-step team building process developed by psychologist Bruce Tuckman. Tuckman first defined the team development process in 1965 and it is still widely utilized today. The stages of team development as described by Tuckman are
forming, storming, norming, performing, and adjourning (Stein). Forming, as the name suggests, is the stage in which the team composition is determined and team members get to know one another. In the case of the Capstone project, teams were determined by the CME professor teaching the Capstone class, Mr. Gill. He assigned students to projects based on three criteria. The first criteria used to determine team composition is each student’s actualized leader profile. At the beginning of the Capstone project, senior CME students were asked to complete a questionnaire to determine their actualized leader profile. This test separated students into one of three categories, asserter, affirmer, or achiever and also gave students a self-actualization score. These results allowed CME faculty to create teams with diverse personality types. The second criteria upon which teams were determined was individual interest in project ideas. Students listened carefully to each project pitch and then ranked five projects they would have interest in working on. Individual interest in a project was important in team determination so that team members would be more likely to be engaged in the project. Finally the third criteria was the academic backgrounds of students. As the project encompasses production and full-scale projection of the product, it was important to have team members of varying areas of expertise. The team assigned to this project consisted of three students studying mechanical engineering and two students studying accountancy.

The next phase of team development is storming. In this phase, individual personalities emerge and team goals are determined. This stage can contain conflict as the team must overcome obstacles, mitigate individual differences, and work through conflicting objectives. During this phase, the Capstone project team spent time
determining team goals and understanding each individual’s schedule. As every team member has conflicting personal goals and commitments, this was a difficult stage. The team had to find a suitable meeting time for all team members, which was not as easy as it seems, considering each team member had their own schedule. The third phase of team building is norming. During the norming phase, a sense of unity develops amongst team members and a team leader emerges. The team becomes accustomed to working with one another and learns how to work effectively as a unit. The Capstone Team nominated a team leader to gather the team and also to be a point of contact between CME faculty and the team. The team goals determined during the storming phase brought members of the team together under a shared purpose.

The fourth stage of the team development process is the performing stage. During the performing stage, the team is established and high-performing. Team members work well together and are committed to achieving the team’s goals. The team structure is defined and understood by members of the team, and this structure is utilized to make progress towards goals and constructively solve problems. The performing stage is where the team achieves synergy, as the team working together is able to accomplish more tasks at a faster rate than if team members worked separately. Finally, the last stage of the team development process is adjourning. During the adjourning phase, team goals have been accomplished and team members are wrapping up final tasks. Once the project is complete, the team will either separate or take on a new project.
2.2 Capstone Team Roles

Jackson Sneed served as the team leader of the Capstone project. He was the point of contact, responsible for communication between the group, the factory floor technician James McPhail, and instructor Mike Gill. As team leader, Jackson was tasked with managing the goals of the group, monitoring team progress, and finalizing decision making. Jackson, a mechanical engineering major, also served as the Lead Engineer of the project. He was involved in all production runs and design changes. Christian Niehoff, a mechanical engineering major, was the Design Engineer. Throughout the project, Christian worked in Creo Parametric to design the product specifications and assess problems concerning design. This role also encompassed material research and selection. Christian had the responsibility to analyze how material and design components would affect the manufacturing process. Henry Jefferies utilized his mechanical engineering background to fulfill the role of Manufacturing Engineer. He worked closely with Jackson and Christian to assist in Creo Parametric design of the firepit and was actively involved in the production process on the factory floor. Henry was responsible for assessing the manufacturability of the firepit, focusing on issues regarding production, and determining the most efficient way to produce the firepit.

Sydney Ferguson and Cooper Hoskins were the Financial and Business Consultants of the Capstone Team. As Accounting majors, both Sydney and Cooper used their business knowledge to assist the team. Cooper and Sydney have experience in accounting, finance, marketing, and management which was very useful to the team. One of their primary responsibilities during the Capstone project was developing and
controlling the budget. Each Capstone Team had a $1,000 budget each semester. Cooper and Sydney monitored team spending and were actively involved in material selection and purchasing, as this was the primary direct material cost. Cooper and Sydney were responsible for creating a marketing plan for production. They pioneered the development of a survey to gage market interest in the firepit, determine a feasible selling price, and understand market demographics. Sydney and Cooper projected full-scale production financials and completed a sensitivity analysis across varying levels of production.

2.3 Full-Scale Production Roles

Projecting production to full-scale, the company organizational roles change slightly from the Capstone Team organization. Jackson Sneed will serve as the Chief Executive Officer (CEO) in the proposed company. He will oversee all aspects of the product as well as the business. Sydney Ferguson will be the Chief Financial Officer (CFO). This role is responsible for financial planning, record-keeping, financial reporting compliance, and assessing and managing risk. Departments under CFO include Accounting, Financial Planning, and Purchasing. Cooper Hoskins will be appointed the Chief Marketing Officer (CMO). Cooper will be in charge of developing and implementing the marketing strategy. The CMO heads the Advertising, Public Relations, and Market Research divisions. With these roles, Cooper and Sydney will oversee the business side of operations. Their knowledge about the production and specifications of the product will be very useful for success in their roles. Henry Jefferies will serve as the Chief Operations Officer (COO). Henry will be responsible for monitoring the day-to-day
operations of the company, with a focus on production. The COO will be responsible for Human Resources, Quality Assurance, and Logistics Departments. Christian Niehoff will be the Chief Product Officer (CPO). Christian’s in depth knowledge of the design, materials, and production process of the product will be inherent to this role. The CPO will be in charge of the Manufacturing and Research & Development divisions. Figure #3 below depicts the organizational structure of the proposed company.

![Figure #3]

Figure #3
3 Problem Definition

The idea for the Portable Fire Pit was created by the project team leader in order to help resolve some of the common issues he observed in the design and functionality of fire pits currently found in the market. Describing these issues and how they led to the product idea is essential for this case study because it provides a better understanding as to what the product is intended to do that isn't already being done. Additionally, it is important to document the original goals of the project idea so that the final product's ability to meet them can be accurately evaluated.

The drawbacks of existing product designs addressed by the Portable Fire Pit were first observed in an existing product owned by the founder of the product idea. He received the fire pit as a gift and placed it on his patio to be used for bonfires when people came over to socialize, but ended up mostly just using it once a month to burn shipping and pizza boxes. Despite not being used as often as originally hoped for, as time passed it became dirtier and full of ash that was nearly impossible to remove, becoming a permanent eyesore that took up space in his already limited patio area. To fix these problems, the idea for a fire pit that could easily be disassembled and assembled was conceived and dubbed “The Portable Fire Pit”.

