

Design and Production of a UM Photo Album

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Abstract

The following project attempted to design and manufacture a wooden photo album. The final product needed to fully satisfy customer demands as well as turn a profit. The development proceeded in two phases. The design phase sought to take the product from ideation to a fully viable final design for manufacturing. The manufacturing phase sought to create a production process that would both meet customer demands in an efficient and waste-free way. This would be accomplished by implementing principles of Project Management, Toyota Production System, and LEAN. The final product was successfully designed and produced to be a high-end oak photo album with leather and brass accenting.

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List of Abbreviations

DFM – Design for Manufacturing

PDG – Pensieve Design Group

TPS – Toyota Production System

PM – Project Management

DFA – Design for Assembly

CEO – Chief Executive Officer

PMBOK - Project Management Body of Knowledge

WBS – Work Breakdown Structure

PMP – Project Management Plan

NPV – Net Present Value

Chapter 1: Introduction

The concept of the million-dollar idea is one familiar to most modern people. A scheme, product, or new line of thought is described in detail, with the confidence that the notion could make a difference. Often, they become tired, worn out anecdotes relegated to the water cooler on a Tuesday afternoon or the living room at Thanksgiving. There seems to be some force separating these little lights from the raging fires that we see truly disrupt marketplaces. Is it the resources to actualize? Is it the will to produce? Is it simply the quality of the idea itself? The project at the focus of this paper will strive to bring just such an idea to life. The idea will be designed, improved, and manufactured to its full intention.

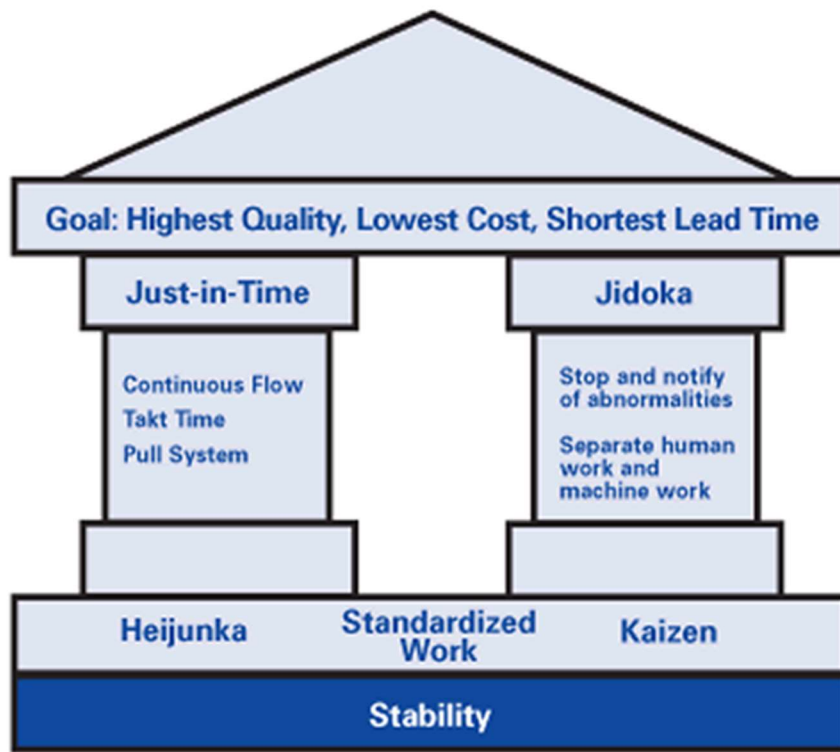
The challenge is a structured one. The realization of the idea must happen within a structured environment. The realization of the idea, or product hereafter, would occur in three main phases. Phase 1 would be an invention phase. Products would be pitched by each member of the Center for Manufacturing Excellence senior class. This totaled around 50 products. These pitches would include a preliminary design, target market, manufacturing processes, and costs. From these products, six products would be chosen for development and have teams formed around them. This would lead to the second phase, design. The design phase would include prototyping and development of the product's final design. This would be done using feedback from customers, mentors, and lessons learned from prototyping. Market surveys analyzing similar products will also be conducted. Accounting documents estimating production costs and overhead will be created in this

phase. These should naturally produce a preliminary sales price for the product. At the end of the design phase, the final product would be taken into the manufacturing phase. The manufacturing phase entails applying LEAN manufacturing principles to the production of the product. This will be accomplished via an iterative process involving several production trials and Takt time studies. Takt time will be explained at length in following sections. Quality assessments will also be an important piece of this portion of the project, with the output being a quality assurance plan.

The fruition of these three phases in combination should be a viable product that is both profitable and meets the customer's needs. The businesses built around these productions should be reasonably viable given the resources available during the duration of the project. The desired outcome for the students is to have gained a more real understanding of what goes into cradle to grave product development. These criteria being met, and product, business model, and team can be deemed successful.

Toyota Production System

Principles taken from the Toyota Production System were the foundation for many decisions made for the project. TPS was developed from initial concepts of, "Just-in-time production," developed by Sakichi Toyoda, Kiichiro Toyoda, and Taiichi Ohno. The system was developed between 1948 and 1975 [1]. A visualization of the Modern TPS can be seen in Figure 1 [2].



Toyota Production System "House."

Figure 1. TPS House

The house shows many principles that were implemented in the project to follow. The particularly important pieces were Kaizen, Standardized Work, Takt time, Continuous Flow, Machine Work vs Human Work, and Jidoka.

TPS emphasizes two main points. The first is Jidoka which emphasizes quality being built into the process [2]. One form this takes at Toyota is the ability for any member of the manufacturing team to stop the entire production line when defects are detected. This allows the problem causing the defect to be identified, isolated, and eliminated before it is

allowed to effect further products. It is estimated the cost of a defect for a company when it reaches the final customer vs when it is identified in production is about 10,000 times higher. Jidoka also allows the team members who are closest to the problem to have a great impact on solving it. Often solutions that come from the top of an organization can be disconnected with the reality of the problem at product level. This is one reason people also refer to TPS as “Thinking People System”. A second foundational principle in TPS, and one more visible in the project to follow, is the principle of “Just-in-Time” manufacturing. This means that each process should only have what is needed to produce what is needed. There should be no excess in any point of the process. This also manifests itself as an emphasis on only taking the minimum required amount of time to produce a quality piece at each point in the process. This principle would manifest itself in the project to follow as, “one-piece flow,” or simply focusing on moving one part at a time as opposed to a batch process where multiples of each part created by an operation are made at a time.

Another principle that is often associated with TPS, or Lean, is 5s. 5s is a system that helps insure quality in each process of production. 5s principles are illustrated in Figure 2 [3].



Figure 2. 5S circle

The first point of 5s is sort, which means each workstation should only have what is needed for that process. Straighten means each workstation should have all tools and materials stored in an orderly way with each item given a specific home to be taken from and returned to in the quickest and easiest way possible. Shine, sometimes also given as “sweep”, means that the station should be cleaned daily, or between shifts, and always kept tidy and organized. Standardize means a process is done the same way every time, regardless of the particular team member doing it or which line the process is on. Sustain means that all of these principles are kept in the forefront of all team members minds. 5s must be a culture just as much as it is a process. This method is proven to create and sustain quality in manufacturing.

These ideas, which each student/team member has been trained in, would be the base, upon which the product and production are designed and built. The success of each team would largely depend on how effectively these principles were applied.

Project Management Body of Knowledge

One position that was on each team was that of the Project Manager (PM). The role of the PM is to create clear and attainable project objectives, build project requirements, and balance the constraints of the project management triangle, pictured below in Figure 3 [4].



Figure 3. Project Management Triangle

The project management triangle illustrates the three main factors that must be balanced to retain quality in a project. For example, as the scope expands, there will need to be more time or resources allotted. If the cost must go down, the scope must shrink or there must be fewer resources allotted. This is a complex balancing act and is always the center of a PM's work. The PM will be enabled to successfully reach these goals via coursework in

Project Management. This coursework is primarily founded in the project management body of knowledge, or PMBOK. The PMBOK is produced by the Project Management institute was founded in 1961 with the goal of further maturing the project management profession, providing standards, providing professional developments for PMs, and offering certificates. In short, this organization has refined the most efficient stratagem for successful project management [5]. The PMBOK is the gold standard for project management and, “contains the fundamental practices that all project managers need to attain high standards for project excellence” [6]. There are many useful tools and strategies in the PMBOK that aid the PM in keeping things running smoothly and well documented through the life of a project. Examples of such tools are a risk register, project schedule, and work breakdown structure. The PMBOK would prove to be an invaluable resource for PMs throughout the capstone projects.

Chapter 2: The Team

One of the main advantages of the CME is the diversity of the students therein. Not only are at least 5 different areas of study represented, but the experiential backgrounds from student to student are often remarkably unique. Therefore, the team assembled around the product could expect to have spectrum of skillsets and perspectives. The team at the center of this report is just such a team. Six members made up the initial team. Peyton Adams was chosen to be the CEO of the venture. Peyton's background was in finance and included considerable amount of experience with woodworking and metalworking. Nick Brons also had a business background and some skillsets in material acquisition. Kelly Morris was one of two accountants on the team, and the original inventor of the product to be developed. Katie Whitman was the second accountant who had a considerable deal of experience with excel and cost tracking. Daniel Kennedy was one of two engineers on the team. He is pursuing a career in the medical field as a doctor. Finally, David Johnson is the second engineer who had a background in project management and Computer Aided Design (CAD). This team would come together around the product and leverage its strengths to produce a quality product within the given parameters.

To ensure that all problems and tasks were appropriately manned and accomplished, an effective org structure needed to be implemented. Because of the relatively small size of the team and large number of responsibilities and tasks, members of the team would all have to be, "dual hatted," so to speak. This would require each

member of the team to have both a lead and an operational role within the organizational structure, as is apparent in Figure 4.

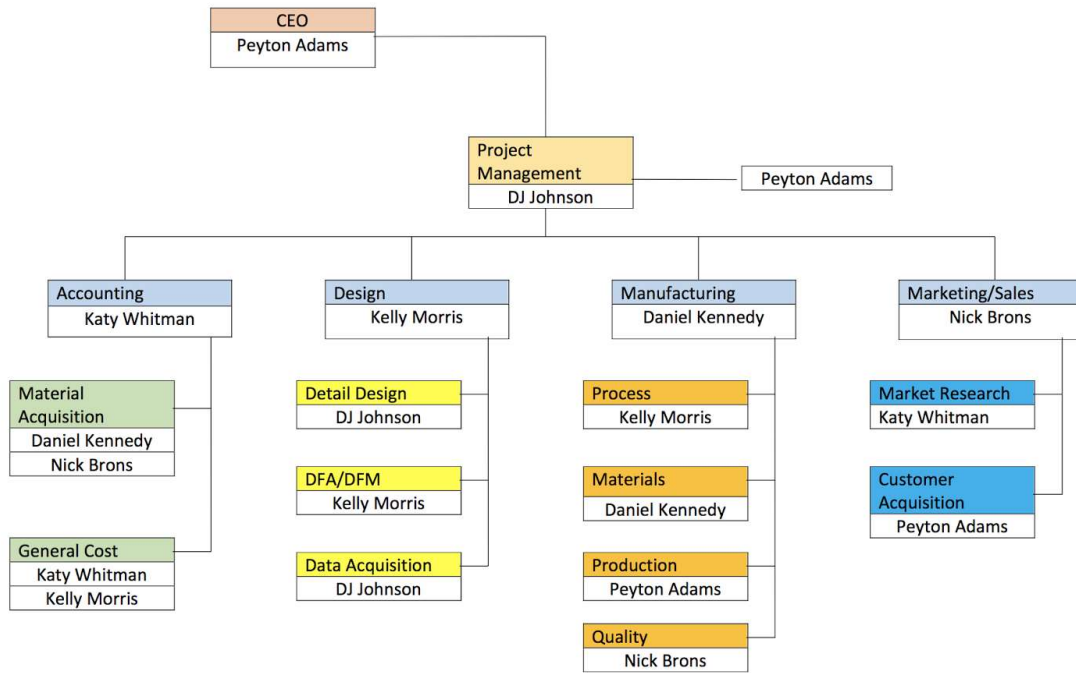


Figure 4. Organizational Structure Chart

The org structure hinges on 4 operational groups. The Accounting group would be responsible for all costing issues and determining things like selling price of the product. The design group would be responsible for the design of the product and documentation thereof. The Manufacturing group would have the role of planning and mapping the processes necessary for the fabrication of the product. This group would also govern material selection and quality control. Lastly the Marketing/Sales group would tackle the product pitch, value proposition, and would be the primary communication path with the customer.

The last thing that was needed to finalize the team was the creation of a name for the venture. While the product would retain its' originally pitched name, the team thought it necessary to create an organizational title. Pensieve Design Group (PDG) was chosen as the name, as a nod to the Harry Potter series. The pensieve was a glass bowl of water in which one could store memories to clear the mind and have them available for review later [7] [8]. This seemed to be an appropriately fantastic approximation of the product. With the team created and branded the design phase could begin.

Chapter 3: Design Phase

The design of the product was conducted using an iterative feedback loop. Designs would be made, feedback would be gathered, and designs were improved. A visualization of the flow can be seen in Figure 5.

