Fall 2018

Automatic Pizza Cutter

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Executive Summary

(200-300 words) The goal of this project was to design and build an automatic pizza cutter that could function based off specific design goals. These design goals were to cut a large pizza into 8 slices in under 60 seconds, to cut a small pizza into 12 slices in under 60 seconds, and to implement a safety mechanism so the blade would not function if someone reached their hand next to the blade. The project was design to fit a loose budget of $250 dollars. Different designs were considered, and multiple prototypes of different complexity levels were built to evaluate these designs. The Pizza Cutter final prototype consisted of a lead crew with an attached pizza cutter blade connected to a stepper motor to move the blade across the pizza. The pizza was placed on a cutting board that rotated using a servo motor. The final prototype was able to meet our design goals. A large pizza was cut into 8 and 12 slices in 40 and 60 seconds respectively. A door was implemented on the prototype with a limit switch as a safety precaution. When the door was open, the pizza cutter would stop operation similar to a microwave or oven. If the door was opened during operation, then closed, the cutter would continue where it left off.

MEMS 411: Mechanical Engineering Design Project
Fall 2018

Automatic Pizza Cutter

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1 INTRODUCTION

The purpose of this project is to design an automatic pizza cutter that can cut any normal sized pizza into different amounts of slices. The pizza cutter will ideally cut the pizza in under 60 seconds and into even slices. The goal of this pizza cutter is to provide a simple tool to use in households as well as restaurants. Our design will feature a blade that cuts across the pizza. After each cut, the pizza will rotate a specified amount, based on the desired number of slices, cut again, and repeat this process until it has completely cut the whole pizza.

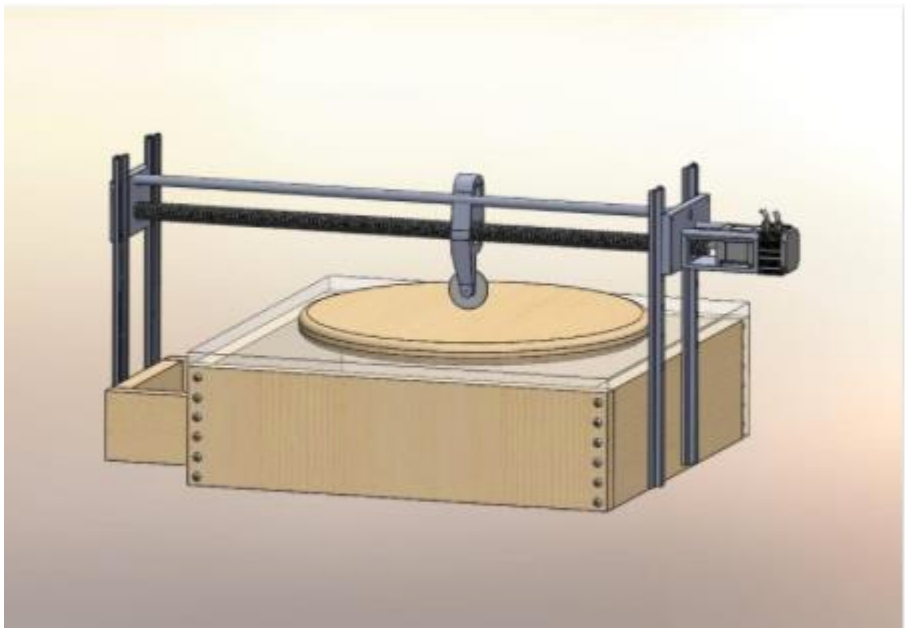


Figure 1: CAD Model

2 PROBLEM UNDERSTANDING

2.1 BACKGROUND INFORMATION STUDY

2.1.1 Existing designs

Product 1: Moretti Forni Commercial Pizza Cutter

Link: http://www.archiexpo.com/prod/moretti-forni/product-10399-505511.html

Figure 2: Table top pizza cutting machine

This pizza cutter is a manual pizza cutter that more closely represents a press. It is limited to a single sized pizza and a specific number of slices for that pizza size. Simply pull the lever arm down to lower the blades and cut the pizza. This design does feature a nice safety rim around the blades to help prevent unwanted objects from being cut by the blades.

Product 2: PC500 Automatic Pizza Cutter

Link: https://www.youtube.com/watch?v=NF9lcQ7SRnI

Figure 3: Pizza cutter with conveyer belt

The PC500 Automatic Pizza cutter is a pizza cutter intended for usage when mass amounts of pizza are being cut. It does not have the ability to vary the number of slices to the customers desires. It has a pre-set blade that can be changed depending on the number of pizza slices desired. The blade is lowered up and down three times in order to ensure that the pizza has been cut. The sliced pizza is then moved on a conveyor belt to another location.

Product 3: Automatic Pizza Cutter Concept

Link: https://www.youtube.com/watch?v=2QZIkqiwaR8

Figure 4: Rotary pizza cutter

This automatic pizza cutter features both a rotating table for the pizza and a blade that rolls and cuts up to the center of the pizza. This pizza cutter cuts single slices. It does not appear to be collapsible, which means that it may take up a good amount of space in a kitchen. It does not display how the user inputs the number of slices that they would like to have cut.

2.1.2 Existing Patents

Patent 1: Even-Slice Pizza Cutter

Patent number: US6557260B1

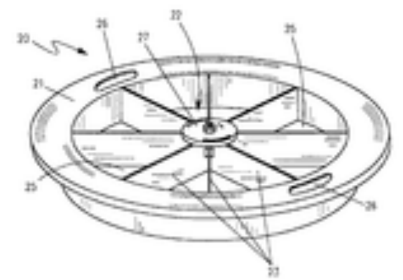


Figure 5: Hand press pizza cutter

This patent is one big circular pizza cutter that cuts the pizza into 6 slices. The blades are placed so that the pieces are evenly cut. The user places the cutter on top of the pizza and puts pressure down on top of the pizza to cut it. This pizza cutter can cut pizzas of all sizes, as long as it's not larger than the cutter itself.

Patent 2: Cutting Machine for Pizza

Patent number: KR20120018481A

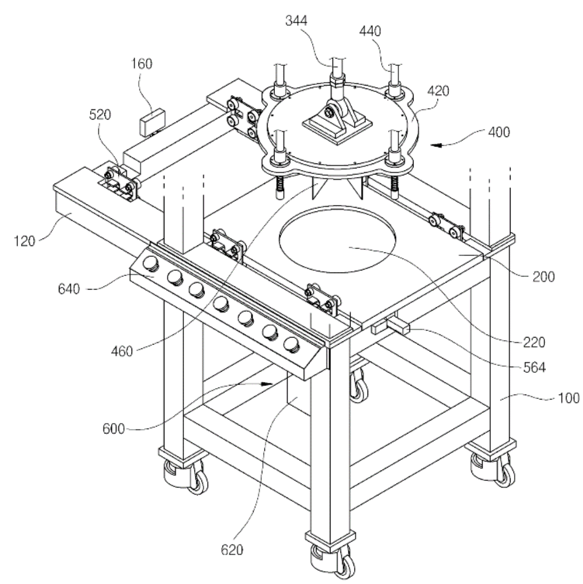


Figure 6: Rolling pizza cutter cart

This patent consists of a pizza cutter that is attached to a table. The pizza is placed inside of the circle located on the table. The top, or lid of the design (where the pizza cutter is located) is then lowered down, cutting the pizza into even slices. Once the pizza is cut, it is then removed from the table.

