Spring 5-1-2021

Apiary Wagon Frame

Katelyn Franklin
University of Mississippi

Ryoma Thomas
University of Mississippi

APIARY WAGON FRAME

by
Katelyn Franklin & Ryoma Thomas

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 2021

Approved by

Advisor: Dr. Jack McClurg
Professor of Practice of the CME

Second Reader: Eddie Carr
Professor of Practice of the CME

Third Reader: Dr. Scott Kilpatrick
Interim Executive Director of the CME

DEDICATION

For the bees. Katelyn would like to thank her father, Charles Franklin, for the idea for this project and for teaching her about beekeeping. Additionally, we would like to dedicate this paper to our families who have supported us through our four years here at the University of Mississippi.

ACKNOWLEDGEMENTS

We like to say a special thanks to Dr. Jack McClurg for being an excellent mentor to us throughout the progress of our thesis. Additionally, we would like to extend that thanks to Mike Gill for being an outstanding instructor for our capstone project. We are also very appreciative for Mark McAnally and Andy Gossett. They were our on-site advisors on the manufacturing floor and we could not have completed it without their support and expertise. We sincerely appreciate all of the CME faculty for helping us every step of the way towards completing our four years here at Ole Miss. Also, we would like to thank our teammates, Holt Hederman, Nancy Newman, and Chase MacArthur for being invaluable for the entirety of this project. We could not have done it without them.

ABSTRACT

The objective of this thesis to demonstrate how our senior capstone project team took a product from a concept to a mass production manufacturing operation, using the knowledge and experience gained through our four years in the Haley Barbour Center for Manufacturing Excellence (CME). Our product, the Apiary Wagon Frame, is an opportunity to reduce the barrier to entry into the hobbyist beekeeping community. In the design process for the Apiary Wagon Frame, we tested several prototypes and different fabrication methods, ending with a product capable of holding twenty hive frames. After building our final prototype, the group created a plan to scale our manufacturing process to the level of mass production. This theoretical scaling of the manufacturing process will result in an effective process for manufacturing our product at a sufficient rate to meet expected demand while maintaining profitability, with a focus on continuous improvement, and eliminating waste.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I: INITIAL CONCEPT

1.1: Background information

Beekeeping as an industry has an enormous ecological and economic impact both globally and in the United States. Honeybees are the most economically valuable pollinator of worldwide crop monocultures. While often not as effective as wild native pollinators, honeybees are often used to ensure crop pollination when wild pollinators are not available [1]. This is especially true in the United States, where rather than compete with cheaper imported honey, professional beekeepers primarily use their honeybees for crop pollination services. Millions of beehives are transported on trailers all around the country to pollinate crops, from the apple and cherry orchards of Washington State to the clementines and tangerines in Florida. Using over 1.5 million out-of-state bee colonies each spring, California's almond crops are the most important stop for migratory beekeepers. Other crops that use migratory bee colonies include squash, blueberries, cherries, pumpkin, and potatoes [2].

While apiculture has been declining in the United States since 1961, recent sudden losses of bee colonies and "Colony Collapse Disorder" (CCD) has attracted significant public attention to the United States' agricultural dependence on domesticated honeybees [3]. While there are many possible factors in the losses threatening honeybees in the U.S., that very agricultural dependence and the resulting commercial beekeeping practices may be one of the leading causes. Migratory beekeeping is a response both to the massive demand for pollinators created by crop monocultures and their destruction of the habitats of local wild pollinators and the inability of U.S. beekeepers to compete with imported honey prices [4]. However, as a beekeeping practice, it introduces several problems of its own. When millions or even billions of bees from different colonies converge on a single area, such as the almond crops of California, they share viruses, mites, and fungi with each other. Additionally, transportation puts hives under stress, feeding from a crop monoculture denies them the superior nutrition of wild local plants, and a lack of genetic diversity weakens their resistance to disease [2].

Although it cannot solve the larger problem of pollinating the U.S.'s massive monocrop fields or restore the native pollinators whose habitats have been destroyed, small-scale local beekeeping is healthier for the honeybees. With a smaller-scale operation, a beekeeper can devote more time and focus to the wellbeing of a few hives, and the bees will be saved the stress of transportation and competition with hundreds of other hives for food. Ideally, a stationary hive would have less exposure to diseases, since it would not pick them up from other hives from around the country. Beekeeping as a hobby has many benefits, including the production of valuable honey and beeswax. Honey has a high cash value relative to its weight and bulk, and is nonperishable if stored properly, making it an ideal crop for small-scale producers. Beeswax is also nonperishable, furthermore, it is easily stored and can be used by craftsmen and artisans for candles, wood polishes, tanning, and leather working [5, pp. 17-19]. Small scale beekeeping can also be used as an educational tool for schools and youth clubs. The scope of this project, therefore, is focused on small-scale operations and hobbyist beekeepers.

The "bee space" is one of the most important concepts in modern beekeeping, and almost all beekeeping tools are built around it. Discovered by Reverend Lorenzo Langstroth, the bee space is the exact distance removable frames in a bee box should be spaced apart. If frames are too closely spaced, the bees will seal them together. If frames are too far apart, the bees will build honeycomb between them. Langstroth discovered that spacing the frames ⅜" apart resulted in the bees leaving a gap between the frames, making it possible for beekeepers to remove one frame at a time. The discovery of the "bee space" revolutionized beekeeping when Langstroth's book was published in 1852. Between then and World War I, much of the modern beekeeping tools and techniques were developed, in what would later be called "The Golden Age of Beekeeping."

Because of this valuable contribution to beekeeping, the most commonly-used bee boxes are called Langstroth Hives [6, pp. 2-3].

A Langstroth Hive typically contains 10 frames, or less often, 8 or 12 frames. Brood chambers are frames that store bee eggs and larvae, which is called brood, and frames that store honey are called supers [6, p. 8]. While the frames for a Langstroth hive are a standard width of 19", they come in three heights - shallow, medium, and deep. Shallow frames are 5-⅜" tall, medium frames are 6-¼" tall, and deep frames are 9-⅛" tall. Medium and deep are the most commonly used frames [7].

1.2: Identification of need

A medium frame weighs about 6 lbs. when harvested and full of honeycomb [8]. For a 10-frame hive, this adds up to 60 lbs. Considering that many beekeepers stack multiple boxes to accommodate larger hives, the total weight of frames to be harvested may be even higher.

Due to their shape, with only two small tabs on either side to serve as hand holds as shown in the Figure 1 below, frames with full honeycomb are unwieldy to carry.

Figure 1: Empty hive frames (Tilmann)

When harvesting frames, beekeepers must carry them one at a time to their house or workshop where the honeycomb will be cut off the frames and the honey will be harvested.

Stacking the frames on a cart or wagon could crush the honeycomb and waste the honey that spills out. This process is a messy, tedious, inefficient use of a beekeeper's time.

There is a need for a cart or wagon specifically designed to hold hive frames. The Apiary Wagon Frame was designed to fulfill this need. This wagon would hold the frames upright and securely to prevent them from swinging into each other, but space them apart to prevent crushing the honeycomb. It would also include storage for the tools necessary to harvest honey, giving the beekeeper easy, quick access to tools.

The initial concept of the Apiary Wagon Frame was to be a 19" wide wagon long enough to hold at least 10 hive frames. The frames would be placed in a single row down the length of the wagon, and grooves would be cut into the top surfaces of the wagon side walls to prevent the frames from sliding or rocking as the wagon moved.

CHAPTER II: PROTOTYPING PROCESS

2.1: Project Scope

The scope of the product, the Apiary Wagon Frame, is to carry 10 or more full frames of honeycomb, without spilling or breaking the comb. The wagon will also carry a hive tool, a frame brush, and a smoker, as seen in the figures below. These three tools are the most essential for harvesting honey. The hive tool is used to help remove the frames from the bee box when they have become stuck or sealed to the box with propolis, which is a glue-like substance produced by bees. The frame brush is used to gently brush bees off a frame that is being harvested. The smoker is filled with a small amount of tinder and wood chips, which are then lit on fire to produce the smoke used to drive bees away from the hive temporarily while honey is being harvested.

Figure 2: Hive tool [9]

Figure 3: Frame brush [9]

Figure 4: Smoker [9]

The scope of this project includes the design of the product, building prototypes and a final product, analyzing the pricing and cost, and designing the manufacturing process needed to mass produce the Apiary Wagon Frame. It also includes a written report and a report-out presentation.

2.2: Team Members and Roles

Katelyn Franklin, a Mechanical Engineering major, pitched the initial concept of the Apiary Wagon Frame. She took on leadership as project manager, coordinating with all team members to plan and delegate tasks and keeping record of the team's progress. As an engineer, she also contributed to the design and manufacturing processes.

Ryoma Thomas, a Mechanical Engineering major, was one of the design/manufacturing engineers of the project. He contributed to product design, building and improvement of each prototype iteration, and the development of the production plan.

Nancy Newman, a Chemical Engineering major, was also one of the design/manufacturing engineers of the project. She was responsible for creating engineering drawings of the wagon and its components in SolidWorks for building prototypes and creation of CNC machining programs, as well as the production plan.

Holt Hederman, a Business major, aided with the building and planning process of the project and took on the role of point of contact. He was responsible for staying in contact with professors and lab technicians to update them on the project's status and confirm the dates of when the team would work on the manufacturing floor.

Chase MacArthur, an Accounting major, was responsible for keeping the project within budget, tracking costs, and estimating the final price of the product. He performed a financial analysis on the product to determine the pricing and net profits. He also managed the team's purchasing, going through the CME to order materials and supplies.

2.3: Prototype I

The project began with the team gathering together to brainstorm the requirements of the cart. It was determined that creating an entire wagon from scratch would not be an efficient use of time and materials. We decided to instead purchase a well-built wagon that fit the desired dimensions and could handle the estimated weight of the frames and travel across outdoor terrain. Our design and manufacturing efforts would be focused on creating structure to attach to the wagon to hold hive frames. The structure would be compatible with any wagon large enough to hold it and could be easily removed from the wagon, allowing the wagon to be used for other purposes than exclusively beekeeping.