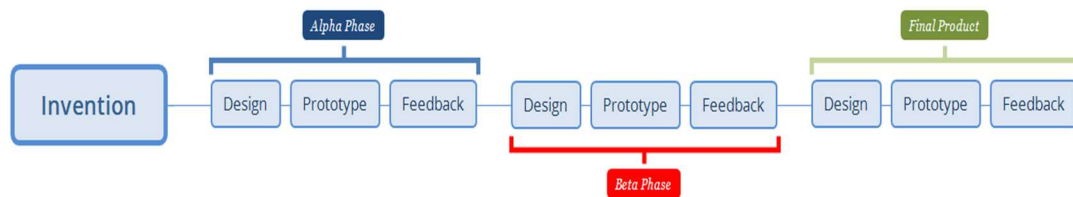


Figure 5. Design Process Flow

These iterations each produced a prototype. The prototypes allowed visualization of the design as well as allowing issues with the production process to be identified and mitigated. The initial design and prototype were provided by the inventor. This allowed the team a solid jumping off point from which to begin improving the design.

Project Management Plan

While there are many useful project management activities outlined in the PMBOK, only a few were selected to be implemented in this project. There were a few reasons not all the PMBOK tasks were implemented by the PM, the first being the rapid nature of the project. Because of the speed and agility at which the product needed to be developed, it was important to carefully select PM resources that would aid the team without slowing down

the development unnecessarily. Secondly, the team hierarchies were such that the project manager would have collateral duties beyond PM. This means that the way the PM duties were conducted had to change to accommodate other responsibilities. Lastly, the peer relationships would be somewhat of a hurdle. Though all members of PDG were dedicated to the success of the project, there were times where real authority was needed for the PM to properly motivate the team to buy in with certain PM strategies. For all these reasons, the PM decided that the best course of action, at least for the design phase, was to focus on three major PM documents all dealing with time management. The Work Breakdown Structure (WBS), Activity Sequencing Chart, and Schedule were the main PM tools implemented in the Design phase [8].

The WBS, which is pictured below in Figure 6, was created by having each group lead submit the expected activities to be accomplished by their respective groups during the design phase.

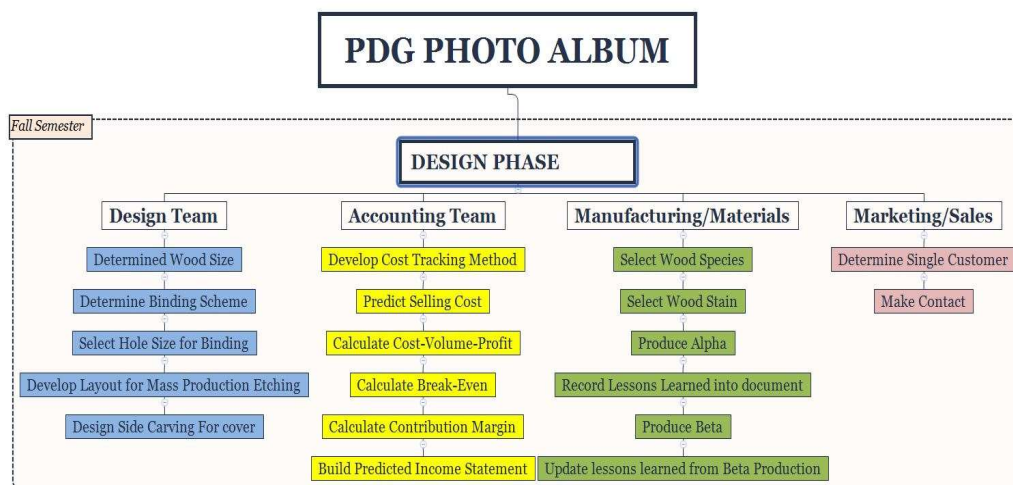


Figure 6. Work Breakdown Structure Design Phase

From there the individual activities were sequenced by creating a rudimentary flowchart showing which activities had to precede others as seen in Figure 7.

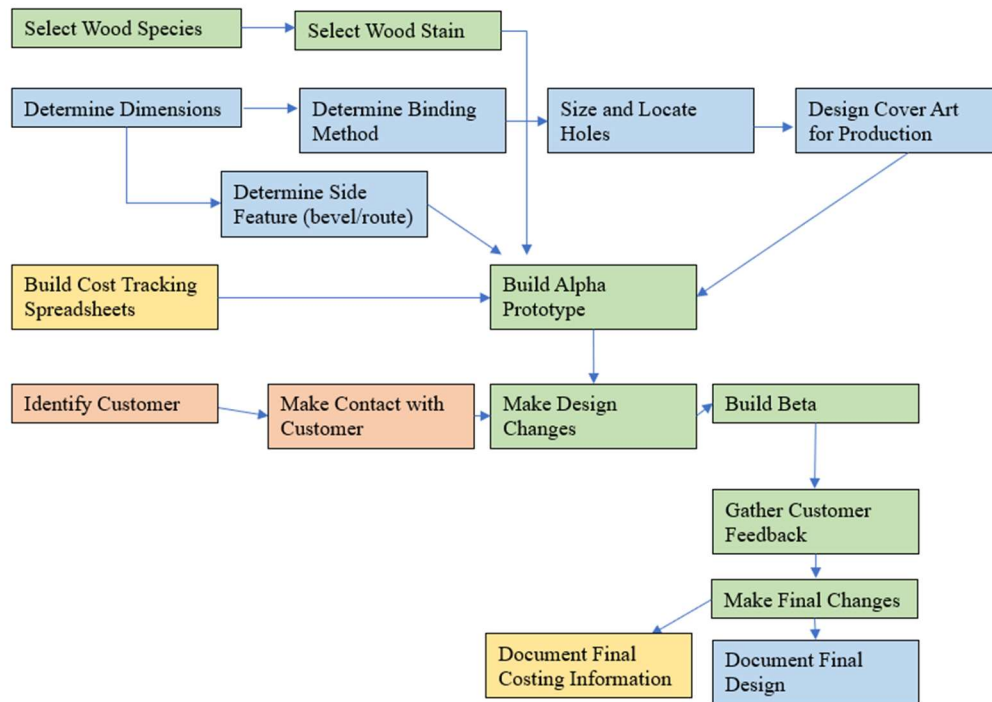


Figure 7. Process Sequencing

Lastly, the key dates for the project were analyzed. By creating milestones based off project due dates, the schedule began to take shape. The hard deadlines of the project allowed for a better allocation of time to each activity. This could be done using several different estimation methods mentioned in the PMBOK. This method was only used after milestones were established because of the existence of customer prescribed deadlines.

Invention

The original invention pitched was a wooden photo album. It was inspired by a craft project that had been made as a gift by the inventor. The photo album would consist of

two wood panels bound by 3 binder rings. These rings would also allow for photo sheets to be held in between the wooden panels. Figure 8 shows the original concept [9].



Figure 8. Initial Design Concept

Two of the suggested target markets would be University of Mississippi alumni or graduating seniors. These potential customers would be willing to pay for a product that reminds them of time spent at their alma mater and could serve as a talking piece in the home. The product would retain a hand-made feel due to the use of wood, as well as a natural, earthy look via the oak species. The choice of oak for the panel material also has sentimental ties to the University, whose oak grove is one of its crown jewels.

While information sources were not provided, some general unit cost estimations were given for costing. It was assumed that material and labor costs would combine to roughly \$8 per unit. Table 1 shows these costs [9].

Table 1. Invention Costing Estimates

| Material | Quantity | Cost |
|-------------|----------|---------|
| wood | 1 ft | \$ 4.54 |
| metal rings | 3 rings | \$ 1.80 |
| wood stain | 1/20 can | \$ 1.50 |
| | total | \$ 7.84 |

This is assuming 3 manufacturing associates at \$8/hr and a production rate of 20 units per hour. With these costs in mind, a preliminary selling price was set at \$16. This was justified by market survey suggesting similar products were being sold around the \$30 price point. This also allowed for some profit margin.

With the idea sound and vision clear, the prototyping would begin, and the product would begin to evolve. While the initial idea was solid, it is inevitable that the product would enter a period of evolution as the team around it begins to seek improvement.

Alpha Phase

The primary emphasis during alpha phase was material testing. These tests were performed to select an appropriate species of wood and wood stain for the product. Figure 9 shows some of the wood samples that were part of the initial test group. Four samples of each wood species were cut. Six different species/composites of wood were used, creating the six rows seen in the Figure 9. The columns show 3 stains and 1 control while the Rows show wood species.



Figure 9. Test Samples for Wood Stain

The results of these tests were analyzed by the team to select a suitable material and stain for the alpha prototype. One of the standouts from the material testing was redwood board. This departed from what the original inventor had in mind. As previously mentioned, oak board was the wood of choice for the pitch. The group decided that similar aesthetic results could be achieved with the redwood, however. The material seemed to be easily machined and had a beautiful color to it. When potential issues with supply were investigated, it became apparent that availability of the material would become an issue. A consistent supplier was unavailable. Due to the conflict with the original pitch and the supplier issues, the team was lead to shelf the wood species selection issue until further design choices

were made. This would allow stain and species testing to continue through the subsequent iterations of the design in Alpha and Beta Phase. Because it was believed that the customer desired a quality feel and build ahead of the grain pattern and stain, this allowed some freedom of schedule to the team. The initial prototype was produced from the $\frac{3}{4}$ " plywood and can be seen pictured below. Figure 10 shows the original invention next the alpha phase panels.



Figure 10. Alpha Panels Above Original Invention





The fabrication of the alpha brought a few important issues to light. The first major issue is that the rings must be kept within a certain diameter, and the wood kept around $\frac{1}{2}$ " thickness, in order to allow the product to open and close smoothly. Secondly, the design

utilizing the rings lacked a certain level of quality in aesthetics that the team desired from the product. After further market research, mostly consisting of price survey and similar product analysis, it was determined that implementing a leather spine might prove to be a cost-effective way to add value to the product.

Beta Phase

The team reached a cross-road for the product at Beta phase. At that point a discussion was had about what the product was really destined to be. As is often the case with this sort of idea, there were two paths that PDG could go down with the photo album. The group observed two different kinds of products that the customer would be willing to buy. High production volume and inexpensive was the first of these options. Continuing to hold near to the fairly simple initial design would allow the product to be manufactured simply and easily. The whole process could be reasonably boiled down to four or five operations. The selling price could also be kept around \$20 with a few minor changes to the design. This sort of product would offer more of a trinket appeal. It would act as an inexpensive reminder of the university that could be lost or discard without much loss. The second route PDG investigated, was to produce for higher end. The idea of the photo album as a treasure chest filled with memories was put on the table. The customer would be purchasing an object that would be intrinsically tied to the memories of their time at Ole Miss. It would be a durable, well built, carefully designed and manufactured product that is meant to hold great emotional value. Preliminary market surveys were performed to investigate acceptable pricing. Table 2 summarizes initial findings [10] [11] [12] [13].

Table 2. Market Survey

| Market Survey | | | |
|--|--|----------|------------------------|
| Product | Image | Price | Supplier |
| No. 96 Rustic Handmade 4x6 Leather Photo Album |  | \$ 42.00 | Amazon |
| Wooden Photobook/ Wedding Guestbook |  | \$ 57.00 | Etsy |
| Monogram Photo Album/ Rustic Guestbook |  | \$ 55.00 | Etsy |
| Hunting Memories Photo Album |  | \$ 69.95 | Whitetail Woodcrafters |

In various forms, customers are willing to pay \$40-70 for a high-quality photo album or scrapbook. With this in mind, drawings were made with ideas for how to raise the quality of the product, while keeping cost under \$30/unit.

The main quality adding feature that would become part of the design was a leather binding. The use of leather to hold the front and back panels together would create a more solid feel to the photo album as well as adding a rustic feel to the product. The leather could hide the metal rings when viewed from the outside. It was also suggested that the same leather could be used to make a clasp or snap to hold the book shut. This furthered the product vision of the album being a place to keep safe treasured memories. Initial quotes from suppliers for leather showed that the cost per unit would be

workable. This required a new scheme for the attachment of the photo paper to the photo album. The best idea put forward was a three-ring binding system found in common binders being mounted into the leather backing. Background research showed that these mechanisms were typically riveted into the backing. A supplier survey showed that the mechanisms could be purchased in brass for around \$1.25/unit. They could also be attached by simply riveting them to the leather using commonly available rivets and rivet press. Results from initial riveting tests are pictured in Figures 11 and 12.



Figure 11. Leather Riveting Tests 1



Figure 12. Leather Riveting Tests 2

The brass rivet used in test 2 complemented the wood well and therefore was selected for use in the detailed design. The last piece of the puzzle was binding the new leather backing

to the wood. After consulting woodworking forums and a few craft-making websites, it became obvious that simply using wood glue for the leather-wood interface should suffice. It was noted that this may result in a somewhat naked looking attachment point. Brass tacks were added to the material order with the idea of adding character to the interface. Materials were ordered in order to prototype the new binding scheme. When initial tests for ease of binding were favorable, the new binding scheme was implemented in the design. Another key point was the shift of material to a birch plank. This gave a cleaner and more finished look than the plywood that was used in the alpha prototype. The wood, when stained with “natural” color, also drew a sharp contrast with the darker leather. The design team found this desirable and believed it would appeal to the customer. The Beta Prototype 1 is pictured below in Figure 13.