2.1.3 Codes and Standards

Code 1: NSF/ANSI 8: Commercial Powered Food Preparation Equipment

Provides material specifications and design and construction guidelines as well as sanitation requirements for commercial food equipment under the category of mixers, slicers, grinders, etc. Understanding these requirements could impact what materials are chosen to work for components of the design that will come into contact with the food, and how these materials are handled during the fabrication process.

Code 2: ISO 97.040.50: Small Kitchen Appliances

Provides specifications for the design and function of medium to small kitchen appliances. Specifies materials that can be used that are in direct contact with food or drink, as well as design requirements relating to energy/water usage where applicable. This could impact what components to power the slicer, as well as the structural design of where certain components are housed, particularly with regards to safety concerns.

2.2 USER NEEDS

Product: *2 Degree of Freedom Pizza Cutter*
Customer: Mass Retail Supermarket Consumer

Notes: The 3 existing products of the Pizza Cutters were displayed to the customer. After displaying the 3 existing products, we then interviewed the customer which took approximately one hour.

Date: September 7th, 2018

Question	Customer Statement	Interpreted Need	Importance
How big should the system be?	"Big enough to accomodate a large pizza".	The system can accommodate 18" diameter pizzas.	5
How heavy should the system be?	"Light enough to pick up-30lbs".	The system should be light enough to hold without much effort.	3
Should the controller be attached to the system or on a wire?	"On a box on the device".	The system's controller should not be exposed with a wire.	2
Where should it be able to be stored?	"Needs to fit in a kitchen cabinet".	The system should not take up a lot of space.	5
Should there be an age range for use?	"12+"	The system should not be used by children without supervision.	3
Should there be a password to use the system?	"Yes, because otherwise people may try to cut the wrong objects".	A password should be used to prevent unauthorized use.	4
How should the user be prompted to cut the pizza? Number of slices or degrees of rotation?	"Ask user to input the number of slices-this corresponds to degrees".	The user can input how many slices they want cut.	5
How quickly should it be able to cut the pizza?	"It should be able to cut the pizza in under 3 minutes".	The pizza cutter should not take much time to use.	3
Should the components be detachable?	"Yes, an arm that you can detach would be nice".	The system should have detachable components for easy storage.	4

Table 1: Customer Interview

Need Number	Interpreted Need	Weighted Importance
1	Can accommodate 18” pizzas	5
2	Light enough to easily hold	3
3	Controller should not have exposed wire	2
4	Should not take up much space	5
5	Safe to use (childproof)	3
6	Should have protection against unauthorized use	4
7	Number of slices input selection	5
8	Quick slicing time	3
8	Easy to store	4

Table 2: Interpreted User Needs

2.3 DESIGN METRICS

Metric Number	Associated Need	Metric	Units	Acceptable	Ideal
1	2	Total Weight	lb	20-50	30
2	9	Total Volume	ft^3	4	3.5
3	8	Slicing Time	sec	5-20	10
4	1	Max Pizza Size	in	16-20	18

