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Design and Production of a Bathtub Caddy

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DESIGN AND PRODUCTION OF A BATHTUB CADDY

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ACKNOWLEDGMENTS

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ABSTRACT

The purpose of this thesis is to document and discuss the design and manufacturing process used to produce a bathtub caddy on a large-scale production process for the Center for Manufacturing Excellence Senior Capstone Project. This project was carried out over the Fall of 2020 and Spring 2021 semesters by a team consisting of an Undergraduate Chemical Engineering Undergraduate, two Mechanical Engineering Undergraduate, a Finance Undergraduate, and an Accounting Undergraduate. The objective of this project was to design the product and then a manufacturing process that could be used to at first produce a prototype before planning a ramp up in production to produce large quantities of the product. In addition to just manufacturing the product, the economics of the product were analyzed to determine if the product would be economically viable in a scale up situation. Lean manufacturing techniques were used heavily throughout the project in an effort to remove any unnecessary waste as well as get as much value out of the final product as possible. The team used the Toyota Production System model to design a lean manufacturing process and culture throughout this process. This thesis will walk through the product and the process as well as analyze the manufacturing principles applied to maximize the total value of the project.

TABLE OF CONTENTS

List of Tables

List of Figures

1 Introduction

The pursuit of the perfect manufacturing process is an everlasting chase. While there may not be a perfect process or a perfect product, the goal of the manufacturing engineer is to get this process as close to perfection as possible. Experts in the field have worked for years to perfect the process, but there is always room for continual improvement. With this in mind, the Center for Manufacturing Excellence senior class is ready to give their best effort to continually improve this process. With what started out at over 40 potential products, 9 were selected to move forward into the design and prototyping phase. This thesis in particular focuses on the design and production of a bathtub caddy along with the engineering and manufacturing principles applied throughout the project. The designing and manufacturing thought process throughout this Capstone Project were recorded and analyzed in the thesis below. Lean manufacturing principles were the key driving factor in decision making in the ultimate goal to provide the most valuable product possible to the customer.

1.1 Center for Manufacturing Excellence

The Center for Manufacturing Excellence (CME) is multidisciplinary program formed in 2010 designed to teach the principles of engineering, business, and accountancy through the lens of manufacturing. The diverse yet selective group of students that get accepted into the CME bring a wide variety of skills and knowledge from their respective academic departments.

The CME is designed to replicate the real work world of modern manufacturing and leadership by having students participate in academic and experiential learning courses. By getting students out of the typical classroom setting, they are able to work with their hands and learn on the spot with some classes being held on-site at manufacturing facilities.

Beyond the classroom, the CME focuses on personal development and leadership skills. One of the fundamental purposes of the program is to develop servant-leaders in the manufacturing industry. Throughout educational programs, extension services, and economic developmental initiatives the CME is able to help students grow and learn beyond the hard skills that are taught in the classroom.

By senior year, all of the academic and experimental classes culminate in a senior Capstone project in which teams design and manufacture a product from scratch to potential full-scale operation. This full-scale operation includes both the manufacturing side as well as the marketing and economic considerations for the product. Students utilize their knowledge gained in previous classes such as product design and development, manufacturing processes, and team building to bring this project from an idea to a finished product. While the students are put in a class, it does not meet for the final semester as the teams are expected to work amongst themselves to plan out their time and complete the project. Outside of the technical advisor to assist them with working on the factory floor, the students are expected to manage their time appropriately and professionally to have a high-quality finished product that lives up to CME standards.

1.2 Capstone Team Members and Roles

The Capstone team for the bathtub caddy project consisted five members:

- John Marquez, Chemical Engineering Undergraduate
- Reagan Rutland, Mechanical Engineering Undergraduate
- Grace Herfurth, Mechanical Engineering Undergraduate
- Silas Cosby, Finance Undergraduate
- Bridget McMillan, Accounting Undergraduate

For the capstone project, several key roles had to be defined within the group to divide the work as well as hold the team accountable. Three of the major roles included the team spokesperson, team financial advisor, and head technician. Silas Cosby served as the team spokesperson. With this title, Silas had the job of being the main line of communication between the faculty and the team. All major announcements sent out to the team as well as any team communication with CME faculty ran through Silas for this project. The role of financial advisor was held by Grace Herfurth. Each team was given a budget of $1,000 to complete their Capstone project. Grace's job consisted of keeping tabs on how much the team was spending as well as being the line of communication when purchasing materials. The final position was the head technician, which was held by Reagan Rutland. With the most experience using CAD software, Reagan held the responsibility of building the design in Inventor and making the team's ideas and designs come to life.

1.3 Lean Manufacturing

The Capstone project was heavily influenced by key manufacturing principles; however, the main manufacturing ideology followed can be credited to lean manufacturing.

Lean manufacturing is a methodology focused on minimizing waste within manufacturing systems while simultaneously maximizing production. While it may appear that the only goal of lean manufacturing is to remove waste from the system, the ultimate goal is to deliver sustainable value to the customer. (3)

A lot of the lean manufacturing principles are based off of the Toyota Production System (TPS). TPS was founded by Taiichi Ohno and Eiji Toyoda in Japan in the mid 1900's. (3) TPS can be summarized by three main objectives which are to design out muri (overburden), mura (inconsistency), and eliminate muda (waste). To simplify, the main objectives are to focus the design in order to create a more consistent and sustainable flow to create more value and less waste. (6)

The Toyota Production System defines eight major sources of waste that need to be removed from the process in order to maximize its value. These forms of waste include:

- Waste of overproduction
- Waste of time
- Waste of transportation
- Waste of processing
- Waste of inventory
- Waste of movement
- Waste of defects
- Waste of underutilized workers

Toyota believes that by removing these eight main forms of waste, any manufacturing process can be optimized to produce a better product and provide better value for both the company and the customer. (1)

