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A Study of the Product Development Process for the Transparent Kitchen Knife Block

Benjamin Payne

A STUDY of the PRODUCT DEVELOPMENT PROCESS for the TRANSPARENT KITCHEN KNIFE BLOCK

by

Benjamin Payne

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Approved by

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Advisor: Dr. Scott Kilpatrick

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Reader: Dr. Jody Holland

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Reader: Rick Hollander

ABSTRACT

The purpose of this document is to summarize the research and planning, design, market evaluation, cost analysis, and production process for a kitchen knife block. The team began by researching multiple knife block designs and evaluating what strengths and weaknesses existed with the basic models that are currently offered in different marketplaces. After collecting data on material costs and discussing different design features, the team created a survey in order to gauge consumer preferences and gain a better understanding as to what features and price point the average customer would consider purchasing. The resulting information was used to create an initial product design that would evolve throughout the prototyping phase. Once the product design was finalized, the team generated a cost estimate for manufacturing the product and established a production process that featured a factory floor layout and a conceptual workflow chart to guide production. However, complications resulting from the COVID-19 global pandemic interrupted plans for product production and the inability to utilize Center for Manufacturing Excellence facilities and tools eliminated the possibility of conducting an actual production run. Regardless, the team still focused on improving the product and its manufacturing process by creating a detailed standardized workflow chart along with an improvement log.

ACKNOWLEDGEMENTS

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I. INTRODUCTION

Capstone Structure

The Center for Manufacturing Excellence (CME) is one of four special academic programs at the University of Mississippi. The CME offers a unique undergraduate interdisciplinary educational opportunity, bringing together an assortment of students who will take courses focused on developing the professional skills needed to be successful in the manufacturing industry. Topics covered in CME classes include the fundamentals of manufacturing, accounting, communication, human resources, leadership, management, and marketing. Throughout the four year undergraduate program, CME students complete a number of team-oriented problem-solving projects that include visits to manufacturing facilities and hands-on workshops facilitated at the CME's 12,000-square-foot manufacturing floor.

Every student in the CME participates in a manufacturing capstone project before graduation. Interdisciplinary teams consisting of business, accounting, and engineering students are assembled and assigned a project that they are challenged to plan, design, manufacture, and market a commercial product in an effort to simulate the development process that companies encounter when developing and manufacturing a new product line. Prior to being assigned a capstone project, each student is required to submit at least one product concept to the instructor. CME faculty members evaluate the proposed projects and make final project selections. Students then rank the remaining projects based upon which product they would prefer to develop. Finally, project teams consisting of four or five students are organized and assigned a capstone project based on individual preference and academic background.

From there, the team establishes specific roles and responsibilities for each team member in order to utilize the unique skillsets associated with the diverse academic backgrounds present within the team. In the fall semester, the team develops an initial design which will be prototyped. In the spring semester, the team develops a formal manufacturing process and floor layout plan that will be followed during the manufacturing of the product. The project culminates with an hour long production run which tests the efficiency of the floor layout and manufacturing process.

Problem Definition

Knife blocks are a staple of nearly every kitchen across the country. They function as a means of safely storing an assortment of knife types and can be created in a wide range of styles, making them yet another customizable aspect of a kitchen style or layout. The standard design features a wooden block with multiple angled slots where the knives are placed and is typically stored on the kitchen countertop. Also, the standard block design typically holds the knives such that the knife blades are enclosed within the block which allows for easy access. This feature is safer than storing knives in drawers where finger to blade contact could occur during knife handling [1].

Despite the convenience of storing knives in one convenient location, the standard knife block has several key design flaws. Blocks tend to dull the blades as they routinely are removed or reinserted into the block. Vertical storage knife blocks often allow the blade to rest on the inside of the slot in a manner that can dull the knife blade in as little as 70 insertions into the knife block [2]. Also, the dark crevices that hold the knife in place are difficult to clean and provide an environment where bacteria and mildew could grow. Dust and debris could also accumulate in a high-use area like a kitchen countertop, and inserting knives into a block while still slightly wet could increase the likelihood of bacteria and mildew growth. So every time a knife is removed from the traditional wooden storage blocks, it brings the risk of contamination with it [3].

To address these potential deficiencies, the design of the TKB 3000 offers a practical and stylish solution. By utilizing a vertical design with a transparent and removable cover, the TKB 3000 is easily cleanable and will not dull blades upon insertion, removal, or during storage. The TKB 3000 is constructed utilizing high quality materials that can be cleaned and do not hold moisture and features a unique look that is aesthetically pleasing. Additionally, the see-through exterior allows for quick identification of specific knives while also showcasing the beauty of designer knives that are popular with experienced chefs and cooking connoisseurs.

Preliminary Scope of Work

The scope of this project involved the development of multiple prototypes that ultimately resulted in the unique design and features offered by the TKB 3000. In order to develop a product that met the project objectives of providing an improved kitchen knife block, the team established an efficient manufacturing process that was conducive to manufacturing the product at a target price point. The team performed a business case analysis to forecast tooling, materials, and manufacturing costs and evaluated different design concepts, materials, and manufacturing methods to identify feasible products that could be sold with attractive profit margins. The conceptual design phase included the development and implementation of a customer survey that utilized the Lean 7 Ways methodology to brainstorm a variety of design concepts. Once the initial optimal design was selected, the team focused on developing a detailed materials list, procuring the necessary materials, and also established a standard work procedure that outlined the manufacturing process. Upon creation of a finalized standard operating procedure, the team would have conducted a one-hour production run and utilized the data obtained to developed a final cost analysis. However, the final stage of this project was derailed by complication resulting from COVID-19.

Project Team Roles and Responsibilities

After convening a project team kickoff meeting to identify and select the overarching goals of this project, the team delegated certain responsibilities to each team member in accordance with their areas of expertise and educational background as shown in **Table 1**. Each team member was responsible for participating, sharing ideas and concerns, completing assigned actions, as well as being present for every team meeting while also collaborating on the fall and spring semester presentations.

Jacob Commer	Design Lead - Jacob was in charge of creating and designing a working model. He also researched different materials and analyzed multiple designs.
Tyler DiGiacomo	Manufacturing Lead - Tyler coordinated all of the activities on the factory floor. He also worked with technicians to construct the TKB 3000.
Benjamin Payne	Marketing and Risk Management Lead - Benjamin was in charge of collecting and evaluating market research. He also managed risk analysis and safety standards.
Austin Uhl	Cost Lead - Austin was in charge of the financial aspects of this project. His primary focus was to record all purchases and ensure that the project budget was not exceeded. He also assisted with preparing financial reports for the team.
Chet Wilson	Project Manager - Chet was the point of contact for the team. He was in charge of relaying information between the team and CME faculty. He was also responsible for assisting Jacob and Tyler with all design and engineering components.
James McPhail	Operations Manager - James was responsible for production management and oversight of all Manufacturing processes.

Table 1: Team Roles and Responsibilities

Plan for Gathering Information, Materials, and Data

In order to gain a better understanding of the challenges involved in the design, production, and marketing of this product, the team performed a thorough analysis of similar commercial products. This involved trips to local retailers where similar items are sold in order to gain a better understanding of currently available knife storage systems while also exploring online offerings to gauge the competition. Also, the team conducted research on successful knife blocks and their parent companies to gain an understanding of the different approaches to marketing and sales used by each firm. Additionally, the team investigated materials and their costs to prepare for the production of the TKB 3000.

To fully understand the consumer’s requirements for this product, the team also surveyed potential customers. Surveys included questions about price, materials, the overall function of the block, additional features, and the final design of the TKB 3000. This provided invaluable information that helped shape the design of the final product and provided guidance during the establishment of a final price for this product. The team's research culminated with the creation of a prototype that incorporated the selected features and design agreed upon after compiling and analyzing data from the research phase.

Anticipated Challenges/Risk Analysis

The primary risks identified included the possibility that the proposed design concept or aesthetics of a storage system that utilized clear components may not be an attractive alternative to the traditional wooden storage block. However, this risk was minimized by successfully articulating and demonstrating how the TKB 3000 design concept would offer a more sanitary, safer, more effective, and more stylish method of storage for kitchen knives. Another potential risk was the possibility that the customer would not be willing to invest in a new and improved knife block design thus requiring an adjustment of the product's price point. To address these risks, the team utilized the input received from the surveys to gauge what design components are most valued and likely of interest to potential customers. This strategy fell in line with business strategist Fred Reichheld's research dealing with the importance of understanding and improving consumer satisfaction [4]. Thus, by ensuring that the TKB 3000 capitalizes on successful existing knife block designs and includes features desired by the consumer, the team determined that the risks were minimal based largely on customer input.

Furthermore, the production and assembly of this product could have revealed unanticipated challenges associated with materials, design, or manufacturing processes; however, the simplicity of the design was expected to minimize and address these risks. Finally, the team had to ensure that the product meets the objective of being easy to clean and therefore less susceptible to bacteria or mold. The fundamental design concepts that addressed cleanliness are that the selected materials can be sanitized, and that the product provides the capability for easy disassembly and cleaning, including the ability to be washed in a dishwasher. Also, the final product had to be structurally sound enough to hold a knife set so that there is no risk of failure, leading to user injury or damaged cutlery.

Initial Budget/Anticipated Expenditures

Prior to the creation an official prototype, the team decided to estimate how much money should be allotted towards the initial design stage. The project team was assigned a target budget of $1,000.00, and the team agreed that it was paramount that the project development costs be a limited portion of the total budget. This allowed for increased spending on final materials and for a larger margin of error during the prototype development phase if changes were required.

Typically, manufacturing firms align innovation investments with revenue targets by allocating roughly three to four percent of total expected revenue towards research and development [5]. With this in mind, the team decided to spend as little as possible on the resources needed to construct the initial prototype and instead utilized resources such as cardboard and plywood to build the first physical model. As the design matured throughout the prototyping phase, the team upgraded the materials utilized. This helped keep costs relatively low and allow for fewer restrictions on the number of initial designs the team was able to mockup and evaluate.

In order to track expenses and establish which materials would be used during each product development phase, the team created an initial budget as shown in **Table 2.** Throughout the initial design phase, the team relied on cardboard since it was essentially free and could be easily assembled or adjusted. After the team evaluated the initial prototypes and finalized design dimensions, more expensive materials were procured in order to construct a more representative prototype. Also, the reason prototype materials were upgraded was so that a few key unknowns could be addressed including: the surface finish on polycarbonate knife support material (Lexan), the machining method for knife slots (plywood can't be used to simulate polycarbonate machining), the design geometry with different wood thicknesses (design specified wood thickness that is not a widely offered plywood thickness), and exploration of moisture sealing method using production-quality wood rather than plywood. Once the prototype was constructed and evaluated by the team, the remainder of the budget was dedicated towards bulk material purchase for the final design.