Table 3: Target Specifications

2.4 PROJECT MANAGEMENT

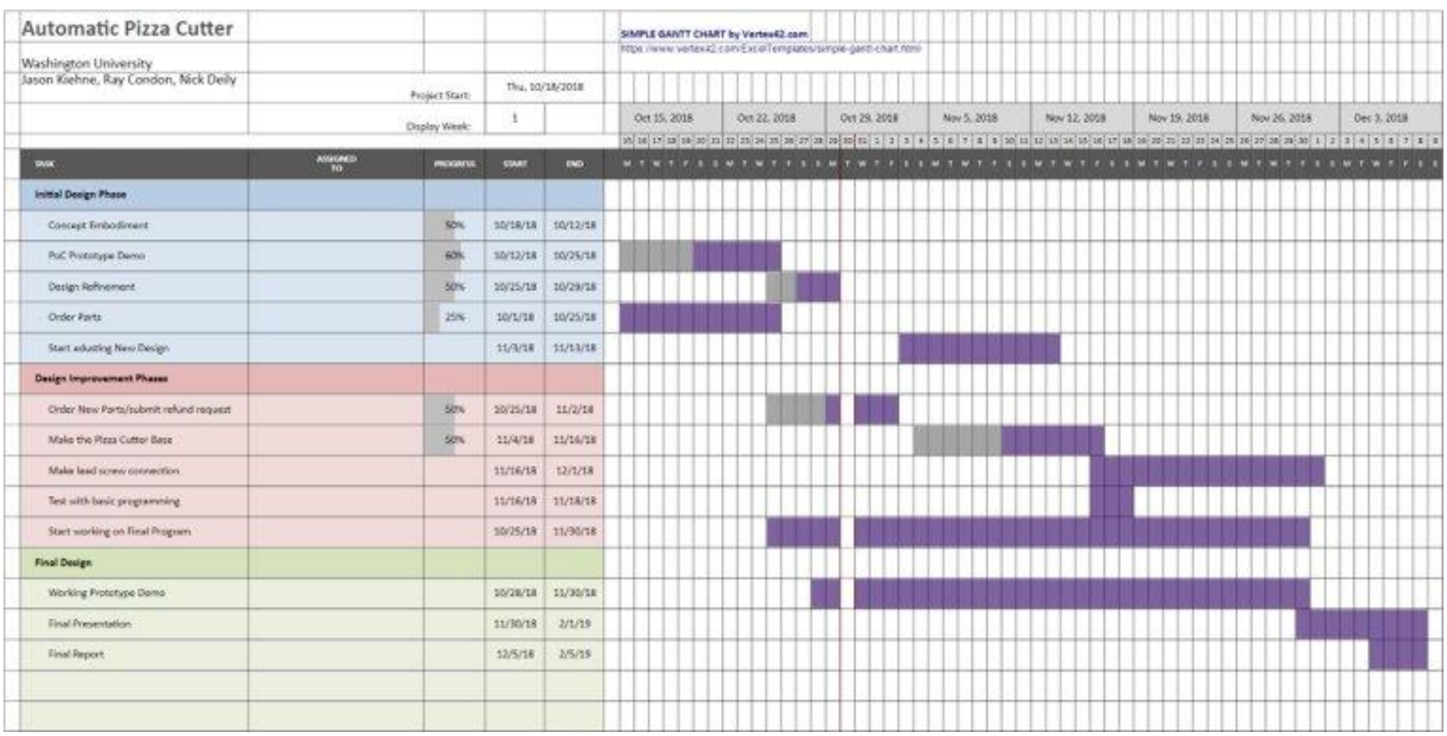


Figure 4: Final Gantt Chart showing project timeline

3 CONCEPT GENERATION

3.1 MOCKUP PROTOTYPE

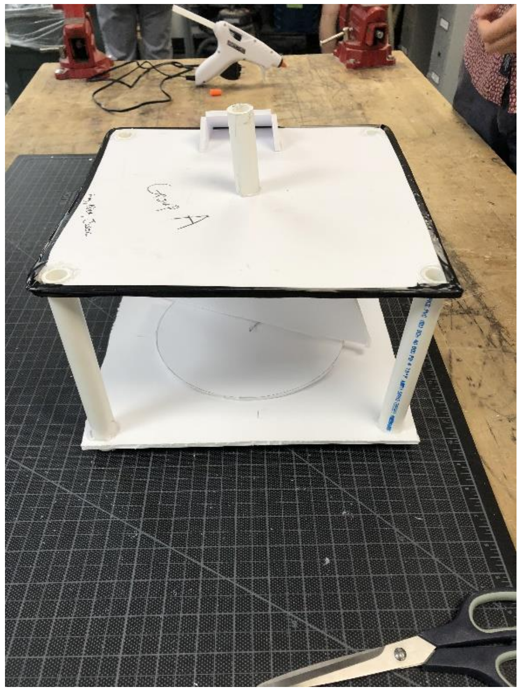


Figure 1: Angled view of mock Pizza Cutter

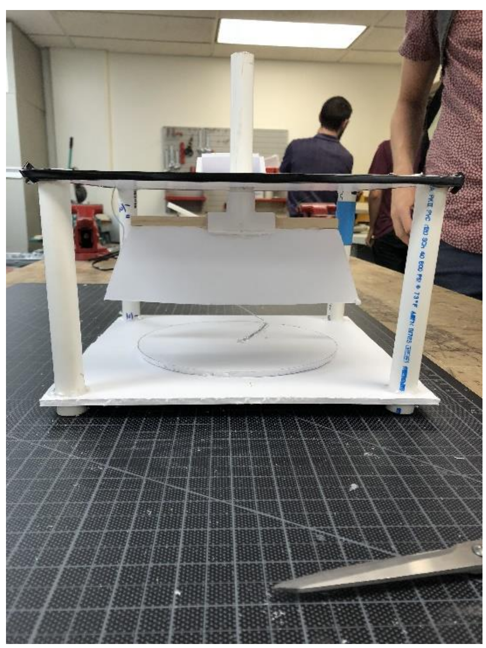


Figure 2: Side view of mock Pizza Cutter

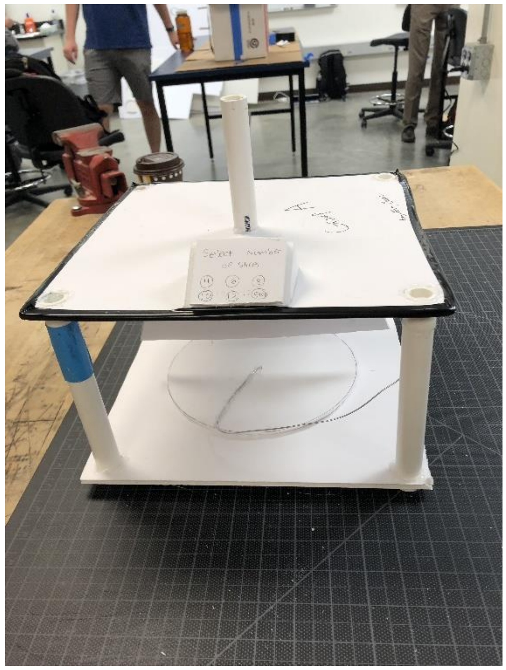


Figure 3: Arial view of Pizza Cutter mockup

Creating a mockup of our variable slice electronic pizza cutter with the provided materials, including ¼" foam boards, PVC pipes, hot glue guns, scissors, box cutting knives, and electric tape as well as the provided machines such as the drill press, disc sander, band saw proved to be very helpful in getting our initial ideas and thoughts out of our minds and into a tangible prototype. Not only did building this preliminary prototype help in eliminating a few preliminary ideas for the design but it also helped spark some new potential ideas and add-ons to our original thoughts. In particular, it allowed us to visualize what will be involved with the rotating base as well as the slicing mechanism that will actually cut the pizzas.

3.2 FUNCTIONAL DECOMPOSITION

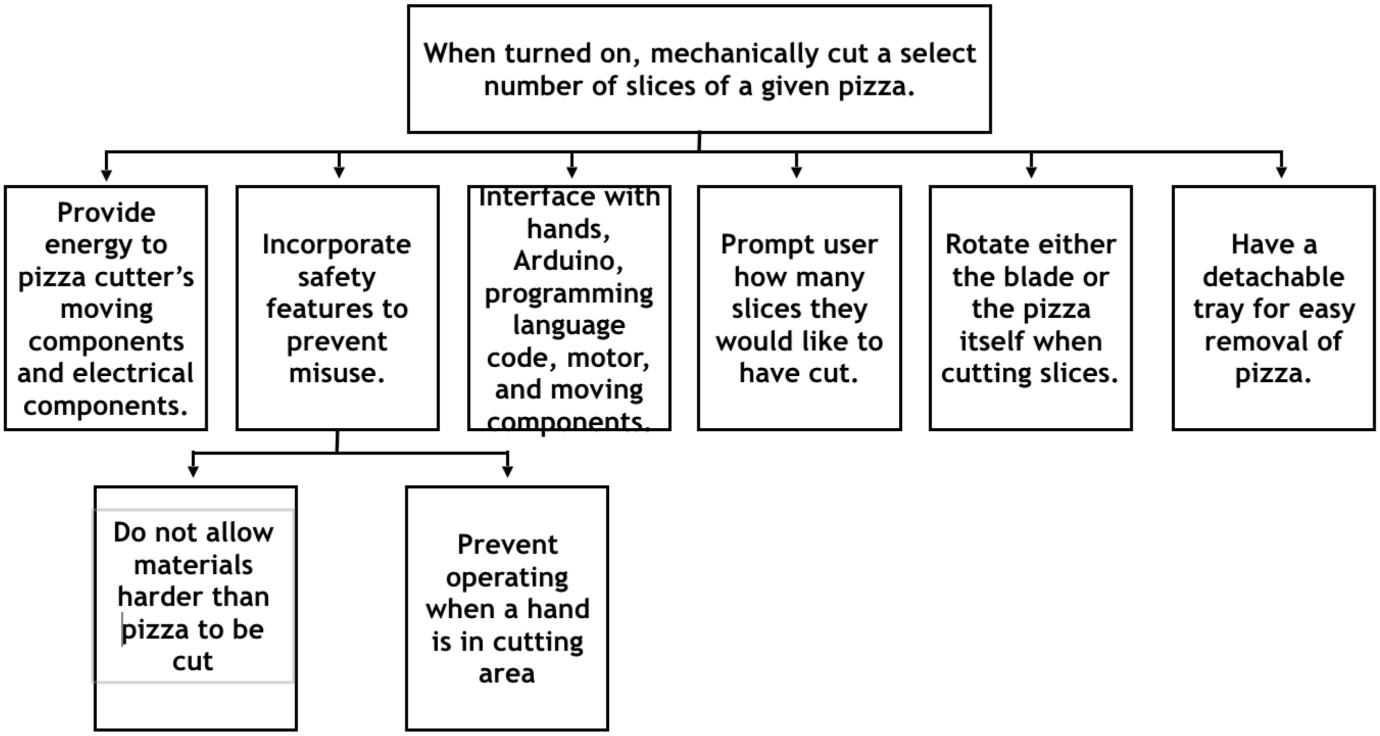
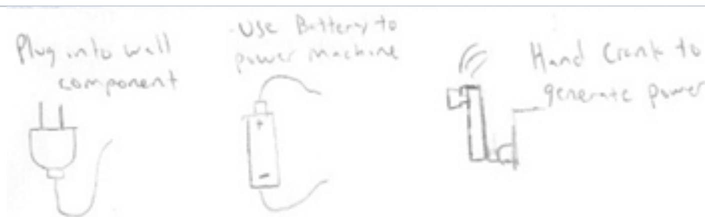