In order to produce a manufacturing process with the best value and least amount of waste, the Toyota Way uses a fourteen principle guideline. These fourteen principles can be summarized into four main ideas. (3)

The first of these main ideas is that management decisions should be based on long term philosophy. This principle can be difficult in the moment because at times it does involve sacrificing short term financial loss. While the financials are important, it is not the only thing that should be considering in the long-term philosophy. This philosophy serves as the foundation for the remaining principles so it should focus on an organizational goal to strive for excellence and create the best product possible. The main goal should revolve around generating the value of the customer, society, and economy and producing a process to best exemplify this. (3)

The second main idea revolves around creating the right process in order to produce the right results. (3) This idea encapsulates the second through sixth principles from the guideline. In order to produce the right process, TPS states you should create a continuous flow, use a pull system, standardize repeatable tasks, and creating a culture based on quality. By creating a continuous flow and using a pull process, a company is able to eliminate wastes of time, inventory, overproduction, and underutilized workers. This means that the process is based off of customer demand and that it avoids batch processes within the system. By standardizing repeatable tasks, defects can be reduced and time can be saved. Removing any source of differences and oddities within the process helps it to run much smoother. The final part of this idea is to create a culture of quality. Anytime a defect is found or there is a problem in the system, it should be identified and corrected immediately. If quality is the top priority in the company, then problems within the system are able to be corrected much easier. (2)

The third main idea is to add value to the organization through personal development. Just as the process itself needs to be taken care of and developed, every person in the process needs to be respected and put in the best position to succeed. Lean manufacturing believes that humans are the greatest asset to an organization and they should be treated that way. By improving the environment around employees, customers, vendors, suppliers, and anyone else involved in the process an organization is able to encourage growth and continuous improvement overall. (3)

The final main idea is to continuously solve problems and to learn from them. As the old saying goes, every mistake creates a learning opportunity. Lean manufacturing takes every mistake and analyzes and discusses it to learn and grow as organization to be able to prevent it or similar problems from happening in the future. This concept can be applied directly with the principle of kaizen, or continuous improvement. (6) Lean manufacturing companies strive to learn from mistakes and constantly better their process. This culture of learning is essential in the pursuit of quality and value. (3)

In addition to the main four principles of TPS, the team also applied a few other manufacturing principles, mainly poka yokes. A poka yoke is a Japanese term that means "mistake proofing" or "inadvertent error prevention." The goal of a poka yoke in a process is to avoid defects by preventing, correcting, or drawing attention to any potential human errors as they occur in the process. (1)

2 Problem Statement

The idea behind the bathtub caddy was created by the project leader in order to help resolve some of the common issues found in similar products on the market. These issues ranged from design flaws, functionality, and pricing. The idea behind this product is important to understand because it will help to document the intentions and goals of the team.

The bathtub caddy is a product that serves as a table that can be brought into the bathtub with you in order provide a place for you to put your items and keep them safe while using them. Because everybody is different and has different ideas of what they would like to do during their time in the bath, the product had to be versatile and provide many different options. These potential options range from reading, watching a show, listening to music, writing, eating, drinking, and anything else one could want to do in the bathtub. On the market, there are many different designs for the bathtub caddy, but none quite seemed to provide all the options while keeping the cost affordable to the average person. The goal of this project is not to design to the highest-class product possible, but rather a product that can provide the best value while remaining at a reasonable price.

In order to reach this goal, many different ideas and designs were tested in order to find the perfect balance between quality and cost. The final goal of this project is to determine whether or not this product would be economically viable to scale-up and produce in a large-scale manufacturing process.

3 Design

The bathtub caddy had to go through three major design changes before it was able to reach its final form. After each design was completed, the team evaluated the product as the well as the manufacturing process to discuss how to maximize value and efficiency.

3.1 Original Design

The original design was a very bare bones product. The design consisted of three main parts: The main board and two sliding arms. The main board had a large rectangle cut out in the middle to place a laptop along with a cup holder and a slot to place a phone. The main board had slits cut in to the side of it where the two sliding arms could be inserted. These sliding arms allowed for the length of the board to be extended and created versatility in the width of tubs that the product could be used. Supports also had to be glued to the bottom of this design in order to add stability and strength for the sliding arms. Prototype I along with the Inventor designs can be seen in the figures below (1-4).