Figure 13. Beta Prototype 1

Direct contact was made with an assigned customer at this point. The customer was the University of Mississippi Special Events Committee. They often host donors, keynote speakers, and prestigious alumni, to whom they give university specific gifts. These gifts range from Ole Miss lapel pins costing around \$2 to leather messenger bags with an embossed lyceum logo at \$300. They expressed interest in the wooden photo album as a gift for returning young alumni. The Beta 1 iteration was presented to the customer. The customer gave three important pieces of feedback. First, they preferred that the binding and wood-leather interface stand out less. Second, they would like to see a feature that would convey to the customer that this product was part of a senior capstone design. Finally, they preferred a darker stain to be used on the wood. These changes were implemented into what was referred to as the “Beta 2”. The first and most obvious improvement was the use of oak wood. The oak gave beautiful grain lines in combination with the selected stain. The oak also added special significance to the University. One of the University of Mississippi’s crown jewels is its large oak grove in the center of campus. The stain used on the oak wood was Minwax “Honey” stain. This, applied in 2 coats, gave the wood a rich dark brown color and caused the grain lines to pop. Beta 2 can be seen in Figures 14, 15, and 16 below.



Figure 14. Beta Prototype 2 Front



Figure 15. Beta Prototype 2 Side



Figure 16. Beta Prototype Inside (top) and CME Logo (bottom)

While the Beta 2 was much closer to the customer requirements, the design still needed some tweaking to create a final product. The leather on the Beta 2 was not centered and overlapped the routed edges of the wood. This is pictured in Figure 17.



Figure 17. Leather Overlap

The team decided to reduce the leather length to 11” to allow the leather to sit between the rounds. The binding rings on the Beta 2 were painted gold instead of being actual brass pieces. A supplier was found that could provide the brass rings at a reasonable per unit price. Lastly, the tack and screw placement were affected by the hardness of the new oak wood. This was addressed by adding a hole-punch process. A steel punch was used with a mallet to create pilot holes in the wood for the tacks and the screw to allow better seating. These solutions all provided great results and allowed the final product to be made efficiently and with great quality.

Final Product

The final version of the wooden photo album was reached after an arduous, iterative design process. Material, design, and manufacturing challenges all lead to important

lessons learned that allowed the design to be more informed and more robust. These final designs were used to create one last prototype as a presentation piece for the customer and CME faculty/staff. The details of this final product that would be taken into the production phase follow. Images of the final version of the Wooden Photo Album are in Figures 18, 19, and 20.



Figure 18. Final Product Front



Figure 19. Final Product Side



Figure 20. Final Product Inside View

Material

The final materials list was determined from the lessons learned during the design phase. The main components were the wood, leather, and binding mechanisms, with various attachment pieces needed for assembly. The materials are listed in the Bill of Materials, Table 3.

Table 3. Bill of Materials

| Bill of Materials | | |
|-------------------------------|--------------------|----------------|
| Item | Quantity per Unit | Cost/unit (\$) |
| 1" x 12" oak board | 24" | \$ 15.71 |
| Leather | 1/25 of order size | \$ 7.20 |
| Brass Snaps | 1 set | \$ 0.65 |
| #2 1/4 in brass plated screws | 1 screw | \$ 0.29 |
| Brass Tacks | 7 tacks | \$ 0.15 |
| Wood Glue | .5 oz | \$ 0.06 |
| Early American Stain | 3.2 oz | \$ 1.29 |
| Rivets | 2 rivets | \$ 0.12 |
| Total | | \$ 25.47 |

The items listed in the bill of materials provided a total material cost of \$25.47 including shipping costs. The cost for the wood includes a 15% scrap rate on boards. The largest material costs were from the leather and the wood. Two material changes were made from previous designs. First, the wood dimensions were changed, which will be discussed in the following portion titled, "Design." The second change was from Honey wood stain to Early American stain by Verathane. This provided a faster drying time with a similar aesthetic. The honey stain was taking over 12 hours to cure and was therefore deemed not feasible for production.

Design

A design change was made for manufacturing purposes (DFM). The availability of wood dictated that wood panels of dimensions 11 ¼” x 11 ½” would be more cost effective. Standard sizes of the Oak were 1” x 12” and 1” x 10”. Because the 1” x 10” would not be wide enough to allow the grain to be oriented vertically, the 1” x 12” was selected. If a 1” x 11” were readily available, this may have been a better choice, however it was not. Also, because standard wood sizes allot for a loss of a quarter inch at under 9” lengths and three quarters of an inch at over 9” lengths, the board’s true cross section would be ¾” x 11 ¼”

The change did not have a major impact on the quality or value of the product and was therefore adopted into the final design. This change allowed the removal of a process which would lower process time during production trials. The panels would retain a .25” round across the three edges not interfacing with the leather. The leather binding was sized at 5” x 11” with the binding mechanism riveted down the center. Wood glue and 3 brass tacks per panel would be implemented to attach the leather to the front and back panels. The leather strap that snaps the photo album closed is of dimensions 1” x 5”. The female portion of the snap would be riveted .5” from one end of the strip along the center line, while the other end would be attached to the rear panel with a brass tack and wood glue. Drawings of manufactured pieces can be found in Appendix A.

Process

The final processes used to build the prototypes could be reduced into three categories: woodworking, leatherworking, and assembly. A summary is given in Table 4. Tasks listed with the process # in blue are considered woodworking tasks. Tasks in yellow are leatherworking tasks. Tasks in green are assembly tasks.

Table 4. Process List

| Wooden Photo Album Processes | | | |
|------------------------------|-------------------------|--|---|
| Process # | Title | Description | Equipment |
| 1 | Plane Boards | 54" red oak boards will be planed down from ~.75" to ~.5" with +-.05" tolerance | Planer |
| 2 | Cross Cut Boards | cut panels from boards with 11.5" cuts | Table Saw |
| 3 | Route Panels | route 1/4" round on 3 panel edges for 2 panels | Table Router |
| 4 | Laser Etch Panels | etch cme and UM logos into front panel | Laser Etcher |
| 5 | Sand Panels | sand both panels with 180 grit sandpaper | Festool hand Sander Dust collection rig sand/stain table |
| 6 | Stain Panels | apply poly stain combo to panels | Small Fan Staining jig sand/stain table |
| 7 | Cut Leather Strips | cut and hole punch 11"x5" and 1"x5" strips from leather | rotary leather cutter twist punch leather templates sand/stain table |
| 8 | Rivet binder to leather | attach 3 ring binding clips to large leather piece | Rivet Press leatherworking table leather scribe |
| 9 | Rivet snap to leather | attach female snap interface to small leather strip | Rivet Press leatherworking table |
| 10 | Attach snap to board | attach male snap interface to front panel | Assembly Table Glue Jig cordless drill |
| 11 | Assemble and glue | glue large leather piece to front and back panels, small leather piece to back panel, and place 7 brace tacks through the leather into panel | Assembly Table Glue Jig |

The woodworking began with planing the 1"x12" boards down to ½". They were typically ¾" to begin. This was done with a planer. They were then cut into 11 ½" lengths; two per unit. This was done with the table saw. The panels were then given a ¼" round on three sides using a routing table. At this point the front panel was laser etched on the outside and inside cover. Once the wood was etched, it was sanded using a hand sander and stained. The leatherworking processes began with cutting the leather binder strip and snap strip from the uncut leather piece. Holes for riveting were placed in the leather strips using a rotating punch. The binder was riveted to the binding strip and the snap to the snap strip using rivets and an arbor press. The final assembly began with running a bead of glue ¼" from the edge of each side of the leather binding strip. The strip is then placed on the panels to bind them. The snap strip is glued to the back panel at this point. From here, a scratch awl was used to create pilot holes through the leather for the tacks and one into the bare front panel for screwing in the male portion of the snap. The tacks were placed using a rubber mallet. The male end of the snap was screwed in with a hand drill and Philips head attachment.

Costing

As cost was a major consideration during every design change, it is important to have the necessary metrics to evaluate the project value and profitability. The first evaluation was cost/unit based off of the bill of materials. This can be found in the preceding Materials portion. The next step was to evaluate machine cost and determine whether to rent or buy the machines. The tipping point for Renting machinery vs buying machinery was evaluated by production volume in Figure 21.

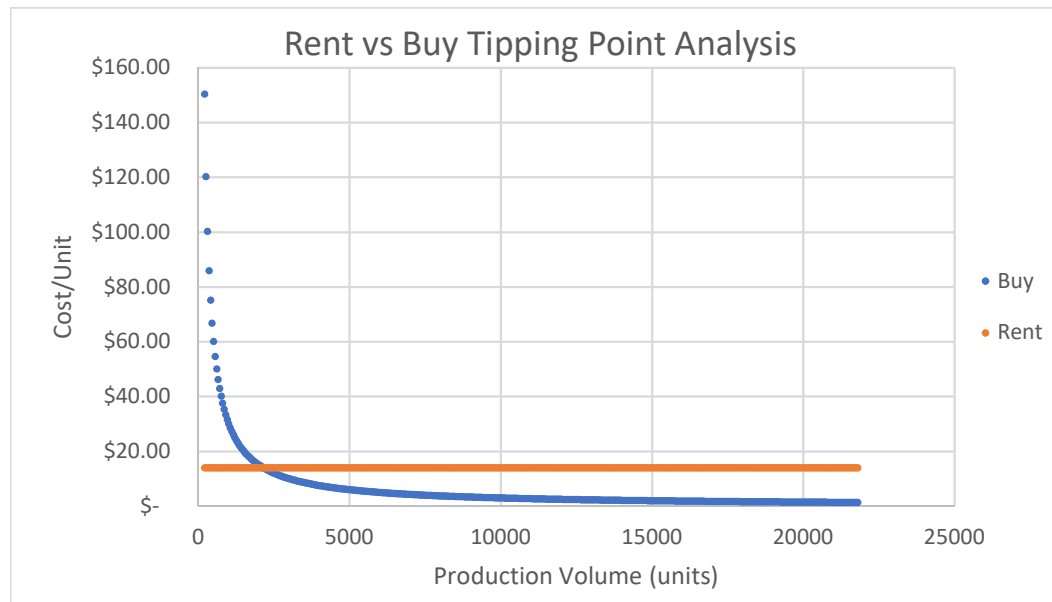


Figure 21. Rent vs Buy Tipping Point Analysis

The above analysis was performed based off of two key assumptions. A salvage value of \$0 was assigned. It also assumes that machine times used to calculate rent remain constant. An analysis could possibly be done using an assumed learning curve. The tipping point is located at a production volume of 2553 units. Assuming a production rate of 10 units/hr, this would take 32 days of production time. At this volume, the cost of machine depreciation per unit is \$13.99 and the rent per unit is \$14. The next figure shows the final cost analysis based around this tipping point. The team would expect to reach greater profit margins at higher volumes buying the machinery and have a standard profit margin per unit at lower production volumes based on renting machines. Table 5 shows the costs assuming machines were rented.

Table 5. Cost Per Unit at End of Design Phase

| Costs (Rent) | |
|---------------------|----------|
| BoM Cost | \$ 25.47 |
| Other Material Cost | \$ 0.20 |
| Machine Rent | \$ 14.00 |
| Labor | \$ 2.18 |
| Labor Overhead | \$ 0.87 |
| Sell Price | \$ 45.00 |
| Income/unit | \$ 2.28 |

The above calculations include a few new numbers. The Other Material Cost refers to cost per unit of gloves and masks needed for manufacturing associates in production. The Labor is based on \$7.25/hr minimum wage and 3 associates creating photo albums at a 6 minutes/unit pace. The fixed costs were assessed as 40% of labor. The final sell price chosen was \$45 based on prices of similar products. This only leaves a modest profit margin of less than 10%. For this reason, a long-term model would be applied in the manufacturing phase.

Chapter 4: Manufacturing Phase

The manufacturing phase is where the product truly comes to life. People can design, modify, and prototype ideas in their garage without every getting serious about production, leaving their million-dollar idea as nothing more than the aforementioned water cooler pitch with co-workers. When the focus shifts to how this product can actually be produced, however, the value truly comes to light. Production may bring forward tiny aspects of the product that could be overlooked during the design phase as well as obstacles in the architecture that could complicate mass production. The choice of sacrificing quality or resizing dimensions for the sake of manufacturability is certainly a difficult one. Is it really worth increasing the width by a couple inches so that the raw material better suits the equipment? Will changing the color reduce wasted time and increase our efficiency? These challenges are nearly impossible to detect during the design phase because of the limited capabilities of machines and unforeseen complications during production.

Design for Manufacture (DFM) is an important quality of a product that can lead to this million-dollar idea coming to life, or if neglected can lead to failure. The first objective for the manufacturing phase of the creation of the Wooden Photo Album was to identify any design flaws or possible improvements to the product by means of the DFM (design for manufacture) principle. The next goal was to create an effective process layout to make production as cost efficient as possible by means of the 5S principles. Lastly, the team wanted to make a profit off of the sale of our product after all costs have been

considered by analyzing the costs associated with the processes and materials required and set the selling price at a profitable point that consumers would deem appropriate.

Design for Manufacture is a comprehensive approach to integrating the design process with production methods, materials, process planning, assembly, testing, and quality assurance. Figure 22 [14] shows how simple changes in the design of certain pieces can increase the manufacturability of the product and cut down on problems that could possibly occur.