In total, materials were expected to cost approximately $222. The remaining budget was saved in case additional material or tool expenses were identified later. The remaining budget could also be redirected towards packing or employee expenses as well.

Intial Budget for Transparent Knife Block Project					
Amount Avialable for Anticipated Expenditures:					$1,000
Anticipated Expenditures:					
	Materials				
	Material	Dimensions	# of Orders	Cost per Order	Material Cost for Prototype
Mockup	**Duct tape**	--	1	$3.00	$3.00
Mockup	**Cardboard**	--	3	$2.00	$6.00
Initial	**Plywood**	3/4" x 2' x 2'	3	$9.07	$27.21
Initial	**3D printer ink**	TBD			
Initial	**Fasteners**	#8 x 2-1/2"	1	$3.98	$3.98
Final	**Maple plywood**	3/4" x 4' x 8'	1	$55.98	$55.98
Final	**Acrylic**	24" x 36" x .177"	2	$37.95	$75.90
Final	**Wire mesh**	48" x 96"	1	$50.00	$50.00
	Total Material Cost				$222.07
Remaining Budget After Anticipated Materials Expenditures					$777.93
The remaining budget amount will be cash avialable for:					
	Tooling				
	Troubleshooting Expenses				
	Ink for printing				
	Packaging				
	Miscellaneous				

Table 2: Initial Budget

Fall Semester Initial Timeline

The final preliminary task completed by the team was the creation of a timeline that identified due dates for the fall semester milestones. The team thought the creation of a schedule would help to manage internal expectations and also provide a transparent view into the team's plan for the Center for Manufacturing Excellence technicians and staff. By creating a comprehensive timeline, the team was able to avoid certain scheduling conflicts and establish a greater degree of accountability for specific team member responsibilities. Although a few schedule changes were needed as the project matured, the majority of the deadlines seen in **Table 3** were accomplished in accordance with the original plan.

October 2, 2019	Lean 7 Ways event - product conceptualization
October 15, 2019	Design finalized and approved by technician
October 18, 2019	Low-cost mockup complete
October 25, 2019	Manufacturing procedure defined (standard work)
October 25, 2019	Midterm progress report
November 1, 2019	First prototype complete
November 15, 2019	Manufacturing process finalized
November 15, 2019	Final prototype complete
December 13, 2019	Team Presentation
December 14, 2019	Report due date

Table 3: Initial Timeline

II. RESEARCH AND PLANNING

Market Research

The kitchen appliances market is currently valued at $237 billion and is expected to reach $377 billion by 2027 due to an increased demand for easy and efficient cooking appliances around the globe [6]. This market is made up by hundreds of different companies from around the world that specialize in different product areas including Kitchen Aid, Cutco Corporation, Maytag, and LG to name a few. Currently, North America is the largest consumer in the global kitchen appliance market and is the primary consumer of the more high-end products such as smart kitchen appliances [6]. However, the Asia-Pacific market is likely to grow in profitability due to the demand for new and innovative appliances thanks to an increase in disposable incomes [6].

In 2019, the market for the kitchen knife industry represented almost $1.4 billion in sales [7]. Knife accessories were a large part of this number, accounting for nearly $150 million and is expected to increase roughly 5 percent over the next five years [7]. This creates the opportunity to attract customers from all over the world, increasing the reach of any kitchen product without region specific advertising. In addition, a recent attitude shift towards preparing meals at home is also helping to boost the kitchen gadget market. A 2018 poll conducting by the NPD Group, an American market research company, found that 82 percent of all meals consumed by Americans were prepared at home [8].

This drastic shift has largely occurred due to the new convenience and ease associated with preparing meals at home thanks to new innovative tools designed to aid any chef, experienced or not, in the kitchen. This also comes at a time where consumers are focused on living a healthier life which entails integrating more home cooking into their daily routines. Furthermore, a recent article in *The Economist* examining American consumer habits found that households are spending far less at restaurants but far more on groceries as well as certain kitchen related tools as a result of the stay-at-home orders that are currently in effect worldwide; however, the recent surge in unemployment may temporarily alter this trend [9]. In short, these new attitudes and habits will likely present a unique window of opportunity for firms interested in expanding into the kitchen appliance market.

The current market for cutlery storage devices is made up of thousands of products that range in price anywhere from $30 to $300. The designs vary in size and material as well as in customization ability. A majority of the knife blocks are made of low costing wood and bamboo while others feature acrylic and rubber exteriors. As far as storage styles go, there are four basic models that each have with their own pros and cons featured in **Figure 1**. There is the magnetic wall strip, the counter block or dock, the interior cabinet drawer dock, and the mounted storage block that attaches to the underside of the cabinet [10].

Figure 1: Kitchen Knife Block Styles

As shown in **Figure 2, t**he best selling knife block on Amazon features enough slots to hold 20 knives, measures 5.25" (W) x 11" (L) x 8" (H), is made of bamboo, and costs roughly $30 [11]. Additionally, the block features anti-skid rubber feet which prevents it from sliding around on one's counter thus reducing the possibly for injury or damage and also contains wide angled horizontal openings that may result in less wear on the blades.

Figure 2: 20 Slot Universal Knife Block

Additionally, the recent outbreak of the COVID-19 virus has confined essentially every individual to their residence leading to a spike in home cooking. Considering that there are roughly one million households in Mississippi, there is a high potential to successfully circulate a cutlery related product during these unique circumstances since most families are preparing food at their place of residence [12]. Regardless, the average household needs a safe, sterile environment to store their knives and most likely currently utilizes some variation of the kitchen knife block.

Government Regulations and Compliance

In the United States, kitchen appliance regulations are organized and enforced by Title 21 of the Code of Federal Regulations. This code provides general provisions applicable to indirect food additives used in kitchen appliances such as metals and plastics [13]. The Food and Drug Administration is responsible for overseeing and enforcing this policy. The materials used in kitchen appliances must be generally recognized as safe for food, which is commonly referred to by manufacturers as 'food grade' or 'FDA compliant' materials. For example, plastic containers in contact with the food or beverage shall not contain an excessive amount of restricted heavy metals and chemicals, which could pose health issues to consumers in long term use.

In order to verify 21 CFR compliance, third-party companies such as Bureau Veritas and SGS are required to conduct lab testing in order to certify that each product is safe. Food contact material testing costs approximately $200 per product and cost can increase due to the different materials and colors that the product is made out of [13]. Kitchen appliances must also comply with packaging requirements when shipping within the United States. Labeling requirements also apply to product packaging. For example, you shall also include Country of Origin and other compliance marks on the product's packaging.

Customer Analysis and Survey

In an effort to collect data regarding what consumers believed to be the most ideal design for a knife block, the team created an eight-question survey (**Appendix C)** that was administered to 80 individuals. The team believed that this would be a practical means to identify the features customers valued along with what material, size, and utilities would be attractive to most customers. The team decided to perform the survey prior to brainstorming design concepts in order to ensure that the initial design was driven by customer preferences. This input was very valuable and it was considered throughout the initial prototyping stage.

The questions included in the survey focused on design aspects such as desired material, cleaning method, size, exterior aesthetic, and overall individual preferences. Internally, the team was most interested in the resulting data related to the material and size of the knife block since these were the two aspects of the project that would make up the largest portion of the overall cost associated with producing the product. The resulting data would also guide the initial design since each team member had their own personal preference and ideas for the optimal knife block. However, the team was also very curious about what feature was most important to the customer since this would drive marketing efforts as the project evolved.

Unsurprisingly, 86 percent of participants preferred wood as the primary material for the knife block instead of metal or plastic. When asked about what would be the ideal cleaning method for the knife block, respondents favored either using the dishwasher or cleaning it by hand in the sink. In reference to the overall size, the most popular design was a short and wide block that would be 10 inches tall by 10 inches wide. Respondents also valued displaying their knives and the option to engrave the exterior surfaces of the knife block. This preference was again apparent in a separate question that asked what component was most important to the consumer which found that 40 percent of individuals preferred aesthetic. These results can be seen in **Figure 3.**

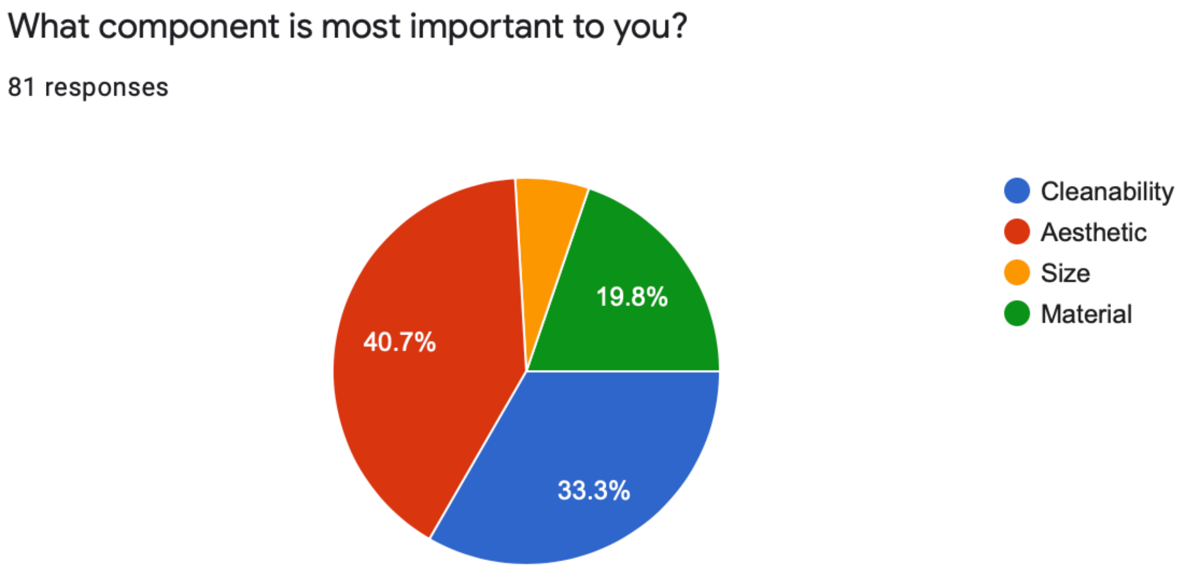


Figure 3: Survey Results - Overall Preference

Ultimately, the survey helped guide the team's understanding about which specific aspects consumers valued and what features would be most attractive to potential customers. Additionally, the survey helped align the team regarding the ideal size and material that the knife block should have been built with as well as if engraving the final product was a priority. This was also an effective means to gauge public interest in the proposed product and to evaluate what issues were actually affecting the average customer and how our product could stand out in the market.