The team purchased a four cubic-feet steel utility cart by GORILLA CARTS as seen in Figure 5, as a base to build our design onto. It has a steel mesh deck that is 40 inches long and 21 inches wide. The cart was picked because its dimensions could fit the desired number of frames, while still a common cart size. Other factors were the pneumatic tires and removable sides.

Figure 5: GORILLA CARTS 4 cu. Ft. Steel Utility Cart

Due to the slight divot in the middle of the side panels, the group decided to remove the sides and build a walled structure on top of the wagon base. After purchasing the wagon, we met and brainstormed the initial prototype. Each engineer in the team was asked to produce a drawing that would be presented to the entire group, and the team agreed on features of each drawing to include in the design for the prototype. The most important feature decided on was that grooved pieces would hold the sides of the frames, instead of the grooves being on the top surface of the walls. Frames would be held in two rows perpendicular to the wagon, making loading the frames ergonomically easier for a user standing beside the wagon. Based on the dimensions of the base and arrangement of the frames, the wagon would hold twenty frames. It would be tall enough to deep, medium, and shallow frames. Nancy created a SolidWorks drawing of the design to be used to build the first prototype.

Since pine wood is cheap and easily machinable, it was used as the material for the first prototype. Chase ordered two 10-ft 2x4's and a package of 3" deck screws, and a sheet of ¼" plywood was taken from CME storage. We cut a 19" long section from the 2x4's to be the middle piece of the cart to support the hive frames. Then we cut two 19" long sections from 1" boards in CME storage to be the support for the front and back of the structure. A laser cutter was used to cut out pieces of the ¼" plywood for the walls of the support to create a "grooved-like" shape that would secure the frames as seen in Figure 6. A staple gun and brad nails were used to fasten the ¼" thick divider pieces to the three 19" long 2x4's. Two of the 19" boards had dividers on one side, and the thicker middle piece had dividers on both sides.

Figure 6: Prototype I "Grooved" Middle Support

To test if the frames would fit within the divider and in the cart itself, we held the dividers in the wagon and placed frames in them to confirm the concept of the wagon would work. This prototype confirmed that the frames could be securely held and fit inside the grooved pieces as expected. However, our method of creating dividers and fastening them to the walls resulted in measurement inaccuracies that made it difficult to line up the frames on both sides of the wagon. We determined that with the next prototype, we should cut the grooves into the boards instead of attaching dividers, to increase the accuracy of the groove dimensions and properly align the frames.

2.4: Prototype II

To build our second prototype, we first cut our boards to the required lengths using the SawStop table saw and set them aside. We used the Laguna Planer machine to reduce the thickness of the four 19" sections of 2x4 from 1.5" to 1". We then used the Bridgeport CNC mill to create slots in the four 1" wood planks. The Bridgeport had a monitor attached to it displaying its cutting tool's position on an x and y axis relative to our wooden planks. By referencing the monitor when milling, we were able to accurately mill grooves in the planks. However, this method of using the milling machine was time consuming and took around 25 minutes per plank. Additionally, it caused splintering to the ends of the grooves, which led us to believe using the SR100 CNC sheet router would be a better choice in machining for our next prototype. We assembled the structure using the 3" screws and a drill, however, several of the smaller pieces cracked when drilled into. For those smaller pieces, we used a nail gun and brad nails. The completed second prototype is shown in Figure 7.

Figure 7: Prototype 2

To test the cart assembly over winter break, we needed a temporary solution of attaching it to the cart, so Nancy provided some hay string to tie it down to the cart. This prototype was tested by both Katelyn and Nancy over winter break.

After winter break, Katelyn and Nancy updated the rest of the team about their testing with the cart. The cart worked fine initially, even with just the temporary hay string tying it down. However, the main issue was the wood itself. The grooves in the planks, where the beehive frames were to be placed, were too tight for some of the frames. Initially, we hypothesized that the humidity could have caused a slight expansion in the wood. However, it was later discovered that our design was created with too tight of a tolerance. There was no room for the frames to slide into the cart due to the grooves having almost the exact same width as the frames. As a result, this led to the conclusion that our dimensions and tolerances must be adjusted.

2.5: Final Prototype

We created our new specifications while keeping in mind the length of typical 2x4s. We also decided to use untreated pine wood as our material for the cart. The frame will be supported with smaller boards on the corners and the sides. We increased the length of the sides of the frame to 39” to cover the entirety of the cart when placed on top. The grooves for our frames increased in width by 0.5” to allow the frames to slide in and out with ease even when encased in honeycomb. Our designs assembly can be seen in Figure 8 and the new design specifications can be seen in Figure 9 and Figure 10.