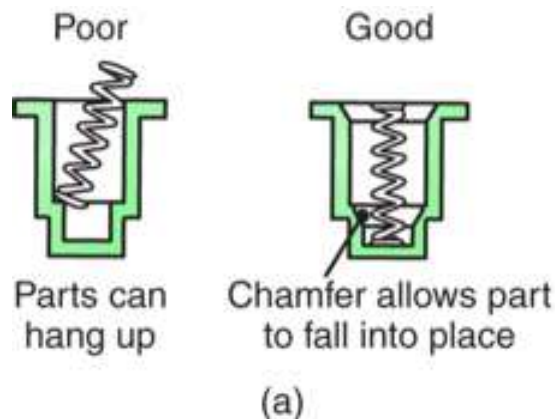


Figure 22. DFA examples

DFM can reduce total costs of production because this way of thinking leads to less wasted time, more efficient use of materials, and standardized work so that any process can easily be replicated by anyone without much special training.

PDG did its best to consider all elements of the photo album in relation to how to machine the separate pieces and still ran into unanticipated restrictions. One good example of PDG's efforts to align with good DFM practices is the problem with the photo album pages. The photo pages that are used to hold the pictures inside the book did not fit into the original design because during the closing of the book the binder rings would reorient so

that the pages would hang out the side of the book. This made the original raw material wood board, 1" x 10", too small to fit the pages, as pictured in Figure 23.



Figure 23. Photo Sheet Overhang issue

PDG now had the choice to either cut the photo pages to fit into the original design or reconsider the dimensions. The team decided to size up the board, and therefore the width of the photo album so that the photo pages would fit correctly. This was the best

choice because the alternative would have added another step in the process, which is against DFM principles. Also, by sizing up the board the team was able to keep the grains of the wood vertical with respect to the photo album orientation, which is an important aspect of the design because vertical grain pattern was deemed to be more aesthetically pleasing than a horizontal grain pattern.

An important tool during the manufacturing phase was the process layout. A process layout gives an aerial view above the manufacturing floor, showing the way the machines used in production are laid out in space with scaled dimensions. This was a useful tool because it helps in determining worker placement, orientation and placement of machines in space, eliminating bottlenecks, and organizing a product flow. A good process layout minimizes worker movement by having the machines orientated in such a way that the space is used as efficiently as possible. A simple example of a process layout for a generic manufacturing floor may look like is shown in Figure 24 [15]. This layout shows the basic “U” shape that is often encouraged, but things get more complicated as process layouts get more specific because there can exist restrictions on ways the machines can be arranged due to machine size or safety restrictions; likewise, a different shape may be more efficient due to different machines having longer run time or in the way other pieces come to join in the process. This is what makes creating a process layout complicated.

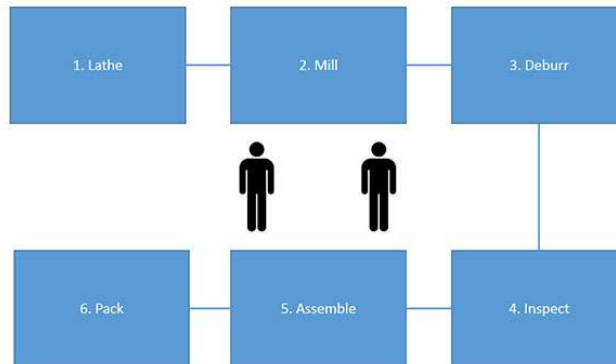


Figure 24. Ideal Product Flow

When creating a process layout one must consider factors such as the order in which operations happen to a certain material in process, what material is being worked on, where that material is added to the product in process, how long the operation takes, and any safety issues or requirements for that step in the process (such as a paint spray being in a well vented environment away from other process so that the paint doesn't get where it isn't meant to be). The goal was to create the most efficient use of space in an effort to make a manufacturing floor layout that meets takt time and reduces lead time.

Takt time is the maximum amount of time in which a product needs to be produced in order to satisfy customer demand and is often measured by taking the available time in that facilities work day, excluding any breaks, and dividing that by how many products are needed. The formula for takt time is shown in Equation 1.

$$\text{Takt Time} = \frac{\text{Available Time to Produce Product}}{\text{Customer Demand}}$$

Equation 1. Takt Time Equation

Keeping track of the takt time is helpful when trying to synchronize the rate of production with the rate of demand. The word “takt” is a German word meaning “pulse” or “beat”, so it makes sense to think of takt time as the beat that the manufacturing team needs to follow to be on schedule [16]. It was determined that the team had two hours of available work time, and the goal was produce ten photo albums in one hour. Thus, the team’s takt time can be calculated as shown in Equation 2.

$$\text{Takt Time} = \frac{\text{AT}}{\text{CD}} = \frac{120 \text{ mins}}{20 \text{ products}} = 6 \frac{\text{mins}}{\text{product}}$$

AT = Available time to produce product
CD = Customer demand

Equation 2. Takt Time Sample Calculation

Lead time, in the case of the Wooden Photo Album, was the time between the initiation and completion of the process. A process layout helped to improve lead time by eliminating waste using principles of 5S. 5S is a useful organizational principle in lean manufacturing

that comes from five Japanese words that translate in English to “Sort, Straighten, Shine, Standardize, Sustain”. The process layout really became useful when addressing the “Straighten” aspect of 5S because it helped to organize the machines with a focus on the frequency with which it is being used and the path the worker takes when getting to and operating the machine. This reduced extra motion and unnecessary transportation, which are common wastes in manufacturing.

Other factors that affected the layout of the process include the material being worked on, when that material is added to the product in process, and cycle time. Cycle time was the time spent at each stage of the process. Although a process layout cannot change how long each step in the process takes, it helped to arrange the machines in a way that minimized the time wasted when standing still waiting for a machine to finish its operation. The total lead time for manual processes was calculated to be 1087 seconds, or 18.11 minutes. This time was determined to be high due to lack of practice and an assumed learning curve. The team estimated it could reduce 18.11 minutes down to 16.8 minutes if given the chance to practice the process. Using the calculated takt time and the recorded lead time, a theoretical number of workers can be calculated. The calculation for theoretical number of workers is shown below in Equation 3. Assuming no wasted time, takt time can be used as the time per worker, being 6 minutes per worker.

$$\text{Workers}_{\text{theoretical}} = \frac{\text{Time}_{\text{manual}}}{\text{Time}_{\text{worker}}} = \frac{16.8 \frac{\text{mins}}{\text{product}}}{6 \frac{\text{mins}}{\text{worker}}} = 2.8 \frac{\text{workers}}{\text{product}}$$

Time _{manual} = total manual time

Time _{worker} = time per worker

Equation 3. Manpower Calculation

These figures and calculations can get confusing. For clarity's sake, Figure 25 [17] ties together the concepts of lead time, takt time, and cycle time together in a clean and comprehensive manner.

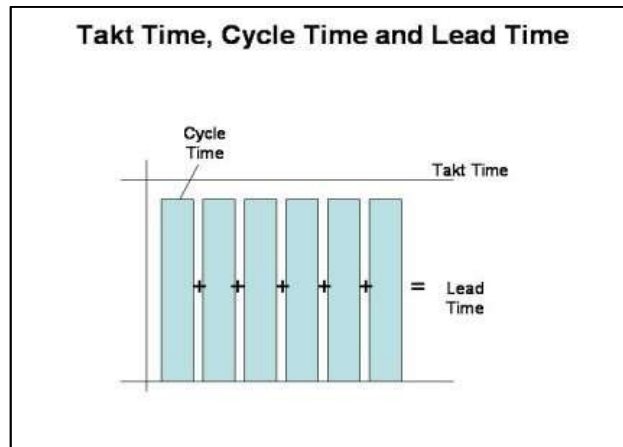


Figure 25. Cycle Time vs Lead Time vs Takt Time

Pre-Trial Run

The process layout has been a living document throughout PDG's life time and has evolved as the manufacturing phase has brought different issues to light previously overshadowed in the design phase. The very first draft of a process layout came during the design phase when the team had not yet spent considerable time of the manufacturing floor

as it related to the Wooden Photo Album, so naturally this layout was full of flaws and impractical. The initial process layout can be seen in Figure 26.

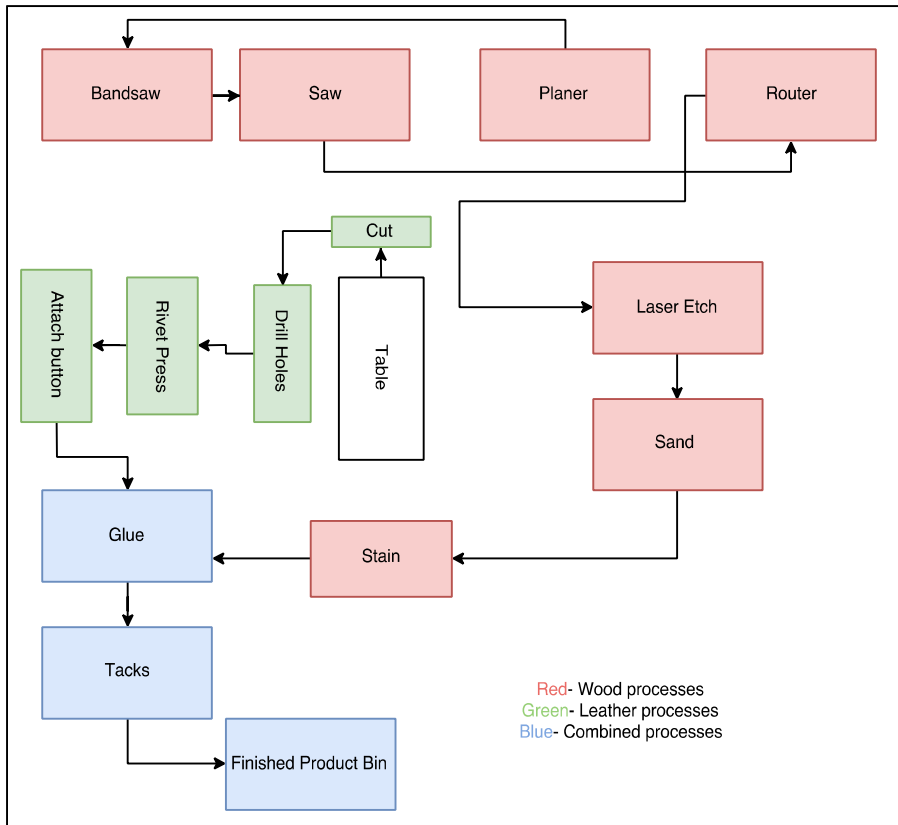


Figure 26. Initial Process Layout

The document describing the initial process layout did not show where the machines were located in space relative to the actual manufacturing floor on scaled dimensions, meaning the document was incomplete. It also did not efficiently orientate and arrange the machines to create a flow that minimized backtracking or wasted movement by workers. The order of operations appears to be out of order, or at the very least inefficient. This layout may not seem so bad to the unfamiliar eye, but after the team had

spent ample time on the manufacturing floor it became easy to notice the wasted movements in this layout and the improper design. As the members of PDG spent more time on the manufacturing floor it became obvious that a design change was needed. After brainstorming and drawing possibilities on white boards, a new standard was determined. Although it wasn't perfect, it was decided that the process layout needed to resemble the brainstormed sketches pictured in Figure 27.



Figure 27. Process Brainstorm

Moving forward from these sketches, the team came up with the process layout to be used during the first trial run of production, named process layout two. It was decided that a “U” shaped flow would be more ideal because this would allow our two separate materials to meet without having to backtrack. The wood processes would be done on one side of the floor while the leather processes would be happening simultaneously on the other side of the floor in a parallel manner so that the two materials join at the final assembly table. The way in which the machines were to be orientated had to be taken into account as well because of where the worker stands to operate it. For example, the direction the planer ejects the worked board needed to be perpendicular to the table saw because this is the most efficient way to transfer the board to the table saw by requiring minimal walking. If the table saw was parallel to the planer, the worker would need to walk a greater distance to get into position to operate the table saw. Unnecessary walking is a waste in manufacturing and goes against the principles of 5S. Process layout two is pictured in Figure 28.

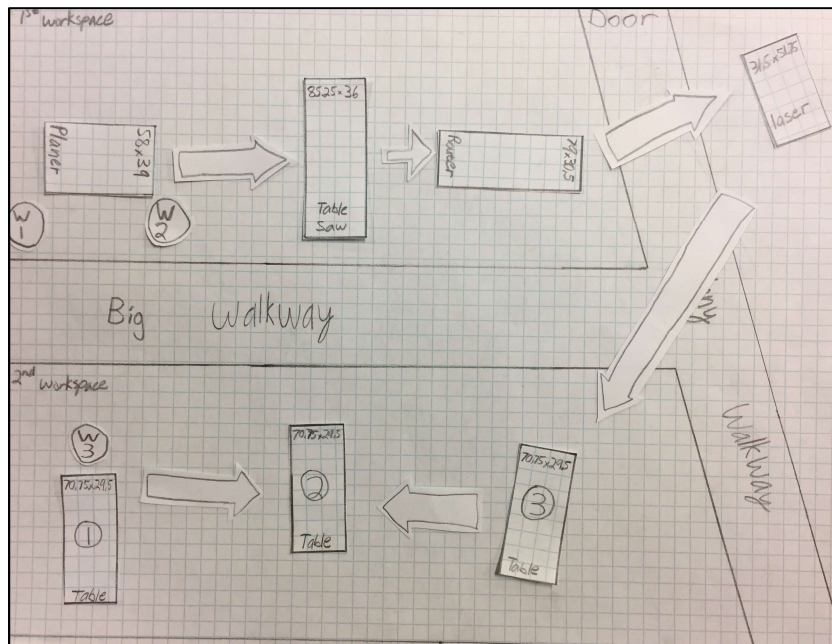


Figure 28. Process Layout Two

Process layout two was still not complete, as it did not capture all the worker movements and steps in one figure.