Figure 4: Function Tree of Variable Slice Electronic Pizza Cutter

1. Provide Energy to Pizza Cutter Components	
2. Incorporate Safety Features	
3. Prompt User how Many Slices	

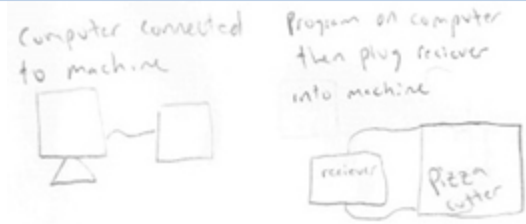
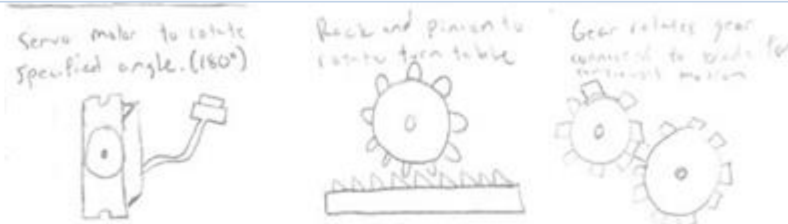
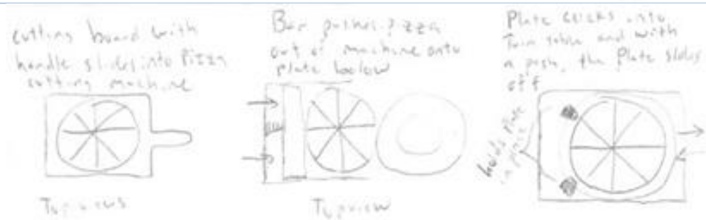
4. Interface with all the components	
5. Rotate Pizza or blade	
6. Easy Removal of Pizza	

Figure 5: Morphological Chart for Pizza Cutter

3.3 ALTERNATIVE DESIGN CONCEPTS

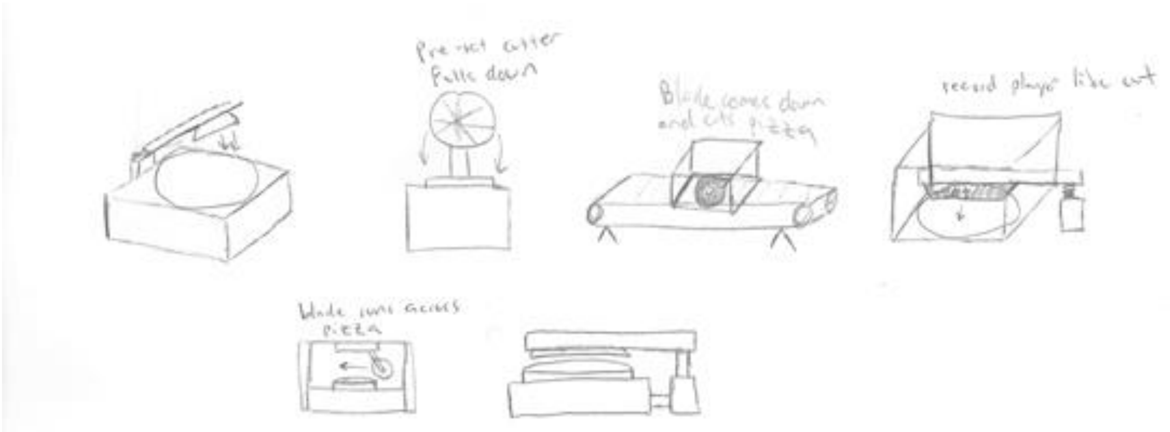


Figure 6: Preliminary Sketches for Pizza Cutter (Jason Kiehne)

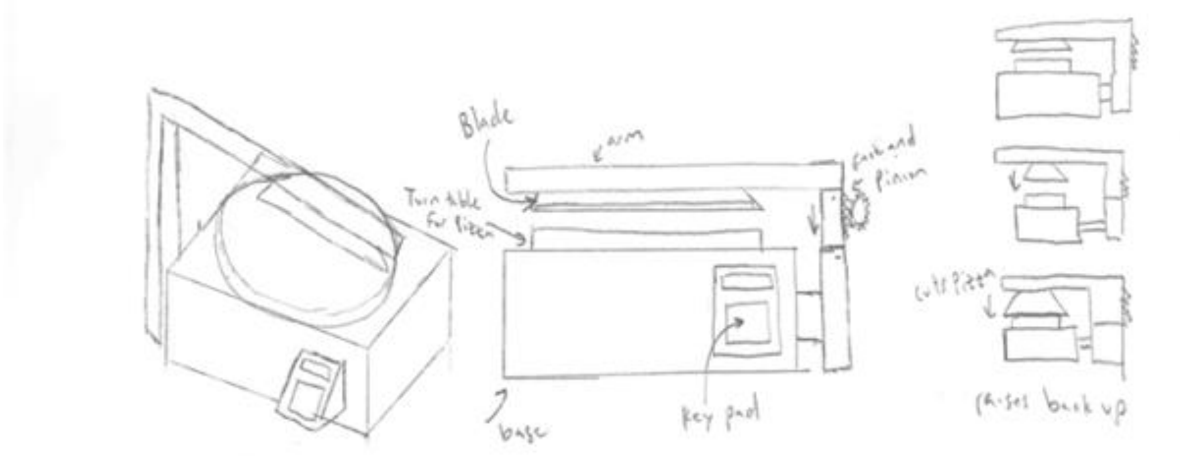


Figure 7: Final Pizza Cutter design (Jason Kiehne)

Description: This design consists of a rotating plate with a blade attached to a lowering arm. The plate rotates a specified amount and the arm lowers and cuts the pizza once the pizza stops rotating. The arm then raises up, allowing the pizza to be rotated again. This continues until the pizza is fully cut. The pizza is then removed from the turn table and onto a plate where it is fully cut and ready to be served.