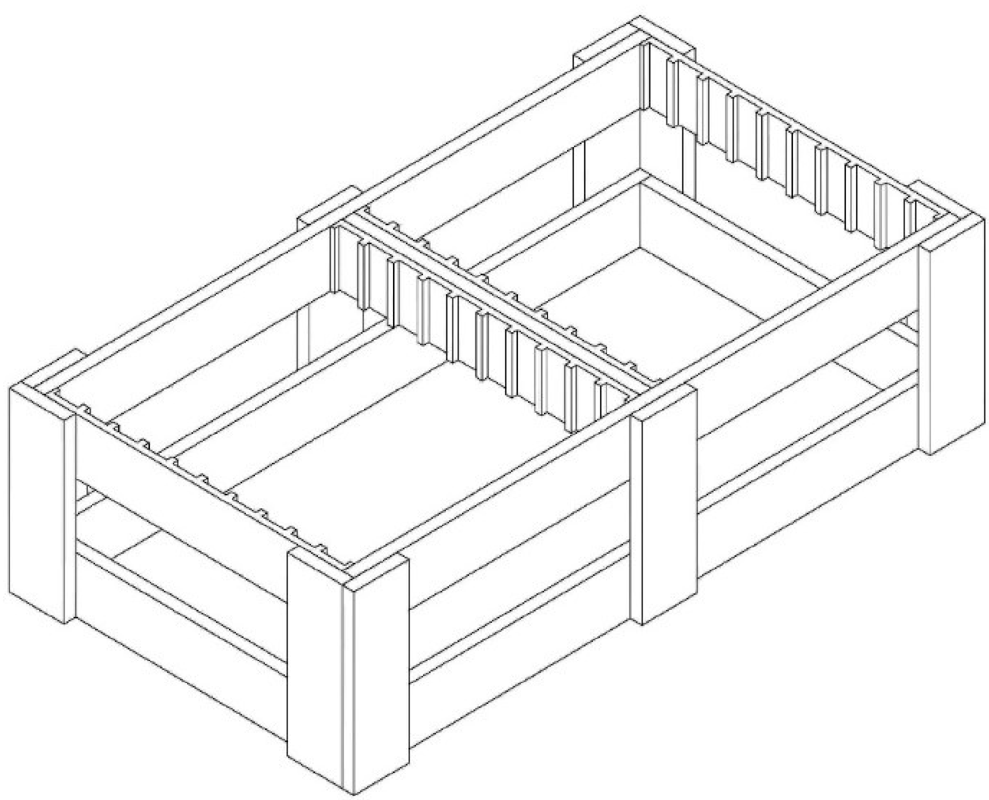

Figure 8: Assembly Design

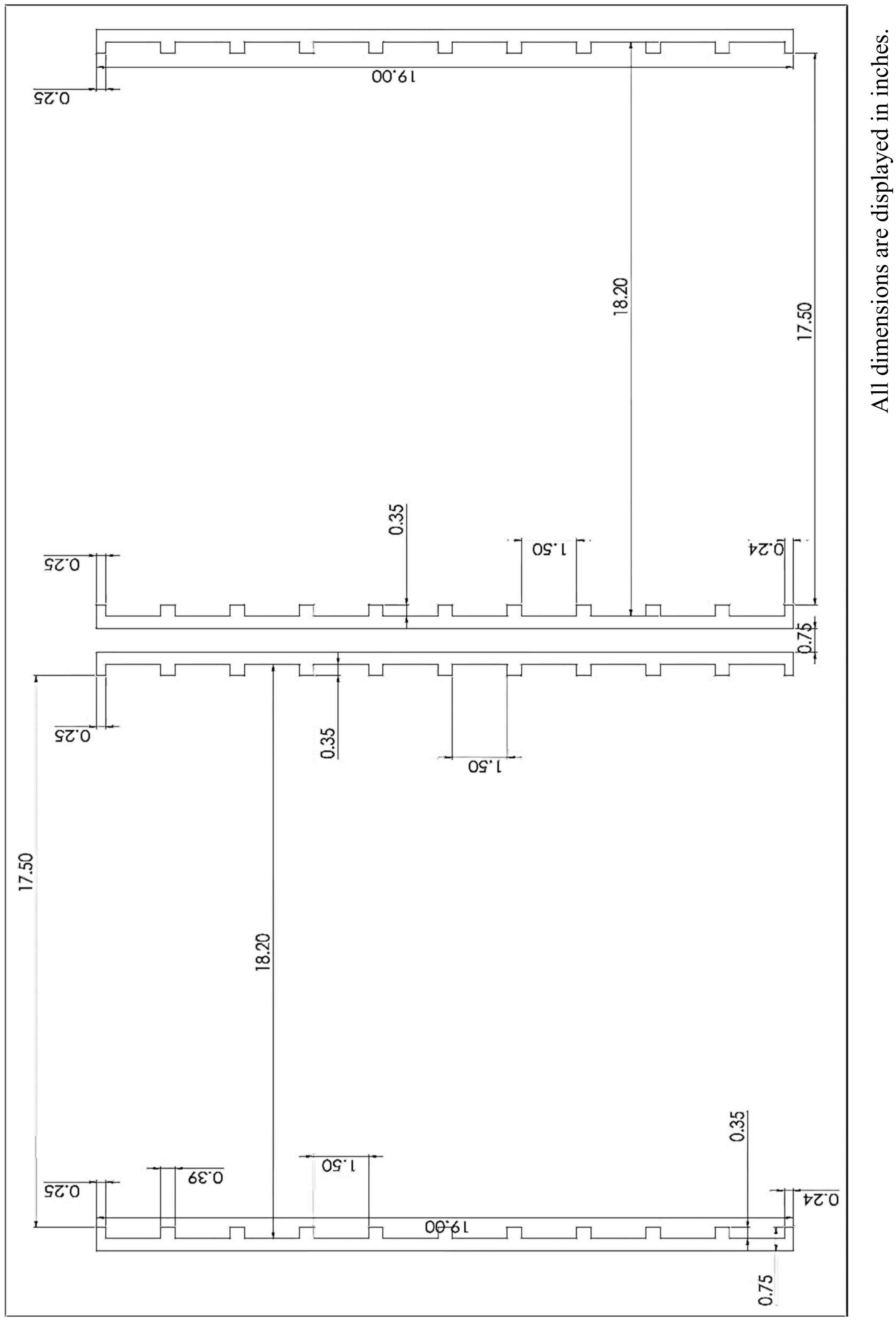

Figure 9: Groove Design Specifications

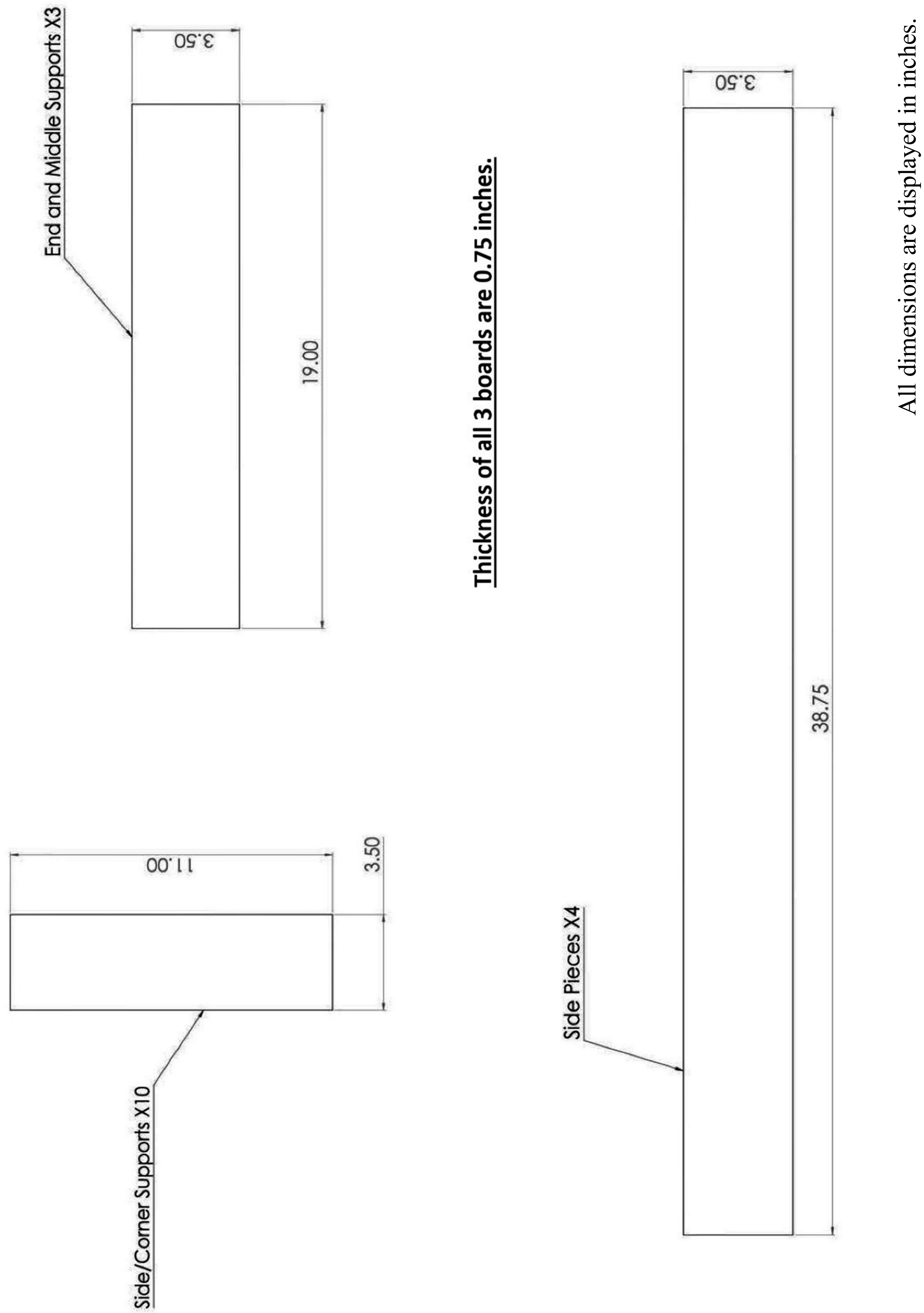

Figure 10: Support Plank Design Specifications

Rather than using the previous “T” shaped blocks of wood to support the upper and lower layers of the cart as in Prototype II, the final prototype utilizes ten support pieces of wood. Two on each corner and two supporting the center of sides of the cart. In order to acquire material for this project, we had to send an order form to the CME. They relayed that order to Home Depot, where our materials were set aside for pick up. The funds were then taken out of our budget. We purchased four 1”x4”x8’ boards with 1” wood screws for the future assembly. We calculated that a total of six 19” boards, four 38.75” boards, and ten 11” boards could be created out of the boards we had purchased.

After retrieving our wood and materials, Mark McAnally and Andy Gossett advised us on using the Haas SR 100 Vacuum CNC Mill to cut out the grooved pieces. Using the Haas SR 100 CNC instead of the Bridgeport, would significantly decrease our production time due to the machine being automatic in the cutting process. Rather than cutting the grooves out by hand with the Bridgeport CNC machine, the Haas SR 100 CNC not only had a wider base to cut our materials on but it also had the capability of cutting out our pieces specific to our design sheet. Andy took in our solid CAD model and converted it into data that the machine could utilize. The quality of the grooves would increase, and the cuts would be more precise.

In anticipation of using the different CNC machine, we cut out the 19” pieces of wood to Figure 10’s specifications. However, we realized that these 19” pieces did not have a large enough surface area for the vacuum of the Haas SR 100 Vacuum CNC to properly seal the pieces down on the cutting surface. Andy suggested we create a fixture to hold the boards, which would have enough surface to be held down by the vacuum. Without the fixture, the boards would come loose from the cutting surface when they came into contact with the drill head.

Andy recommended medium density fiberboard (MDF) as the fixture material because it was easily machinable and the CME already had a surplus of it in storage. Initially, we agreed upon the fixture having to be about 90% the length of the boards so that it would give us something to grab when pulling them out of the tight fixture. The fixture needed to be at least half the thickness of the board. The boards would be then spaced 1” apart. Our team member, Nancy, came up with a drawing that fit those specifications so that the boards would fit. The fixture drawing can be found in Figure 11.

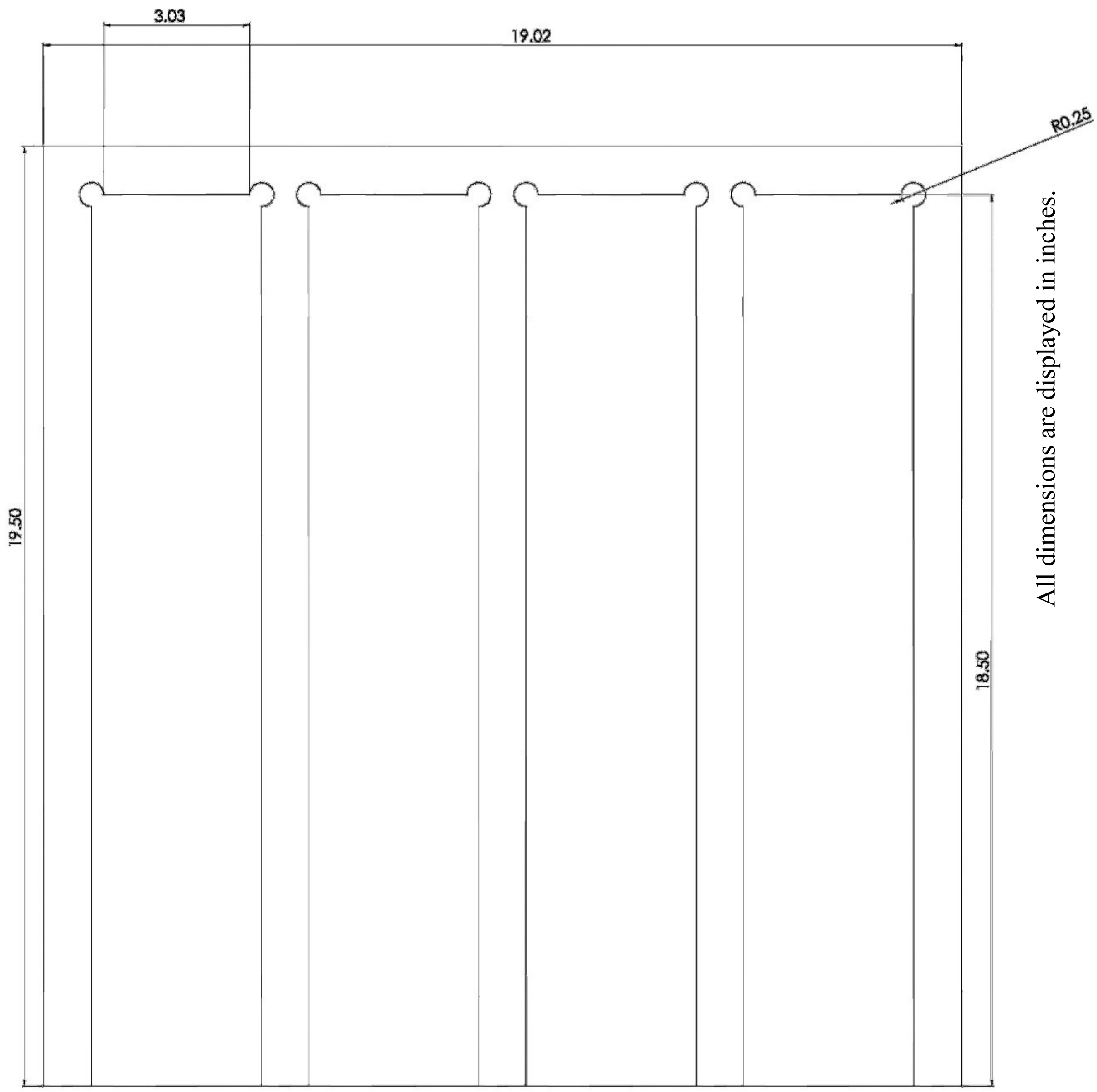

Figure 11: Fixture Drawing

The drawing was sent to Andy, so that he could create a program for the SR 100 CNC machine. First, the pattern shown in Figure 11 was cut into a sheet of MDF. We then used the

SawStop table saw to cut the excess MDF material off the sides. Additionally, Andy recommended us to drill three evenly spaced holes into each fixture slot in order to allow the vacuum a better grip on the wooden pieces. A Milwaukee hand drill with a 5/16” bit was used to drill in the holes in the fixture. After the holes were drilled, the fixture was placed on top of the vacuum table, along with the wooden pieces in the fixture. The SR 100 CNC was turned on and was able to cut the grooves into the wooden pieces. Allowing the boards to overhang the edge of the fixture created a problem when the drill head made contact, because the boards could slip out of that side of the fixture. To prevent this, we had to place an extra board on the open side of the fixture, as seen in Figure 12, to stop any movement of the boards.