Trial Run

The trial run was to be held over two days, scheduled for Tuesday, February 20th and Thursday, February 22. The goal for the team was to produce ten complete wooden photo albums in an hour. In preparation for the trial runs the team set up the machines according to our current layout at the time, process layout two. Also, any jigs the team had prepared were put in place and the machines zeroed to the appropriate measures for the processes. The day of the trial run arrived, and things went well to a certain extent. The trial run was recorded on camera so that the team could review how the process looked in live action and make improvements. Even as the team went through the production run there were some noticeable aspects of the process layout that could be improved without

needing to reference the video. The “U” shape was a good design, but perhaps separating the material process completely was not the best way to allocate the available manpower. The leather cutting tools worked fine, but perhaps this step in the manufacturing process could be improved by means of a better jig. This step in the process requires skilled work that could improve with practice, but one of the goals for the team was to create a process that could be recreated by anyone without needing any prior skill. This became evident by having a team member who had not been practicing on the leather cutting step take a turn and struggle to complete the process. Once the trial was completed and footage was received, the team was able to better evaluate weak spots in the process layout, such as wasted walking time, improper allotment of manpower, and processes that could be standardized with some sort of jig that would reduce human error and therefore lead to less wasted material/reduce overall costs.

Post-Trial Run

The post-trial run stage of the manufacturing phase allowed the team to reflect on what had been learned from the trial run and implement this knowledge to improve the process. One such area that became the most obvious was the process layout. With the footage of the trial run available to be analyzed and studied, the steps in the production process were each individually timed and recorded to come up with the cycle times of each step. Once the cycle times were recorded in a trial run scenario, this enabled the team to make calculations and put together a table that assigned work based on cycle time in an effort to reach a desired takt time and lead time. The previous belief of separating the work by material was determined to not be the most efficient method by this new quantitative calculation. Rather, the separation of work in this new process layout was designated based

off of cycle time. The machines were then rearranged to fit this plan, resulting in a new layout named process layout three, pictured in Figure 29. The tables that resulted from the recordings of cycle time are pictured in Tables 6 and 7.

Table 6. Production Trial 3 Cycle Times

| Trial 3 | | |
|------------------|------------|--------|
| Process | Time (sec) | Worker |
| Planing | 135 | 1 |
| Cut | 36 | 1 |
| Routing | 75 | 1 |
| Laser | 397 | X |
| Sanding | 166 | 2 |
| Staining | 180 | 2 |
| Leather Cut | 139 | 1 |
| Leather Assembly | 176 | 3 |
| Gluing | 180 | 3 |
| Glue Dry | 1200 | X |

Table 7. Process Times by Worker

| Total Process Times by Worker (sec) | |
|-------------------------------------|-----|
| Worker 1 | 385 |
| Worker 2 | 346 |
| Worker 3 | 356 |

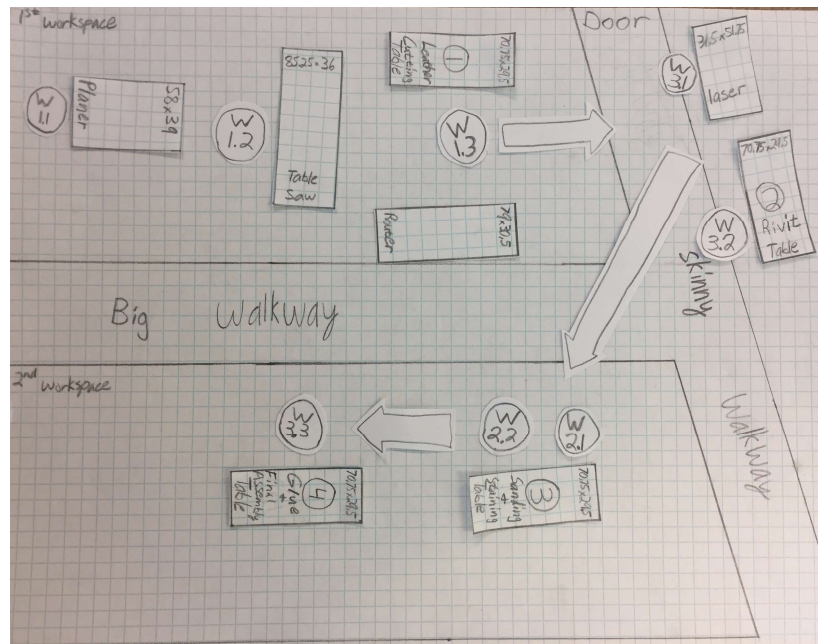


Figure 29. Process Layout Three

Process layout three was complete in that it captured all the movements of every worker, better allotted the available time, and put the team much closer to the desired lead time than previous process layouts. This daunting task of producing ten photo albums per hour now seemed much more within our means.

The team decided to go to the drawing board and brain storm where else the process could be improved. With the knowledge attained from a simulated day on the job, less obvious improvements began to come to light that might not have been realized by theoretical analysis. A table of these ideas is listed in Table 8.

Table 8. Process Improvements Post-Production Trials

| Process Improvements | | |
|----------------------|--------------|--------------------------|
| # | Improvement | TPS/ Lean/ 5S/ Principle |
| 1 | Safety | TPS |
| 2 | Jigs | 5S (Standardize) |
| 3 | Workstation | 5S (Straighten) |
| 4 | Stain Bath | Takt Time, Kaizen |
| 5 | Quality Gate | 5S (Standardize) |

The topics were thought to be necessary to improve our efforts because they follow the main principles and theories comprising the art of efficient manufacturing. These ideas have been proven over time and have scientific evidence to support them, including the principles of the Toyota Production System, LEAN Manufacturing, and 5S.

Safety

The most important aspect to any manufacturing effort, regardless of the product or profitability, is safety. According to the Bureau of Labor Statistics, in 2016 there were over 300 deaths related to manufacturing workplace accidents [18]. Safety is a serious concern in a manufacturing facility, especially when the worker is around moving parts and sharp blades. As the team spent more time on the manufacturing floor constructing jigs for the process, there was one step that seemed to be getting more and more dangerous the more the team tried to jig the machine to cut exactly what was needed. This step was the

table saw. The table saw serves to cut the raw material wood into the wooden planks that would be further worked to become the faces of the Wooden Photo Album. The 12” x 1” board is very long, approximately 11’. Even cutting the raw material board in half would still yield a piece that is large enough to prove difficult to handle. The problem the team ran into with the board is that it would sometimes get knocked away from the guide wall when being cut by the table saw. If the cut was even a little slanted this would affect the product as a whole down the line because this is such an early step in the process and several things are centered off of the faces. A bad cut would mean a bad product, essentially. The team built a jig to hold the board and ensure a straight cut, and it worked great. The board was lined up to the red tape to get the correct length, then pushed over the blade using the handles. This jig is pictured in Figure 30.



Figure 30. Table Saw Jig

However, upon inspection of the jig it was deemed unsafe. This was because the jig was required to be pushed over the moving saw blade, and then pulled back over. Any time a piece is moved across a moving machine blade the wrong way the process is inherently

Jigs

Another improvement the team was able to put together was the use of jigs to ensure standardization as well as create features on the pieces to be as exact as possible. Jigs are an important component of 5S according to the standardize principle. As mentioned earlier, to standardize in manufacturing is to ensure a process is done the same way every time, regardless of the particular team member doing it or which line the process is on. It is important that the jig make the process as simple and intuitive as possible so that when someone new comes to that place on the manufacturing process there is as little of a learning curve as possible and minimal downtime or waste. Jigs that PDG made include the gluing jig and the leather cutting jig.

The gluing jig consists of two parts, the base and the cover. The base serves as a cradle for the Wooden Photo Album's covers. This base, pictured in Figure 32 allows the covers to be placed snug against the corners of the jig, which positions them exactly where they need to be to allow for the leather spine to be glued at the correct placement. The leather spine placement is crucial because the entire book opens and closes around where the leather spine is placed, so if it is even a little bit off center the book will not close flush and will look bad. To ensure correct placement, the cover part of the gluing jig is used to guide the worker on where exactly to place the leather. The cover also serves to help the worker screw in the female end of the button and glue the leather strap to the face of the book. After some testing, it was found that the cover's dimensional tolerances for the button were so tight that the button wouldn't fit through the guide. The gluing jig's cover

had to be redesigned to allow for easier placement of the button. The cover is pictured in Figure 33, with the two components coming together to form the complete jig in Figure 34.



Figure 32. Gluing Jig Base

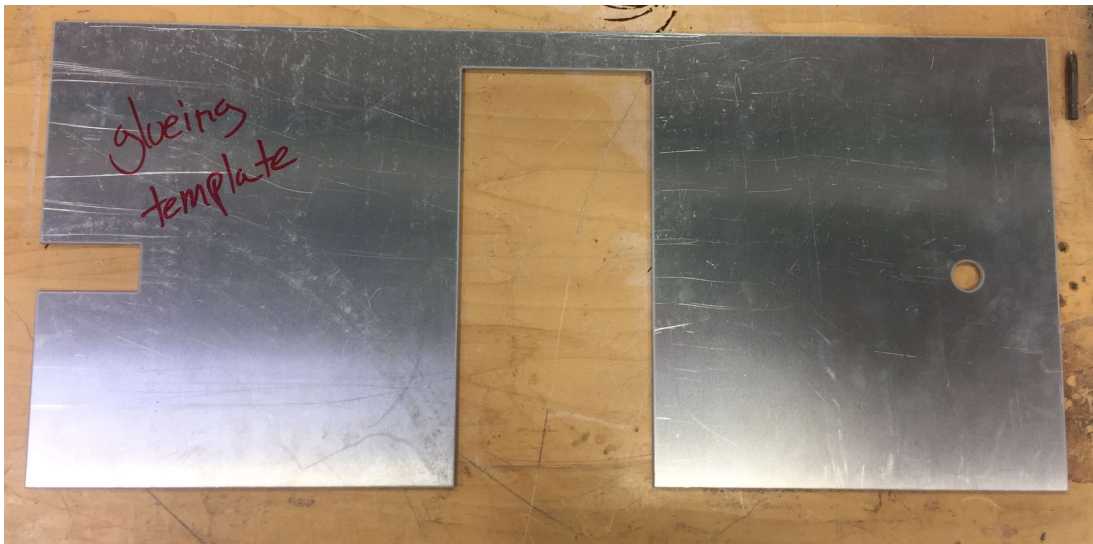


Figure 33. Gluing Jig Cover



Figure 34. Gluing Jig

The leather cutting jig follows the same principle of standardization as the gluing jig, it serves to enable anyone to repeat the process without formal training and with minimal practice. The previous way of cutting one leather spine and one leather strap at a time was proved to be difficult as well as inefficient. The short cuts lead to a lot of fumbling around and defective pieces, especially when cutting the corners. Thus, the leather cutting jig was created. This jig consisted of three parts, the first being a long piece of metal that outlined five leather spines plus five leather straps. This piece used long cuts to make a big rectangle which would subsequently be cut into the proper size of the leather spine with the second part to the jig. Cutting the leather hide into a rectangle with all the surface area needed to create five spines and straps at a time made the process easier because of less leather to handle. The leather straps would be cut from the leather rectangles using the third piece. The leather cutting jig is pictured in Figure 35.

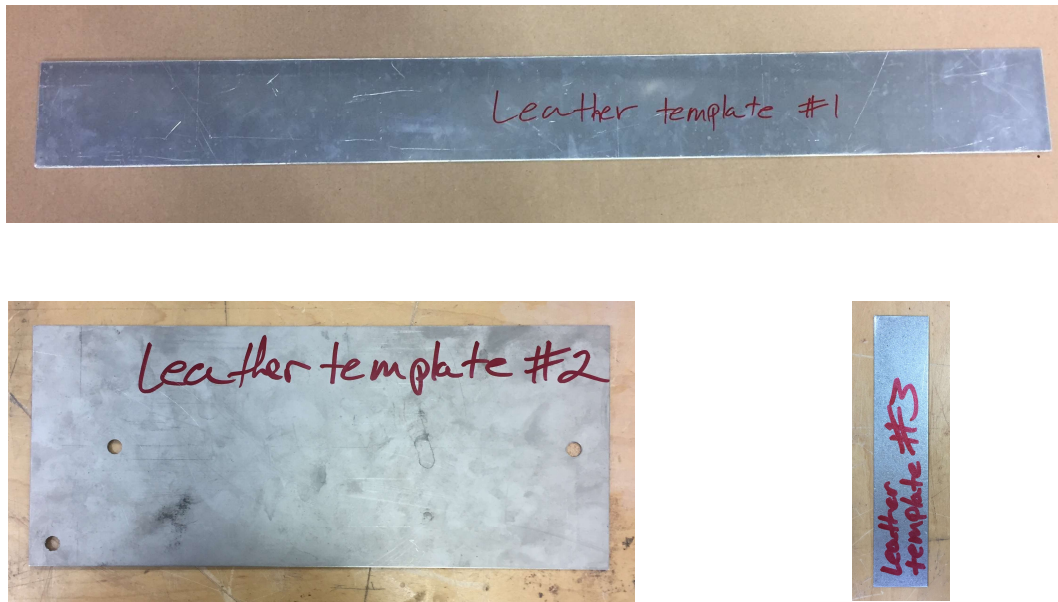


Figure 35. Leather Cutting Jig

Workstations

Workstations are a central aspect to any manufacturing floor. Workstations follow the 5S principles of sort and shine. Sort in manufacturing terms means that each work station should only have the tools and materials necessary to that specific process. This is important because if a worker cannot find something he or she needs, or if there are so many extra pieces on the table that the worker has to sort through them to find what is needed, this leads to wasted time and a less efficient process. Shine is the 5S principle that means that the station should be cleaned daily, or between shifts, and always kept tidy and organized. If materials are cleanly kept in their own bins and tools have a home location so that they won't ever be misplaced, then the whole process can flow more efficiently and

be on schedule. PDG has several manual processes that require different equipment and materials, and because of this they have been separated into their own workstations.