The idea for The Portable Fire Pit was to design a fire pit that was constructed out of multiple flat metal panels rather than one large metal piece like most fire pits. A
design based on this principle would provide The Portable Fire Pit with many advantages over other fire pit designs. One such advantage is that it would be easier to store multiple flat panels rather than a solid metal cube when the fire pit isn’t being used, making the Portable Fire Pit more suitable for people with limited space than its competitors. Additionally, this also makes the Portable Fire Pit easier to transport and therefore allowing it to be used for events like camping trips unlike traditional fire pits which are relegated to being used in only one place. Finally, the Portable Fire Pit would be easier to maintain than traditional fire pits because ashes would fall out when disassembled and the individual panels could be cleaned by spraying them off with a hose which would be much easier than trying to rinse out a solid metal container. All-in-all, the Portable Fire Pit does exactly what its name suggests. It takes a product that is usually considered to be permanent and adds potential uses and functionality by removing the barrier of being fixed to a single location.
4 Planning

The first step, or Phase 0, in the product development process is planning. Unlike the name of the phase suggests, the planning stage doesn’t actually result in a documented plan for the rest of the development process, but instead involves gathering marketing, financial, and engineering information crucial to the rest of development. It is common practice to start gathering information by finding potential markets for the product to be sold and then gathering information on engineering capabilities and financial performance. For this project, the planning process started with gathering information about similar products already on the market and then verifying that a similar product could be produced using the resources provided by the CME.

A majority of the information gathered was found on various websites listing similar products for sale or describing how individuals had built a similar idea for their own personal use. The product listings on websites provided valuable information such as price patterns, common design features, and what competitors advertised as their competitive advantages over similar products. Additionally, the reviews on product listings also provided the team with an idea of what features people found desirable as well as what applications the products were used in. While online customer reviews may appear to be an unconventional source of data, recent studies have shown that
gathering this data on a large scale has resulted in data about consumer product preferences comparable to traditional market research techniques. (Decker, Reinhold, Trusov) From this initial data gathering it was determined that similar products were primarily made out of raw hot rolled steel and were marketed as either small or large in size. A quick analysis of the prices revealed that the products classified as ‘small’ ranged in price from $74.99 to $120.00 with a mean price of $97.50 and the products classified as ‘large’ ranged in price from $179.00 to $250.00 with a mean price of $201.60 as shown in Table #1 and Table #2 below.

<table>
<thead>
<tr>
<th>Product</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>JMC</td>
<td>179</td>
</tr>
<tr>
<td>Grill N Go</td>
<td>180</td>
</tr>
<tr>
<td>Portable Metal</td>
<td>199</td>
</tr>
<tr>
<td>Pyro Cage</td>
<td>199.99</td>
</tr>
<tr>
<td>HBEE</td>
<td>250</td>
</tr>
<tr>
<td>AVG</td>
<td>201.598</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simond Store</td>
<td>74.99</td>
</tr>
<tr>
<td>Grill N Go</td>
<td>74.99</td>
</tr>
<tr>
<td>Minimalist</td>
<td>120</td>
</tr>
<tr>
<td>Collapsible</td>
<td>120</td>
</tr>
<tr>
<td>AVG</td>
<td>97.495</td>
</tr>
</tbody>
</table>

Once this data was gathered, the group consulted with a machining expert employed by the CME, James McPhail, to determine the project's feasibility. Experts outside the team are often consulted in this stage of development because they are able to use past experiences to provide a fairly accurate estimate of what can and can’t be done. The project team presented James with the idea that they had and asked his opinion on whether or not it would be possible to manufacture the product using the resources available for a cost less than what the potential competitors were charging. He assessed that it would be possible and advised the group on potential materials and
suppliers for those materials for production, confirming the feasibility of the product idea for the next stage of development.
5 Product Design

For organizational purposes, 5 Product Design consists of the product development phases of Conceptual Design, Embodiment Design, and Detail Design. During these phases, the product begins to take shape. What was once an idea is now a tangible product, able to go through design changes, testing, and analysis. Although the design process is typically regarded as an engineering process, business personnel are heavily involved in decisions made during this phase.

5.1 Conceptual Design

The Conceptual Design phase of the product development process includes the gathering of information, concept generation, and evaluation of concept. The Capstone Team gathered information through a market survey of potential customers. This information was utilized when developing the concept to be produced. The customer preferences derived from the survey were taken into account while creating the design of the product. Finally, an initial cost analysis determined whether or not the proposed project was feasible, in terms of profitability.
5.1.1 Initial Market Analysis

Near the beginning of the project, the Capstone Team conducted an initial market survey to grasp customer interest in the project as well as project limitations. The Capstone Team asked survey respondents questions regarding preferred material, design, and finish to understand what potential customers were looking for. The survey also sought to determine what potential customers planned to use the firepit for, so that the Capstone Team could integrate these intended uses into the design. Most importantly, the survey determined the percentage of survey respondents that were interested in purchasing the firepit and what these interested respondents would be willing to pay to obtain the fire pit. The survey was distributed to friends, family, and colleagues of the Capstone Team to obtain the desired data. 187 individuals completed the survey, ranging vastly in terms of age, geographic location, occupation, and income level. Of the 187 survey respondents, 79.68% were interested in purchasing the fire pit. The Capstone Team utilized data from interested respondents to estimate the average price they were willing to pay. The average price point was $100, so the Capstone Team felt this was a reasonable selling price and would generate enough revenue to cover expenses.

5.1.2 Concept Generation

The information gathered from the initial market analysis and planning stage were used by members of the team to brainstorm various design concepts that would provide the most benefit to the customer. The team started by narrowing down the potential uses for the product idea based off of the survey responses. The three most
common applications of the product were camping, tailgating, and at home use. The team used these three potential uses for the product to come up with a variety of possible concepts and features that would make the product more suited for one application than another. In some cases these concepts would conflict with each other; specifically the desire for a product large enough to be useful at home was in direct conflict with a product that was also light and portable while remaining within the target price range. In contrast, some of the proposed concepts provided benefits to all three potential use cases. These included making the product easy to assemble and disassemble, and making the product safe in all possible environments. Ultimately, the team decided that in cases where features contradict each other that it would be best for the features providing functionality for camping and tailgating to be given precedence over features for home use since a vast majority of fire pits on the market are already targeted towards home use.

With these concepts in mind, the team developed product design specifications (PDS) that they felt provided the best overall functionality for camping & tailgating and documented them for reference throughout the project. These aimed to make a product that would be easy to store and transport while still being safe and functional. The most important requirement was that the product must be capable of being quickly assembled and disassembled without the use of any tools. Without this requirement, the fire pit would not solve the problem definition, as it would not be easily portable. Other product design specifications are as follows:

- Flat when disassembled for easy storage, transportation, and shipment
• Light enough to be carried yet large enough to support a full-sized fire with logs or cardboard boxes
• Main burning area raised off of the ground to provide better heat dissipation and to prevent damage to the plant life near wherever it is used
• Composed of a strong material that can withstand being left outdoors for long periods of time
• Safe for family use and not pose a danger to plants or animals near where it is used
• As simple as possible in design and
• Easy to clean and maintain
• Aesthetically pleasing design features
• Profitable when sold under or around a $100 price range

The Capstone Team felt that the inclusion of these product design specifications would render a product that would solve the problem definition and provide value to customers while also creating a profitable business venture.