Lean 7 Ways Brainstorming Event

The 7 Ways Idea Generation Form is a brainstorming tool that is used to encourage people to stretch their creativity. It is frequently used as a problem-solving technique but can be adapted to fit nearly any activity that requires an innovative solution. The basic premise is that this workshop is used to push people beyond their comfort zones in order to generate a series of unique ideas that could serve as either a stand-alone solution or as a contribution to another idea. The event outline consists of each team member independently producing multiple sketches that illustrate design concepts and then the team collectively ranks which sketches best address the design objectives and survey results that can most realistically be implemented or utilized [14].

The team decided that this would be an appropriate and useful approach during the early product development stage in order to create a knife holder design concept. The full project team participated in the workshop allowing for every member to contribute at least "7 ways" to solve the problem at hand. After sketching individual designs, the team organized the results into group related concept categories and then cast votes as to which concept group or family was best suited to produce a quality knife block that aligned with the survey results.

The outcome of this event was the selection of a vertical design concept that featured an array of essential characteristics related to the product. The design concept chosen was based on feedback from the customer survey, specifically which design constraints were most important to the consumer. Thanks to the success of the brainstorming event, the team was able to narrow down what specific components would contribute to the success of the knife block while also clarifying what the overall project goals were. Also, thanks to input from James McPhail, the operations manager, the team was able to settle on a design that was practical and achievable with regard to the technology and resources present within the Center for Manufacturing Excellence facility.

Product Requirements

After collecting data from the survey and Lean 7 Ways event, the team narrowed down a list of materials and product requirements that the team determined were essential to the success of the TKB 3000. From the start, the foremost concern was safety. In order to make sure that the finished product was sturdy, the team agreed that the placement of rubber feet on the bottom of the block was essential. The design would also need to incorporate thicker sides in order to provide a stable structure. This would prevent the block from sliding around on a kitchen countertop while ensuring structural rigidity when a knife was removed from the block.

The team also agreed that the finished product needed to be easily cleanable. One issue with most knife blocks currently available in retail stores was the inability to sterilize the entire block and clean out the deep slots that hold the knife in place on wooden blocks. To address this, the team agreed to design the block in such a manner that would not allow for dust, mildew, or bacteria to accumulate undetected. Similarly, it was deemed necessary to design a block that was ergonomic and aesthetically pleasing since it would likely be situated on a kitchen countertop. This led the team to focus on vertical designs with an open interior that could accommodate a variety of knife sets.

It was also important that the knife slots would not dull the knife edges over time since this was a common issue with the average knife block. This meant that the design would need to store the knives in a manner that didn't allow for unnecessary rubbing or blunting of the blade. In order to accomplish this goal, the team focused on a vertical storage design that did not require the knife to rest at an angle. At the same time, the slots needed to be narrow enough that the knives didn't wobble while remaining wide enough for easy removal.

Next, the team focused on appearance and size. The final product needed to be an aesthetically pleasing ergonomic design. To accomplish this, African mahogany and clear Lexan polycarbonate were the materials selected to create a vertically standing transparent knife block. This design allowed the customer to see their cutlery and would only take up a small portion of their kitchen countertop space. Additionally, Lexan has a high level of impact resistance and can handle temperatures up to 240 degrees Fahrenheit meaning it is structurally strong and dishwasher safe [15]. With these goals in mind, the team was ready to begin designing the TKB 3000.

III. DESIGN

Prototyping-Stage One

To better evaluate the overall size of the TKB 3000 design, the team constructing two initial models. Materials and tools used to create the models included ½" thick plywood, cap screws, and an electric drill. For the first model, the team used a radial arm saw to cut two side pieces (14" x 5") and a top piece (12'" x 5"). These pieces were assembled with an electric drill and screws. For the second model, all dimensions were adjusted to create a short and wide design to contrast the original tall and narrow model. This time the sides and the top piece were cut to measure 10" x 10".

After both initial models had been constructed, the team met to examine and discuss the pros and cons of both designs. The second design, a 10" x 10" x 10" square box, was quickly ruled out since it took up too much counter space and could not accommodate the longest knives in a typical knife set. The first model was also problematic because its narrow base was not structurally stable and would require additional support to reduce the possibility of tipping over. To resolve these issues, the team created a new design that resembled the first initial model which can be seen in **Figure 4**; however, a slight adjustment was made reducing the overall height in order to stabilize the knife block. This was accomplished by enlarging the base from 4” to 5” in order to improve its structural strength and stability of the block

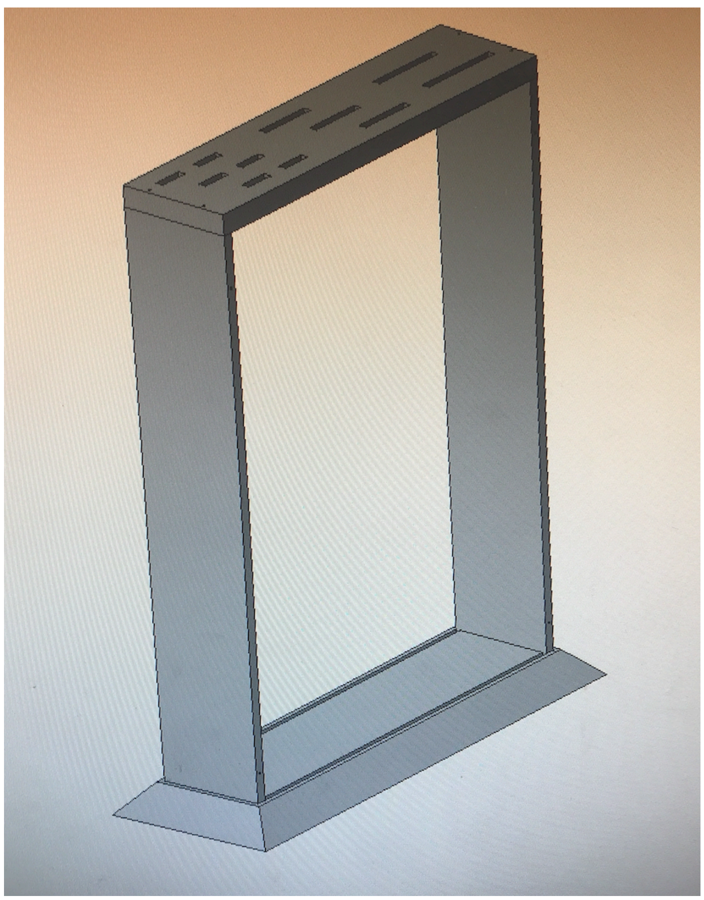


Figure 4: Original TKB 3000 Design

Prototyping-Stage Two

The second prototype was also constructed out of plywood and cap screws; however, this new design would incorporate the Lexan front, back, and top pieces. The two plywood sides were now cut with the radial arm saw to measure 12” x 5” while the Lexan front and back pieces were cut by the CNC water jet cutter with red garnet abrasive additive to measure 9.75” x 11.25”. The Lexan was intentionally cut to leave a small gap along the top and bottom of the block. This design allowed for airflow by shortening side panels, creating a path for air, rather than trapping moisture between knife support structure/top piece and the countertop.

The top piece was cut to measure 11.25” x 5” so that it sat flush on the block. Next, 1/8" pilot holes were drilled into the sides and top of each end piece using a drill press. The holes are located 1.5'' from the end of the wood piece and 0.375” from the side. These pilot hole relations were standardized for all drilling in order to increase quality because one jig can be used to locate every hole being drilled on the assembly. Finally, socket head screws were used to assemble the block.

One challenge that emerged from this round of prototyping was that the Lexan being cut with the water jet had leftover residue from the abrasive material used during the process. This leftover residue introduced a new problem that needed to be solved during this manufacturing process because the smudgy appearance needed to be eliminated or the lexan finish protected in some manner. Early ideas to solve this issue included using another machine to cut the lexan or potential sandblasting the top. This issue would be resolved in stage four with sandblasting.

The Lexan did achieve the desired effect of transparency and the block was now at the optimum height to accommodate the average knife set because the knife slots were designed to be longer than standard knife blade lengths to minimize contact between blade and knife support structure. Additionally, the team agreed to adjust the top piece by incorporating a slight overhang for the final designs. Without the overhang, it was difficult to grasp the knife block for moving or handling it. So, the new revised overhang, which added 1.5” onto the length of the block, allowed for lifting from the knife support surface rather than grasping the wooden sides. The team also agreed to incorporate the use of a clear wood sealant in order to protect the wood and give it a more refined appearance.

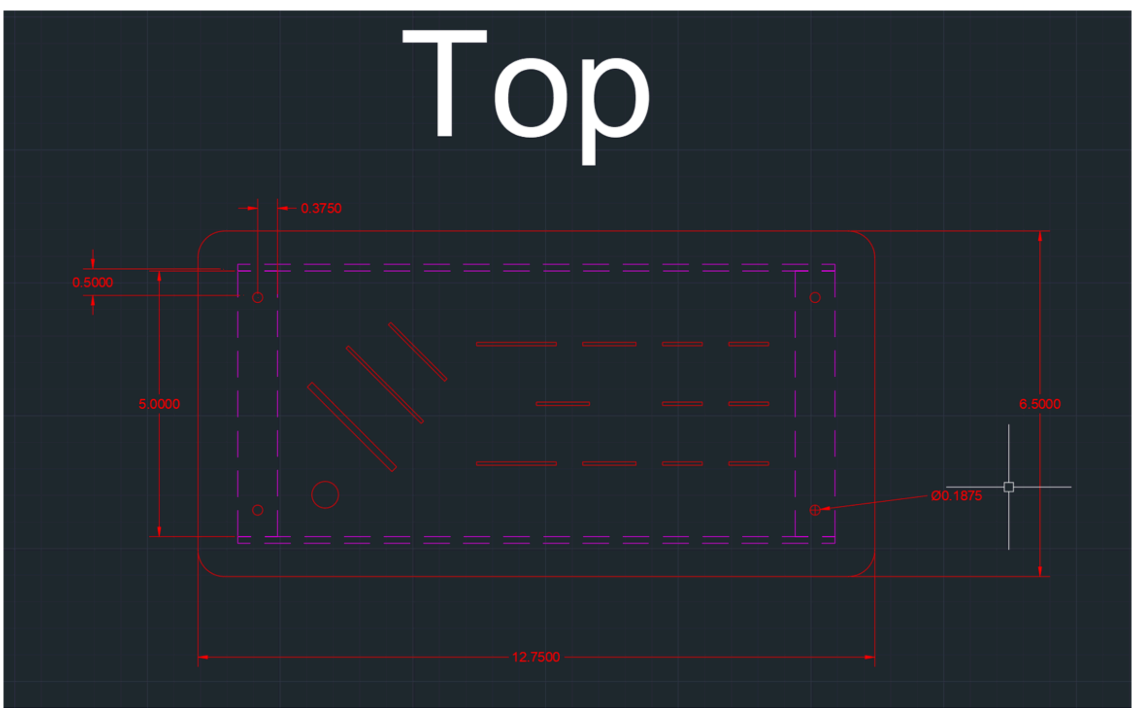
Prototyping-Stage Three

The third prototype was created using African mahogany as well as the Lexan and cap screws. The construction method remained the same; however, the new design incorporated a slight overhang on both ends of the block. The measurement of the top Lexan piece was now 12.75” x 5”. Additionally, the wood sealant was added during this production immediately following when the side pieces were cut. Also, a planer was used to make sure that the African mahogany thickness was exactly 0.75”. This was slightly larger than the plywood and provided a little more overall stability.