The leather cutting workstation is where the raw leather hide is cut into the leather spines and leather straps. This work station requires a rotary cutter, a pilot hole tool to create the pilot holes for the placement of the tacks, a hole punch to create the holes where the rivets will go, and the leather cutting jig. The leather cutting workstation is pictured in Figure 36.

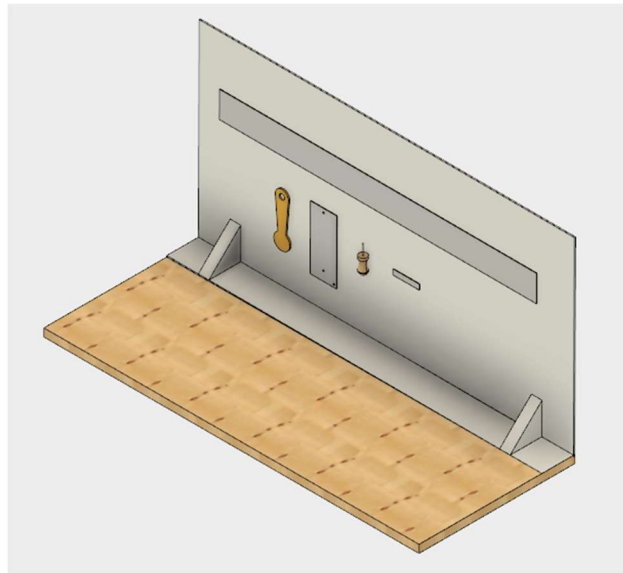


Figure 36. Leather Cutting Workstation

The leather assembly workstation is where the rivets are placed into the leather spine and where the male end of the button is riveted onto the leather strap. This station consists of a bin of binder rings, a bin of rivets, a bin of male button, a bin of rounded ends to cover the male buttons, and a rivet press. Because of the number of pieces at this station, the bins are especially useful in keeping the worker organized and on pace. The leather assembly workstation is pictured in Figure 37.

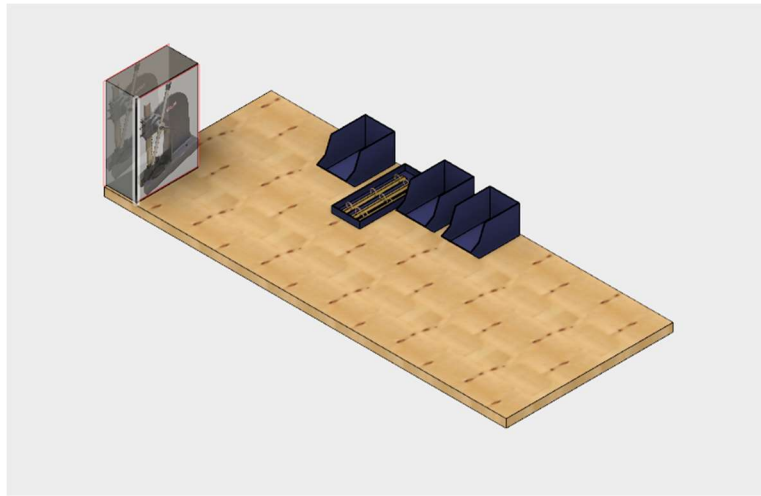


Figure 37. Leather Assembly Workstation

The sanding and staining workstation is where the covers of the photo album go to be sanded to a smooth surface and then stained to achieve a color that is more aesthetically pleasing than the basic unfinished color of the wood. This process has been a tough hurdle for the team, as it has proven difficult to stain the wood to a good color in a time that is fast enough to meet the goal of ten products per hour. The team tried several different methods, but the method that seemed to be the best was the dunking method. It is a very unusual way to stain a piece of wood but was the only way to get the desired color in the required amount of time. The dunking method will be discussed more later. The sanding and staining workstation is fairly simple, in that it only requires the sander, the stain bath, and a wall dividing the table in half so that none of the dust from the sanding gets onto the drying stain. The sanding and staining workstation is pictured in Figure 38.

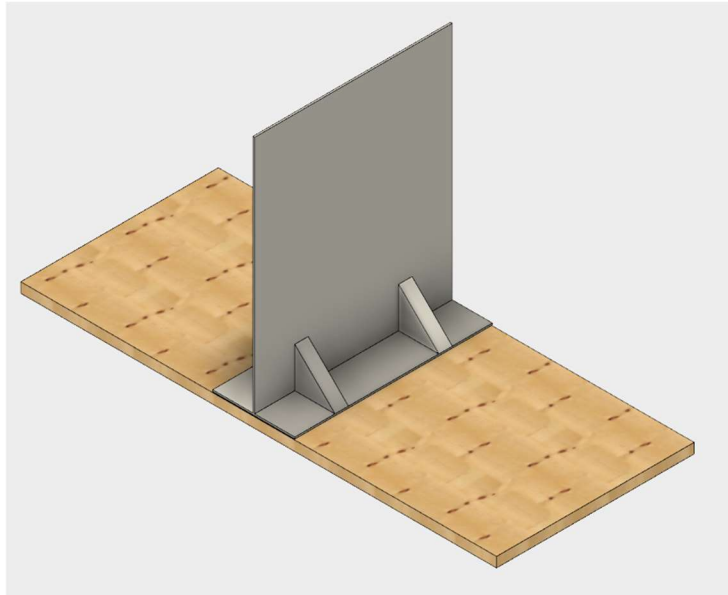


Figure 38. Sanding and Staining Workstation

The last station is the final assembly workstation. This is where the leather and wood come to be glued together, and the tacks are added for aesthetic appeal. This is the last step in the manufacturing process and where the final product comes to life. This station required a rubber mallet to nail in the tacks through the pilot holes created in the leather cutting workstation, a bin for the tacks, a bin for female button ends, a bin for the screws that attach the female button end into the wood, a bottle of glue, and the gluing jig. The final assembly workstation is pictured in Figure 39.

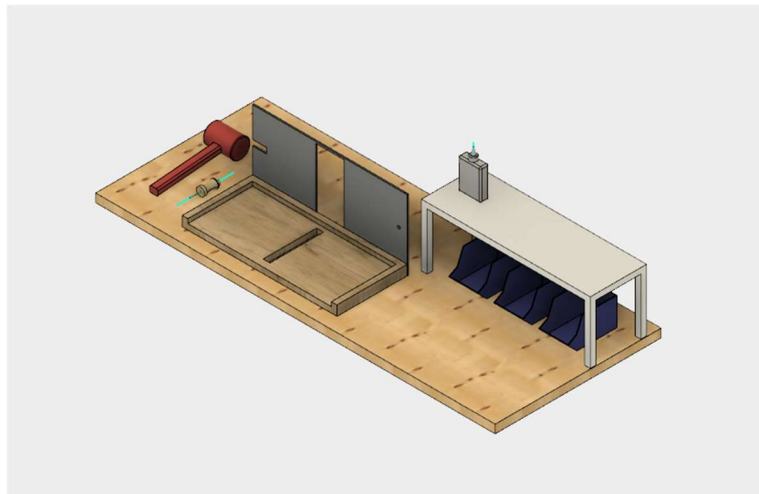


Figure 39. Final Assembly Workstation

Stain Bath

The staining method was a very tricky part of the manufacturing process for PDG. Usually staining is the last thing that happens to finish a woodworking project, so it is not a problem if it has a long drying time. However, for the Wooden Photo Album staining was not the last step. The covers had to be stained before the leather spine and strap can be glued on, meaning the drying time gave the team serious problems. The traditional method to staining is to apply the stain with either a brush or a rag, and then wipe off the stain soon after it is applied. Several coats can be applied to get a darker, fuller color if desired. With this method even after the stain is wiped off there is still a considerable drying time. When the team tested the stain process the traditional way the cure time was around twenty-four hours. This would not work for PDG. The team was forced to get creative and experiment with several different techniques and stains.

After several tests, the team decided to go with a polyurethane/stain blend and use a stain bath method. This method requires the cover to be dunked into a reservoir of the polyurethane/stain blend, wiped off immediately, and repeat the process for the other side. Although an unorthodox method, it proved to give good results in the fastest way possible. The process took 165 second, or 2 minutes and 45 seconds. The team needed to be fast at this stage of the process because of the principles of Kaizen and takt time. Kaizen, also known as continuous improvement, can be seen in the staining step of the process because of the experiments required to get here. It was determined the traditional method was too slow, then a spray gun method was tested and determined it wouldn't work either, then the idea of the stain bath came up and was tested several times before deciding it would fit the team's standards. The principle of takt time can be seen here because if the team was too slow to meet takt time the whole manufacturing process would be thrown off, so adjustments had to be made to meet this critical measure. Speed was key in this step of the manufacturing process, so it was decided to use this method. The stain reservoir is a metal rectangular prism with the corners sealed with liquid concrete to ensure a leak-proof design and keep the integrity of the stain bath. The stain bath reservoir is pictured in Figure 40.

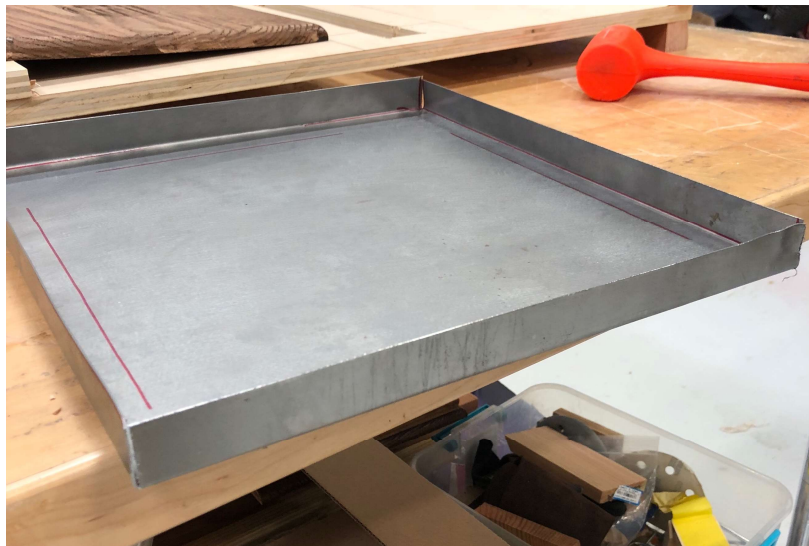


Figure 40. Stain Bath Reservoir

Upon initial inspection of the stain bath method there was concern about the amount of stain used per product and how cost efficient this method was. Tests were conducted, and it was seen that this method uses 45 grams of stain per 11.25” x 11.5” board, which is 90 grams per product. In a one quart can of Early American Stain there is roughly 907 grams of stain, giving the team roughly 10 photo albums per can.

Quality Gates

Quality gates are an essential part to any manufacturing operation. They help the workers know whether the product is still acceptable at the current stage or if there is a defect and work on that product should be stopped. If a defect continues to be found at that stage in production, then that is indicative of a malfunction in a piece of equipment before that stage. PDG was careful to include quality gates at several points throughout the process by setting up guides or building the quality gates into the jigs used throughout the operation. Quality gates check for accuracy and acceptability by requiring the pieces to

physically fit within dimensional tolerances to pass to the next operation. This follows the standardize principle of 5S, meaning that each piece will be operated on the exact same way because each piece will be nearly identical in size. Examples of quality gates in PDG's manufacturing operation include the router guide, cover of the gluing jig, and base of the gluing jig. The router guide in Figure 41 ensures that the wood has been planed down to the proper dimension by requiring it to fit underneath the guide, the black piece in the picture. The cover of the gluing jig, pictured above, checks for quality in the leather spine by requiring it to fit within the cutout while also having straight cuts. The base of the gluing jig, pictured above, checks for quality by requiring the wood covers to fit snug in the corner. If the piece has room to wiggle when placed in the base of the gluing jig, this means the cuts were not straight.