5.1.3 Initial Costing

Before conducting the initial market survey, the Capstone Team had not yet chosen the metal best suited to the needs of the fire pit. The chosen metal would have to withstand high heat, be relatively lightweight, and be easily attainable. To create an initial budget at the beginning of the fall semester, the project team used a standard 11 gauge steel to estimate the prices for the metal that would actually be used, which was unknown at this point in the project.
Based on an initial design as a two foot cube, the team predicted the fire pit would require six sheets of 2’x2’ 11 gauge steel. The preliminary budget for the fall semester was created upon these specifications, shown below in Table #3. Market price for 2’x2’ sheets of 11 gauge steel was $35 per sheet, resulting in a materials only cost of $210 per prototype. The Capstone Team planned to create two full-size prototypes of different metals to compare the two, choose the preferred metal, and then create two full-size final prototypes during the fall semester of 2019.

| Table #3 |
|-----------------------------|-----------------|-----------|-----------------|-----------------|-----------------|
| Initial Budget - Portable Firepit |
| Material | Size | # of Units | Price Per Unit | Price per Prototype | Total Price |
| First Prototype (2) | |
| Test Metal #1 | 11 gauge steel 2’ x 2’ | 6 | $35 | $210 | $210 |
| Test Metal #2 | 11 gauge steel 2’ x 2’ | 6 | $35 | $210 | $210 |
| Final Design (2) | |
| 11 gauge steel 2’ x 2’ | 12 | $35 | $210 | $420 |
| | | | | $840 |

However, after conducting preliminary market research, the Capstone Team concluded that the size and material utilized for the first budget would not be practical. Although the initial budget shown above in Table #3 fell below the allowed $1,000 spending limit per semester, the cost of the materials in the firepit was over twice the projected sales price. Labor, variable overhead, and fixed costs would only add to the cost to produce and the project would not be profitable. Thus, the team began searching for other options.

The Capstone Team decided to utilize scrap metal from the CME factory floor to create initial prototypes to test both the feasibility of design and production as well as
different kinds of steel. The Capstone Team also decreased research and development costs by scaling down the size of the initial prototypes. Throughout the first semester, the team created four quarter-size prototypes utilizing 22 gauge galvanized steel and one half-size prototype using 18 gauge hot rolled steel. These prototypes were created at no monetary cost and allowed the team to evaluate both the 22 gauge galvanized steel and the 18 gauge hot rolled steel. The Capstone Team preferred the hot rolled steel and decided to make the final two prototypes using 16 gauge hot rolled steel. Each fire pit required one sheet of 48” x 96” 16 gauge hot rolled steel, which cost $50 each. This new material lowered the materials cost substantially from what was previously anticipated and allowed the project to move forward as it would be profitable. The four quarter-size prototypes and two half-size prototypes allowed the team to make design changes and test the production process before making a substantial financial investment. The revised budget for the fall semester of 2019 is shown below in Table #4.

### Table #4

<table>
<thead>
<tr>
<th>Material Description</th>
<th>Size</th>
<th># of Units Purchased</th>
<th>Price Per Unit</th>
<th># of Firepits Created</th>
<th>Price per Firepit</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quarter Sized Prototypes (4)</td>
<td>22 Gauge Galvanized Steel</td>
<td>Scrap-Various</td>
<td>0</td>
<td>$0</td>
<td>4</td>
<td>$0</td>
</tr>
<tr>
<td>Half Sized Prototypes (1)</td>
<td>18 Gauge Hot Rolled Steel</td>
<td>Scrap-Various</td>
<td>0</td>
<td>$0</td>
<td>1</td>
<td>$0</td>
</tr>
<tr>
<td>Final Prototype (2)</td>
<td>16 Gauge Hot Rolled Steel</td>
<td>48” x 96”</td>
<td>2</td>
<td>$50</td>
<td>2</td>
<td>$50</td>
</tr>
<tr>
<td>Total Estimated Expenditures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$100</td>
</tr>
</tbody>
</table>
5.2 Embodiment Design

Phase 2: Embodiment, or System, Design for the project started with the formation of a plan for taking the product from the initial design idea and concept requirements all the way to a final design. The plan was to start by sketching an initial design on paper and then model it in a CAD software. A single prototype of a similar material was then to be made on a \( \frac{1}{4} \) scale out of a test material using a CNC laser cutting machine. The prototype would then be assembled and physically tested. Based on the results of testing the design would be changed and another prototype made until a final design was reached. This iterative prototyping design process should result in a final design that not only meets all the product design specifications but is also capable of manufacturing with the machines available to the group.

5.2.1 Initial CAD Design

Creating a 3-Dimensional model in a computer aided design software is necessary for CNC machining and allows the product to be assembled and tested virtually before consuming the time and resources necessary for physical production. For this project, the CAD software originally used was CREO Parametric but changed to Solidworks after there were issues uploading the CREO drawings to the Laser Engraver control unit. Before Solidworks was even started up, the design for the first prototype was sketched out on paper as a reference for the team since the parts were delegated to multiple members of the group. This allowed for us to work simultaneously and complete the model significantly faster than if one person had drawn it themselves. Having a sketch gave the team a clear design goal and prevented parts not matching
when the individual pieces were finally assembled. When the individual parts were completed they were added to an assembly in CREO that ensured that they would fit together and proved the design was ready for prototyping.

The original prototype design was meant to implement multiple aspects of DFMA and lean manufacturing while maintaining the product design specifications. It minimized the total number of parts, standardized components, required no finishing operations, and was easy to fabricate. Overall, the design incorporated four of the ten designs for manufacturing principles. In addition, the design minimized the total number of parts to 6 essential parts without any separate fasteners, two principles of DFMA. Eliminating fasteners is beneficial to the design because they can represent upwards of 75% of assembly labor costs despite sometimes only taking up around 5% of material costs. (Deiter, 567) The original prototype design is shown in Figure #4 below.
5.2.2 Rapid Prototyping

Once a starting point for designs had been designated, iterative prototyping officially began with the goal of establishing a final product architecture, part configuration, dimensions, and tolerances. The final design at the end of this stage won’t necessarily resemble the final product visually, but it should have an identical number of the same sized parts that perform similar functions and are similar located in relation to each other. As in the case of this project, these prototypes often are made
out of different materials and are less visually appealing than the final product. This is such because it allows for physical tests to be carried out and design changes quickly made with minimized financial risk or time lost. Rapid prototyping of the system design was especially essential for the success of the fire pit project because the cost of materials for the final product were expensive in comparison to the team's overall design budget, so it was crucial that all major design flaws be ironed out before final prototypes were made.