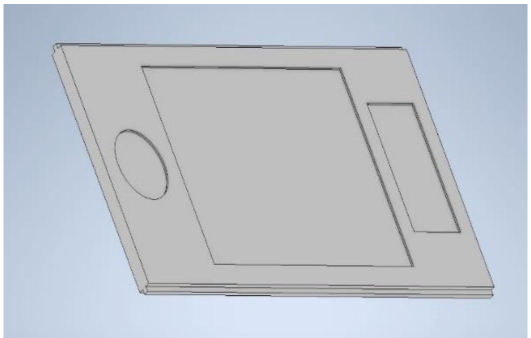

Figure 1: Inventor Design of Prototype I Main Board

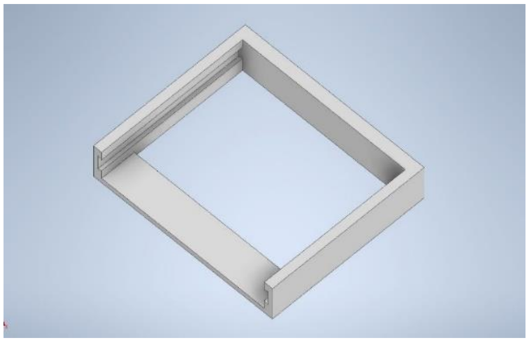

Figure 2: Inventor Design of Prototype I Sliding Arms

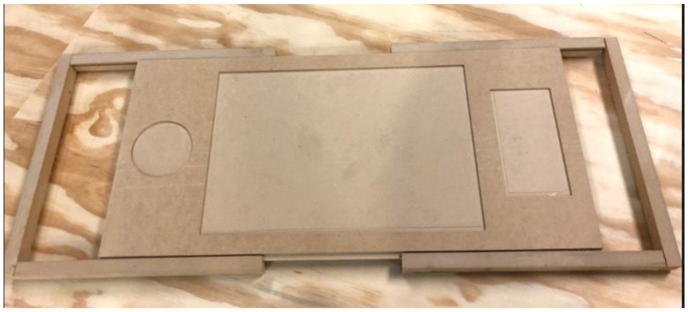

Figure 3: Prototype I Top View

Figure 4: Prototype I Bottom View

3.2 Design II

After discussing and analyzing the initial prototype, the team decided that major changes needed to be made to simplify the product and the manufacturing process. In order to accomplish this goal, it was decided that the sliding arms should be removed from the product. The sliding arms added many unnecessary manufacturing steps that had to be done by hand and could not be standardized. This included having to nail together the arms and inability to machine them due to the strange shape as well as glue on the support boards to the bottom of the main board. Since the arms could not be made out of one piece of wood, they were very weak and would fall apart if too much pressure was put on them.

To fix the issue with the sliding arms, they were removed from the design and replaced with undercuts on the main board that could sit on the edges of the bathtub to give the support necessary. These undercuts were able to be performed on the CNC Router along with the designing of the main board, so it cut out the un-standardized steps that had been involved in the process. The length of the board was set at 28.5”, which is roughly the average size of the standard bathtub. The average width is 30”, but that includes the wall thickness, so 28.5” fits on the walls. (5) Without the sliding arms, the length was an essential parameter because it limits the number of viable customers for the product based on their bathtub width.

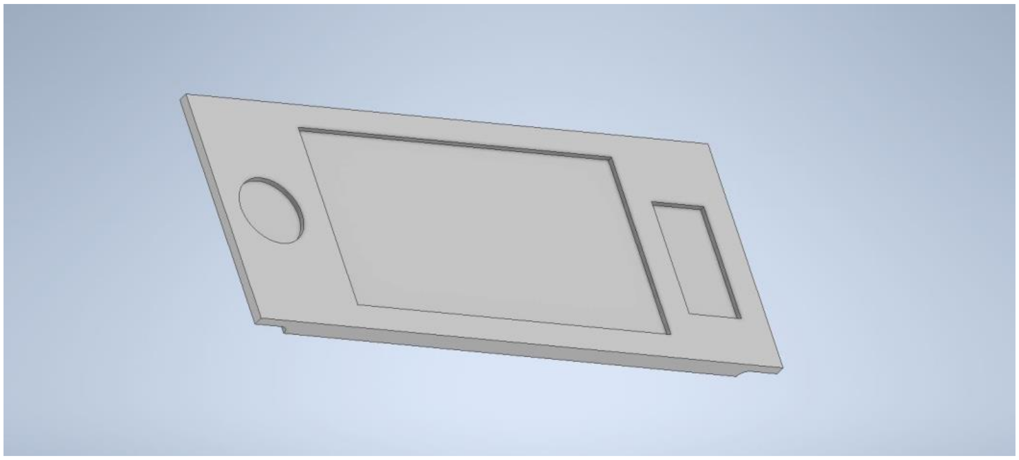

Figure 5: Prototype II Inventor Design

3.3 Design III

Once the second design was complete, the product was re-evaluated to determine how value could be added to the process. The team concluded that with the sliding arms no longer needed, the focus of the project could shift towards designing the face of the main board to maximize its space and provide utility. In order to make up for the lack in flexibility in terms of actual length, the face of the board would need to be able to accomplish as many things as possible. This was also heavily considered due to the face of the board all being able to be completed by the same piece of machinery, so the manufacturing side was fairly simple.

In order to maximize the space on the face of the board, a second cup holder was added along with a slot to put a pencil or pen, a hole where the stem of a wine glass could be inserted. Additionally, the original slot for the computer was redesigned to give it more value. For the computer slot, a top cover piece was added so that it could also function as a back board to support a book or tablet. Several slits were drilled horizontally across the computer slot as well as one on the top of the board, so that the back board could fit into them and stand up. This process added great value to what was before just a simple cut-out and allowed the space to be used for multiple purposes for which the customer might need. To make sure that the top board would be able to stay in place when not being used or when the product was being transported, holes were drilled into the main board and the top board to insert magnets. Prototype III along with the Inventor drawings of the design can be seen in the figures below (6-8).

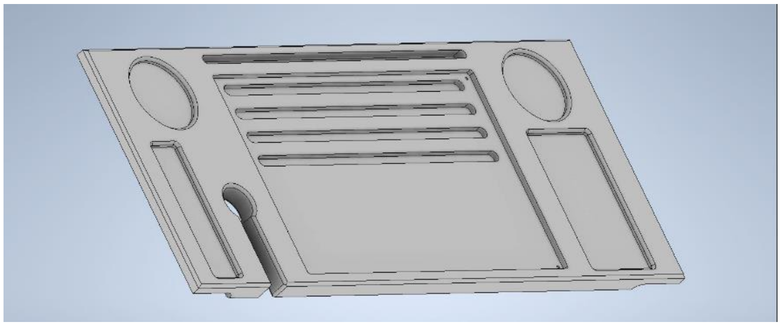

Figure 6: Prototype III Inventor Design

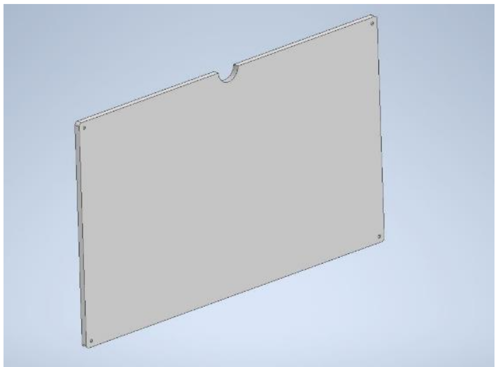

Figure 7: Top Board Inventor Design

Figure 8: Prototype III Top View

3.4 Final Design

With Prototype III complete, the final design focused on improving the quality without making major changes. There were a few issues with Prototype III regarding the dimensions and placement with some of the pieces on the main board. The first major issue was that the wine glass holder overlapped with the undercut on the board which made an uneven cut. To fix this, the wine glass holder and the pencil slot switched places on the board. The pencil holder did not have any problems being over the undercut because it does not cut all the way through the board like the wine glass holder. Next, the phone slot needed to be increased in size to make it more versatile for larger phones. The ever increasing size of phones was considered, so it made the design more sustainable to have a larger phone slot. In addition to fixing dimensions, the final design also included rounding off all the edges in all the designs on the main board to improve the aesthetic. The final product can be seen below.