Figure 12: Fixture in Use

We moved all of our cut wood into the paint room of the manufacturing floor. There we retrieved a pack of 3M Pro Grade Precision sandpapers from one of the lab technicians. To achieve a clean finish when applying the spar urethane, we used the sandpaper to even out any slight chips or breaks in the wood pieces. We used 3M Pro Grade Precision 9”x11” 150-grit sandpaper initially to get rid of any course edges. We then finished it with a 220-grit sandpaper to smooth out the edges and faces of the planks. Once we finished sanding, all of the wood was placed onto a layer of cardboard on top of a table and then moved underneath a finishing booth. Three coats of Spar Urethane were applied to each board, allowing the boards to fully dry for at least four hours between each coat. The process took two weeks due to school and tests, however, if consecutive coatings were done without delay, it would have taken two days.

After removing all of the planks from the finishing booth, the planks were laid out onto a different table and prepped for assembly. We acquired tape measures, framing squares, pencils, screws, a brad nail gun, a drill gun, and a few bar clamps in order to begin our assembly. The side planks were measured and marked on the front and back ends to ensure correct placement of the outside grooved pieces of wood. After lining up the corners with a square, where the side planks meet the grooved planks, a brad gun was used to nail the four pieces together. Next were the center groove pieces. Much like the outside grooved pieces, the side planks were measured and marked in the center for the desired placement. Again, with the use of the square and brad gun, the center grooved pieces were attached with a 0.75” distance between the two grooved pieces. The corner supports were added next. Three types of #8 screws were used: 1” screws, 1 ½” screws, and 2” screws. Starting with one corner, two of each type of screw were used to securely fasten the support to the first half of the cart. The four corners were aligned with the square to ensure a right angle. Before inserting the screws into the support, a pilot hole was drilled to guide the screw into the desired position and prevent the board from cracking. The side supports used the 1 ½” screws to attach to the length side of the cart. One 2” screw was screwed into the front/back support and into the side plank of the cart. The other 2” screw attached the side support plank to the front/back support plank. This process was repeated three more times to complete the “top” half of our wagon frame. To make sure that the “top” half was aligned with our “bottom” half, we used Irwin Quick-Grip tools to fasten the “bottom” to the other half of the wagon via the corner supports as shown in Figure 13: Clamped “Bottom” of Wagon Frame.

Figure 13: Clamped “Bottom” of Wagon Frame

The fastening process was repeated with the next four support corners. However, due to the front and back planks having a 0.75” thickness, the 1” screws had to be replaced with 1 ½” screws to fully attach itself to the corner supports for those boards. As each corner supports screws were attached, the Quick-Grips were taken off one by one. After fully attaching the top and bottom layer of the wagon frame, the entire assembly was flipped 180 degrees to have the assembly in its correct position with the grooved plank layer on top. The side support planks were attached to the assembly next. The side planks were measured and the marked in the center where the supports were to be aligned. The side support planks were aligned with their marks and pilot holes were drilled so that there would be a hole connecting to the support to both the top and bottom layer of the assembly. Two 1 ½” screws were retrieved and screwed into the pilot holes.

This process was repeated for the other side support plank as well and thus final prototype was completed as shown in Figure 14.

Figure 14: Completed Final Prototype w/ Side Supports

CHAPTER III: SELECTION OF FINAL MATERIALS

3.1: Selection of Frame Material

One of the most critical decisions of the project was selecting the materials to use in production. For the main body of the product, the three types of materials considered were metal, plastic, and wood. Deciding on materials would determine the machines to be used for production and assembly and ultimately the final cost of the Apiary Wagon Frame.

The first material evaluated was metal. Several metals were considered, with varying properties such as strength, machinability, and price. Metals such as steel or iron had the benefit of high strength, but would have been too expensive and difficult to machine, and resulted in the product being too heavy to easily use. Aluminum was less expensive and lighter, but the difficulty of welding or otherwise fastening aluminum pieces, in addition to the high cost, caused the team to remove it from consideration. It was decided that metal overall would be too expensive to be able to mass produce and too difficult to assemble for a product of our size specifications, especially considering the cost of skilled labor that a welder would incur.

The second material evaluated was plastic. Many types of plastic were considered such as polyethylene terephthalate (PETE), high-density polyethylene (HDPE), and polyvinyl chloride (PVC). Plastics would be easier to shape than metal, with more precise dimensions than wood. Using plastics would also result in a lighter final product. Considering that the wagon will be able to hold up to 60 lbs. at maximum capacity, the frame must be as light as possible to ensure the customer will be able to pull the wagon as easily as possible. While light and precisely formed, plastic was found to be expensive and would drive the price of the wagon much higher than originally planned. This dramatic price increase would not be feasible to put the wagon into production.

The third and final material that was evaluated was wood. The team compared hardwoods such as oak and softwoods such as pine. Although oak had superior strength and slightly better water resistance than pine, the team ultimately decided to move forward with pine. Pine was extremely easy to machine and assemble, relatively light, and if built correctly should meet the strength requirement to hold the full 60 lbs. of frames. It was also inexpensive, and more readily available nearby than any other type of wood. The main drawback for using pine was durability, with concerns that water absorption would cause the frame to quickly deteriorate. The wagon would be used outdoors, exposed to the weather, and would need to be washed off if honey spilt in it. Treated pine would be more durable to weather and outdoor conditions, but the chemicals used to treat the wood would make it unsafe to transport a food product for consumption. The team decided to use untreated wood, but coat it in a food-safe protective finish. This would meet the criteria for cost, machinability, weight, assembly, and strength.

3.2: Selection of Wood Finish

Next, we began to research different types of wood finishes that would most benefit our product. Our research was based on the criteria of curing time, weather resistance, and food safety. Tung oil, shellac, and polyurethane were the main three finishes we considered and compared. The costs of Tung oil, shellac, and polyurethane were similar, but polyurethane had superior water resistance and durability. All three finishes were food safe after completely curing. After looking into polyurethane more, however, we found a similar product, spar urethane. Sometimes used for marine applications, spar urethane had better water resistance than polyurethane and contained UV blockers to protect wood from the sun's deteriorating effects. Spar urethane had a similar price to polyurethane and was also food safe after completely curing, so the team decided to move forward with spar urethane, as our finish.

CHAPTER IV: PRODUCTION PLAN

After completing the final design, a manufacturing process was developed for mass production of the Apiary Wagon Frame. There are five operations in the production plan: cutting lumber, routing grooves, sanding, applying finish, and assembly. Six operators are needed for this process. One operator runs the routing and cutting stations, cutting lumber to length while the CNC sheet router is running. One operator runs the sanding station. The finishing station is run by two operators: one applies the first coat on sets of boards, and the other applies the second coat. The final two operators run the assembly station, which sets the pace for all the other stations with a cycle time of 20 minutes. Each operation has a cycle time of 20 minutes, for a total cycle time of 100 minutes, not counting the drying times after coats of spar urethane. In an 8-hour workday with two 15-minute breaks, a 15-minute prep time at the beginning of the day and a 15-minute cleanup time at the end of the day, there will be a 420 minutes of production time. With a cycle time of 20 minutes, we will produce 21 units per day.

4.1: Routing Operation

The routing operation is performed using an SR-100 CNC sheet router, four 19" long boards, and a jig to hold the four boards. As shown in Figure 15 below, the boards are placed into a jig (right) and banked utilizing another piece of lumber (left) on the CNC vacuum table, as shown in the figure below. Then the CNC routing program for the grooved pieces is run, which takes 12.8 minutes.

Figure 15: Routing Operation

4.2: Cutting Operation

One cycle of the cutting operation is performed during one cycle of the routing operation, while the operator is waiting for the CNC router to finish running. The cutting operation utilizes the SawStop table saw and four 1” x 4” x 8’ boards, which is the amount of lumber needed for one wagon. Table 1 lists the complete set of pieces to be cut from the 1” x 4” x 8’ boards.

Figure 16 shows how the 8’ boards are to be cut to produce the pieces listed in Table 1. In the figure, the red dotted lines are where the board should be cut with the table saw. The cut sections are organized in a way that minimizes waste, and allows for the stop on the saw to be moved only when necessary.

Table 2 on the next page lists the steps of the cutting and routing operations, showing how the cutting operation is performed during the wait time for the routing operation. After completing the steps listed in the table, the operator begins again from the top of the list.

Table 1: List of pieces required for cutting operation

Part	**Lumber**	**Part Size**	**Quantity**
Middle Pieces	1" x 4"	19"	4
End Supports	1" x 4"	19"	2
Side/Corner Supports	1" x 4"	11"	10
Side Supports	1" x 4"	39"	4

Table 2: Cutting/routing operation steps

Step	***Supplies/Machine***	***Activity***
1	1"x4"x8', Table Saw	Cut an 8' board into five 11" pieces and one 39" piece.
2	1"x4"x8', Table Saw	Repeat step 3
3	1"x4"x8', Table Saw	Cut an 8' board into three 19" pieces and one 39" piece
4	1"x4"x8', Table Saw	Repeat step 5
5	10x 11" pieces, 4x 39" pieces, 6x 19" pieces	Place boards on cart, return to CNC router
6	4x 19" Pieces, jig, board	Place 4 of the 19" pieces in the jig on the CNC router and begin the program
7	4x 1"x4"x8' boards	While the CNC program is running, bring four 8' boards to cutting station.