The first fire pit prototype produced was a testament to the importance of this design phase. The prototype was made out of a sheet of galvanized steel scrap provided by the CME for free. The dimensions of the prototype were one quarter of the dimensions in the product design specifications so that the first prototype could be quickly made using the laser cutter. The first prototype revealed that the initial design the team had come up with was physically impossible to assemble without bending the metal out of its original shape. This problem was the result of tolerances that were too tight and a design that was overconstrained. Additionally, the prototype was not structurally sound and didn’t seem capable of being used as intended. The original prototype is shown in Figure #5 below.
This resulted in a design revision that was aesthetically different from the original, but still fundamentally followed the product design specifications of the chosen concept. Like the original, the revised design was assembled using notches that the other panels would slide into, but it reduced the number of bottom slots, removed the flimsy legs, and added bends to increase structural rigidity. The cad model for the revised design is shown by Figure #6 below.
The first prototype of the revised design was made out of a similar material as the first and at the same reduced scale. After it was cut from the blank metal sheet with the laser cutter it was assembled and tested. The new design appeared to be a significant improvement over the original even before adding the strengthening bend like had been planned. Subsequently, two more prototypes were made based off of this design with small revisions to the dimensions removing material originally added for the bending operation that was removed, and also relocating the handles so that they didn’t cause the fire pit to come apart when lifted using them. All three prototypes were made on the same day within a two-and-a-half hour time span, proving the important role that advanced CNC machines like the laser cutter play in making rapid prototyping possible and the system design phase crucial to reaching the final product design both cheaply and quickly. The three prototypes are shown in Figure #7 below demonstrating the degree of change that can be achieved in a few hours using rapid prototyping.
After the first three prototypes of the revised design were produced, more complex elements, such as vent cutouts, were added to the prototype design and another larger prototype was made out of a material more closely resembling the final product. The fourth prototype of the revised design was made out of hot rolled steel and had dimensions one-half of the size of the full sized product (1’x1’x1’). Using the laser cutter to produce the larger prototypes revealed some issues using the current design for a production run. Primarily, it revealed risks of production delays due to the slow resupply of essential consumables and dangerous increases in machine cycle times per unit. These issues all derived from the multiple types of vents added to the design.
Some of the prototype parts had extensive patterns of a small detailed design that increased the amount of time it took to cut the part by nearly 500%. The increased machine usage time also revealed the machines dependency on Nitrogen gas canisters that could take multiple days to be refilled. Despite these new issues, the overall system design passed physical testing and was determined suitable to enter into the detailed design phase including changes addressing the issues discovered in this phase. This prototype is shown in Figure #8 and Figure #9 below, and similar images were added to the first survey sent out by the team to collect feedback from potential customers.
5.3 Detail Design

In the Detail Design phase of the product development process, the engineering description is completed. Any missing information regarding the dimensions, form, tolerances, materials, arrangement and manufacturing is added. During this phase, the quality assurance process is defined and product design specifications are finalized, if they were not already. The Detail Design phase includes the major manufacturing decisions, such as process flow and whether to outsource or produce in-house.
5.3.1 Machinery

During the Detail Design phase, the project team makes decisions about whether the product will be produced in-house or outsourced to a third-party. When considering full-scale production, the Capstone Team completed a rent versus buy analysis to determine whether it would be more profitable to rent or to purchase machinery. Using rental costs of necessary equipment and cycle time, the Capstone Team calculated the rental cost of machinery for every firepit produced, shown in Table #5. As the cost to rent the equipment costs more than the sales price, renting the equipment would cause a loss at any level of production.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Cost to Rent (per hour)</th>
<th>Hours Utilized (per firepit)</th>
<th>Cost Per Firepit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trinco Bead Blast Cabinet 48/BP</td>
<td>$10</td>
<td>0.75</td>
<td>$8</td>
</tr>
<tr>
<td>Powder Spray System</td>
<td>$10</td>
<td>0.15</td>
<td>$2</td>
</tr>
<tr>
<td>MaxFlo portal paint flow booth</td>
<td>$10</td>
<td>0.15</td>
<td>$2</td>
</tr>
<tr>
<td>National shear (green)</td>
<td>$50</td>
<td>0.25</td>
<td>$13</td>
</tr>
<tr>
<td>Wisconsin Oven walk-in oven</td>
<td>$100</td>
<td>0.5</td>
<td>$50</td>
</tr>
<tr>
<td>IPG Fiber 4 KW Laser Cube</td>
<td>$100</td>
<td>0.4</td>
<td>$40</td>
</tr>
<tr>
<td><strong>Total Cost to Rent Machinery per Firepit</strong></td>
<td></td>
<td></td>
<td><strong>$113</strong></td>
</tr>
</tbody>
</table>

Another viable production option would be outsourcing the production to a third party. The Capstone Team decided against outsourcing because they thought that the specificity of the machinery and the process required the production to be completed in-house. In-house production would allow the company the greatest influence over how the product is produced and could ensure a quality product. The Capstone Team felt their potential company could produce the best product if they were involved in both the
production and business side of the project, as this would create a greater understanding of the product.

Due to the high costs of renting the necessary equipment and the lack of involvement associated with outsourcing, the Capstone Team decided the proposed company must make an initial capital investment and purchase the necessary equipment. The equipment will be capitalized and depreciated over periods used, to satisfy the matching principle of accounting and match revenues with expenses. According to the IRS, the estimated useful life for engineering or scientific equipment is 10 years. The project team has decided to use the straight line method to depreciate the acquired machinery over 10 years, assuming no salvage value. Table #6 below shows the costs to purchase each machine and the related depreciation per year.

<table>
<thead>
<tr>
<th>Machine</th>
<th>Cost to Purchase</th>
<th>Estimated Useful Life (Years)</th>
<th>Depreciation Expense Per Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trinco Bead Blast Cabinet 48/BP</td>
<td>$1,099</td>
<td>10</td>
<td>$110</td>
</tr>
<tr>
<td>Powder Spray System</td>
<td>$4,299</td>
<td>10</td>
<td>$430</td>
</tr>
<tr>
<td>MaxFlo portal paint flow booth</td>
<td>$7,853</td>
<td>10</td>
<td>$785</td>
</tr>
<tr>
<td>National shear (green)</td>
<td>$29,910</td>
<td>10</td>
<td>$2,991</td>
</tr>
<tr>
<td>Wisconsin Oven walk-in oven</td>
<td>$70,250</td>
<td>10</td>
<td>$7,025</td>
</tr>
<tr>
<td>IPG Fiber 4 KW Laser Cube</td>
<td>$288,000</td>
<td>10</td>
<td>$28,800</td>
</tr>
</tbody>
</table>

**Total Depreciation Expense per Year per Production Team** $40,141
6 Testing and Refinement

The testing and refinement phase of the product realization cycle is important to the overall success of the development of the product because it is when the initial manufacturing process flow, product material choices, product finish, and overall design begin to near their completion. The project team began this phase in the same way it is commonly done, with a full sized Alpha prototype made using the final product material, but not with the final planned manufacturing process. The Alpha prototype should be fully tested and analyzed before a final Beta prototype is designed and produced.