Unfortunately, the new overhang also looked objectionable so the team worked to improve the design again. The team agreed that a uniform overhang would look better and so the design was once again changed. Since production grade material was wasted during this prototyping stage, the team reverted to using plywood in order to cut expenses and avoid using up the bulk order of mahogany. After editing the design again, the team was ready for another build. Up to this point, prototyping had gone smoothly besides a few minor adjustments and the team was ahead of its self-imposed deadline.

In light of this, production temporarily slowed allowing for a chance to experiment with different methods of cutting the Lexan. This was an important development since the reliance of the CNC water jet had the potential to slow production and consume a large portion of the team's budget. Also, the team was able to redesign the top piece so that the CNC cut knife slits were slightly tighter. The final knife slot dimensions were 1" x 2.25" (chefs knife), 1" x 2" (kitchen/ utility knife), 1" x 1.75"(carving knife), 2" x 1.5" (bread & slicing knife), 3" x 1" (paring & filet knife), 6" x .75" (steak knife). This eliminated a slight wobble that occurred when a knife was placed in the slot and contributed to a more uniform appearance overall. Additionally, the number of slots on the top piece was finalized to include room for nine small blades, three medium sized blades, two large blades, and one knife sharpening rod which can be seen in **Figure 5**.

Figure 5: CNC Layout - Top



Prototyping-Stage Four

For this design, every dimension remained exactly the same except for the top Lexan piece. The new piece was cut to 12.75” x 6.5” to allow for total overhang. This adjustment created a more uniform look on the knife block and would be the final dimension adjustment made throughout the process. However, the team identified ways to improve the Lexan’s appearance and durability by applying a Krylon clear coating as well as sandblasting the top piece. The desire to sandblast the top arose after a blade scratched the top during insertion of a steak knife, resulting in an unattractive blemish. To resolve this, the team incorporated an additional production step in the standardized work chart as well as ordered a can of Krylon to experiment with.

Figure 6: Fourth prototype before krylon coating

Prototyping-Stage Five

Finally, the team entered the last prototyping stage. The last design incorporated all improvements up to this point and was built using production grade material. The resulting knife block was quite different from the original design. Both the wood and Lexan had been coated with protective finishes in addition to the sandblasting of the top Lexan piece. The CNC cut knife slots were tighter, the overhang had been perfected, and the team was satisfied with the results. Additionally, the rubber pads were finally attached to the bottom of the wooden side pieces to enhance overall stability. Thus, it was finally time to showcase the final design that can be seen in **Figure 7** and prepare for the manufacturing floor production run.

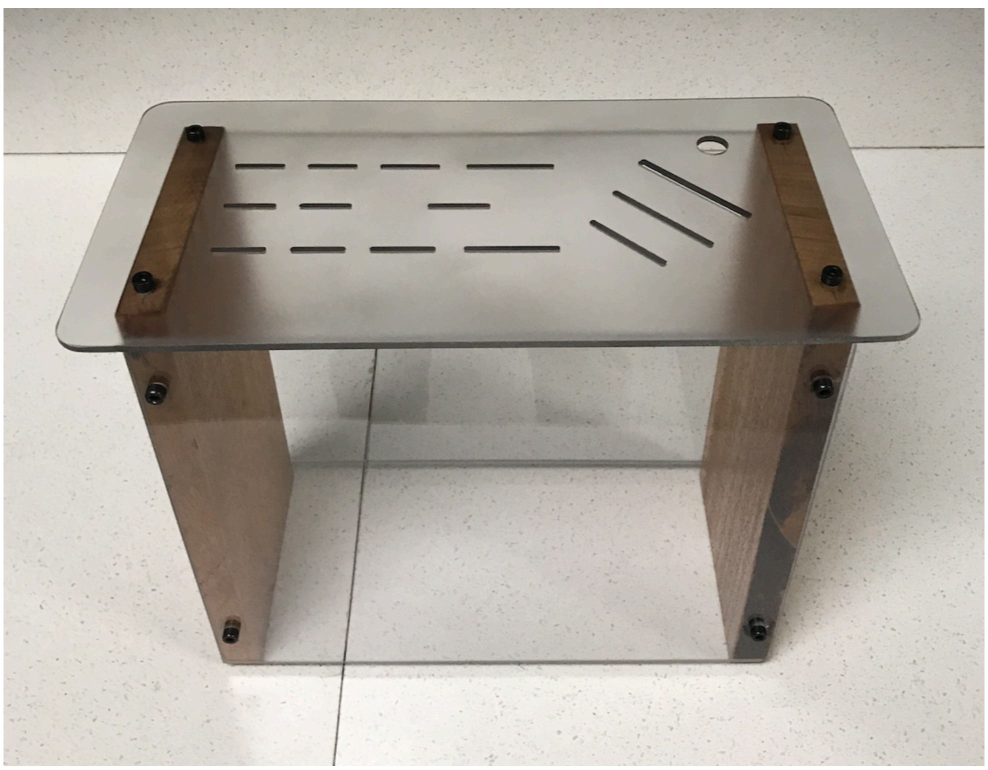


Figure 7: Finalized Design of the TKB 3000

Lessons Learned: Materials and Procedures

At this point, multiple resources had been utilized to construct the TKB 3000. On the CME factory floor, the team had utilized the CNC Router, CNC water jet cutter with red garnet abrasive additive, manual drill press, radial arm saw, planer, electric drill, belt sander, and the sandblaster. The switch from the water jet to the CNC occurred due to the determination that the water jet was a costly tool to operate and would unacceptably impact project profit margins. Although still expensive, the CNC router was more cost effective and quicker to set up so the tooling change was incorporated into the production plan. Materials at this point included the African mahogany boards, Lexan sheets, hand screws, Krylon coating, wood sealant, rubber pads and plywood.

The use of plywood in the early stages aided with saving valuable materials and provided a comparable resource that could be used to experiment with. The dimensions of the plywood were nearly identical to the African mahogany boards allowing for comparison between prototypes of different material. Also, the iterative prototyping process allowed the team to gain a better understanding of the tolerances and challenges associated with building this product. This period also helped the team identify design limitations while also planning for future challenges of a full-scale, streamlined production process like tolerance limitations on different tools. The construction of multiple prototypes provided ample time to test different construction methods and understand how to efficiently perform the manufacturing procedures. The prototyping stage created a unique opportunity to identify strengths and limitations of the chosen materials. For example, the team learned the importance of the pilot holes early on when the wood side pieces split while being drilled together.

Furthermore, having the chance to test the TKB 3000's functionality was an important part of the process that enabled multiple improvements for both aesthetic and functional components such the knife slot tolerances and the Lexan top overhang. The team was also able to showcase the many prototypes to different audiences in order to gauge consumer response and gain valuable input as to which materials and coatings were preferable and would support a higher profit margin. Additionally, the chance to work together and brainstorm as a project team served as an educational experience that required frequent communication between team members. Fortunately, the team worked well together and were always receptive to suggested improvements and procedural adjustments.

Financials

Throughout the design process, the various costs incurred during prototyping were recorded and considered in an effort to estimate the potential cost and price of a mass-produced knife block. The material cost estimate for the prototype was developed prior to fabrication and adjusted as new materials were introduced. The material costs for the prototype was broken down to a per unit basis in order to better evaluate how each expense impacted the overall value and return on investment. Material costs also accounted for any scrap produced during the production process. Additionally, since the cost was estimated based on prototyping and small-scale production costs, freight or shipping costs were not included in the initial estimate.

Based on the team's market research, customer input, and goal to produce a profit margin of at least 20%, the original target price of the TKB 3000 was set at $110. When determining the profit margin, the team agreed that it was ideal to start at a higher product price in order to accommodate higher manufacturing costs if necessary. Using the roughly 20 minute takt time (takt time is the average time between the start of production of one unit and the start of production of the next unit, when these production starts are set to match the rate of customer demand [16]) from the prototyping runs and a 2080-hour work year, the annual sales volume was calculated to be 6,240 parts which can be found in **Table 5**. The labor costs were rough estimations based on minimum wage labor rates in the state of Mississippi [17]. Material costs are shown in the BOM in **Table** 6, the equipment rental rates are shown in **Table 7**, and the price of purchasing the equipment is shown in **Table 8**. Overhead costs were taken into account with the profit margin calculation performed on the total material and labor cost per unit, as some of the profit margin could cover overhead costs as they were incurred.

Once the final design was complete, a Bill of Materials was developed for the final version of the TKB 3000. The costs presented in the Bill of Materials were expected to decrease as process improvements and efficiencies identified cost saving opportunities. The team had also hoped to reduced the need for one of the operators, thus reducing direct cost and potentially simplifying the production line all together. The team had also anticipated future outsourcing of the fabrication of the Lexan components since this accounted for the largest expense associated with the use of the CNC router. This is evident in the rent vs. buy analysis illustrated in **Table 11** as the option to rent never becomes more cost effective.

The purchase price and rental prices were based on cost estimates given in the Center for Manufacturing Excellence equipment log [18]. The rent vs. buy analysis was performed based on a 5-year projection and a 5-year, straight-line depreciation method on the purchased equipment. The annual profit subtotal used in the analysis was based on the assumption that 6240 units would be fabricated and sold each year for $110.00 each. When using rented equipment, the cost to fabricate each unit sold was $131.05. This costed -$21.05 per unit and -$131,356 per year to operate. When using purchased equipment, the cost to fabricate each unit sold was $94.55, yielding a $15.45 profit margin per unit and totaling $96,393.95 of profit per year. The rent vs. buy analysis showed that if the required equipment was rented, the TKB 3000 would lose almost $2,000,000.00 after five years of operations. However, obtaining the $84,250.05 needed to purchase the equipment would yield a profit of nearly $230,000.00 after five years.

Even in the face of tool depreciation, the obvious choice would be for the team to invest in their own means of production if the goal is to produce the TKB 3000 with outsourcing production. If 6,240 units can be produced and sold, the annual profit would accommodate for the $76,000 expense of purchasing another CNC router if required in the future.