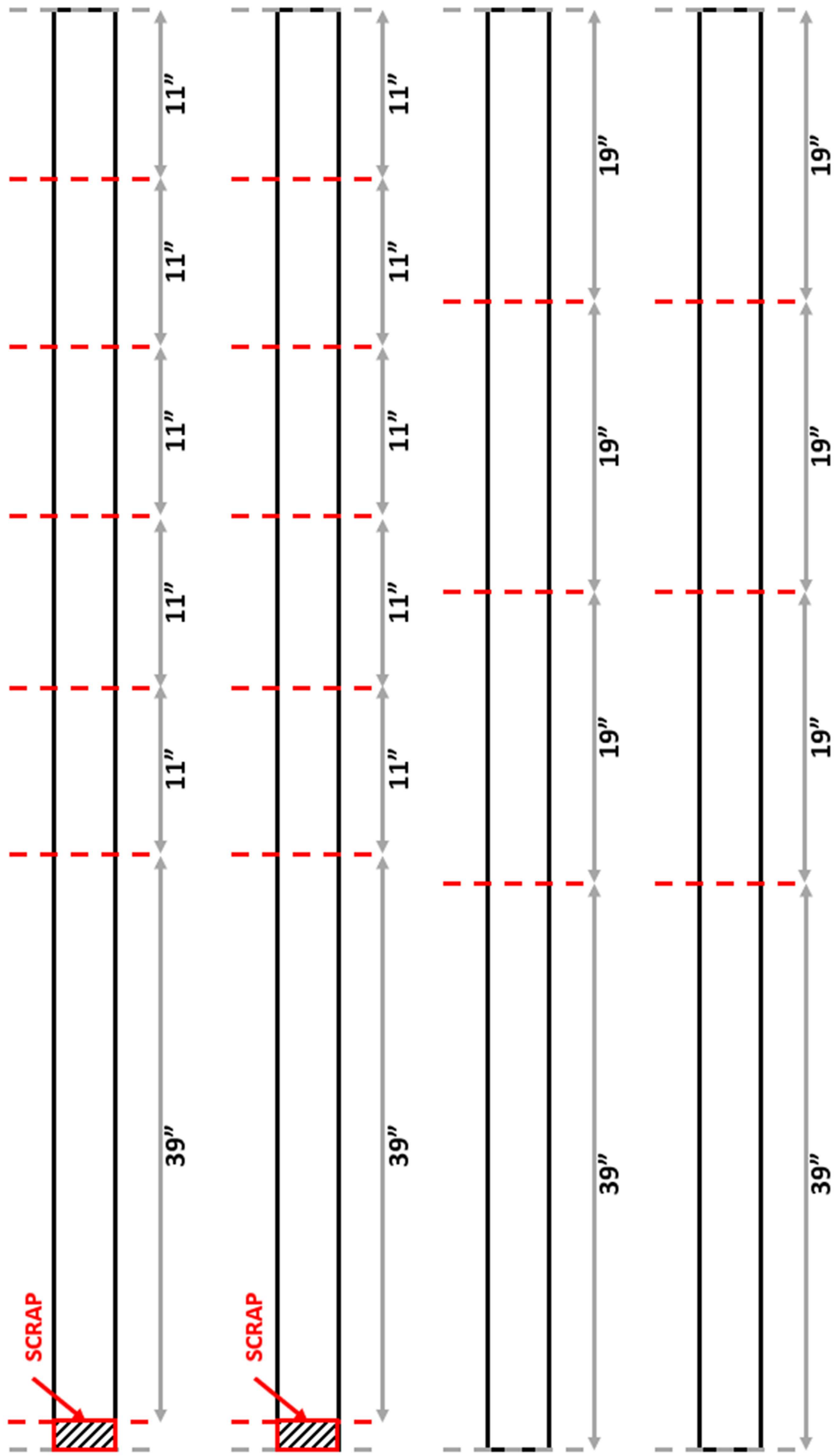

Figure 16: Cutting operation diagram

4.3: Sanding Operation

The sanding operator sands the grooved pieces are by hand and the flat pieces using a power sanding machine. A 150-grit sandpaper is used first, then each piece is sanded again using a 220-grit sandpaper. Table 3 outlines the steps for the sanding operation.

Table 3: Sanding operation steps

Step	***Supplies/Machine***	***Activity***
1	One complete set of cut/routed boards	Retrieve cart with cut and routed boards from CNC station
2	4 grooved pieces, 150-grit sandpaper	Sand by hand with 150-grit sandpaper
3	4 grooved pieces, 220-grit sandpaper	Sand by hand with 220-grit sandpaper
4	All other pieces, power sander	Sand all other pieces with 150-grit followed by 220-grit sandpaper
5	Shop towels	Wipe excess sandpaper off all boards
6	One complete set of boards	Place on cart and bring to finishing station

4.4: Finishing Operation

When sanding is complete for all pieces of one wagon, the set goes to the first finishing station, where the first layer of spar urethane will be applied. After the finish is applied, the pieces are placed on a mesh rack so that all sides can dry simultaneously. The set of boards for each wagon is placed together on its own shelf on the rack. While it dries, the set enters a queue of drying wagon sets. The cycle time for all operations is 20 minutes, so a set will enter and leave the first coat drying queue every twenty minutes, and it should take each set four hours to make it through the queue. If 12 wagons are ensured to be in the queue at all times, then a wagon set will be ready for a second coat of spar urethane every 20 minutes.

After receiving its second coat, a wagon set will enter an identical queue to dry for another four hours. There will also be 12 wagons in the second coat drying queue, which will ensure that a wagon set is completely dry and ready for assembly every 20 minutes.

<u>4.5: Assembly Operation</u>

The top of the wagon is assembled first, upside down with the supports facing up as shown in the figure below. A square jig or cradle will be used as a poka-yoke to ensure that the pieces are perfectly square. First, the 39” side boards and the four grooved pieces on the ends and middle are brad nailed together as a temporary hold. Then the corner supports are placed. Pilot holes are drilled into the corner supports and frame to guide placement and prevent cracking the boards, then screws inserted to permanently hold the frame together. Figure 17 below shows the top frame of the wagon with one corner support assembled. In the figure, the top surface of the wagon is on the table.

Figure 17: First corner support assembly

In the drawing on the left of Figure 18, a top view of the corner of the wagon and the corner supports is shown. First, two 1.5” screws fasten a support to the 39” side board on the frame, as shown by the red dotted arrows on the drawing. These screws do not require precise placement as long as they fasten the support to the side of the wagon as shown. The picture on the right shows the corner of the wagon for clarification. The two screws shown in the picture correspond to the two screws shown in the drawing.

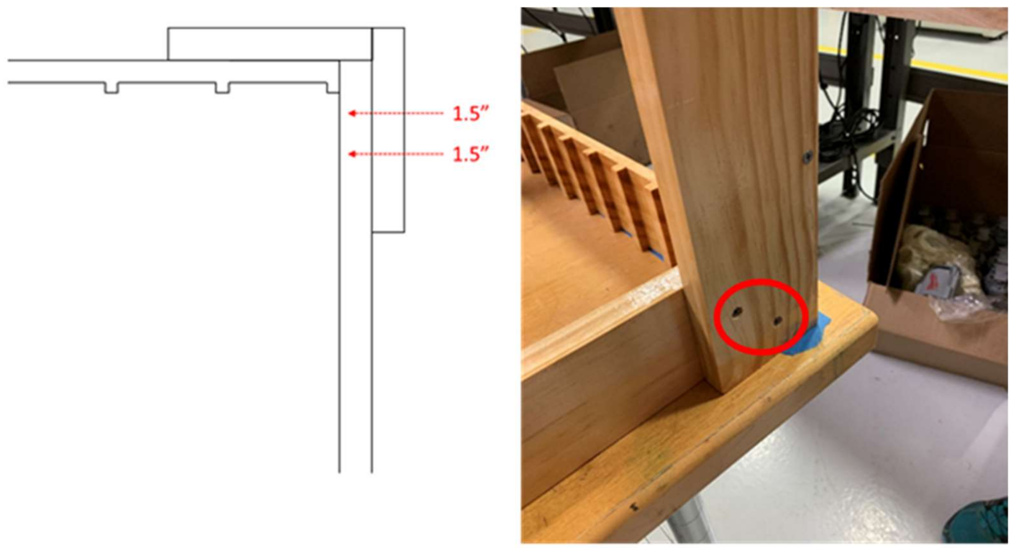

Figure 18: Corner assembly - 1

Next, two 1” screws fasten the grooved piece to the other corner support as shown in Figure 19. The two screws are approximately aligned vertically, their placement shown by the red dotted line in the drawing. Again, precise placement does not matter as long as the screws fasten the grooved piece to the support as shown. Note that when this step is repeated for the bottom of the wagon, 1.5” screws should be used to fasten the 19” front and back pieces because they have no grooves and are therefore thicker and require a longer screw to secure.

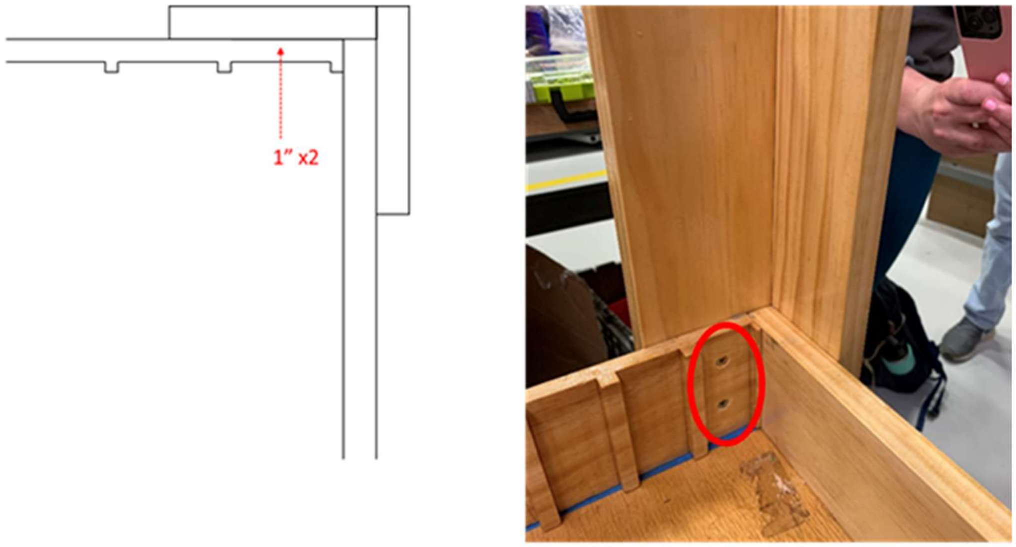

Figure 19: Corner assembly - 2

For the last step a 2" screw fastens the 39" piece to the support perpendicular to it, and the two supports to each other. Figure 20 shows the approximate placement of the two screws. To avoid interfering with the previously placed screws, the screw fastening the two supports together is placed above the 39" side board.