6.1 Alpha Prototyping

The Alpha prototype was a full sized version of the detailed design with small changes that consolidated and simplified many of the more complicated elements of the design. The scaled up design was 2’x2’x2’ in size and consolidated many of the small intricate designs that required multiple individual cuts into fewer large slots that could be made with fewer cuts at faster feed rates. This reduced the overall cut time of the prototype despite the design doubling in size from the previous prototype. An example of the design modeled in Solidworks is shown in Figure #10 below.
The full-scale prototype was made using the final product material and built primarily for testing the functionality of the product design. The only raw material required to make the prototype was a 4’x8’ sheet of 16 gauge hot rolled steel. The steel was cut to size using hydraulic shear and the prototype was cut from the blanks using the laser cutter. The full sized prototype passed assembly, strength, and flame resistance testing. However, the Alpha prototype still had three major problems. The first problem was that a majority of the team and peers who were presented with the prototype felt that the full-sized prototype was too large and wouldn’t be practical for
transportation. The second problem was that the fire pit was subjected to weathering testing and was exposed to the outdoors for a two-month long testing period which it subsequently failed. The final problem was that other members of the Capstone class observed that the handle cut-outs were small and had sharp edges, making them uncomfortable for carrying a large metal object. Overall, the feedback on the firepit from other students was largely positive, and seeing it in use like in Figure #11 below, led to individuals approaching the team and suggesting the target price of the final product be raised.

Figure #11
6.2 Beta Prototyping

Using the lessons learned from the Alpha prototype to design and produce the Beta prototype was instrumental in developing the process flow to be implemented for production and transforming the prototype design into a finished product ready for sale. Transitioning from Alpha to Beta prototypes, a few essential changes were made. The first change was a reduction in size from 2’x2’x2’ to 1.5’x1.5’x1.5’ which on top of making the product more practical for transportation, also made it possible to produce two whole units from one sheet of raw material, making it easier to develop a standardized process that maximized material usage. Additionally, the handle design was revised to consist of two blackened steel U-Bolts that were not only more ergonomic than the original design, but also served as a way to bolt the individual product parts when disassembled. Finally, the last major design change was the addition of a high-heat black powder coat finish to the product which protected it from rust and improved the visual appeal of the product. The first beta prototype is pictured assembled in Figure #12 below, and appears drastically different from the previous prototypes.
At this stage of the process the appearance of the final product has largely been finalized. The only changes that occurred after the first Beta prototype was produced were made to improve manufacturability. Multiple versions of the Beta prototype were produced using a variety of processes to gain a better understanding of which would result in a final product that best met the PDS. Specifically this involved producing a Beta prototype using a water jet cutter instead of a laser cutting machine to cut out the fire pit parts from the sheet metal blanks. This trial failed dramatically and it took multiple days to produce one unit as the water jet cutter couldn’t consistently pierce the sheet metal requiring pieces to be reworked multiple times before being completed. On top of that, the water jet cutter produced a large noise that could possibly require
workers to wear hearing protection and caused a mess of water and abrasive on every surface within 6 feet of the work area as demonstrated by Figure #13 below.

Figure #13

This solidified the laser cutter as the option for production as it was the only machine capable of consistently cutting the pieces without requiring constant reworking and supervision. In addition to different fabrication processes being tested, multiple finishing processes were trialed in order to determine which process flow would result in the highest quality finish in the least amount of time. Before being powder coated and cured, panels were tested being sandblasted, not being sandblasted, being degreased
with mineral oil, and being both sandblasted and degreased with mineral oil. These combinations of prepping processes for powder coating were tested because they each required a significant time, material, and labor commitment and being able to produce a piece of acceptable quality when limiting prep processes would allow for a more streamlined production process. Ultimately it was decided that sandblasting and degreasing were both required for a consistently acceptable finish on the final product. Once the team had achieved a better understanding of the materials, machines, and labor required to produce the final product, a full business review was able to be performed to justify entering the final and most expensive phase of the product realization process with the current product design.

6.3 Business Review

At the end of the Testing and Refinement stage, a more comprehensive business review is conducted. This business review is important, as it determines whether the project should move on to the final stage of the product development process, Production Ramp-up. Production Ramp-up is a huge financial investment, so the project team must be sure the project is profitable and fits a need of the target market. This review determines whether the work was conducted in a quality manner and if the product adheres to the problem definition. During this phase, marketing personnel develop a marketing plan and sales personnel finalize the sales plan.
6.3.1 Market Research

The project team conducted a survey of 55 individuals to determine the marketing strategy of the product. Survey respondents were diverse in age, geographical location, education, and income level. Respondents were between the ages of 18 to 64, however the majority of respondents were aged 18-24. This majority is due to the reach of the project team, as they reached out to peers and family members for their opinion. Refer to Figure #14 below to see the geographic locations of respondents. The variety of geographic locations suggests that the portable fire pit does not appeal to only one geographic location, but rather would be applicable to all due to its versatility. Figure #15 below shows the distribution of education levels amongst survey respondents. Although over 80 percent of respondents have some experience at a four-year university, it is not necessary to be interested in the Ole Miss design.
Out of the 55 survey respondents, 53 said they were interested in purchasing the portable fire pit, this percentage is depicted below in Figure #16. This means that the vast majority of respondents felt the portable fire pit could fill a need in their lives. Respondents admired the portability, design, size, easy cleaning capability, handles, and grill of the firepit. Many of the respondents said they would use the portable fire pit for multiple events, including camping, tailgating, parties, and casually in the backyard. The appeal of the firepit’s portability allows the fire to move in between locations and thus fill several needs easily.
6.3.2 Marketing Strategy

The marketing mix is a tool used by businesses to plan a successful product offering. The four elements of the marketing mix are product, price, place, and promotion. The product must fill a customer’s need or solve a customer’s problem. The portable fire pit fills the need for an aesthetically-pleasing yet versatile firepit with the added benefits of easy-cleaning and safety. This firepit can be easily transported to be used in the backyard, camping, tailgating, or for outdoor gatherings. With the grill top included, it doubles as a venue to grill burgers or safely roast marshmallows.

The second element of the marketing mix is price. Price refers the sales price at which the company intends to list the product. The sales price must represent a good value to the customer, as most customers will not purchase a product that they perceive
to represent a lower value. Customers are willing to pay more for a product that works well for them, however they would not overpay for an average product. The Capstone Team has priced their portable fire pit at $100. This price is close to the prices of competitors, but it comes with additional luxury features such as a bonded powder coat, a top grill, top-of-the-line cutouts, and handles.