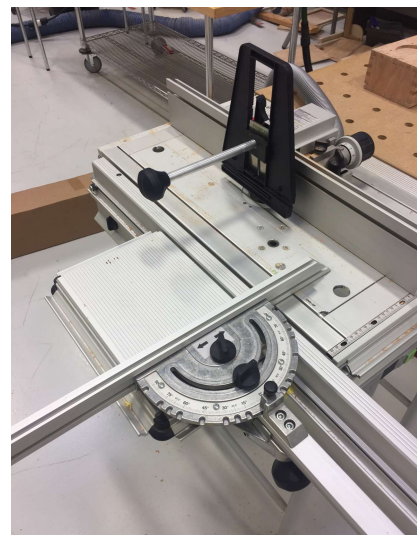


Figure 41. Router Guide

Chapter 5: Final Results

The final product retained all design features given in the final product section at the end of the design phase of this report. In summary, the photo album is a 11 ¼” x 11 ½” Oak binder with leather binding and brass accenting. It features the UM Lyceum Logo ® on the front and CME senior capstone branding on the inside cover. The product will not include photo sheets.

The product will be produced at a pace of 10 units / hour. The Wooden Photo Album was proven to be a financially lucrative product. The final cost/unit during production was found to be \$16 This price per unit includes shipping considerations and is evaluated at a production volume of 83,200 units over 5 years. This would be expected to decrease as cycle times would shorten due to learning curve and volume discounts could be expected from suppliers. Relevant tables for this calculation can be found in Appendix B, along with the following calculations. The allotted 6 minutes per unit process time and 80% uptime for production left the payback period at roughly 7.3 weeks, or 39 work days. This was based on an initial investment of \$5000 for development, \$2000 for hand tools and other equipment, \$2000 for jigging development and layout costs, and just over \$30,000 invested on heavy machinery. This also leads to an annual income, assuming 52 weeks of production per year, of \$257,112. Based on this income annually over 5 years, 10% interest rates, and the previously mentioned initial investments, the project carries a Net Present Value of \$935,575.

The project had some future work associated. It was recommended that a replacement for the stain bath method be found. While the bath method worked for small quantities, it was the belief of the team that when implemented in long uptime scenarios, defects are likely to occur. This was due to the large number of variables associated with the process. A fast-drying spray system, possibly automated should be investigated as an alternative to the bath. Secondly, replacements for the laser engraver should be tested. While the laser offered excellent resolution and simple setup, the process was time consuming. The team recommended looking into a brand-style system that would quickly burn images into the wood. This would add manual time, but also improve the linear flow of the overall process. Lastly, all the improvements recommended since production trials need to be tested in a full production simulation. This would validate assumptions and allow unexpected issues to be worked out. This being said, the belief of the team was that the product and process at the time of the report were sound.

Chapter 6: Conclusions

The creation of this product and breathing of life into it during the manufacturing phase was not without challenges. This should be fairly apparent to the reader at this point. However, as the saying goes, “A calm sea never made a skilled sailor.” For this reason, the lessons learned from such challenges are considered worth their weight in gold. Due to the broad scope of the project, many conclusions and lessons can be taken away from a number of different perspectives. The takeaways from the following three points of view seemed to stand out: the designer, the manufacturing engineer, and the project manager.

The conclusions from the standpoint of the designer will first be analyzed. It can be clearly seen that all ideas are destined to change. No design is so robust as to resist iteration and improvement. In the case of the wooden photo album, the original invention underwent a shift in scope. What was once imagined to be an inexpensive product became a higher end quality piece. This would lead one to conclude that the designer must be willing to pivot with the product. The overall success of the product must be put in front of emotional attachment to original invention or initial design. The inventor of the wooden photo album was extremely gracious and willing to flow with the tide of change, which, it is the belief of the team, allowed the iterative design process to proceed smoothly. It can also be concluded that every design suggestion need be weighed against return. This is a well understood principle that PDG could have stood to benefit from. Often features or design changes were suggestions that wouldn't necessarily add value to the product. The team learned this is a difficult line to walk when much of the product's value come from it's

aesthetic appeal. How does one weigh the value of a feature that simply makes something, “look better.” A great example of this was the addition of the brass tacks to the leather interfaces. They were a very cheap addition that changed the overall look of the photo album in a profound way. Take for example the side by side seen in Figure 42.



Figure 42. Beta Prototype 2 Side by Side

One can objectively say that the leather-wood interface on the right looks higher quality than that on the left. While the tacks added no bond strength between the leather and wood and were therefore unnecessary for assembly, they added marked aesthetic value and for only seconds of process time and pennies of cost. These sorts of decisions were weighed constantly by the team. It was therefore a great takeaway for the designer to be constantly looking for small ways to create value at little cost.

Manufacturing engineers play a big role in any kind of product realization, whether it is small-scale production of a simple toy, or a large-scale production of complicated device requiring both mechanical and electrical inputs to come together seamlessly. For any dreamed-up product to come to life there has to be a manufacturing engineer involved to make the production feasible. Anyone can imagine a product and draw up a design that

seems intuitive enough, but the actual creation of that product can lead to complications. As mentioned above, design specification can change, and the product may end up looking entirely different than when the idea was first hatched. However, these changes are necessary to make the product profitable and therefore possible to be released to the market. The design of the manufacturing process is not an easy task, and often times this process can change and evolve just like the initial design of the product. Realizations made on the floor sometimes cannot be thought of in the design room because manufacturability can be limited by the capabilities of the machines. This became very apparent as the process layout was developed. The process layout was a living document that evolved as the team became aware of new problems or of better ways to operate. The manufacturing engineer must be open minded, because if he or she believes that the first idea presented is the best idea then the project is almost sure to fail. For example, as the process layout adapted there was a very drastic change that occurred due to a realization that the two materials, wood and leather, did not actually need to be separated. For a long period of time there was a belief that it would not be feasible to have one worker operate on both the leather and wood as they were seen as completely different processes. Even though they are very different processes, when the processes were analyzed from a time consumption perspective it made perfect sense to have one worker due both the wood and leather processes because these operations together added up to a proper amount of work to reach the takt time with the allotted worker number. It was because of principle concepts of lean manufacturing such as 5S, Kaizen, and TPS that these realizations were made and enabled the Wooden Photo Album to be produced in a profitable way.

The lessons learned from the perspective of the project manager were many. Three of the prominent conclusions were concerning the role of the PM in ensuring the team utilizes PM resources, the interaction with team tasks, and the PM's role in fostering communication. To begin, it was very apparent to the PM that better efforts could have been made to encourage, "buy in," concerning the PM documents. While the existence of PM documents such as the WBS or schedule is helpful, they are not fully utilized if the team is not committed to the project management plan. Without a thorough understanding of the benefits of sticking to the schedule and quantifying work, these resources often seemed more like burdens than boons. Therefore, the PM learned that laying a foundation of understanding concerning the driving PM documents is very important to the successful completion of the project. The second glaring lesson was that some degree of separation between the PM and the everyday work of the project is desirable. While it is very important for the PM to be at product level, some separation from every day operations allows a PM to be available to focus efforts on planning project operations so that the next step is always clear to the operations team. It also allows all the PM tools to be more effective in their application. This could also reinforce the hierarchy that is an important factor in project management plan adherence. Lastly, the PM learned that in order to maximize effectiveness of all team efforts, constant and clear communication was key. There were times where particular team members remained idle because they did not fully understand where the project was moving and what their role was in that movement. This is an area that could have been improved on from the PM standpoint. A constant encouragement of a communication culture would have improved the efficiency of the

team. There were also breakdowns in communications concerning material orders. Because there was not a plan in place for what to do if issues were encountered with material order, the issues were not communicated at all. This was a problem that could have been solved by an early establishment of clear communication channels for specific issues. A system of reporting progress was not in place, and if it had been, it is the belief of the PM that many issues would have been avoided. Although the project is considered a success overall, the PM was not left without areas to improve on in future projects.