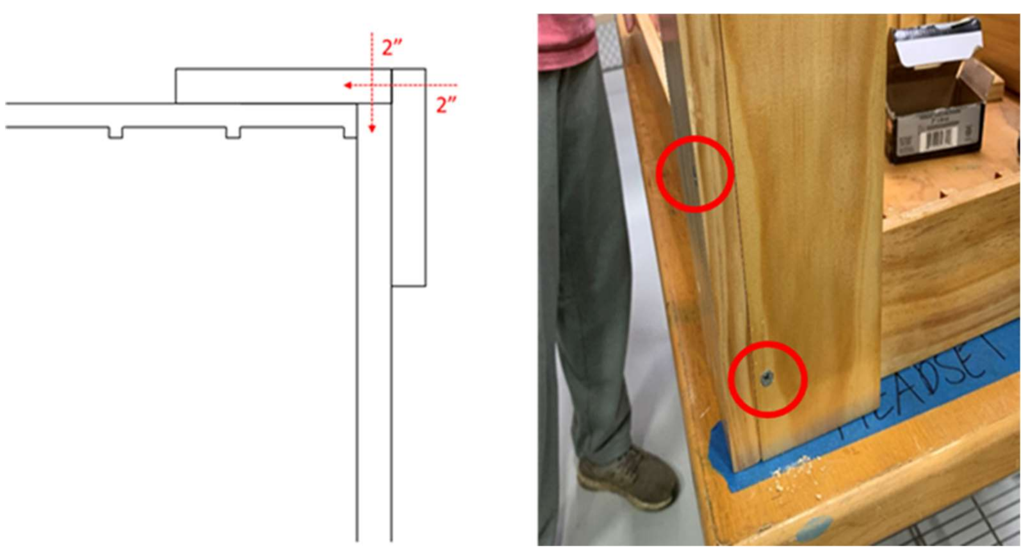

Figure 20: Corner assembly - 3

To ensure the pieces fit together properly, opposing corners of the frame are assembled first, then the other two corners. Once the side supports have been fastened to all four corners of the top frame, the two bottom 39” side boards and two 19” front and back boards are clamped to the corner supports as shown in the Figure 21.

Figure 21: Clamping for bottom frame assembly

The corners are then screwed together following the same steps as before, removing clamps as they become unnecessary. Finally, the two side supports are fastened to the middle of the sides and the grooved pieces using 1.5” screws, as shown in Figure 22 below.

Table 4 on the next page lists all the steps of the assembly operation. Brad nails are used first to temporarily hold the frame in place after it is squared, then the corner supports are fastened in as shown in Figure 18 through Figure 20. The top of the frame is assembled on the table first, then the bottom. Clamps are used to temporarily hold the bottom together before the corners are fastened to complete the assembly.

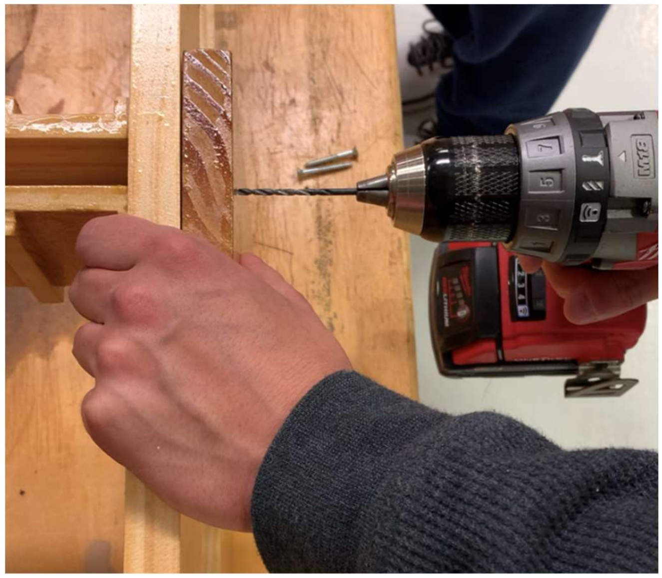

Figure 22: Drilling pilot holes for side supports

Table 4: Assembly operation steps

Step	***Supplies/Machine***	***Activity***
1	2x 39" pieces, 4x grooved pieces, brad gun	Square the pieces and brad-nail the top outer frame and the two middle grooved pieces together
2	2x 11" pieces	Place the corner supports against the frame as shown in Figure 17
3	2x 1.5" #8 screws, 2x 1" #8 screws, 2x 2" #8 screws, drill	Fasten the corner supports to the frame as shown in Figure 18-Figure 20, drilling pilot holes each time before screws are inserted.
4	3x (2x 1.5" #8 screws, 2x 1" #8 screws, 2x 2" #8 screws, drill)	Repeat step 2 for the opposite diagonal corner, then the other two corners
5	Clamp grips x6	Clamp the bottom frame to the top of the assembly as shown in Figure 21
6	4x (2x 1.5" #8 screws, 2x 1.5" #8 screws, 2x 2" #8 screws, drill)	Repeat step 2 for the four corners of the bottom frame, removing clamps as necessary
7	2x 11" pieces, 4x 1.5" #8 screws, drill	Fasten the side supports to the frame sides as shown in Figure 22
8	Complete frame	Place frame on cart, move cart to packing

4.5: Overview & Floor Layout

Figure 23 on the next page shows the layout for our theoretical manufacturing floor and the flow of the product from the beginning of operations to the end. An Apiary Wagon Frame begins the manufacturing process as a set of 1"x4"x8' boards, which are first cut to length in the cutting operation. The resulting set of boards is exactly the quantity needed to produce one unit, and that set will stay together throughout the entire manufacturing process. Next, the set moves to the routing operation, where grooves are machined into the four boards that will hold the hive frames, while the rest of the pieces wait on a nearby cart. Once the grooves are routed, the entire set goes to the sanding operation, where each piece is sanded with a medium grit sandpaper, then a finer grit. Next, the set goes to the first finishing station to get its first coat of spar urethane. It is then set aside in a queue to dry for four hours. It will reach the end of the queue after four hours and enter the second painting station to receive its second coat of spar urethane. It then enters a second queue to dry for another four hours. When it leaves this queue, it goes to the assembly process, where the pieces are assembled into a complete product.

Throughout the manufacturing process, the sets of pieces that make up a whole wagon will be transported together on a cart. In Figure 23, the locations of these carts during each operation is shown. The blue arrows shown the movement of the carts as they transport the product, showing how the product flows from one operation to the next, starting at lumber storage and ending in the packing area. After the finished product is taken off the cart in packing, that cart will return to lumber storage to receive another set of four 1"x4"x8' boards.