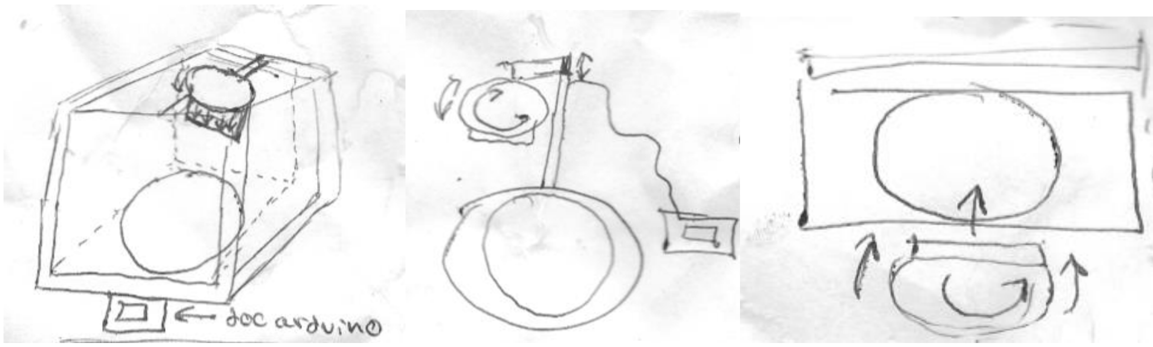


Figure 8: Preliminary Sketches for Pizza Cutter (Raymond Condon)

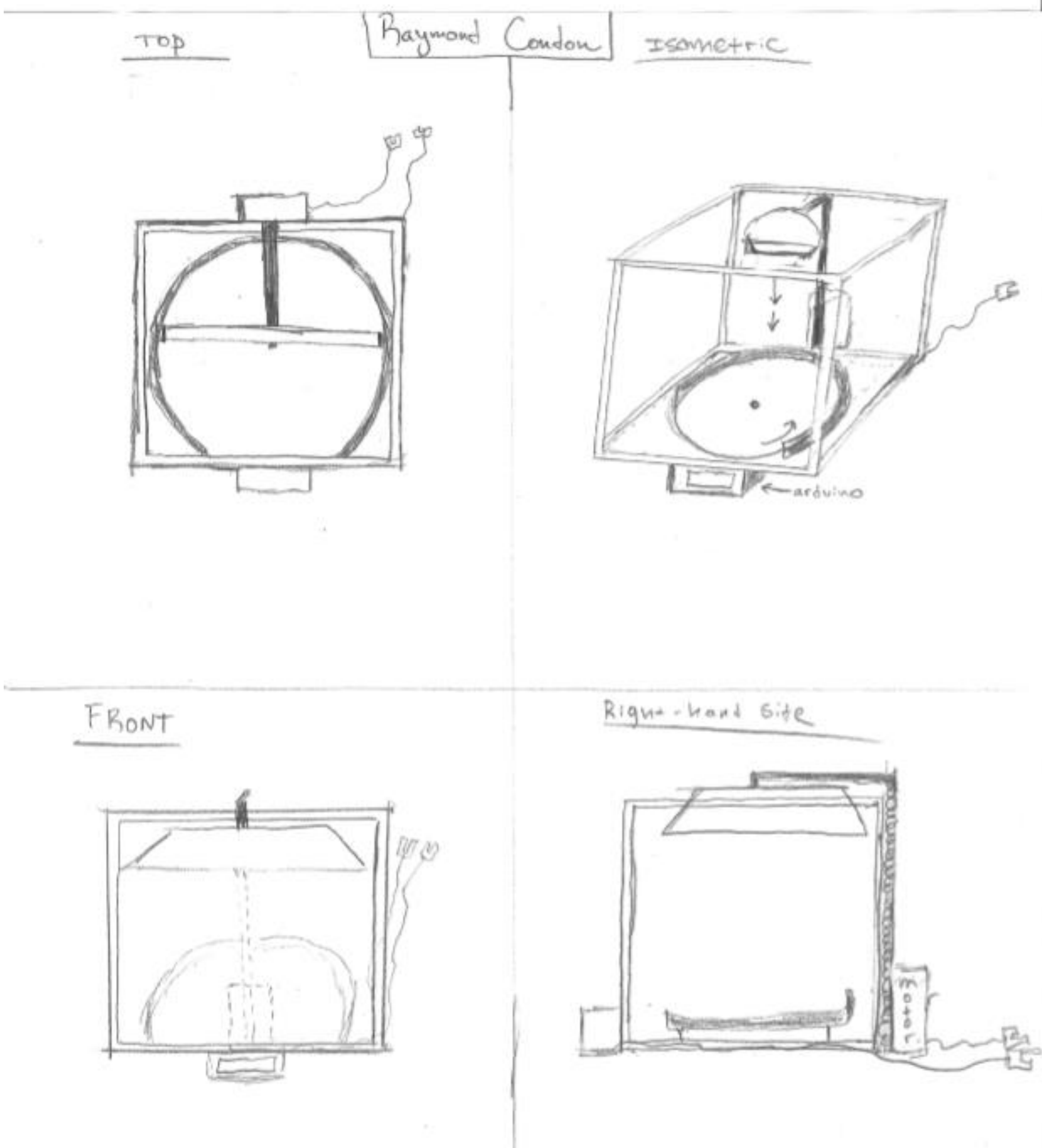
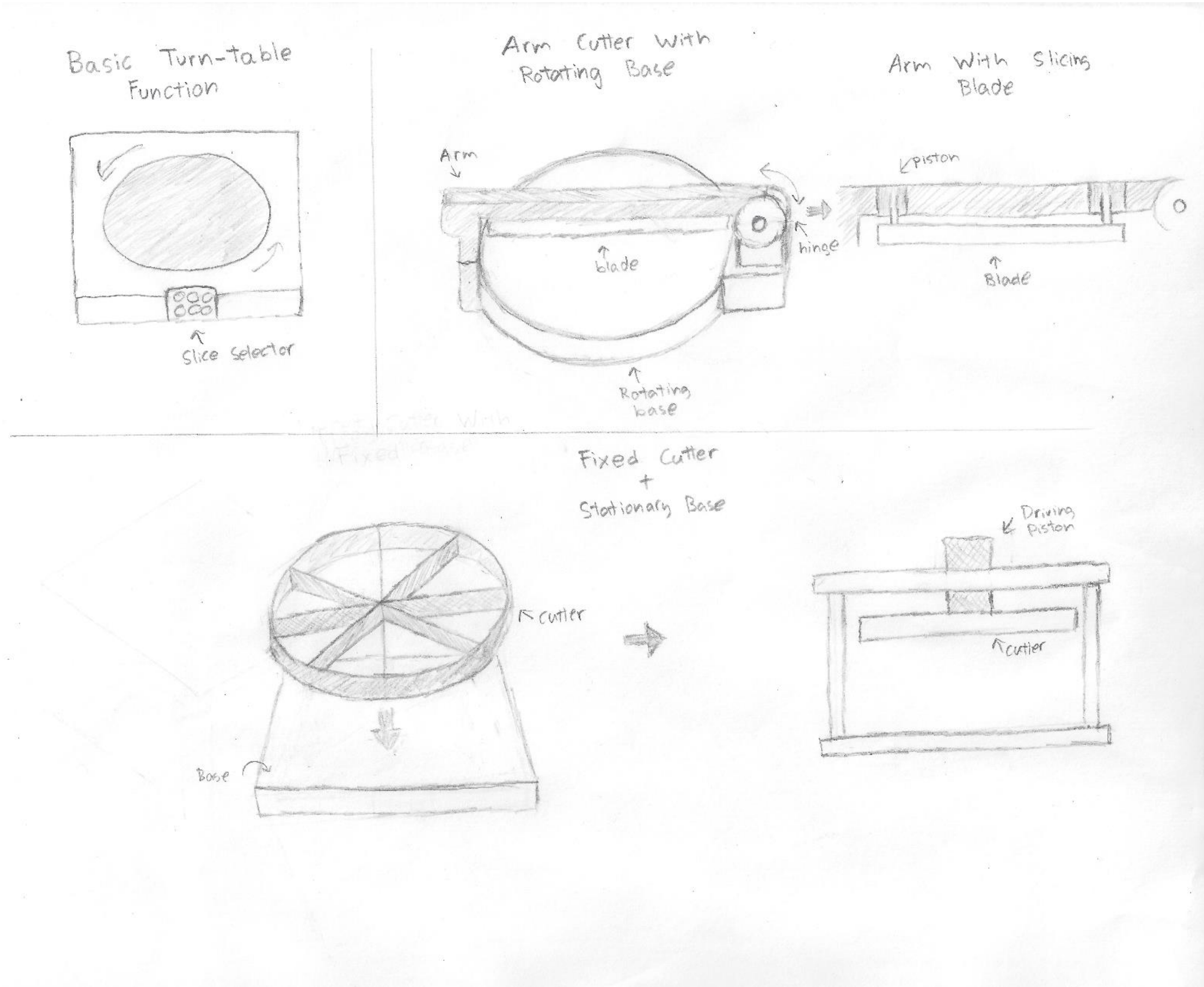