Figure 9: Final Design

4 Production Overview

4.1 Process Flow Overview

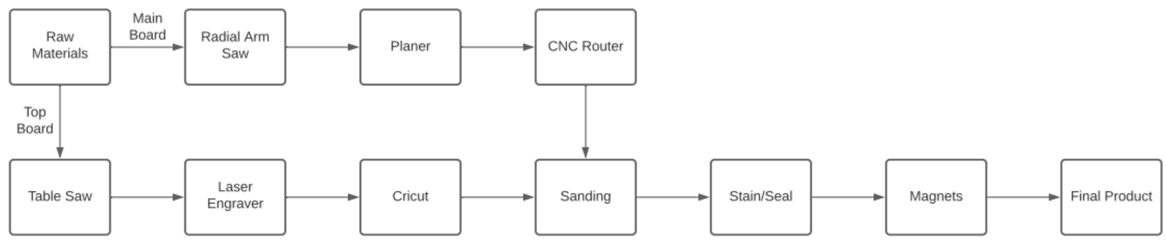

Figure 10: Process Flow Diagram

The production of the bathtub caddy begins with the raw materials for both the top board and main board. The main board raw material is a 8'x 18"x 2" yellow pine board, and the raw material of the top board is a 4'x 16"x .5" laminated spruce panel board. The material flow can be seen above in Figure 10.

The main board is first sent to the radial arm saw where the board is cut to the correct length of 28.5". Once the length is correct, it is sent to the planer to be brought down to the correct height of 1". Once the board has the correct dimensions, it is sent to the CNC Router where the face of the design is created as well as the undercuts and rounded edges.

The top board is sent to the table saw where it is cut to the correct dimensions. Once the dimensions are correct, it moves to the laser engraver where the magnet holes are outlined and the shape of the board is cut out. The top board is then sent to the Cricut where an "Ole Miss" logo is cut out for the board. The logo is not put onto the board until after it has been sanded.

The top board and main board then meet again at the finishing station in the process. They are both sanded down using a hand sander before being sent to the paint room. In the paint room, both boards are painted with a coat of clear polyurethane. With the polyurethane coat painted on the board, the final step in the manufacturing process is to insert the magnets. Four magnets are glued into each board using wood glue in order to keep the top board in place when it is not being used as a backstop. Once the magnets are inserted, antislip tape is put onto the undercuts to add stability, and then the product is complete and ready to be shipped.

4.2 Main Board Assembly

4.2.1 Raw Material Selection

The raw material selected for the main board was yellow pine. While other types of wood such as teak, bamboo, and white oak were considered, yellow pine was ultimately decided upon based on availability and price. Using one of the other types of wood listed above would have driven the cost of the board up significantly without giving it that much more value. The dimensions of the boards that were being purchased for the prototyping were 8’ x 18” x 2”.

4.2.2 Radial Arm Saw

The first unit operation in manufacturing the main board is to use the radial arm saw. The piece of wood that is being used for the main board is originally 8 feet long. With a product length of 28.5”, each board of yellow pine is able to produce three products with a remaining 10.5” of waste material. There were a few problems that were encountered when using the radial arm saw due to warping in the raw material board. In order to correct this, it is essential that the warped portion of the board face away from the saw head. If the warped side is facing the saw head, the saw would get jammed and slow down the process considerably. Another potential solution for this issue would be to find cured wood. For the scope of this project, the team was unable to find high quality wood at Home Depot and other local vendors, but in the event of a scale-up process, cured wood could be used to prevent this issue.

4.2.3 Planer

The second unit operation in the manufacturing of the main board is the planer, where the height of the board is reduced to 1”. While the raw material board has a nominal height of 2”, it actually comes in at roughly 1.5”. The planer should be set to take off $\frac{1}{32}$” with every run through. After each run through the planer, the board should be flipped over to allow each side to go through an equal number of times. After running multiple trials, it was determined that the board would have to go through the planer approximately 16 to 17 times in order to reach the desired height. To safeguard, the operator should start taking measurements after 15 runs through the planer. Once the height is within $\frac{1}{32}$" of 1”, the planer can be set to take off a specific amount depending on what is needed to satisfy the dimensions. Potential solutions to avoid this process step in general could be buying thinner wood to begin with. Just like the problems with the wood for the radial arm saw, the team had difficulty finding quality wood for this prototyping. In the event of a scale-up where the wood could be purchased in bulk, a thinner piece of raw material could be purchased to drastically reduce the use of the planer if it would even be necessary at all.

4.2.4 CNC Router

The bulk of the manufacturing on the main board occurs on the CNC Router. In order to run the router, a design of the product had to be constructed in Inventor which was then sent to the technical advisor who converted it to SolidWorks. The SolidWorks design was input to the CNC Router to program it to manufacture both the top side and the undercuts on the board. The board is locked into place on the router by using bolts and a vacuum feature on the router to ensure it is held steady. The bottom and top side were both separate designs, so they have to be done one at a time with the bottom being completed first. Once the undercuts are made, the operator flips the board over and repositions it to the correct location. The CNC Router then cuts out the entire design of the face of the main board.