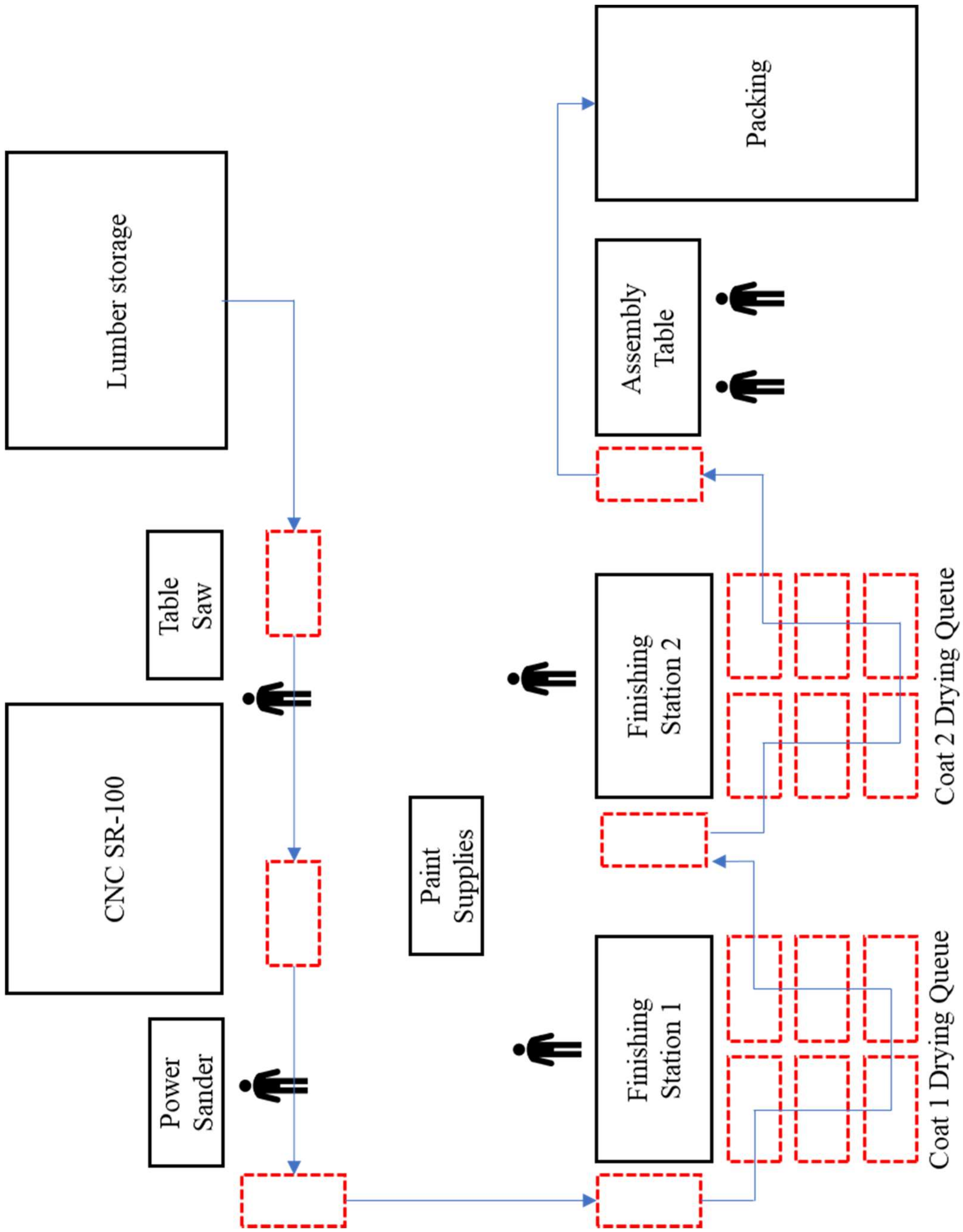

Figure 23: Flowchart of Manufacturing Process

CHAPTER V: COST ANALYSIS AND PROJECTED FINANCIAL

5.1: Materials Expense Report

Throughout the prototyping and production phases of the project, a record of purchased materials was kept in a Materials Expense Report shown in Table 5 to ensure that the project stayed within budget. This expense report also functioned as pricing list when it came time to determine the unit pricing for the materials used in the final product. Before our team could determine a selling price for our product, a thorough examination of the final production plan's cost structure was required.

The unit referred to in this chapter is the structure made to sit on top of a garden wagon, not the wagon base itself. Customers are intended to purchase the product to place on top of their own garden wagons. Therefore, a 'unit' or 'the product' refers to the wooden structure only, and does not include the cost of the garden wagon. The garden wagon purchased by the team was only used for the prototyping process and testing the product.

5.2: Unit Pricing

The first step in this examination was determining the unit pricing for a finished wagon frame. The team determined that there were three variable cost drivers and one fixed costs driver for the production of a wagon frame. The variable costs include the raw materials, labor, and machining time on a rented machine, whereas the single fixed cost is attributable to rent for a production warehouse.

5.2.1: Variable Costs

In Table 6, the raw materials required for one entirely assembled wagon frame are listed. The table also includes the exact number of each material and its unit price, which then gives the total cost of raw materials for a finished wagon frame.

Table 5: Materials Expense Report

Materials Expense Report	Units	Unit Price	Total Cost	
Beginning Cash Balance				$ 1,000.00
Expenses:				
Gorilla Cart	1	$ (119.00)	$ (119.00)	
2x4x8 boards	2	$ (4.44)	$ (8.88)	
#8 x 3" phillips screws	1	$ (8.97)	$ (8.97)	
1 in. x 4 in. x 8 ft. Select Pine Board	4	$ (12.33)	$ (49.32)	
#8 x 1 in. Coarse Zinc-Plated Phillips Wood Screws (50 per Pack)	1	$ (3.97)	$ (3.97)	
1 qt. Clear Gloss Oil-Based Exterior Spar Urethane	1	$ (17.48)	$ (17.48)	
1.5 in. Flat Cut Utility Paint Brush	4	$ (2.78)	$ (11.12)	
#8 x 1-1/2 in. Zinc Plated Phillips Flat Head Wood Screw (100-Pack)	1	$ (7.98)	$ (7.98)	
#8 x 2 in. Phillips Flat Head Zinc Plated Wood Screw (50-Pack)	1	$ (6.25)	$ (6.25)	
Rubber Bungee Cords with Hooks 9" (10 Pack)	1	$ (22.99)	$ (22.99)	
1-1/2 in. x 18-Gauge Galvanized Brad Nails (2000 per Box)	1	$ (11.68)	$ (11.68)	
7.5 in. x 10.25 in. x 5.5 in. Wall Mount Metal Basket	1	$ (10.64)	$ (10.64)	
3M Pro Grade Precision 9 in. x 11 in. 120 Grit (4-pack)	1	$ (4.97)	$ (4.97)	
Milwaukee 7/64 in. Cobalt Red Helix Twist Drill Bit	1	$ (2.97)	$ (2.97)	
Total Expenses				$ (286.22)
Ending Cash Balance				$ 713.78

*items in red were already owned by the CME; however, the team still felt inclined to account for these cost

Table 6: Variable Costs Table

Materials	Quantity	Units	Unit Price		Total Cost
1 in. x 4 in. x 8 ft. Select Pine Board	4	boards	$ 12.33		$ 49.32
#8 x 1 in. Coarse Zinc-Plated Phillips Wood Screws (50 per Pack)	10	screws	$ 0.08		$ 0.79
#8 x 2 in. Phillips Flat Head Zinc Plated Wood Screw (50-Pack)	28	screws	$ 0.08		$ 2.23
#8 x 1-1/2 in. Zinc Plated Phillips Flat Head Wood Screw (100-Pack)	16	screws	$ 0.06		$ 1.00
3M Pro Grade Precision 9 in. x 11 in. 120 Grit (4-pack)	1	paper	$ 1.24		$ 1.24
1.5 in. Flat Cut Utility Paint Brush *	1/3	brush	$ 0.93		$ 0.93
1 qt. Clear Gloss Oil-Based Exterior Spar Urethane **	1/2	quart	$ 8.74		$ 8.74
1-1/2 in. x 18-Gauge Galvanized Brad Nails (2000 per Box)	16	nails	$ 0.01		$ 0.09
Rubber Bungee Cords with Hooks 9" (10 Pack)	6	cords	$ 2.29		$ 13.74
7.5 in. x 10.25 in. x 5.5 in. Wall Mount Metal Basket	1	basket	$ 10.64		$ 10.64
Total					$ 88.72

*unit cost is based on the team's assumption that a single brush can be used for 3 wagon frames
** unit cost is based on the team's assumption that a single 1 qt can of urethane can cover 2 wagon frames

The production plan requires six production workers, one of which is a CNC operator and the other five being a production line worker for the sanding, painting, finishing and assembly portions of production. These workers will be paid an hourly wage, and our wages are based on Mississippi averages for CNC operators and production workers. [10] [11] Table 7 outlines the wages associated with each position and shift times, which gives Labor Cost per Day. Then the Labor Cost per Unit is found in the Table 8.

Table 7: Labor Cost per Day

Job Description	Hours/Day	Hourly Rate		Cost of Labor/Day
CNC Operator	8	$ 16.00		$ 128.00
Sander/Painter/Assembly	8	$ 12.50		$ 100.00
Sander/Painter/Assembly	8	$ 12.50		$ 100.00
Sander/Painter/Assembly	8	$ 12.50		$ 100.00
Sander/Painter/Assembly	8	$ 12.50		$ 100.00
Sander/Painter/Assembly	8	$ 12.50		$ 100.00
Total				$ 628.00

Table 8: Labor Cost per Unit

Cost of Labor/Day	# of units/Day		Cost of Labor/Unit
$ 128.00	21		$ 6.10
$ 100.00	21		$ 4.76
$ 100.00	21		$ 4.76
$ 100.00	21		$ 4.76
$ 100.00	21		$ 4.76
$ 100.00	21		$ 4.76
Total			$ 29.90

The final major cost driver is the cost of renting the HAAS SR 100 Vacuum CNC Mill, which is used at the beginning of the production process to mill the slots in pieces that hold the hive frames. This was the only piece of equipment the team decided to rent due to the large capital investment required to purchase the machine. Table 9 shows the run time required for a single wagon frame, 12 minutes 53 seconds, and with a rental price of $100 and hour the unit price for machine time comes out to $20.83.

Table 9: HAAS SR 100 Vacuum CNC Mill Running Costs

Machine	Time (hours)	Per hour Cost		Total Cost
HAAS SR 100 Vacuum CNC Mill	0.208	$ 100.00		$ 20.83
Total				$ 20.83

Adding up the variable costs calculated for materials in Table 6, labor in Table 8, and the machine rental in Table 9, the total variable unit cost is $139.47.

5.2.2: Fixed Costs

In determining a price for leasing a warehouse, the team decided to find an actual warehouse in Mississippi that was for rent and would fit our production needs. The building we decided on is located in McComb, MS and is 7,526 square feet. The monthly rent for this building is $1,499 which is $0.20 per square foot a month. Assuming we meet our production goal of 420 units a month this allocates $3.57 per unit to cover rent as seen in Table 10.

Table 10: Warehouse Cost per Unit

Cost per Month	# of units produced each month		Rent Cost allocated per unit
$ 1,499.00	420		$ 3.57
Total			$ 3.57

Table 11 below lists all the components of the variable and fixed costs per unit, which are summed to get the total cost per unit. The variable cost includes materials, labor, and machine rentals, which totals to $139.47. The only component of fixed cost was the warehouse rent, which was $3.57 per unit. Adding the fixed cost per unit of $3.57 to the variable unit cost of $139.47 gave us a unit price of $143.04 for a finished wagon frame. The team felt that a profit margin of

13.5% was reasonable and consistent with industry standards. To reach a profit margin of 13.5% the team set the selling price of the wagon frame at $162.50.

Table 11: Total Per Unit Costs

Per Unit Costs	
Variable costs:	
Materials	$ 88.73
Labor	$ 29.90
Machine Rental	$ 20.83
Fixed Costs:	
Warehouse Rent	$ 3.57
Total	$ 143.04

5.3: Capitalized Investments

As mentioned prior, the team decided to only rent the CNC machine due to its substantial cost. However, there are a number of other tools and machines needed for our production plan. It was the team's decision to capitalize these investments and depreciate them over their useful life. This depreciation expense was included in the operation expenses portion of the income statement. Table 12 lists the required tools and machinery along with estimated useful lives and yearly depreciation, for a total yearly depreciation cost of $996.43. [12]

Table 12: Cost and Depreciation of Utilized Machinery

Machinery/Tools	Cost	Est. Useful Life (years)		Depreciation Per Year
Original Saw - radial arm saw	$ 5,119.99	15		$ 341.33
Global Finishing Solutions – Industrial Fast Pak Finishing hood	$ 5,724.00	15		$ 381.60
Milwaukee M18 FUEL 1/2 in. Drill/Driver	$ 149.00	2		$ 74.50
Milwaukee M18 FUEL 18-Gauge Brad Nailer	$ 279.00	2		$ 139.50
Milwaukee M18 5 in. Random Orbit Sander	$ 119.00	2		$ 59.50
Total	$ 11,390.99			$ 996.43

5.4: Overhead Calculations

Online sources were used as a reference to estimate overhead costs for our production. The yearly utilities cost was found to be $16,671.60 by adding the estimated monthly cost of HVAC maintenance, electricity, and insurance [13], then multiplying by 12 months as shown in Table 13.