Appendix

Appendix A: Design Drawings

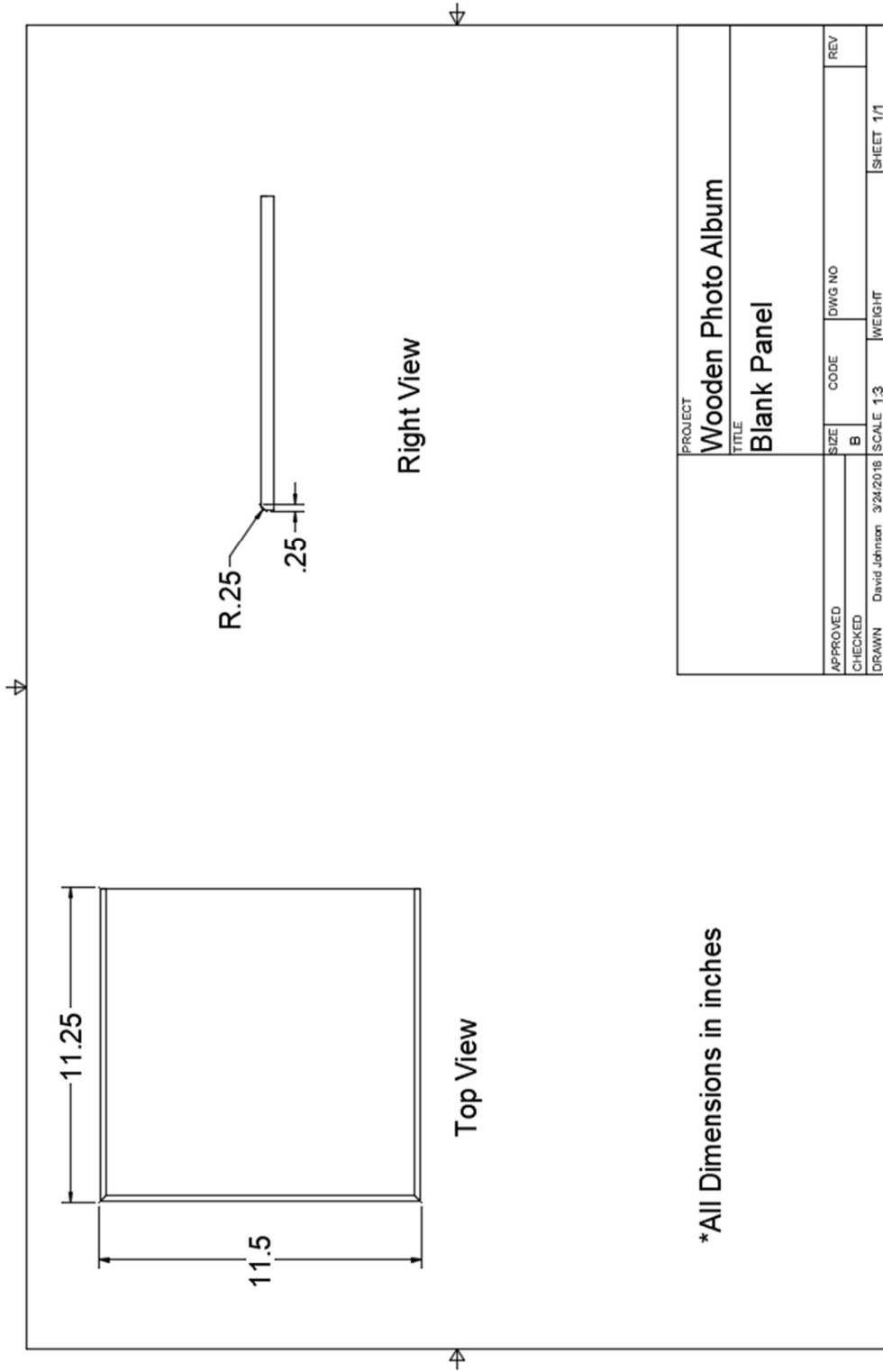


Figure A1. Panel Design Drawing

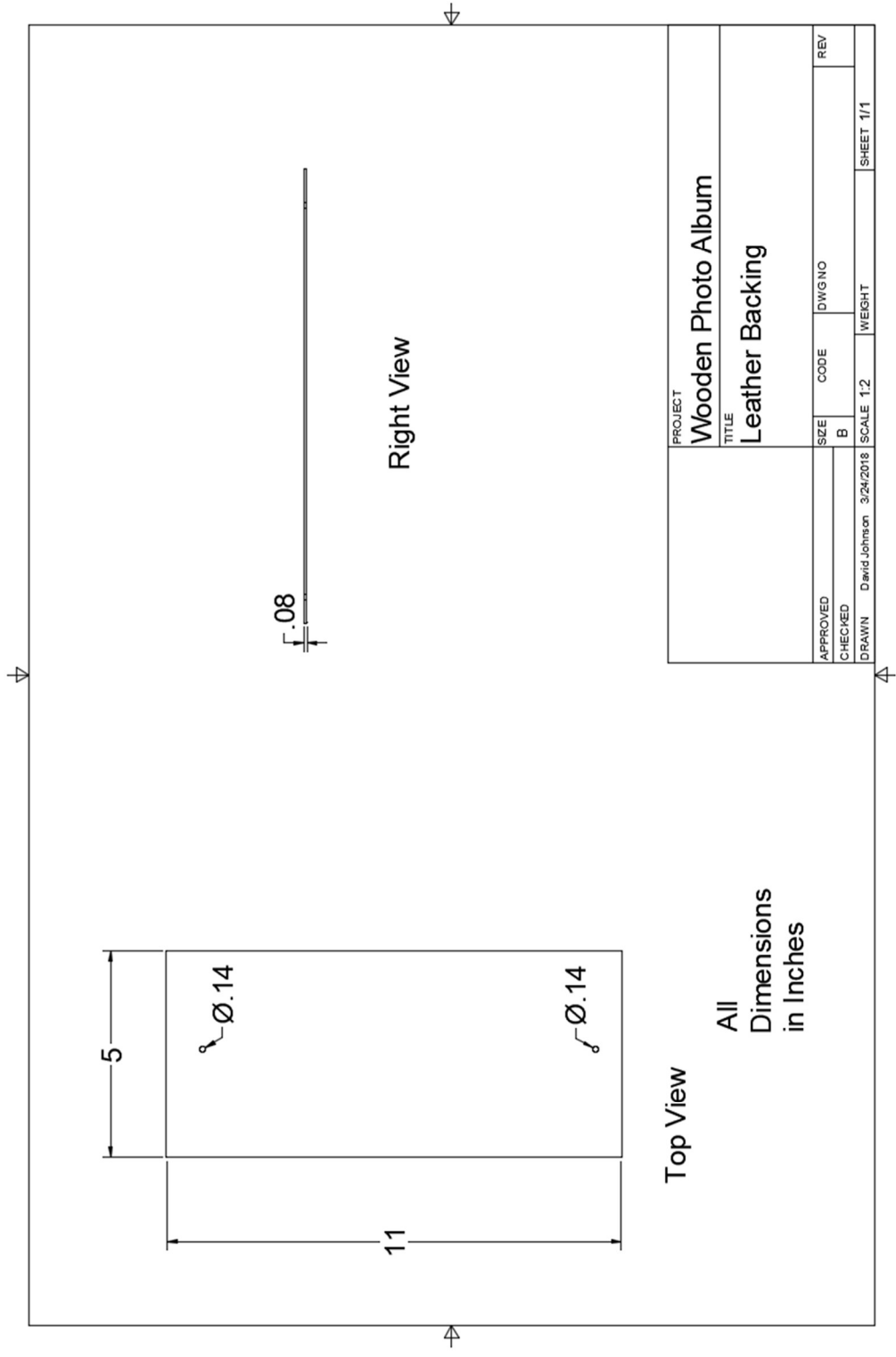


Figure A2. Binding Strip Drawing

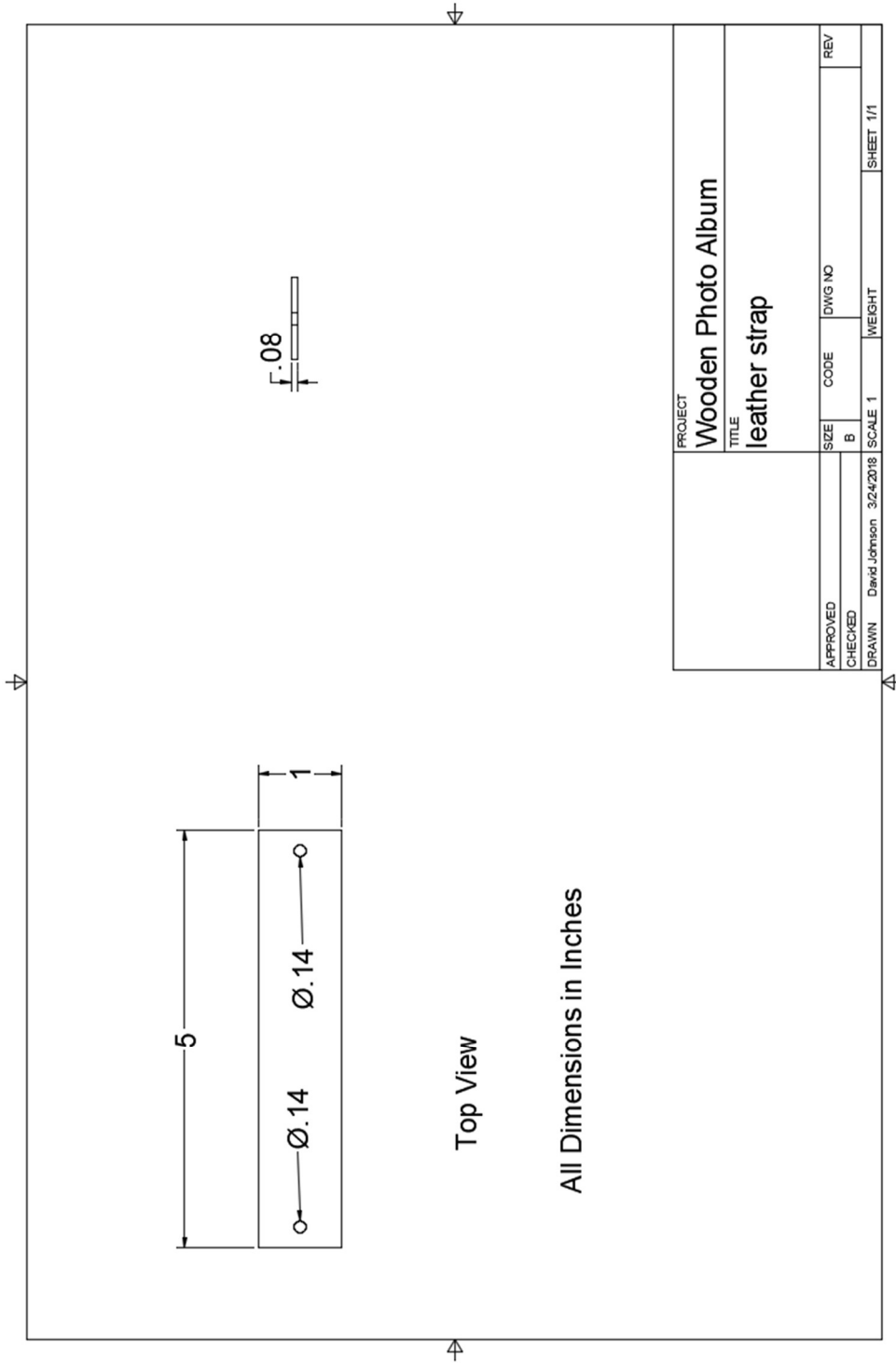


Figure A1. Leather Strap Drawing

Appendix B: Financial Tables

Figure B1. Buy Analysis

| Buy | | | | | | |
|----------|--------------|----------------|---------|---------------------|-------------------------|-------------------|
| Machines | Cost | Lifespan (yrs) | Salvage | Annual Depreciation | Annual Production | Depreciation/Unit |
| Laser | \$ 26,000.00 | 5 | \$ - | \$ 5,200.00 | 20800 | \$ 0.25 |
| Planer | \$ 4,082.00 | 5 | \$ - | \$ 816.40 | 20800 | \$ 0.04 |
| | | | | | Total Depreciation/unit | \$ 0.29 |

Figure B2. Labor Analysis

| Labor | |
|-------------|---------|
| rate | \$ 7.25 |
| time/unit | 0.1 |
| # needed | 3 |
| labor cost | \$ 2.18 |
| Labor Fixed | \$ 0.87 |

Figure B3. Other Materials Costs

| Other Materials | | | |
|-----------------|-----------------|-----------|------------|
| Item | Use Rate | Item cost | Cost/ unit |
| latex gloves | 1 pair/20 units | \$ 0.16 | \$ 0.01 |
| sanding pads | 1/4 units | \$ 0.77 | \$ 0.19 |
| | | total | \$ 0.20 |

Figure B4. Breakeven

| Breakeven | |
|-------------------------|--------------|
| initial investment | \$ 39,082.00 |
| income/unit | \$ 16 |
| time/unit | \$ 0.12 |
| units to breakeven | 2443.36 |
| time to breakeven (hrs) | 293.2 |
| time to breakeven (wks) | 7.33 |

Figure B5. Annual Revenue Analysis

| Annual Revenue | |
|---|---------------|
| Customer Pace (units/hr) | 10 |
| Yearly Work Hours (hr/yr) | 2080 |
| Percentage of Work Hours as Yield Hours | 80% |
| Annual Production Volume (units/yr) | 16640 |
| Profit per Year | \$ 257,112.14 |

Figure B6. Initial Investment Breakdown

| Initial Investment | |
|--------------------------|--------------|
| Prototyping Costs | \$ 5,000.00 |
| Jigging and layout Costs | \$ 2,000.00 |
| Initial Machines | \$ 32,082.00 |
| Initial Total Investment | \$ 39,082.00 |

Figure B7. NPV Calculations

| Net Present Value of Project | |
|------------------------------|---------------|
| Initial Investment | \$ 39,082.00 |
| Annual Cash flow | \$ 257,112.14 |
| Interest Rate | 10% |
| Project Life (yrs) | 5 |
| Present Value | \$ 974,657.29 |
| Net Present Value | \$ 935,575.29 |

Works Cited

- [1] Toyota, "The origin of the Toyota Production System," Toyota, 2018. [Online]. Available: http://www.toyota-global.com/company/vision_philosophy/toyota_production_system/origin_of_the_toyota_production_system.html. [Accessed 25 3 2018].
- [2] Toyota, "Toyota Production System," Toyota, 2018. [Online]. Available: http://www.toyota-global.com/company/vision_philosophy/toyota_production_system/. [Accessed 25 3 2018].
- [3] Staff Electric Company, "Lean Construction Practices," Staff Electric Company, 2018. [Online]. Available: <http://www.staffelectric.com/safety/programs/>. [Accessed 28 3 2018].
- [4] D. Stiffler, "Triple Constraints Model," Global Knowledge, 1 6 2009. [Online]. Available: <https://www.globalknowledge.com/blog/2009/06/01/triple-constraints-model/>. [Accessed 14 1 2018].
- [5] Project Management Institute, "About Us," Project Management Institute, 1 1 2018. [Online]. Available: <https://www.pmi.org/about>. [Accessed 14 1 2018].
- [6] Project Management Institute, "PMBOK Guide and Standards," Project Management Institute, [Online]. Available: <https://www.pmi.org/pmbok-guide-standards>. [Accessed 14 1 2018].
- [7] J. K. Rowling, "Mad-Eye Moody," in *Harry Potter and the Goblet of Fire*, Bloomsbury, 2000.
- [8] Project Management Institute, Project Management Body of Knowledge, Newton Square: Project Management Institute, 2013.
- [9] K. Morris, *Wooden Photo Album*, Oxford, 2017.
- [10] Amazon inc, "No. 96 Rustic Handmade 4x6 Leather Photo Album," Amazon inc., [Online]. Available: https://www.amazon.com/No-96-Rustic-Handmade-Leather-Photo/dp/B0096C7F4M/ref=sr_1_10?s=furniture&ie=UTF8&qid=1522612822&sr=1-10&refinements=p_n_material_browse%3A3248905011. [Accessed 26 2 2018].
- [11] Walden Goods, "Wedding album, Wooden Photobook, Wedding guest book, wedding Scrapbook, Custom wedding guest book, Wedding Gift, Personalized , Walnut," Etsy inc., [Online]. Available: https://www.etsy.com/listing/523564545/wedding-album-wooden-photobook-wedding?ga_order=most_relevant&ga_search_type=all&ga_view_type=gallery&ga_search_query=wooden%20photobook&ref=sr_gallery-1-1. [Accessed 26 2 2018].

- [12] woodlack, "Monogram Photo Album, Photo Album, Wedding Album, Custom Wedding Album, Wood Photo Album, Monogram Guest Book, Guest Book, Rustic Guest Book," Etsy inc, [Online]. Available: https://www.etsy.com/listing/492836252/monogram-photo-album-photo-album-wedding?ga_order=most_relevant&ga_search_type=all&ga_view_type=gallery&ga_search_query=monogram%20photo%20album&ref=sr_gallery-1-7. [Accessed 26 2 2018].
- [13] Whitetail Woodcrafters, "Hunting Memories Photo Album," Whitetail Woodcrafters, [Online]. Available: <http://www.whitetailwc.com/hunting-memories-photo-album-large>. [Accessed 26 2 2018].
- [14] L. C. S. George Dieter, Engineering Design, New York: McGraw-Hill, 2013.
- [15] B. Warfield, "Cellular Manufacturing: Lean Manufacturing Principles, Part 10," CNC Cook Book, [Online]. Available: <https://www.cnccookbook.com/cellular-manufacturing-lean-manufacturing-principles-part-10/>. [Accessed 15 3 2018].
- [16] iSixSigma, "iSixSigma," [Online]. Available: <https://www.isixsigma.com/dictionary/takt-time/>. [Accessed 4 April 2018].
- [17] B. Presec, "leansixsigma," 17 June 2016. [Online]. Available: <https://leansixsigma.community/blog/view/8811/takt-time-cycle-time-lead-time>. [Accessed 4 April 2018].
- [18] Bureau of Labor Statistics, "bls.gov," 2016. [Online]. Available: <https://www.bls.gov/iag/tgs/iag31-33.htm#workforce>. [Accessed 4 April 2018].
- [19] Lean Enterprise Institute, "Toyota Production System," Lean Enterprise Institute, 2018. [Online]. Available: <https://www.lean.org/lexicon/toyota-production-system>. [Accessed 25 3 2018].
- [20] D. E. Lackey, Interviewee, *Design for Assembly*. [Interview]. 14 2 2017.