4.3 Manufacturing the Top Board

4.3.1 Raw Material Selection

The wood selected to be used for manufacturing the removable top tray was a laminated spruce panel board. The spruce board was selected due to its similarity to the yellow pine that was used for the main board and came in dimensions that were able to be adjusted without wasting too much. The dimensions of the board were 4’ x 16” x .5”. The spruce board was similar enough in color to the yellow pine while also providing a slightly different look.

4.3.2 Table Saw with Dado Blade

First, the spruce board was cut from 16” to 10” for the appropriate width using the table saw with the dado blade. The mobile fence was adjusted according to the poka-yoke marking 1 for the width. The final width of the board was set to be 9.4", so this left about ⅓" of clearance on either side of the board for laser engraving the outline of the board. The mobile fence was then adjusted to marking 2 for cutting the length to 16". This allowed for three pieces to be cut from the raw material, still leaving ⅖" of clearance on either side of the board for the engraving, as the final length of the board was set to be 15.2".

4.3.3 Laser Engraving

The board was taped around the edges in order to counteract the char caused by heat of the laser. A rendering of the top tray was created in CorelDraw, and then printed to the laser engraving. After several trial runs, the settings were adjusted to finish the cut in a timely manner, while making sure the laser had a minimal burning effect on the wood. The final settings chosen for the vector cut were a power of 60, a frequency of 50, and a speed of 2. Originally, the power was set much higher to make sure that a through cut was made, yet that resulted in a lot of char. Therefore, the settings for the speed were adjusted to make it go slower at a lower power to ensure that the vector was cut all the way through as well as minimizing the burning effect. Any burning that remained on the board was able to be sanded off easily in the finishing stages. The laser engraving was also used to engrave outlines of the four magnet holes so that they could be drilled in the correct spots to line up with the main board. The settings used for making the small engraving for the holes were a resolution of 600, a speed of 90, and a power of 70. This allowed for the engraving to be deep enough to show where the holes were to go, yet not add too much time to the process.

4.3.2 Cricut

A couple of different ideas were experimented with in adding a logo to the product. The first idea was to engrave a logo onto the top board. After trial and error through different settings, an “Ole Miss” logo was engraved onto the board. The problem with the logo was that it was difficult to have a consistent coloring throughout the engraving due to the laminations of the three different boards together. The different grains of wood proved difficult to engrave evenly. After many attempts, it was determined that a much slower speed needed to be used with a lower power in order to have the best look. After running this trial, it took 55 minutes for the laser to complete the engraving, driving up the takt time as well as the costs. The Cricut was ultimately chosen to cut a logo into a piece of vinyl to be applied to the top board. The Cricut program was used to create the image of the “Ole Miss” logo. After hooking up a laptop with the appropriate software to the Cricut and loading the vinyl into the machine, the logo was cut with the press of a button. The total time that this took was about 3 minutes, and was a fraction of the cost.

4.4 Finishing

4.4.1 Sanding

Once both the top board and the main board were fully manufactured, the boards were ready to move onto the finishing process. The first step in finishing is to sand each board. They were each sanded using an electric hand-sander with all sides of each board needed to be covered. Once the bulk of the sanding was done, a piece of sandpaper was used to come back through and make sure all of the corners and crevices got proper sanding. Sanding is critical to the finishing process because it gives the product a smooth, even texture and allows the polyurethane to stick and have an even coat. The logo is out on the top board after it has been sanded and before the polyurethane coating.

4.4.2 Polyurethane Coating

After both boards have been sanded, a coat of clear, glossy polyurethane is painted onto both boards. While a spray can of this product was considered for this portion, the paint on product was chosen due to its ability to provide an even coat. The drawback to the paint on product is that it takes longer to apply and has a longer drying period. The spray on product is able to be applied in roughly 30 seconds with a complete drying time of only 5 hours while the paint on product has an application time of 2 minutes and a complete drying time of 24 hours. In the event of a scale up, the wood could be cured post application to speed the drying process up. The polyurethane serves the purpose of protecting the product as well as providing a better aesthetic than the raw wood. While a few different stains and paints were considered for coloring the board, the team decided that the clear polyurethane provided the best looking product.

4.4.3 Inserting Magnets

The magnet holes have already been drilled in both the top board and the main board, so the final process is to insert the magnets. Four magnets are put in each board and glued in using wood glue. It is essential that the magnets are facing the right direction in order for them to perform their job. In the scope of our project, the magnets had to be inserted using wood glue, but in the event of an actual scale up a press fit would be used to ensure higher quality. Once the glue is dried, the bathtub caddy is a completed product and ready to hit the shelves.

5 Poka Yokes

5.1 Main Board

5.1.1 Radial Arm Saw Bumper Attachment

In the first step of the bathtub caddy production, the main board must be cut to a length of 28.5” from the plank of wood. As a team, the conclusion was made that it would be very easy to cut the board either too short or too long, which would later cause issues with CNC machine making incorrect cutting locations. To ensure that the main board would be cut to the correct length, a bumper would be made to attach to the radial arm saw to guarantee the correct board length is cut. When creating the bumper, the distance from the cutting location on the saw to the edge of the table would be measured then find the difference between the desired length of the board. With the difference measurement found, that is how long the bumper attachment would need to be. Another important concept to consider is when there is bowing in the plank of wood. This is important because it can cause the wood to be sawed incorrectly or cause the saw to get jammed. The bowing location in the wood was marked before sawing in order to ensure that the board was aligned and cut properly.

5.1.2 Planer Clicker

The plank of wood that is purchased for the main board of the bathtub caddy comes at a thickness of 1.5”, but for our final product the board needs to be 1” thick. The planer has to be run several times over the main board because it only shaves off 1/32” each pass, therefore the amount of times the board is passed through needed to be tracked. A clicker could be used to keep track of the amount of passes the board makes to make sure there are not too many or too few passes applied to the board. In addition to the clicker, a 3-D printed jig could be printed that resembles a caliper to ensure that the thickness of the board is correct. Once 15 planing passes have been made, the jig would be fitted onto the board to have a thickness check. It should take 16 to 17 passes through to reach the correct thickness, but the board should begin to be tested after 15 passes to ensure quality and consistency due to variance in the thickness of the raw materials.