The third element of the marketing mix is promotion. The Capstone Team has decided to promote the portable fire pit through social media, brand ambassadors, and search engines. Creating a brand on social media platforms will attract potential customers to a portrayed lifestyle. The portable fire pit will portray a lifestyle of fun, family, and the outdoors, but also style, safety, and versatility. Brand ambassadors will be social media influencers who fit this brand. Brand ambassadors will be gifted a firepit and asked to share their experiences to their followers on social media and attach a link for easy access to the fire pit. Part of the promotion plan is to utilize search engine optimization (SEO) to increase the quantity of viewers. SEO will use keywords to attract searchers to the web page. For example, if someone searches for “portable fire pit” on Google, the Ole Miss portable fire pit would be the first link.

Finally, the last element of the marketing mix is place. The place refers to where the product will be available for consumers to purchase. In the modern world, most consumers prefer to browse from the comfort of their own home rather than going to a physical store. The portable fire pit will have a user-friendly website with photos, videos, and reviews from satisfied customers. Consumers can research the product from this website and then order the fire pit right to their door. In the future, the company hopes to partner with home improvement stores such as Home Depot or Lowes to have a show
product in-store which consumers can purchase online through the company or through the home improvement store itself. This would be a low-cost way for potential customers to be able to physically examine the product before purchasing it.

6.3.3 Profitability Analysis

One of the questions in the survey asked respondents to choose what price they would be willing to pay to purchase the firepit, if they were interested in purchasing at all. Figure #17 below shows the distribution of price points across the 53 respondents interested in purchasing the fire pit. Using this data, the financial and business consultants determined the average price a consumer would pay for the portable fire pit is $97.55. However, due to the intricate designs, included grill top, bonded powder coat, and versatile nature the Capstone Team decided to price their fire pit at $100 per unit. The project team thinks that consumers will be willing to pay a little more for these specialized features not offered by other competitors.

![Price Points of Interested Respondents](image)

**Figure #17**
With a sales price of $100 per fire pit, the project would still be profitable. Direct materials cost $39.61 per unit, direct labor per unit is approximately $4.25 per unit, and variable overhead allocated to each unit is $7.09 per unit. This leaves a contribution margin per unit of $49.05 available to cover fixed costs.
7 Production

The detailed design phase of the product realization process is crucial for beginning the ramping up production phase of the process because it provides you with a firm understanding of what processes are required for producing your product before risking investing millions of dollars in machinery for multiple production lines that you may not even fully utilize. The goal of ramping up production is to establish a manufacturing and production process flow and then make changes to it that optimize output and stabilize variability. The foundation for a lean process flow was laid in the previous phases of the product realization process by designing the product with DFMA principles in mind. This has simplified the manufacturing process as a whole and makes it easier to see opportunities to implement process improvement.

7.1 Process Implementation

An important step when applying process improvements is to first fully implement the process flow. This requires precisely laying out the sequence of consecutive and simultaneous individual tasks that must be performed to transform raw material into finished product including the labor, time, inputs, and outputs every step of the way.
The first process of the process flow is transforming the raw material, a 4’x8’ 16 gauge sheet of hot-rolled steel into metal blanks the precise size of the final product parts. This is done using a hydraulic shear machine and requires two people at the start of the process for handling the large metal sheets and only one after the first few cuts. The second process in the process flow is laser cutting the panels. The laser cutter is a computer controlled process, but it requires a worker to physically load and unload blanks and finished products as well as constant oversight to make sure the sensitive laser diode doesn’t crash into metal pieces that may come loose during cutting. Figures #18 and #19 below, showcase the hydraulic shears and the bed of the laser cutter, respectively.

![Figure #18](image_url)
After the metal panels are cut using the laser cutter they are carried to the sandblaster for finishing. The sandblaster consists of a sealed booth and a nozzle that is manually used to blast sand abrasive onto the metal panels, removing scale and surface impurities and preparing the metal to be coated in paint or, in this case, powder coat. The individual parts are then wiped down with mineral spirits to remove any grease that may have gotten on the metal from human skin or surrounding objects and prevent the powder coat from sticking to the surfaces evenly before curing. Once degreased, the panels are allowed to quickly dry and hung on a conduit rack to be powder coated. Powder coating is done in a ventilated booth using a powder coat sprayer that sprays the powder coat in thin layers onto the metal parts. The powder coat sticks to the metal using an electric charge and can easily be knocked or rubbed off.
Figures #20 and #22 below show the sandblasted panels before and after being powder coated.
Once the powder coat has been applied to the parts, they must be carefully loaded into an industrial oven set for 425 degrees Fahrenheit and allowed to cure for 25 minutes. Once cured, they are removed and allowed to cool before being assembled, quality check, and disassembled for packing.

7.2 Process Improvement

Once the process flow has been established improvements can begin to be made to the individual processes and the process as a whole. Process improvements can be a variety of things ranging from physical changes in how the process is performed, adjusting what process has labor assigned to it at any given time, or simply posting instructions describing a standardized method for carrying out the process to the worker. The lean manufacturing philosophy contains various tools not just for implementing process improvement, but also finding where improvement is needed most.

A good way to start process improvement is identifying bottlenecks in the process flow using a bottleneck analysis. Performing a bottleneck analysis requires gathering data on cycle times, input, and output for each process. The bottlenecks in the process flow are going to be the processes with a long queue of products before them. In terms of the process for manufacturing the firepit, the two major bottlenecks were the Laser Cutter and the Curing Oven, both automated processes that can’t be sped up. However, changing the process in certain ways, like by modifying the inside of the oven to be able to hold two units at once, can drastically decrease the cycle time. Utilizing a batch process rather than producing each unit one at a time is what makes this project
feasible. If each fire pit were produced by one person, following the production steps, the process would require so much direct labor, over two hours per fire pit, that the cost of this labor would cause an overall loss for the company.

Another effective way to reduce process cycle times, minimize material cost, and improve quality is by implementing the lean principle of standardized work as was done by the project team in various steps of the process. Two different standardized work plans were tested at the start of the production line with the hydraulic shears that cut the raw material into metal blanks precisely the size of the outlines of the final pieces. Each set of standardized work instructions describe precisely what length must be cut from the raw material and were optimized to require changing cut length as few times as possible while also producing two whole units per sheet of raw material. Previously, each sheet of raw material was cut without planning and forethought and resulted in a maximum of around one-and-a-half-units per sheet of raw material. This is especially important because the cost of the steel raw material is the most expensive material cost per unit.