Table 4: Original Bill of Materials

Amount Avialable for Anticipated Expenditures:						$1,000	
Anticipated Expenditures:							
	Materials						
	Material	Dimensions	# of Orders	Cost per Order	Material Cost for Prototypes	Material Cost for 8 Final Products	Cost per Final Product
Initial	**Cardboard**	Scrap	1	$ 0.01	$ 0.01		
Initial	**Wood**	Scrap	1	$ 0.01	$ 0.01		
Initial	**Fasteners**	Scrap	1	$ 0.01	$ 0.01		
Prototype	**African Mahogany**	10' x 5" x 1"	1	$ 58.80	$ 58.80		
Prototype	**Lexan**	48" x 96" x 1/8" (27%)	1	$ 50.22	$ 50.22		
Prototype	**Hand Screws**	100	1	$ 26.48	$ 26.48		
Prototype	**Self Stick Rubber Pads**	(16) 2" x 2"	1	$ 9.99	$ 9.99		
Prototype	**Krylon Clear Coating**	6 oz	1	$ 5.69	$ 5.69		
Final	**Krylon Clear Coating**	6 oz	2	$ 5.69		$ 11.38	$ 1.42
Final	**African Mahogany**	48" x 5" x 1/2"	6	$ 25.99		$ 155.94	$ 19.49
Final	**Lexan**	48" x 96" x 1/8" (73%)	1	$ 186.00		$ 135.78	$ 16.97
Final	**Hand Screws**	100	1	$ 26.48		$ 26.48	$ 3.31
Final	**Rubber Pads**	(16) 2" x 2"	2	$ 9.99		$ 19.98	$ 2.50
	Material Cost Subtotals				$ 151.21	$ 349.56	**$ 43.70**
	Total Material Costs					**$ 500.77**	
Remaining Budget After Anticipated Materials Expenditures						**$ 499.23**	
The remaining budget amount will be cash avialable for:							
	Additional Lexan						
	Tooling						
	Troubleshooting Expenses						
	Packaging						
	Miscellaneous						

Table 5: Production Information

Production Information		
Hours per Work Year	hrs/year	2080
Labor Wage	$/man hour	$10.00
# of Workers	man	3
Takt Time	hrs/part	0.33
Direct Labor	$/part	$10.00
Outsourced Labor	$/part	$0.00
Total Direct Labor	$/part	$10.00
Annual Sales Volume		6240

Material	Description	Bulk Dimensions	Quantity per Unit	Bulk Cost	Per Unit Cost	Comments
African Mahogany	Material for side pieces	½" x 8" x 120"	(x2) side piece 5" x 10"	$60.00	$10.00	6 knife blocks per board
Lexan	Material for top, front, and back pieces	⅛" x 96" x 48"	(x1) top piece 12.75" x 6.5" (x2) front/back piece 11.5" x 10"	$186.00	$13.29	14 knife blocks per sheet
Krylon Clear Coating	Coating for protective gloss finish	12 oz (per can)	~3 sq ft	$5.69	$0.95	6 knife blocks per can
Socket Head Screws	Connects wood sides to Lexan pieces	⅜" (100)	12	$26.48	$3.18	8 knife blocks per box
Self Sticking Rubber Pads	Prevents sliding on kitchen counter	2" x 2" (16)	1.33	$9.99	$0.83	12 knife blocks per pack
			Total Material Cost per Unit		$28.25	

Table 6: Updated Bill of Materials

Machine	Hourly Rental Cost
Radial Arm Saw	$10.00
Planer	$10.00
Drill Press	$10.00
CNC Router	$100.00
Belt Sander	$10.00
Sand Blaster	$10.00
Hours per Year	2080
Total Rental Cost per Year	$312,000.00
Total Rental Cost Per Unit	$50.00

Table 7: Equipment Rental Rates

Machine	Purchase Price
Radial Arm Saw	$298.86
Planer	$4,082.19
Drill Press	$1,999.00
CNC Router	$76,047.00
Belt Sander	$724.00
Sand Blaster	$1,099.00
Total Expenditure	$84,250.05
Total Expenditure per Unit	$13.50

Table 8: Equipment Purchase Prices

Production Cost and Sales Price Information (Rent)					
				Total	Per Unit
Sales				**$686,400.00**	**$110.00**
Variable Costs					
	Direct Material		$176,280.00		
	Direct Labor		$62,400.00		
	Variable Manf. Overhad		$167,076.00		
		Total		$405,756.00	$65.02
Contribution Margin				**$280,644.00**	**$44.98**
Fixed Costs					
	Fixed Manf. Overhead		$312,000.00		
	Fixed SG&A Expenses		$100,000.00		
		Total		$412,000.00	$66.03
Operating Income				**-$131,356.00**	**-$21.05**

Table 9: Production Cost and Sales Prices Information (Rent)

Production Cost and Sales Price Information (Buy)					
				Total	Per Unit
Sales				**$686,400.00**	**$110.00**
Variable Costs					
	Direct Material		$176,280.00		
	Direct Labor		$62,400.00		
	Variable Manf. Overhad		$167,076.00		
		Total		$405,756.00	$65.02
Contribution Margin				**$280,644.00**	**$44.98**
Fixed Costs					
	Fixed Manf. Overhead		$84,250.05		
	Fixed SG&A Expenses		$100,000.00		
		Total		$184,250.05	$29.53
Operating Income				**$96,393.95**	**$15.44**

Table 10: Production Cost and Sales Price Information (Buy)

	Rent vs. Buy Analysis - Production of 6240 Units					
Year Number	**Rent Annual Profit: Subtotal**	**RENT**	**Profit: Assuming Rent**	**Buy Annual Profit: Subtotal**	**BUY**	**Profit: Assuming Buy**
Year 1	-$131,356.00	-$312,000.00	-$443,356.00	$96,393.95	-$84,250.05	$12,143.90
Year 2	-$131,356.00	-$312,000.00	-$443,356.00	$96,393.95	-$67,400.04	$28,993.91
Year 3	-$131,356.00	-$312,000.00	-$443,356.00	$96,393.95	-$50,550.03	$45,843.92
Year 4	-$131,356.00	-$312,000.00	-$443,356.00	$96,393.95	-$33,700.02	$62,693.93
Year 5	-$131,356.00	-$312,000.00	-$443,356.00	$96,393.95	-$16,850.01	$79,543.94
5 Year Profit Forecast:			-$2,216,780.00	-		$229,219.60

Table 11: Rent vs. Buy Analysis

IV. PRODUCTION

Challenges

The spread of COVID-19 led to the closing of the CME and suspended indefinitely the team's ability to conduct a manufacturing run on the factory floor. As a result, the team decided to create a standard manufacturing procedure that would guide an operator tasked with constructing the TKB 3000. The standard work chart is made up of 23 separate steps and a cell layout that depicts the process flow and also includes a change log and a list of potential issues that may arise. The chart would also document cycle times, work times, and even walk times to trace every second of production. The original plan was to have three operators working on an assembly line. Each individual would have been assigned a different set of tasks. One individual would work exclusively on the Lexan procedures, one would work exclusively on wood related tasks, and the third would be tasked with assembling the final product and packaging the knife block at the end.

Procedure

Operator A: Begin by retrieving the African mahogany board and proceeds to the planeing station. Plane board to 3/4" uniform thickness (1 pass on each side). Then, use the radial arm saw to cut 2 wood end pieces to 5" x 12". Next, use the drill press with 11/16" diameter drill bit to drill 4 pilot holes in each side and top piece at locations shown on drawings. Once complete, place cut end pieces on the work table and apply spray sealant to end pieces. Leave sealant covered pieces on table in the upright position in fixture to dry. Place wood end pieces in assembly fixture so the front of the knife block is oriented upward.

Operator B: Retrieve Lexan sheet and position it on router table. Initiate program to cut Lexan top, front, and back pieces. Place cut Lexan front and back pieces on assembly area table. Next, take the top piece (slotted) made of Lexan to the sandblast booth and sandblast both sides. Finish by cleaning the piece with compressed air and spray with one coat of Krylon clear coat on both sides before placing the top on drying hooks on work table.

Operator C: Position front Lexan piece (no slots) on wood end pieces and insert 4 socket head screws through Lexan into the side of each end piece. Next, use electric screwdriver to tighten screws until secure and ensure proper alignment. Then flip the knife block assembly and repeat previous 3 steps for rear Lexan piece. Now, orient knife block in the fixture so the top is facing up. Locate the slotted Lexan piece on top of the assembly and hand start thumb screws through Lexan into the top of each wood end piece. Use electric screwdriver to secure all screws. Flip assembly 180 degrees. Remove wax paper from rubber mat and place 1 rubber pad on each wood corner of the assembly flush with the edges at each corner. Perform final inspection for quality, and cleanliness, then package for shipment. Place completed and packed product into “finished goods” bin.

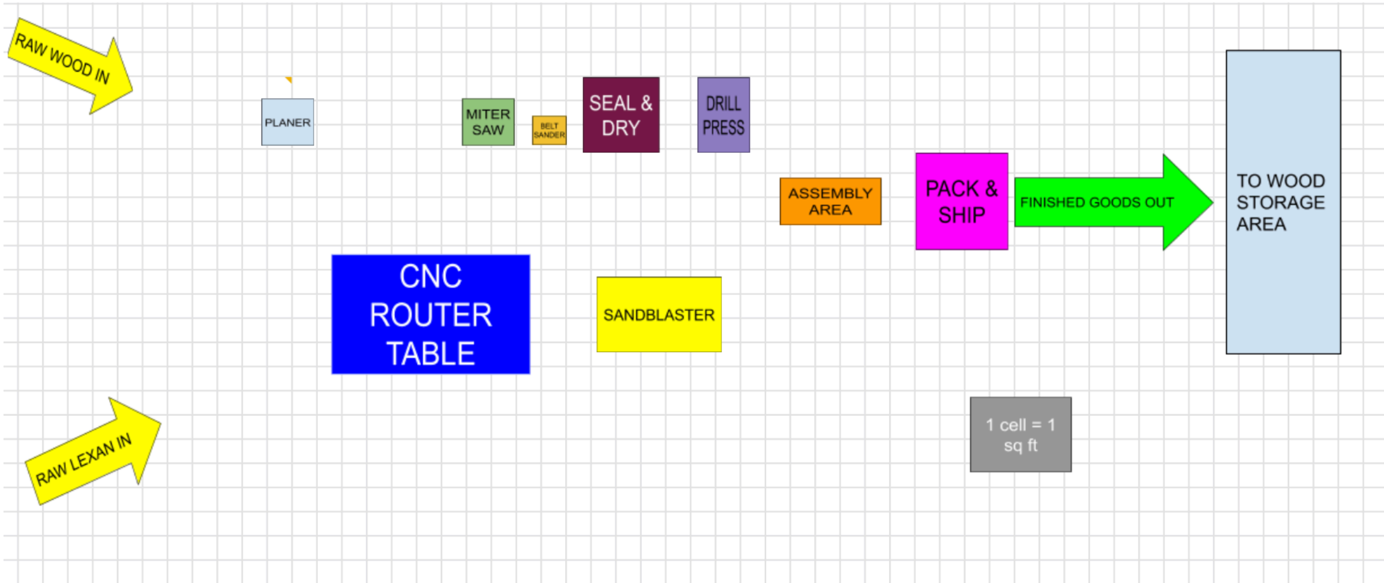


Figure 8: Cell Layout

Unknowns and Potential Issues

One of the main potential vulnerabilities of this procedure is the lack of quality checks at each assembly point. Without having the opportunity to perform a trial production run, it is difficult to identify where quality inspections should be interjected. In the current assembly process, it is very likely that operator A and operator B will complete their tasks prior to operator C. This could lead to a backlog of components waiting to be assembled. The machine runtimes are also unknowns which is a key factor in establishing a routine or path for materials to follow. One solution could be to mitigate operator A & B early task completion by rebalancing work currently assigned to operator C using cross-training. The team could reassign packaging and material preparations (screws, rubber pads, etc) responsibilities to operator A and/or B as time permits.