5.1.3 CNC Router

Once cutting and planing is complete on the main board, the board is CNC milled to create all of the inserts on the top side of the board as well as the wine glass cut out and the undercuts. When the board is first placed onto the CNC machine, a rubber gasket is put into the crevasses of the surface to act as a barrier to ensure that the board is efficiently suctioned to the table before the cutting program runs. When the board is placed on the table, it is easy to improperly align the board on the table, therefore to ensure that this issue does not occur, the bolts on the CNC machine will be unscrewed to the height of the board to ensure proper alignment. Once the top cuts have been made to the board, the suction is turned off and the board is flipped over to create the undercuts and finish the wine glass cut out. After the board is flipped in the correct direction, the bolts would be used again to ensure that the board is properly aligned before the cutting program runs

5.2 Board Insert

5.2.1 Epilog Engraver for Magnet Locations

After the insert has been cut and planned, it is sent to the Epilog engraver to filet the corners of the board insert. Once the laser is done fileting the corners of the insert as well as creating the cut out for the board to be easily lifted from the insert pocket, the laser was stopped so adjustments could be made. The power would be adjusted and the bit would be changed to then go over the insert and put the location and diameter of the magnet location. This extra step would be added because in our current process, the magnet cavities are being manually drilled with little specification as to if the drilled location is correct, so this would help to solve this issue. If we had more time to perfect our process, this extra step would have been added to the current process.

6 Financial Analysis

6.1 Targeted Market

For the scope of this project, the team decided to focus on the state of Mississippi as the target market. According to the United States Census Bureau, there were slightly over 1 million households in the state as of 2019. With this in mind, the goal was set to make 1% of Mississippi households an attainable goal for production in the first year. The 1% was an arbitrary goal set for the scope of this project, so in the event of a true scale up market surveys should be completed to get a more accurate goal. This means that the goal is to sell roughly 11,000 units annually, which equates to approximately 50 units per day.

6.2 Manufacturing Time and Labor Costs

With a target goal of 11,000 units per year needing to be manufactured, the team moved forward with looking into the manufacturing times of each process along the number of operators that would be necessary to reach these goals in order to determine the needed takt time. The manufacturing times for each stage in the process can be seen below in Table 1.

Table 1: Manufacturing Times

Stages	Time (Minutes)
Radial Arm Saw	1.00
Planer	4.00
Loading/Unloading CNC	4.00
CNC Manufacturing (Not manual)	17.00
Table Saw	1.00
Laser Engraver	6.00
Cricut	3.00
Sanding	2.00
Sealing	3.00
Assembly	2.00

In order to reach the production goal of 50 units per day, the process must have a takt time of 9.6 minutes. This means that a finished product is coming off the production line and ready to go every 9.6 minutes. In order to keep the calculations simple and easy to work with, the takt time was rounded up to 10 minutes. This also leaves a little bit of room for error if something were to be moving slow for some reason. This change in takt time leaves a production goal of 10,560 units per year which equates to 48 units per day in a standard work year of 220 days. In order to determine the number of operators required for this goal to be met, a line balancing chart was used which can be seen below in Figure 11.

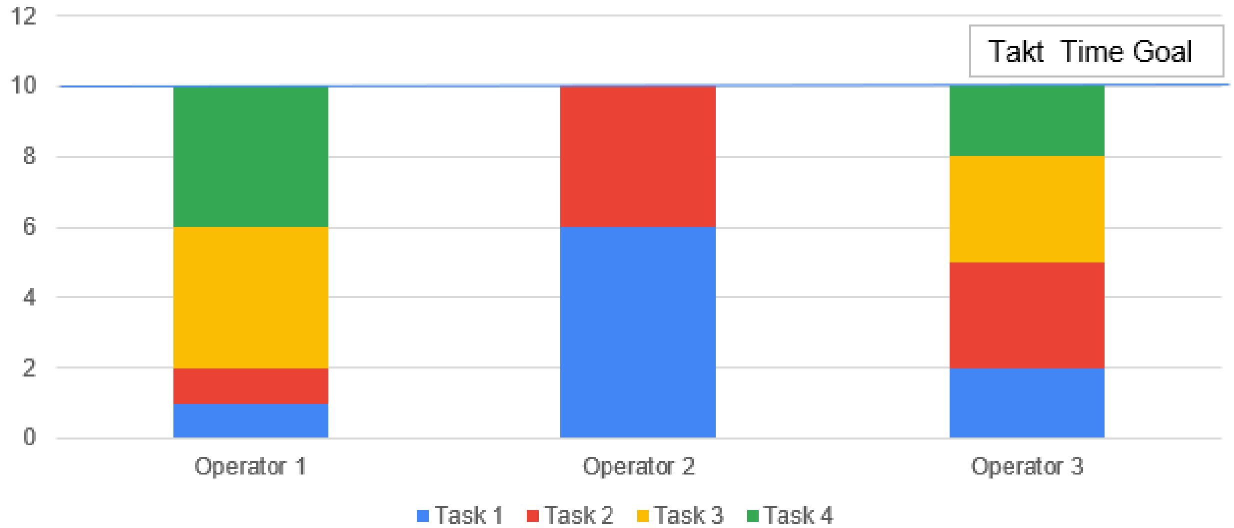

Figure 11: Line Balancing Chart

As seen in the line balancing chart above, 3 operators are necessary in order to keep the process under the 10 minute takt time. The operator tasks are broken down in Table 2 below.