Table 13: Monthly & Yearly Utilities Overhead Cost

Utilities Cost per Month		
HVAC Maintenance	$	75.00
Electricity	$	1,254.30
Insurance	$	60.00
Total	$	1,389.30
Yearly Cost	$	16,671.60

The team determined that with a production crew of 6 people, one supervisor would be needed. Paying the supervisor $20 per hour results in a yearly indirect labor cost of $36,878 [13] as shown in Table 14.

Table 14: Yearly Indirect Labor Overhead Cost

Indirect Labor Cost per Year	
Supervisor in Mississippi	$36,878

Table 15 summarizes the overhead costs associated with maintenance of the machines. A formula was used to calculate the maintenance costs based on the purchase price of the machines [14]. By dividing the new cost of the machine by its expected life in hour and multiplying by 70%, we arrive at our estimated maintenance and repair costs per hour for our machines. The radial saw's new cost was divided by 31200 hours, the total amount work hours in 15 years. It was then multiplied by 70% to receive a $0.115 per hour maintenance cost. Multiplying that hourly maintenance cost with the 2080 hours in a work year, we arrive at a yearly maintenance cost of $238.93 for the radial saw. Similarly, with the finishing hood, we repeated the same calculations with its 15-year life span and its $5,724 purchase price. The cost of maintenance per year found for the finishing hood was calculated to be $267.12 per year.

Table 15: Yearly Machine Maintenance Overhead Cost

Machine	Cost	Est. Useful Life (years)	Cost of Maintenance per Year
Original Saw - radial arm saw	$ 5,119.99	15	$ 238.93
Global Finishing Solutions – Industrial Fast Pak Finishing hood	$ 5,724.00	15	$ 267.12

Table 16 summarizes the overhead costs for machine maintenance from Table 15, the utilities from Table 13, and the indirect labor from Table 14. Adding those costs results in a total yearly overhead cost of $54,055.65.

Table 16: Total Yearly Overhead Costs

Overhead Calculation Yearly	
Machine Maintenance Cost	$ 506.05
Utilities	$ 16,671.60
Wages	$ 36,878.00
Overhead Total	$ 54,055.65

5.5: Projected Financials

Table 17 shows the teams projected income statement for the first year of operation. The revenue was calculated by multiplying the 420 units produced each month by the sell price of $162.35 to get $68,250.00 in projected monthly sales, then multiplying by 12 months for a total yearly revenue of $819,000.00. Likewise, the variable cost per unit of $139.47, which is the total of the variable costs per unit for materials, labor, and machine rentals as calculated in section 5.2.1, is multiplied by 420 units per months and 12 months in a year for a yearly variable cost of $702,924.27. The monthly fixed cost of $1499, which is the rent for the warehouse as shown in Table 10, is multiplied by 12 months for a yearly fixed cost of $17,988.00. The sum of the yearly fixed and variable costs is the total cost of goods sold (COGS), which is $720,912.27. The COGS is subtracted from the revenues to get a gross profit of $98,087.73. Finally, the overhead cost of $54,055.65 and depreciation of $996.43 are subtracted from the gross profit for a net income of $43,035.65.

Table 17: Projected Income Statement for Year 1

Revenues		$ 819,000.00
Cost of Goods Sold		
Fixed Costs	$ (17,988.00)	
Variable Costs	$ (702,924.27)	
Total COGS:		$ (720,912.27)
Gross Profit		$ 98,087.73
Expenses		
Overhead Costs		$ (54,055.65)
Depreciation		$ (996.43)
Net Income		$ 43,035.65

CHAPTER VI: CONCLUSION

6.1: Future Work

The team identified several opportunities for improvement that could be implemented in the future. One improvement would be changing the process for cutting the grooved pieces to eliminate the use of a fixture. If we use an 1x8" board instead of a 1x4", it would have enough surface area contacting the cutting area that the vacuum could properly grip the board. After making this change, the new process for cutting the grooved pieces would be to cut the 1x8" boards into 19" long sections first, then cut the grooves in the CNC sheet router, and finally cut each board in half down the length into two 4" wide pieces. The two pieces would be a matching set, ensuring the frames placed in them would line up perfectly.

Another opportunity for improvement would be moving the side supports in the middle of the wagon to be placed between the two middle grooved pieces, which have a 1" gap between them. Screws would fasten the grooved pieces to the support between them and fasten the support to the side of the wagon. This would help align and properly space those pieces, as well as provide additional support for the 60 lbs. load.

6.2: Lessons Learned

Taking the Apiary Wagon Frame from an idea to a complete product with a manufacturing plan used all the knowledge and skills we acquired throughout our years at the Center for Manufacturing Excellence. Our Manufacturing Processes class helped us choose our materials and make design decisions. Our Product Realization class gave us an understanding of the equipment available on the CME shop floor, which helped us both prototype and choose the processes we could use for our final product. Our Continuous Flow/Layout class helped us design the layout for our theoretical manufacturing facility, and our Standardized Work/Cycle Time class taught us the calculations we used to create our single unit flow production plan.

One of the lessons we learned from this process was to reduce waste in product design. When a design has a high quantity of pieces and fasteners, it becomes more difficult to assemble, and the dimensional inaccuracy increases. When we restructured our design after the second prototype, we used a simpler design with less pieces, resulting in a more structurally sound, accurately assembled product.

We also learned the importance of continuous improvement in prototyping and field testing. The team often discovered improvements that needed to be made while building or after completing a prototype. These improvements would not have been possible to predict before attempting to build the prototype. Therefore, it is crucial to physically test design ideas and build prototypes as early on as possible. In order to refine our ideas, we first had to attempt to put them into practice.

Lean manufacturing played an important role in the design of our production plan, particularly in the use of single-unit flow. Due to the challenges of balance the times for the processes with the long drying times of the multiple coats of spar urethane, a batch and queue method was considered. However, once a cycle time was set, we were able to build a single unit flow system from it, which increased the number of wagons that could be shipped out in a day and, despite the increased headcount required, increased our profits significantly. Although it was initially more difficult to balance and calculate, our use of single unit flow showed us that the concepts of lean manufacturing work when they are put into action.

With the cumulation of knowledge obtained through our four years of studying with the CME, a final prototype to the Apiary Wagon Frame was produced and a theoretical manufacturing processes extrapolated for yearly production was created. The skills we developed through this capstone experience will continue benefit us after we graduate and begin our careers.

BIBLIOGRAPHY

[1] K. Alexandra-Maria, V. B. E, C. J. H, S.-D. Ingolf, C. S. A, K. Claire and T. Teja, "Importance of pollinators in changing landscapes for world crops," *Proceedings of the Royal Society,* vol. 274, no. 1608, pp. 303-313, 2007.

[2] F. Jabr, "The Mind-Boggling Math of Migratory Beekeeping," Scientific American, 1 Sept. 2013. [Online]. Available: https://www.scientificamerican.com/article/migratory-beekeeping-mind-boggling-math/. [Accessed 18 Mar. 2021].

[3] P. Neumann and N. L. Carreck, "Honey bee colony losses," *Journal of Apicultural Research,* vol. 49, no. 1, pp. 1-6, 2010.

[4] M. A. Aizen and L. D. Harder, "The Global Stock of Domesticated Honey Bees Is Growing Slower Than Agricultural Demand for Pollination," *Current Biology,* vol. 19, no. 11, pp. 915-918, 2009.

[5] Peace Corps Knowledge and Learning Unit, "Small Scale Beekeeping," EnCompass, LLC, Sept. 2014. [Online]. Available: https://pclive.peacecorps.gov/pclive/index.php/pclive-resources/resource-library/1852-m0017-small-scale-beekeeping-compressed/file. [Accessed 24 Mar. 2021].

[6] United States Agricultural Research Service, Beekeeping in the United States, University of Illinois at Urbana-Champaign: U.S. Government Printing Office, 1971.

[7] S. E. Tilmann, "Building a Beehive: The Frame," 2015. [Online]. Available: http://www.michiganbees.org/wp-content/uploads/2015/01/Frames_20140701.pdf. [Accessed 14 Feb 2021].

[8] R. Burlew, How much honey do bees need for winter?, Honey Bee Suite, 2014.

[9] Mann Lake, "Tools and Hardware," [Online]. Available: https://www.mannlakeltd.com/shop-all-categories/hive-colony-maintenance/tools-and-hardware. [Accessed 25 Mar. 2021].

[10] "Indeed," Indeed, 2021. [Online]. Available: https://www.indeed.com/career/cnc-operator/salaries . [Accessed 10 4 2021].

[11] "Indeed," Indeed, 2021. [Online]. Available: https://www.indeed.com/career/sander/salaries/MS?from=top_sb . [Accessed 10 4 2021].

[12] J. R. W. H. S. K. Page C. Faulk, "United States Consumer Product Safety Commission," 28 June 2006. [Online]. Available: https://www.cpsc.gov/s3fs-public/pdfs/blk_pdf_tablesaw.pdf. [Accessed 7 4 2021].

[13] Indeed, "Indeed," Indeed, 2021. [Online]. Available: https://www.indeed.com/career/supervisor/salaries/MS?from=top_sb. [Accessed 13 4 2021].

[14] I. Post, "Peterson Portable Sawmills," Petersons Global Sales Ltd., 2021. [Online]. [Accessed 13 4 2021].

[15] "Austin Tenant Advisors," Austin Tenant Advisors, 202. [Online]. Available: https://www.austintenantadvisors.com/blog/costs-involved-leasing-warehouse-space/. [Accessed 13 4 2021].