Figure 9: Final Pizza Cutter Design (Raymond Condon)

Description: This final design features a rotating base and a blade that is able to only move vertically. In order to rotate the base a specific number of degrees which corresponds to the number of slices a user wants, I figured that an arduino will be needed, as drawn. In order to move the blade up and down, I determined that a motor would be needed to move the blade up and down with a belt or some kind of helical rod.


Basic Turn-table Function
Slice selector
Arm Cutter With Rotating Base
Arm
blade
hinge
Rotating base
Arm With Slicing Blade
piston
Blade
Fixed Cutter + Stationary Base
cutter
Base
Driving piston
cutter

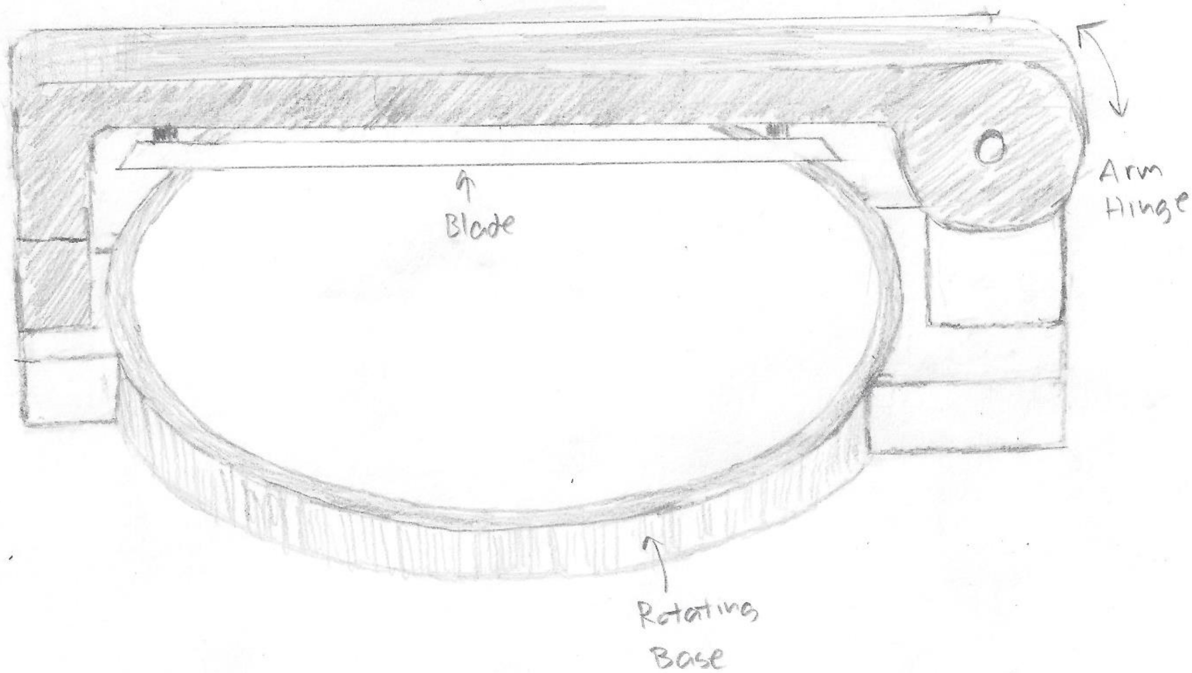


Figure 10: Hinging-Arm Pizza Cutter (Nicholas Deily)

Description: This design features a rotating base the pizza is placed on and an arm that swings down from the top containing the cutting blade. The openness of the design allows for one to easily place and remove pizza from the base (solution 6), and the rotating function of the base allows for any number of slices to be selected (solutions 3,5) when cutting the pizza. The overhead arm hinges down and clicks into the base on the opposing side. From there the blade is pressed down into the base using two small pistons, and when the slicing is done, the arm can be released and raised back up. The advantage of this design is that it allows for easy access to the base and minimized bulk and weight by containing the cutting fixture in a relatively small-volume arm. The major disadvantage is a major safety concern. Because of the openness of the design it would be relatively easy to accidently put a hand under the blade and cut a finger with this setup.