Table 2: Operator Responsibilities

	Operator 1	Operator 2	Operator 3
Task 1	Radial Arm Saw	Laser Engraver	Sanding
Task 2	Table Saw	Load/Unload CNC 2	Cricut
Task 3	Planer		Sealing
Task 4	Load/Unload CNC 1		Assembly

While each operator does not have the same number of tasks, he or she has the same amount of work in terms of takt time. All three operators are able to perform their tasks in 10 minutes or less which allows the product to move through in continuous fashion. The CNC manufacturing was not included in the operator calculations because it is not manual labor that. While it does take time and that has to be considered in the process, an operator does not need to be standing over and watching the entire time. Instead a four minute loading and unloading time was applied to the CNC portion of the manufacturing. A revised process flow diagram was developed to place the operators in the process and can be seen below in Figure 12.

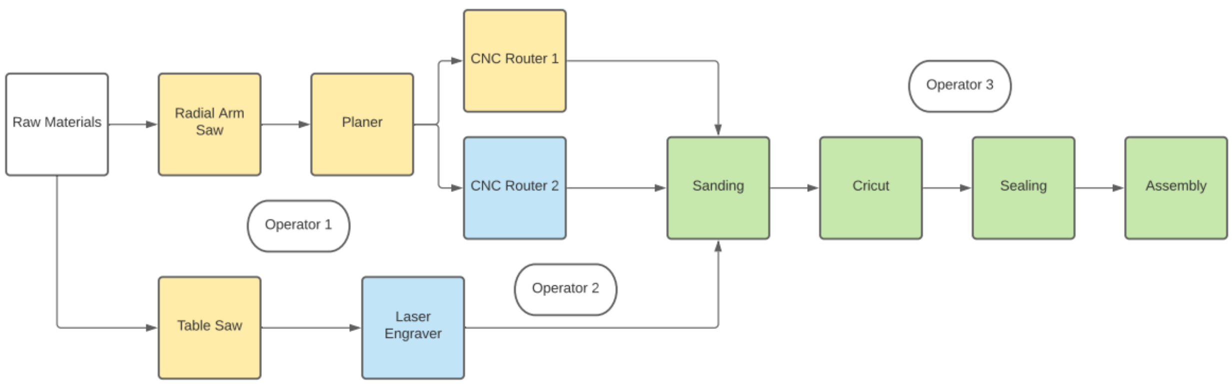

Figure 12: Operator Flow Diagram

As seen in the process flow diagram, the three operators are able to be stationed by their tasks to reduce waste in movement and keep the flow continuous.

Table 3: Labor Costs

Labor Costs	
Workers	3
Per Hour Pay	12.00
Cost Per Day	$288.00
Cost Per Board	$5.76

The financial data regarding the operators can be seen above in Table 3. It was assumed that the operators would receive an hourly wage of $12 and work standard 8-hour workdays. The $12 hourly wage is the average salary for production workers in Mississippi. (4) At this wage, the operators cost of a total of $288 per day which equates to $5.76 per bathtub caddy produced.

6.3 Equipment Rental Costs

For this project, all of the equipment that was to be used was rented at a set price. This played a large role in setting up the process because more expensive equipment was avoided when at all necessary. There were some more expensive pieces of equipment that were used such as the CNC Router and Laser Engraver due to their necessary role in the process. Due to the long operation time of the CNC Router, the team decided that it was best to rent two in order to be able to match the production goal. The machine rental costs for the project can be seen below in Table 4.

Table 4: Machine Rental Costs

Machine	Rental Cost ($/hour)	Time Required (Hours)	Cost per Unit
Epilog Laser Fibermark Fusion 30W engraver (Yellow)	$50.00	0.0833	$4.17
Laguna planar	$10.00	0.0833	$0.83
Saw Trax panel saw	$10.00	0.0083	$0.08
SawStop table saw	$10.00	0.0083	$0.08
Haas SR-100 Gantry Sheet Router	$100.00	0.3636	$36.36
Cricut	$10.00	0.0833	$0.83
Original Saw Company Pull Saw	$10.00	0.0083	$0.08
			$42.44

6.5 Raw Material Costs and Waste Calculations

The raw materials that had to be purchased for each board include pine wood, laminated spruce panel board, magnets, polyurethane, and anti-slip tape. Due to the small-scale operations at this point in the project, the raw materials used were subject to what was available at Home Depot or other retail stores to purchase. The raw materials were attempted to be purchased in large quantities that would produce multiple boards. As seen in Table 5 below, each material was able to be used to produce roughly 3 bath tub caddies and the total cost in raw materials for one product is $21.03.

Table 5: Raw Material Costs

Materials	Order Cost	Expected Boards	Actual Boards	Actual Cost per Board
Pine Wood Plank (8 ft)	$24.47	3.3684	3.0000	$8.16
Laminated Spruce Panel Board (4 ft)	$17.89	5.1064	3.0000	$5.96
Magnets (25 units)	$10.99	3.1250	3.1250	$3.52
Polyurethane (8 oz)	$6.98	3.0000	3.0000	$2.33
LifeGrip Anti Slip Waterproof Clear Safety Tape (2" X 30')	$15.99	15.7895	15.0000	$1.07
	$76.32			$21.03

With the materials being purchased from the store, the exact dimensions that were desired by the team were not always available for purchase. This led to a certain amount of material being wasted. As seen in Table 6 below, a significant percentage of waste came from both the pine wood and the laminated spruce panel board. In future production, this waste of raw materials will need to be addressed by either changing the dimensions of the product or finding a material of better size that can be used.

Table 6: Waste Calculations

Materials	Waste per Order	Percentage Waste	Cost of Waste
Pine Wood Plank (8 ft)	0.3684	10.94%	$2.68
Laminated Spruce Panel Board (4 ft)	2.1064	41.25%	$7.38
Magnets (25 units)	0.0000	0.00%	$0.00
Polyurethane (8 oz)	0.0000	0.00%	$0.00
LifeGrip Anti Slip Waterproof Clear Safety Tape (2" X 30')	0.7895	5.00%	$0.80
			$10.86

6.6 Price Determination

Table 7: Total Production Costs

	($/unit)	
Raw Materials	$	21.03
Machine Rental	$	42.44
Labor	$	5.76
Packaging and Shipping	$	7.00
Total	$	76.23

As seen in Table 7 above, the total cost to produce a bathtub caddy with the current process and materials is $76.23. With the production price in hand, the market was analyzed to determine a competitive price range. The figures below (13-16) show competitor products and prices that were found when determining where our product fell on the market.