There is also a possibility for clutter or disorganization in each operator's work station. A solution to this problem would be a simple assembly table layout bin or outline that shows where to store parts and tools. Also, operators could benefit from having visual aids at the workstations to provide guidance of proper component orientation because there are multiple tasks that require the operator to correctly position parts and secure them with screws. The assembly steps that involve tool use and component positioning could be addressed utilizing a simple poke yoke or outline on the workstation to ensure that the operators perform assembly operations consistently and in an efficient manner. Additionally, rotating components and assembly manipulation was to be mitigated by designing a labeled fixture that the assembly would fit into in different positions at consecutive stages of the production process. This fixture plan was prototyped but not completed or tested due to the COVID-19 pandemic. Providing tight tolerances on assembly fixtures would also serve as a quality check, because out-of-tolerance components would not fit in the fixtures correctly.

There is also the potential to establish a batch and queue system so that parts aren't bottlenecking or so that operators are not without a task while waiting for another operator to complete their tasks. It is important that the operators are provided the same quantity of components though in order to avoid an excessive inventory of parts at one work station or a shortage at another. This could be prevented by implementing inventory controls or storing components in bins with specific quantities to ensure that operators have needed components for the expected production rate.

In order to manage process improvements, design changes, or other revisions, the team has also established a "change log". For example, one team member observed that the hole drilling procedure specified a drill bit that created an oversized hole, which could result in misaligned components during assembly. In another instance, it was identified that the instructions pertaining to assembling the Lexan and wood components were out of order. Both issues were entered into the change log to ensure that they were evaluated and addressed and to create a record for potential future reference.

V. CONCLUSION

Future Considerations

The team performed well at identifying potential issues and collaborating to find multiple solutions to any given problem. The main unaddressed concern of the project is that there may be latent design, fabrication, or assembly issues or improvement opportunities that could have been identified, corrected, or otherwise addressed during the planned production run that could not be performed due to the pandemic. The team had planned to closely observe each fabrication and assembly operation and identify quality control points that could be addressed either through training, operator aides, self-checking, peer checking, quality gates, or adding an independent quality control inspection step to the procedures prior to packaging if necessary. Due to the relative simplicity of the fabrication and assembly steps required, it was believed that additional controls may be unnecessary and therefore not cost-effective, but without the benefit of a production run this determination could not be made with confidence.

In addition, the team believes that the product could be more attractive to potential customers if the option was available to customize different aspects of the product. For example, if the customer was able to either engrave a company or team name or logo, wedding date, etc. on either the wood or Lexan components, choose another wood, or even have the option to sandblast different Lexan parts, the TKB 3000 could become more desirable with a higher resale value and profit margin. If the product is popular, additional lines will need to be added or some steps automated to improve the maximum production rate which is currently estimated at three blocks per hour. This could also involve outsourcing some manufacturing steps which may also result in cost savings or production improvements.

Lessons Learned

Without being able to perform a true production run, the team had to use best judgement on many issues. Takt time/cycle time is also a notable unknown; however, data collected from the prototyping stage indicated that 3 units could conservatively be created each hour. Additionally, the lack of a production run left open the possibility that defects could occur requiring rework or material waste. However, the ability to provide clear directions and guidelines to the operators at each work station should be adequate to address potential problems.