Solutions:

1) Plug into wall component

2) Select number of slices with buttons

3) Microcontroller to connect all moving parts

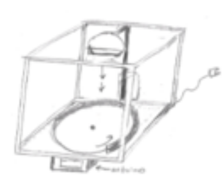
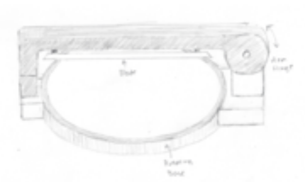
4) Easily remove pizza

4 CONCEPT SELECTION

4.1 SELECTION CRITERIA

	Safety Features	Ask How many Slices	Rotate Pizza/Blade	Easy pizza Removal	Easy to use	Lightweight	Row Total	Weight Value	Weight (%)
Safety Features	1.00	3.00	1.00	5.00	3.00	9.00	22.00	0.28	27.51%
Ask How many Slices	0.33	1.00	1.00	5.00	0.14	9.00	16.48	0.21	20.60%
Rotate Pizza/Blade	1.00	1.00	1.00	7.00	3.00	5.00	18.00	0.23	22.51%
Easy pizza Removal	0.20	0.20	0.14	1.00	0.33	0.20	2.08	0.03	2.60%
Easy to use	0.33	7.00	0.33	3.00	1.00	3.00	14.67	0.18	18.34%
Lightweight	0.11	0.11	0.20	5.00	0.33	1.00	6.76	0.08	8.45%
	Column Total:						79.97	1.00	100%

4.2 CONCEPT EVALUATION

		Alternative Deisgn Concepts					
							
Selection Criterion	**Weight (%)**	**Rating**	**Weighted**	**Rating**	**Weighted**	**Rating**	**Weighted**
Safety Features	8.33	4	0.33	3	0.25	3	0.25
Ask How Many Slices	3.12	5	0.16	5	0.16	5	0.16
Rotate Pizza/ Blade	7.23	5	0.36	4	0.29	3	0.22
Easy Pizza Removal	9.56	2	0.19	4	0.38	4	0.38
Easy to Use	8.33	4	0.33	3	0.25	4	0.33
Lightweight	4.13	2	0.08	4	0.17	4	0.17
	Total score	**1.458**		**1.493**		**1.504**	
	Rank	**3**		**2**		**1**	

4.3 EVALUATION RESULTS

When evaluating the alternative design concepts for electronic pizza cutter, it was determined that six criterions would be utilized to make the final decision. These six criterions include: safety features, the design being able to ask the user for a number of slices, the ability to rotate the pizza and/(or) the blade, an easy removal of the pizza, ease of usage, and the system being light in weight. Each design scored relatively well on allowing the user to select their own number of slices, and ease of use, which were two of the highest weighted scoring criteria. On the highest weighted criterion, Ease of Pizza Removal, Jason and Nick's designs scored the highest, due to the open-table designs. The openness of these models however was further reflected in their corresponding safety scores, where lower than the more enclosed design that Ray had. This in particular highlighted the significance of designing a model that provides maximum safety while still allowing for ease of pizza removal, and how these two factors may be conflicting to a degree.

4.4 ENGINEERING MODELS/RELATIONSHIPS

Model 1: Cutting

The force required to cut through a given material can be modeled by the following equation:

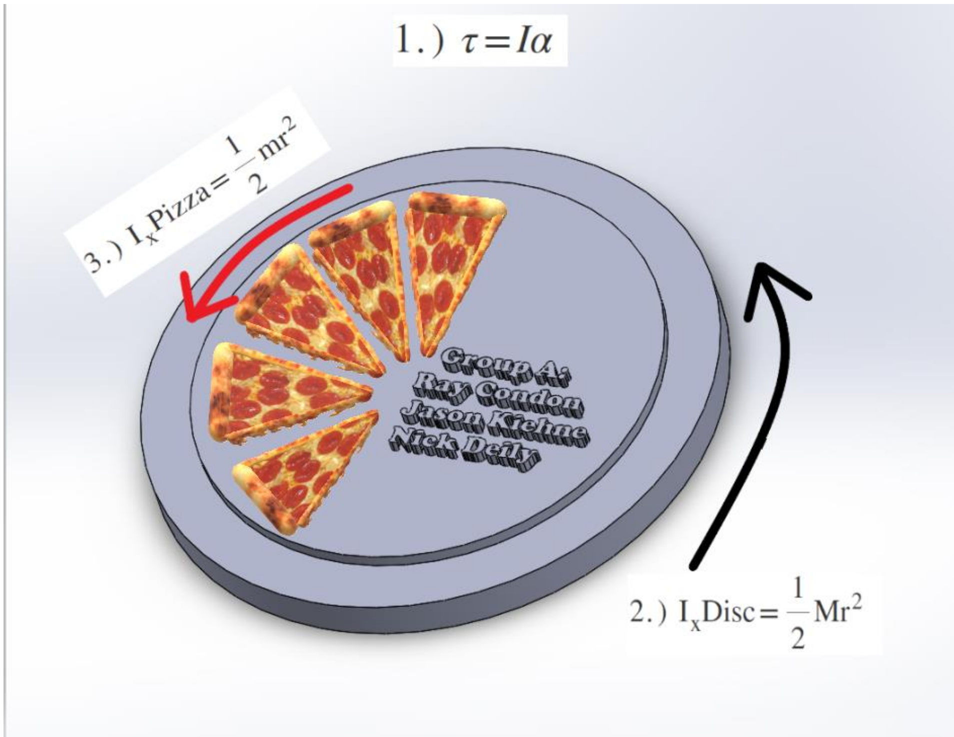
$$F = l\tau n$$

Where F is the applied force, l is the contact length, t is the shear strength of the material being cut, and n is a constant determined by the following relationship:

$$\eta = \frac{(a + w)}{K_s f_8 (y_u, z_u, a, w, \alpha_c)}$$

Where a is the thickness of the edge of the blade, w is the thickness of the base of the blade, K_s is the ultimate strength of the material the blade is comprise of, and f_8 is a function of

Model 2: Motor Torque



1.) $\tau = I\alpha$

2.) I_x Disk = $\frac{1}{2} MR^2$

3.) I_x Pizza = $\frac{1}{2} mR^2$

Where:

τ= Torque [Nm]

$I = moment\ of\ intertia\ [kgm^2]$

M & m = mass [m]

R= radius [m]

This model reveals the importance of including the moment of inertia for the rotating disc and the pizza (assumed to be a flat disk) and the pizza's respective moment of inertia. Knowing these values will allow for us to determine an approximate torque for rotating our system. It is also important to note that the masses of both the disc and the pizza are included in these calculations. Also note that bearing friction is being neglected.