Figure 13: Market Sample 1

Figure 14: Market Sample 2

Figure 15: Market Sample 3

Figure 16: Market Sample 4

As seen in the figures above, the price range of a bathtub caddy can range anywhere from $20 to $150 and beyond depending on the quality and utility of the product. Our product is in the middle range as it is made out of pine, yet provides a lot of value in its versatility and quality of work. With this taken in mind along with the production price, the team determined that a fair and competitive retail price was to be set at $94.99. For the scope of this project, customer surveys and feedback were not gathered, but ideally this information would be important in the planning process of a scale up to ensure that customers have interest in the product at the stated price.

6.7 Income Statement

Table 8: Income Statement

Sales (Units)		10,560
Sales ($)	$	1,003,094.40
Total Production Cost ($)	$	805,030.10
Gross Profit ($)	$	198,064.30
Selling and Marketing Costs ($)	$	12,000.00
Fixed Expenses ($)	$	24,000.00
Net Income ($)	$	162,064.30

Table 8 above shows a hypothetical income statement for the first year of production. The total production cost is the sum of the raw materials, labor, machine rental, and packaging costs. The marketing and fixed expenses were assumed values to try and consider other factors that are not directly included in the production process focused on in this project. Overall, the project would net an income of $162,064 if the production goal of 10,560 units were sold per year.

Conclusion

7.1 Lessons Learned

Many lessons were learned in the design and production phases of the bathtub caddy. Going into the project, the team rushed to decisions and did things that we would not do again in hindsight.

One of the biggest takeaways in the design phase of the project was to take more time in the initial stages and really think over the decisions that are being made. The initial designs of the product lacked true thought and were just thrown together. A lot of time and effort could have been saved if the team had done more thorough research at beginning of the project to determine what would work best.

The second and probably biggest lesson learned was to design the product to the available materials and customer instead of the other way around. Once the design of the product was complete, it became a large ordeal trying to find the right materials with the dimensions that were necessary to complete the design. Because the team did not look into materials before making the design, many extra steps were required in the manufacturing process that would not otherwise be needed. Examples of this include having the yellow pine wood being too long and too thick. If the design had been modeled after the available material, the waste of raw materials seen in Table 6 could have been avoided. Along with the wasted material caused by this, there was a waste in overproduction and time by having to use the planer. If the board could have been purchased at the correct height, there would have been no use in having to use the planer which would save 4 minutes off the production time and $.83 off the production cost.

7.2 Scale Up Process Improvements

If this process were to go through a scale up, many improvements could be made in order to make it more efficient and lean. One of the first steps that could be taken would be purchasing raw materials in bulk and in dimensions that more closely resemble the product. This would help reduce the amount of machining with the planer as well as reduce the amount of raw material that is being wasted.

In the current process, the polyurethane seal has to dry overnight due to the long time that it requires. For the scope of our prototyping, we had no way to speed this process up, but with a scale up the polyurethane could be dried faster by curing the wood.

The process steps of drilling the magnets as well as the inserting the magnets would greatly improve in the event of a scale up. In the current process, the magnet holes for the top board are outlined with the Epilog Engraver before they are punched out using a drill bit. Ideally, the magnets holes could be created by using the laser engraver to reduce the number of steps in the process. Due to time constraints this was not able to be achieved in the prototyping stage. Once the holes are drilled, the magnets still need to be inserted. Currently, they are glued in using wood glue. This step would benefit greatly from a press fit which would simplify the process as well as provide a higher quality product.

Lastly, the "Ole Miss" logo was manually put onto the top board during this prototyping stage. With a scale up, this step would need to be standardized to improve the timing and consistency. This could be achieved through a machine that could put on the logo as opposed to putting the logo on by hand. While this would slightly raise production cost, the quality of work would improve.

7.3 Project Analysis

Overall, the Bathtub Caddy Senior Capstone project can be deemed a success. Over the course of the Fall 2020 and Spring 2021, the team was able to go through the entire manufacturing process from the design phase to prototyping all the way through a potential ramp-up in production. Throughout the entire project, the team was able to focus on lean manufacturing methods as well as team building. While it was difficult at the beginning, by the end of the Spring 2021 semester, the team had come together with the common goal of achieving a total quality product.

Lean manufacturing was used heavily throughout the process as well as in the consideration for future designs. Due to the time constraints on the Senior Capstone, not all of the team's ideas for improvement were able to be implemented; however, the problems were addressed as well as solutions for future designs.

From the original design to the final product, many changes were made in the design itself as well as the manufacturing process. The largest of those changes was the removal of the sliding arms to make the product much easier to manufacture and to ensure quality. This decision was crucial because it removed many un-standardized steps in the process that were having to be completed by hand. The final manufacturing process is a continuous process with the only holdup being the time required for the CNC Router. The flow of materials for both boards runs smoothly and eliminates a lot of waste in time and movement. While it could not be implemented in this project, a change in material was recommended by the team in order to reduce the amount of waste in raw materials that occurred. This could be easily achieved by finding a raw material with dimensions closer to that of the design or altering the design to fit the dimensions of available material.

The financials for the product project a net income of over $162,000 over the course of the first year of production if the team is able to meet the target goal of 10,560 units. This net profit proves that there is hope for the product if the customer demand assumptions made are correct. In order to move forward with a scale-up it would be essential to get an accurate market survey to prove there is customer demand. In addition, the continuous improvement of the manufacturing process could continue to cut costs and allow an even higher profit per board.

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