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VII. APPENDIX

Appendix A: Engineering Drawings

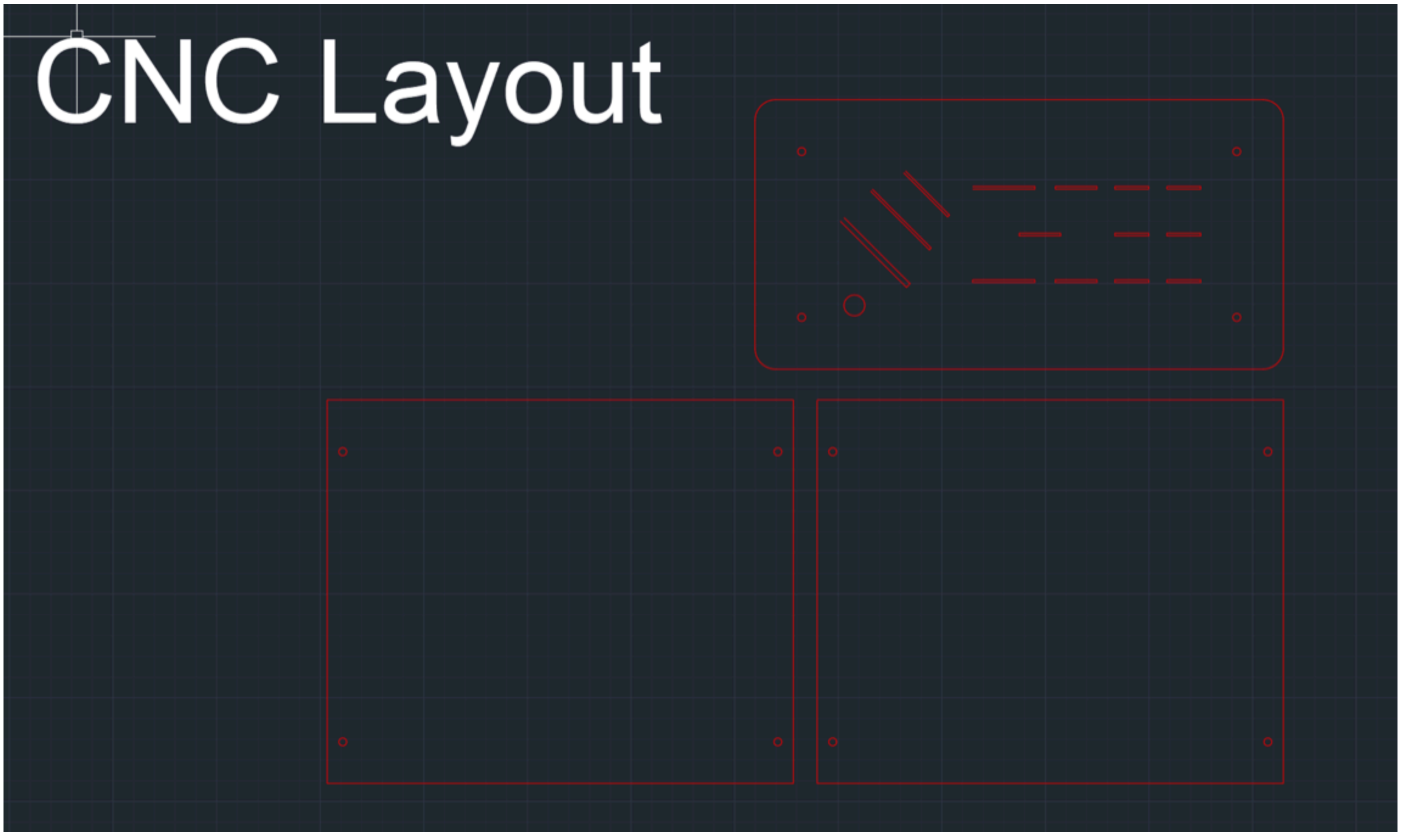

Figure A1: CNC Layout Overview

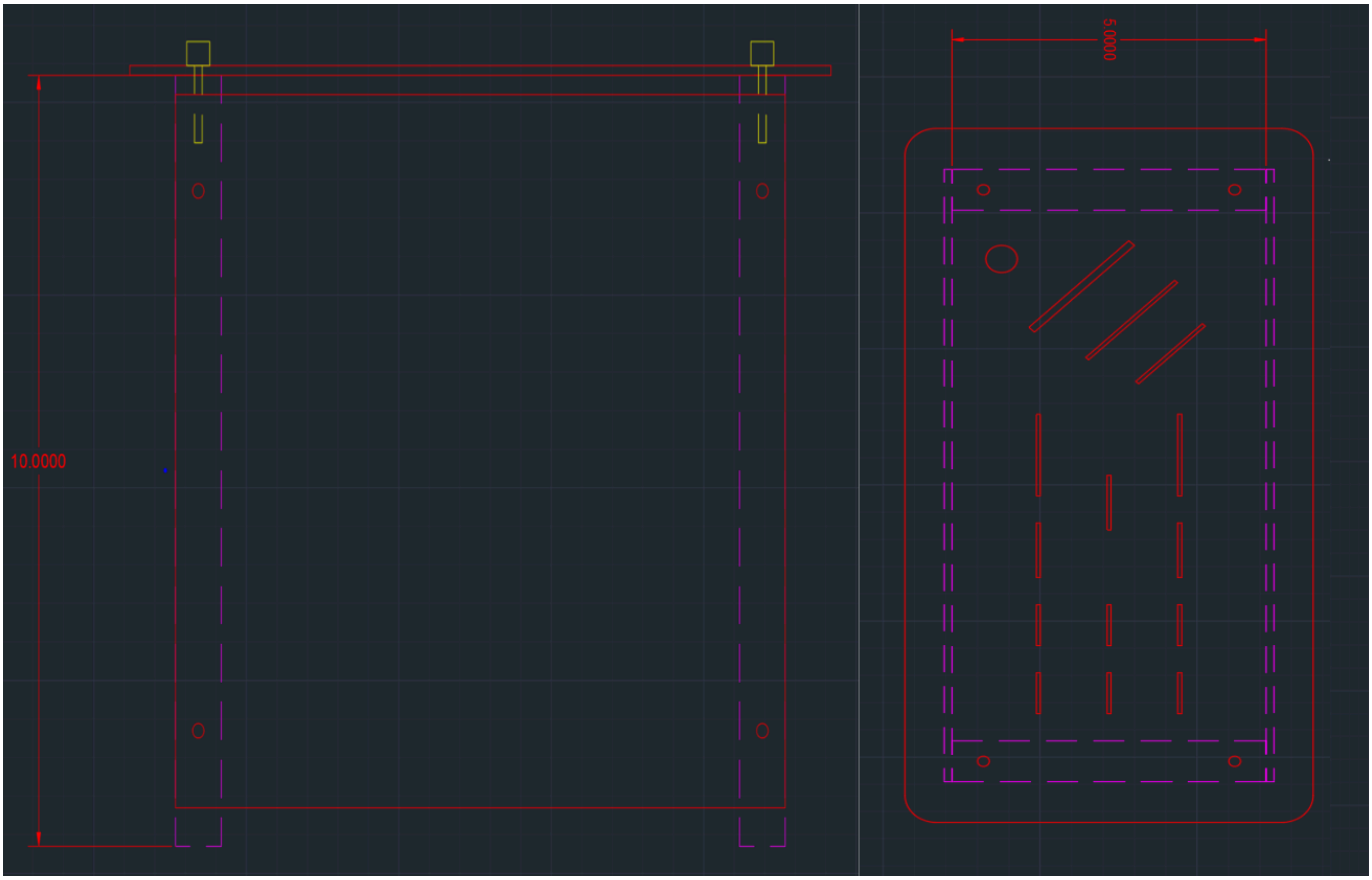

Figure A2: CNC Layout - Top and Side Pieces

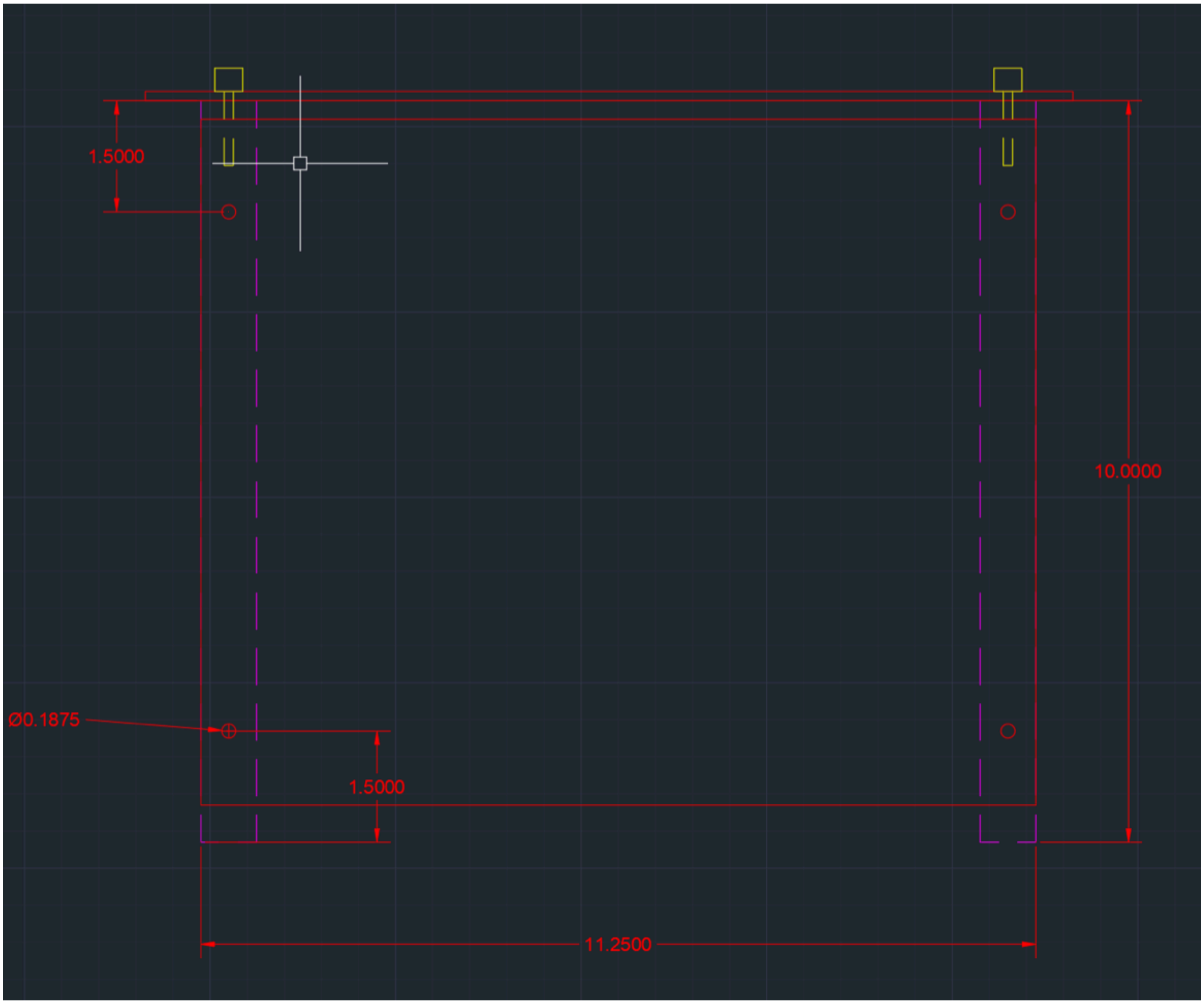

Figure A3: CNC Layout - Side Dimensions

Appendix B: Unit Assembly Standard Work

#	Instructions	Work	Walk	Wait	Actual cycle	Safety/quality	material used	tool used	assembly/fal
1	retrieve african mahogany board		1				African Mahogany	hand	fabrication
2	Plane board to 3/4" uniform (1 pass on each side)	3				S	african mahogany	planer	fabrication
3	cut 2 wood end pieces to 4"x12"	5			6	SQ	African Mahogany	bandsaw/WJ	Fabrication
4	drill pilot holes in sides and top	2				SQ	African Mahogany	drill press/WJ	Fabrication
5	place end pieces on laser etcher	0.5		10			African Mahogany	laser etcher	fabrication
6	place cut and etched wood end pieces on work table		2			Q	African Mahogany	hand	Fabrication
7	apply spray sealant to end pieces and set upright in fixture to dry	1		10			African Mahogany, Sealant	sealant	Fabrication
8	retrieve Lexan		1				Lexan	hand	fabrication
9	cut Lexan top and 2 side pieces	5				SQ	Lexan	bandsaw/WJ	Fabrication
10	sandblast top piece.	3	1			S	lexan top piece only	sandblaster	finishing
11	place cut lexan on work table		1				Lexan	hand	assembly
12	retrieve driver, screws, rubber pieces, thumb screws to work table		2			S	Thumb Screws	hand	assembly
13	place end pieces in assembly fixture.	0.5					African Mahogany	hand	assembly
14	hand start screws through lexan into the side of each end piece	1				Q	Lexan, Thumb Screws	hand	Assembly
15	use driver to fasten screws through lexan into end pieces at drill setting ____ until secure.	1				SQ	African Mahogany, Lexan	electrical screwd	Assembly
16	repeat previous 2 steps for opposite side lexan piece	2.5			9.5	SQ	African Mahogany, Lexan	hand, electrical s	Assembly
17	place top Lexan piece on top of end pieces. place assembly in fixture.	0.5				Q	African Mahogany, Lexan	hand	Assembly
18	hand start thumb screws through lexan into the top of each end piece, leaving 1/2" of the screw exposed	1				Q	thumb screws	hand	Assembly
19	apply spray sealant to joints.	2				Q	African Mahogany, Lexan, Sealant	sealant	Finishing
20	Secure thumb screws into top of each end piece.	1				Q	African Mahogany, Thumb Screws	hand	Assembly
21	place rubber mat on bottom of wooden end pieces	1.5				Q	African Mahogany, Rubber, adhesive??	hand	Assembly
22	place assembly in shipping packaging	3					Packing Materials	hand	Finishing
23	seal packaging	1				Q	Packing Materials	hand	Finishing

Figure B1: Preliminary Standard Work

CHANGE LOG				
Change #	**Change made**	**Date made**	**Document changed**	**Change made by**
1	Remove laser etching step from SW	3/27/2020	Updated-whole process SW	Commer
2	Remove equipment staging step from SW (replaced by Kanban bins)	3/27/2020	Updated-whole process SW	Commer
3	add sand & clean step to SW	3/27/2020	Updated-whole process SW	Commer
4	drop seal & dry walk time due to layout change	3/27/2020	Updated-whole process SW	Commer
5	call out electric screwdriver as assembly tool rather than hand drill	3/29/2020	Updated-whole process SW	Commer
6	detail & work time added to seal spray instruction	3/29/2020	Updated-whole process SW	Wilson
7	2 cuts on miter saw rather than 1 cut on table saw, 1 on miter saw for 5x10"	3/29/2020	Updated-whole process SW	Wilson/Commer
8	pilot hole diameter clarified - 11/16" in prototype, 1/8" on dwg			Wilson

Figure B2: Change Log

Step #	Process step	S/Q	Work time	Walk time	Wait time
1	retrieve african mahogany board from raw material storage.			1	
2	Plane board to 3/4" uniform thickness	S - fingers, sawdust inhalation	10		
3	cut 2 wood end pieces to 5"x10" using miter saw. Cut 10" length then 5" width for each board.Use stops or guides to ensure correct	Q - dimensions	6		
4	drill 1/8" pilot holes in sides and top of each end piece using drill press. The holes are located 1 1/2" from the end of the wood piece and 3/8" from the side.	Q - alignment is critical	2		
5	Using belt sander, lightly sand edges to remove debris. Clean pieces using shop air.	S - sawdust inhalation	3		
6	cut 2 wood end pieces to 5"x10" using miter saw. Cut 10" length then 5" width for each board.Use stops or guides to ensure correct			0.5	
7	Apply spray sealant to end pieces. hang on drying hooks & continue to next step.	S - fumes & sawdust inhalation	1.5		0
8	retrieve Lexan sheet & position it on router table/waterjet.			1	
9	initiate program to cut Lexan top and 2 front and back pieces.		0.5		5
10	place cut Lexan front and back pieces on assembly area table.			1	
11	sandblast both sides of top (slotted) Lexan piece then clean with shop air. spray with one coat of Krylon clear coat on both sides. hang on drying hooks.	Q - even coats of sandblast + sealant	5	0.5	
12	place wood end pieces in assembly fixture so the front of the knife block is oriented upward.		0.5		
13	Locate front (no slots) Lexan piece on wood end pieces.	Q - alignment	0.5		
14	hand start screws through lexan into the side of each end piece	Q - stripped screws/split wood	1		
15	use electric screwdriver to fasten screws through lexan into end pieces until secure. Ensure proper alignment.	Q - split wood, overtightening or misalignment	1		
16	flip knife block assembly and repeat previous 3 steps for rear lexan piece.		2.5		
17	orient knife block in the fixture so the top is facing up. locate the slotted Lexan piece on top of the assembly.		0.5		
18	hand start thumb screws through lexan into the top of each wood end piece.	Q - alignment	1		
19	Use electric screwdriver to secure all screws.	Q - stripped screws/split wood	1		
20	Flip assembly 180 degrees. Remove wax paper from rubber mat and place 1 flush on each wood corner of the assembly.	Q - alignment & not fucking up the adhesive by touching it	1.5		
21	pP		1.5		
22	place assembly in packaging		3		
23	seal packaging & place in "finished goods out" bin		0.5	0.5	