Another lean tool that helps to reduce waste and improve quality is error proofing, or Poka-Yoke as it is referred to as in lean terminology. Error proofing means to implement systems that physically prevent the process from being performed incorrectly or detect defects and remove them from the flow of healthy products. For instance, this was implemented in the laser cutting work bed through the use or a hard gage that prevented the metal blanks from being improperly aligned. Each panel has its own unique dimensions and the gage is marked with these and a label that should correspond to the label on the metal blank as well as the label of the cut path uploaded
to the laser cutter controller. This prevents the program being run on an incorrectly sized or oriented blank and also allows for consistent cuts due to the zeroed in home at the corner of the gage. Overall this helps reduce the potential for defective parts being produced due to human error and helps decrease the amount of reworks over time.
Finally, the last improvement added to the process flow was limiting Muri, or overburden. An even distribution of the workload and limiting both overworking and down time results in a balanced process that will generally take less time than one with overworked workers. It would be easy to have one person assigned to each individual process working in that one spot the whole shift, but there would be a large surplus of inputs and outputs at each station because many of the processes differ wildly in the amount of time they are required to take. Additionally, the amount of direct labor needed to produce each product would push the costs incurred higher than the sales generated, which would cause a net loss. To prevent this, a work hypothetical production schedule was created simulating an average work day. Workers were moved around and assigned tasks in one-minute intervals for the course of the day. When workers finished a task and could do no more, they were assigned to another. Workers that weren’t required were eliminated. Doing this allowed the team to run the whole production process with only four workers for the nine individual processes. Figures #23 and #24 shows an example of the work schedule used for balancing the workload.

![Figure #23](image.png)
7.3 Production Ramp Up Plan

The ultimate goal of the ramp up production plan is to increase production output overtime as a result of gradual process improvement and increasing worker experience. Due to limitations imposed on the project due to the 2019 CoronaVirus Pandemic, full scale production of the fire pit was not able to begin, however the plan that was to be put into place still provides an accurate estimate of the effects if principles this case study aims to test. The planned improvements to aid in product ramp implemented the lean tools of 5S and work standardization.

The first step for ramping up production should be to standardize all production processes. Standardizing these processes involves recording the best practices for completing the process in a step by step fashion. This can only be done once production has begun and a variety of different methods for performing the process are tried. Recording measurable data such as time to complete process and the ratio of defects can be used to determine which practices are best to standardize and train all employees to follow. Standardized production processes will also reduce the variability of production outputs and make identifying root causes of production problems more simple to perform. Documenting the standardized work process also allows for production to ramp up faster due to a consistent communication and
reinforcement of the practices that should be taught during employee training. Additionally, standardized processes allow for full implementation of the 5S lean tools.

Once production processes are standardized, previously unattainable information about workers tendencies and preferences while carrying out a process can be used to implement 5S principles. The five s’ of 5S are sort, set in order, shine, standardize, and sustain. The sorting process involves determining what is and isn’t necessary for the worker to complete the process. This includes things such as extra tools, part inventories, and other features of the worker's surroundings. Setting the process in order simply means organizing whatever was determined to be necessary while sorting. For the production of the fire pit, the plan was to provide racks that would separate each type of blank and metal panels while stored within reach of the sand blasting and laser cutter loading bays, so that inputs and outputs are always easily accessible when needed. To shine the process basically means to clean the area around the process. This involves cleaning dirt, removing trash, and providing proper receptacle for disposing of waste in the future. Standardizing involves documenting not necessarily the process itself, but the practices implemented in sorting, setting in order, and shining. The final step of S is sustaining or maintaining the changes as they are documented over time. This primarily involves planning and scheduling self-reviews over time to ensure that the standards implemented throughout the 5S process are still being maintained as intended.

7.4 Final Business Review

The purpose of the final business review is to utilize the latest sales, costs, and profits to analyze the success of the project development process. A business review is carried out at the end of phase four, but these figures most likely have changed between testing and refinement and production ramp-up. Changes in design, production process, marketing strategy, materials, or anticipated production level can all affect the
sales, costs, and profits of a project or business. These figures will also provide the most accurate information for analyzing the future success of the product.

7.4.1 Bill of Materials

The bill of materials (BOM) is shown below in Table #7. One sheet of 4' x 8' 16 gauge hot rolled steel costs $54 and has the surface area to make two firepits. Thus, each firepit requires one-half of a 4' x 8' sheet of 16 gauge hot rolled steel and represents $27 of the total direct materials cost. One pound of powder coat covers four fire pits completely. At $24.37 per pound of powder coat, the cost associated with each unit is $6.09. Each handle consists of a U-Bolt and two additional hex nuts to fasten the handle. As each fire pit has two handles, the total cost for two U-Bolts and four hex nuts is shown below in Table #7.

<table>
<thead>
<tr>
<th>Table #7</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bill of Materials</strong></td>
</tr>
<tr>
<td>1/2 4'x8' Sheet 16 Gauge Hot Rolled Steel</td>
</tr>
<tr>
<td>Powder Coat</td>
</tr>
<tr>
<td>2 U-Bolts</td>
</tr>
<tr>
<td>4 Hex Nuts</td>
</tr>
<tr>
<td><strong>DM Per firepit</strong></td>
</tr>
</tbody>
</table>

![Table](image)

The cost of direct materials for each firepit is the same amongst varying levels of production over 167 units. This difference is due to the price per pound of powder coat decreasing as the quantity purchased increases. Both levels of production considered in the sensitivity analysis in Section 7.4.2 are well over the production threshold of 167 units.
7.4.2 Sensitivity analysis

A sensitivity analysis measures how changing certain variables affects the outcome of an experiment or other study. The Capstone Team conducted a sensitivity analysis to determine if the proposed company would be profitable over varying levels of full-scale production. The first level of production is based off of the Ole Miss enrollment as of the 2018-2019 school year. The second level of production is based off of the population of the state of Mississippi over 18. The Capstone Team chose these two populations to approximate sales because they would be the most likely customer base for the design of the fire pit, which features Ole Miss logos.

The methods for calculating the sales, variable costs, and fixed costs are the same for both production levels, unless noted otherwise. Sales were calculated using the related population and the data gathered from the two surveys conducted throughout the project. In the first survey, 79.68 percent of respondents were interested in purchasing the fire pit, and 96.4 percent were interested in the second survey. The project team felt it was more accurate to average these two percentages to arrive at a more reasonable percentage of the population which would want to purchase the firepit. This calculated percentage, about 88 percent, was then used to determine the percentage of the related population that would purchase the firepit to arrive at projected sales in units. Both surveys revealed that the average price potential customers would pay for the firepit was around $100, so the Capstone Team will continue to price the product at $100. The project team believes they can sell the fire pit for $100 per unit because of its specialized features of design, portability, grill top,
handles, and powder coating. To arrive at the projected sales in dollars, the sales in units was multiplied by the sales price per unit of $100.

Variable costs included in the pro forma income statements are materials, labor, and overhead. The calculation for direct materials is rather straightforward. The BOM gives a total direct materials cost per unit. The cost of direct materials per unit is multiplied by the sales in units to arrive at the direct materials cost for the related level of production. The cost of direct labor differs amongst the two levels of production. For the pro forma income statement based on Ole Miss enrollment, Table #8, direct labor is calculated only from the four hourly workers needed to run a single process team, which has the capacity to meet the anticipated production quantity. The calculation assumes that the four workers work full-time at 40 hours per week, for 50 weeks a year, earning $20 per hour. Wages approximate the opportunity cost of working elsewhere in Oxford, MS. In the second scenario, shown in Table #9, 216 hourly workers are required to meet the desired production level. These 216 workers are split into 54 teams of four employees each to run the production process. However, when calculating the labor for the second pro forma income statement, additional labor costs have been added. As this level of production is much greater than the first, the project team deemed it necessary to employ five salaried supervisors. These salaried supervisors earn $60,000 per year and are responsible for organization of the factory floor, training of new employees, enforcement of safety rules, and maintaining and improving the efficiency of the production process. The salaried supervisors will also serve as the bridge between the corporate side of the business and the production side.
Variable overhead consists of the indirect costs of electricity, nitrogen gas, mineral spirits, paper towels, and gloves. These are considered indirect as it is difficult to measure exactly how much of each is attached to a single unit. To include these indirect costs in variable overhead, the team attempted to measure how much can be reasonably allocated to each unit. Electricity is considered an indirect variable cost because the laser cutter uses copious amounts to cut the metal. Its usage per unit can be roughly estimated using the maximum output of the laser cutter, the time to cut panels for one unit, and the cost of industrial electricity in Oxford, MS, which is $0.643 per kilowatt. This calculation yielded an estimated $0.10 per unit of electricity costs. Based on usage, the cost of nitrogen gas per unit is approximately $4.6. Mineral spirits are used to degrease the panels to prepare them for the powder coat. Each quart of mineral spirits costs $8.28, and the Capstone Team estimates a single quart will last eight hours of production, or roughly 37 fire pits. Each production team will use approximately a roll of paper towels per hour to degrease. Additionally, employees need gloves for the degreasing process which is estimated at one pair per hour per production team. These indirect costs total to $7.09 allocated to each unit.

Fixed costs include selling costs, administrative costs, cost to rent production space, utilities, and depreciation. Fixed costs are estimated at 60 percent of direct materials and direct labor, which approximates industry standards. The Capstone Team added the projected depreciation expense to this 60 percent to account for the equipment they must acquire to start production. Each production process utilizes four employees for maximum efficiency. In scenario one, based on Ole Miss enrollment, only one process team is required to meet production demands. However, in scenario two,
54 teams of four are needed to meet estimated production. To adjust for this, depreciation expense per year is multiplied by 54 to account for the 54 assembly teams and sets of machinery needed. Based on the sensitivity analysis performed, the proposed company would be profitable amongst varying levels of production.

### Table #8

<table>
<thead>
<tr>
<th>Pro Forma Income Statement</th>
<th>Based on Ole Miss Enrollment</th>
</tr>
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<tbody>
<tr>
<td>Sales</td>
<td>$1,784,923</td>
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<tr>
<td>Variable Costs:</td>
<td></td>
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<tr>
<td>Materials</td>
<td>-$706,953</td>
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<tr>
<td>Labor</td>
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<tr>
<td>Overhead</td>
<td>-$126,572</td>
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<td>Total Variable Costs</td>
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<td>Contribution Margin</td>
<td>$791,398</td>
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<tr>
<td>Fixed Costs</td>
<td>-$560,313</td>
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<tr>
<td>Operating Income</td>
<td>$231,086</td>
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</tbody>
</table>

### Table #9

<table>
<thead>
<tr>
<th>Pro Forma Income Statement</th>
<th>Based on Population of MS over 18</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sales</td>
<td>$200,183,401</td>
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<tr>
<td>Variable Costs:</td>
<td></td>
</tr>
<tr>
<td>Materials</td>
<td>-$79,286,439</td>
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<tr>
<td>Labor</td>
<td>-$8,627,795</td>
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<tr>
<td>Overhead</td>
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<td>Total Variable Costs</td>
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<tr>
<td>Contribution Margin</td>
<td>$97,773,806</td>
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<tr>
<td>Fixed Costs</td>
<td>-$54,916,154</td>
</tr>
<tr>
<td>Operating Income</td>
<td>$42,857,652</td>
</tr>
</tbody>
</table>
8 Project Analysis

One of the main benefits of the product development process is the focus on cross-functional input at each stage of the process. This utilization of techniques and ideas from different functional areas helps to create the most well-rounded product that considers success in all areas. Similar to the Center for Manufacturing Excellence, the product development process brings together disciplines of engineering and business to produce the best results possible. Completing reviews before moving onto the next phase is another integral part of the product development process. Reviewing the progression and future outlook of the product at several points is much more beneficial than only a review at the end of the development process. Reviews allow the project team to see what needs improvement and to make changes before substantial financial investments are made.

An example from this case study that further supports this claim is the discovery of the major design flaws that made the prototype of the original system design. The prototype that was made based on this design revealed the design to not be physically capable of meeting the product design specifications. Ultimately this was not a major setback for the project team because the reduced size, simplified overall design, and cheap prototype material resulted in no major financial or time losses. If the team were to have attempted to produce a full-sized prototype of this design using a final product
material there would have been major setbacks in the development of the product. These would have varied from losing 5% of the budget for the semester, wasting a significant amount of time developing the full-sized complex design and then having to completely change it. The team also wouldn’t have been able to perform iterative prototyping and design improvement because it would be too expensive to be carried out on a full detailed design. Overall, this project demonstrated the importance of the separation of the design process into multiple stages in the product development cycle by preventing the unnecessary loss of financial and time commitments and allowing for more room for innovation to be quickly and cheaply made.

A primary focus of the case study was also to evaluate the effectiveness of applying principles of lean manufacturing to this production process. The lean manufacturing principles employed here include: poka-yoke, 5S, standardized work, bottleneck analysis, and muda and muri, or waste and overburden reduction. While all of these changes were not necessarily fully implemented and their benefits not capable of being fully measured due to the halt of production for the COVID-19 Pandemic, there were still many observable results from improvement implementation that were measured. Two clear examples of the positive effects that implement lean principles can have were the implementation of standardized work and bottleneck analysis. Standardized work was used to develop standard operating procedure documentation for shearing the raw sheet metal material into blanks for laser cutting. Implementing the documented procedure not only resulted in a process time reduction from over twenty minutes to just over thirteen, but it also allowed the output of each sheet of raw material to be maximized from one and a half units per sheet all the way to two full units per
sheet. This change alone resulted in a reduction of $9.16 in material cost per unit. Implementing bottleneck analysis also resulted in a clear and measurable improvement in production. Before implementing bottleneck analysis, there weren’t enough parts being produced per hour for the product to be profitable without drastically increasing the price. However, bottleneck analysis revealed that the two major bottlenecks in production were the laser cutting and powder coat curing processes. A simple modification was proposed for the oven that would allow for two units to be cured at once rather than just one, doubling the hourly finished product output and making the product not just profitable, but lucratively so.

Overall, this case study has provided an abundance of proof that implementing principles of Lean manufacturing, DFMA, and the stage-gate product realization cycle have significant measurable benefits for decreasing production time, reducing unnecessary waste and costs, and improving overall profitability of product development and production.
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