Figure B3: Updated Standard Work

Appendix C: Survey Results

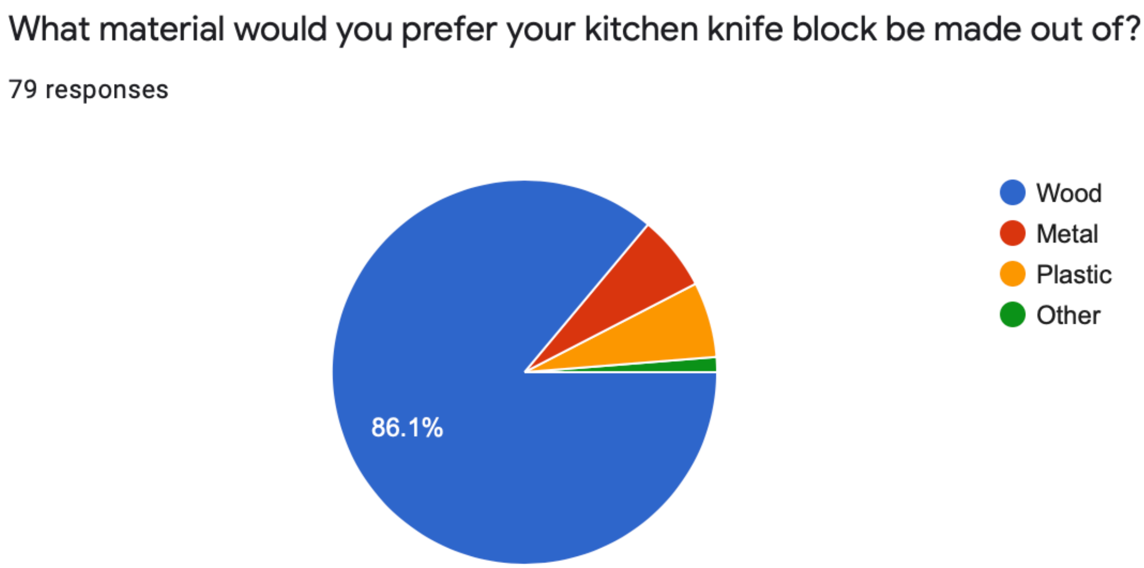

Figure C1: Material

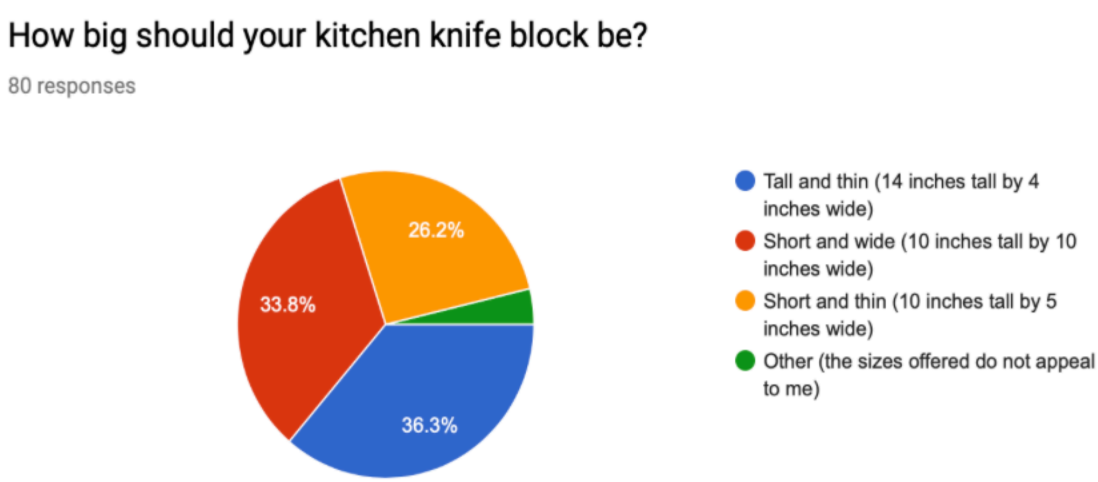

Figure C2: Size

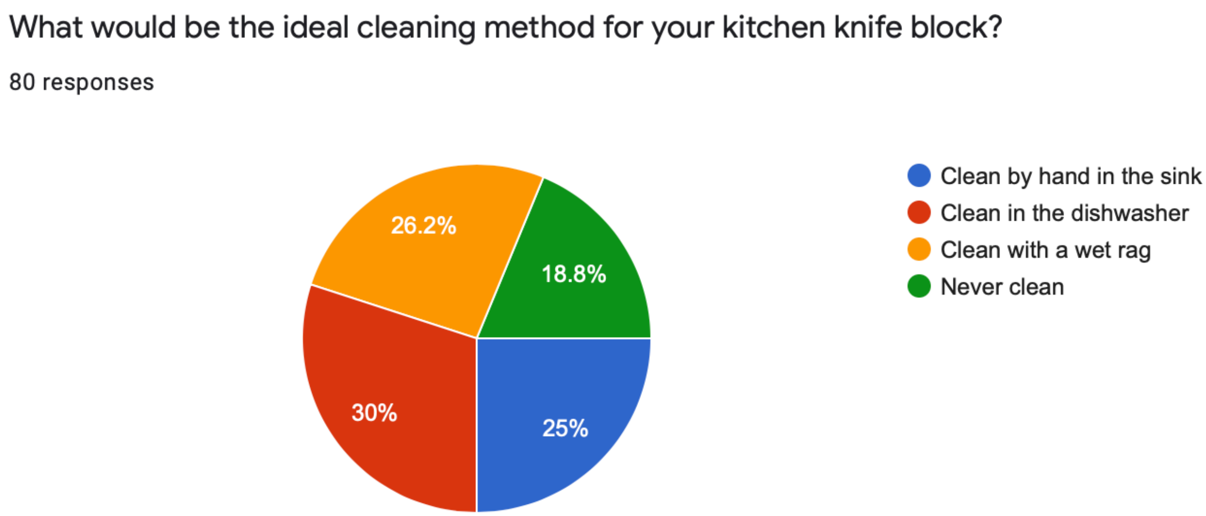

Figure C3:Cleaning Method

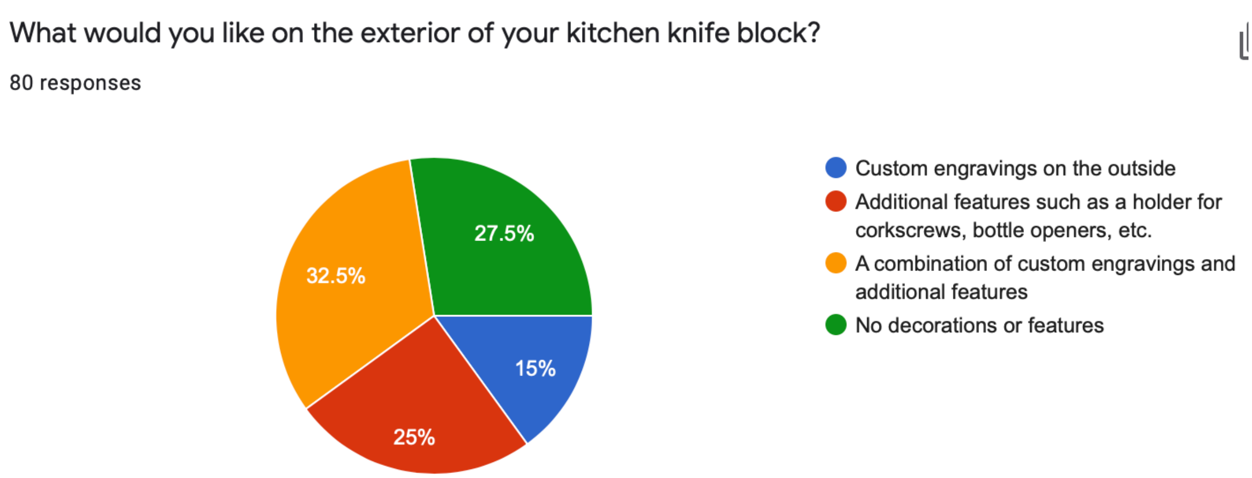

Figure C4: Exterior

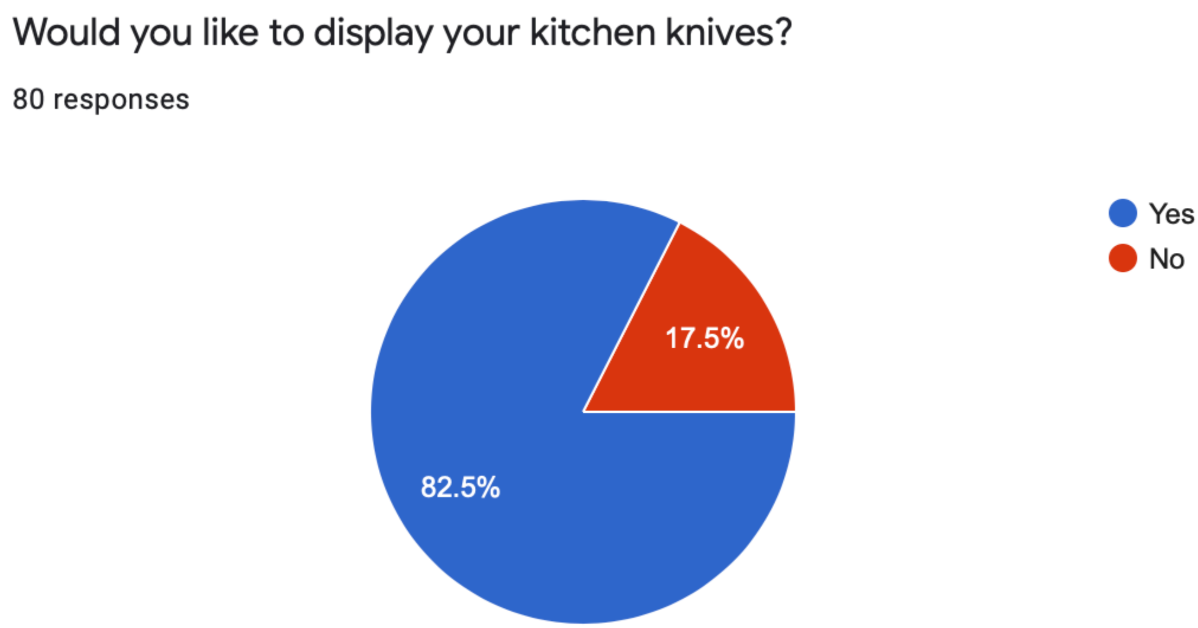

Figure C5: Display Preference