Model 3: Deflection in the beam

Deflection of pizza cutting arm due to applied loads on the arm:

Due to unified load across the whole bar: $\delta_{max1} = \frac{qL^4}{8EI}$

Due to load at end of the bar: $\delta_{max2} = \frac{FL^3}{3EI}$

If load is in the middle of the bar: $\delta_{max2} = \frac{Fa^3b^3}{3EIL^3}$

Total Deflection of bar with force at the end: $\delta_{total} = \frac{FL^3}{3EI} + \frac{qL^4}{8EI}$

If beam is only for support (connected on both sides): $\delta_{max} = \frac{FL^3}{48EI}$

Q = Force per unit length [N/m]

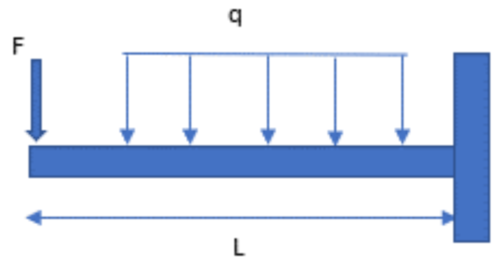
L = Length [m]

E = Elastic Modulus [MPa]

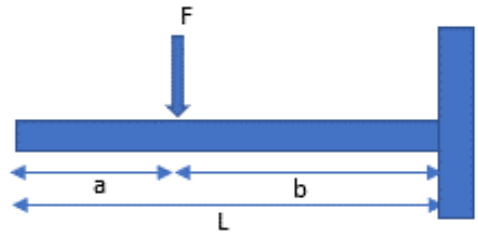
I = Moment of Inertia [m^4]

F = Force [N]

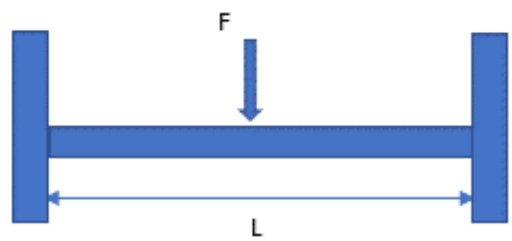
Beam load with force F at the end and uniform force q:



Beam load with force F in the center of the beam



Beam load with force F in the center and supports at both ends of the beam



The deflection of the beam is important to find to make sure the beam does not bend due to the force of the blade pushing on the pizza or because of the weight of the pizza. This can help us make an informed decision on the type of material we should use as well as the optimal length of the pizza cutting arm. There should be little to know deflection in the arm, so we will most likely need a metal with a large elastic modulus. Woods or plastics will not be the best option for the arm based on the deflection calculations.

5 CONCEPT EMBODIMENT

5.1 INITIAL EMBODIMENT

Pictured below are the current schematics for the Pizza Cutter prototype. Fig. 13 shows an isometric view along with a bill of mateirlas for the model.

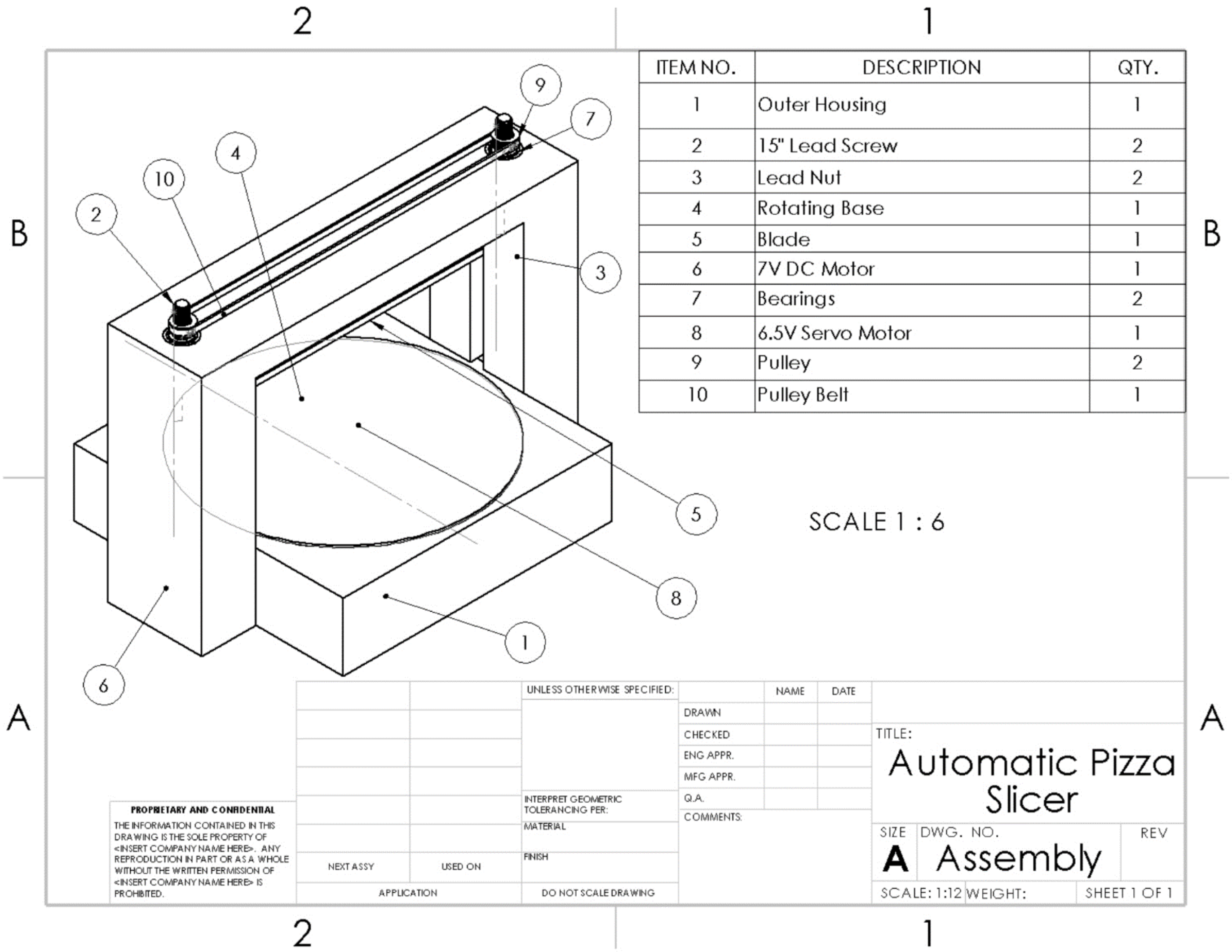


Figure 13: CAD embodiment of Automatic Pizza Cutter with BOM and balloons

Figure 14 below shows an exploded view of the model along with balloons referencing each part from the bill of mateirals.

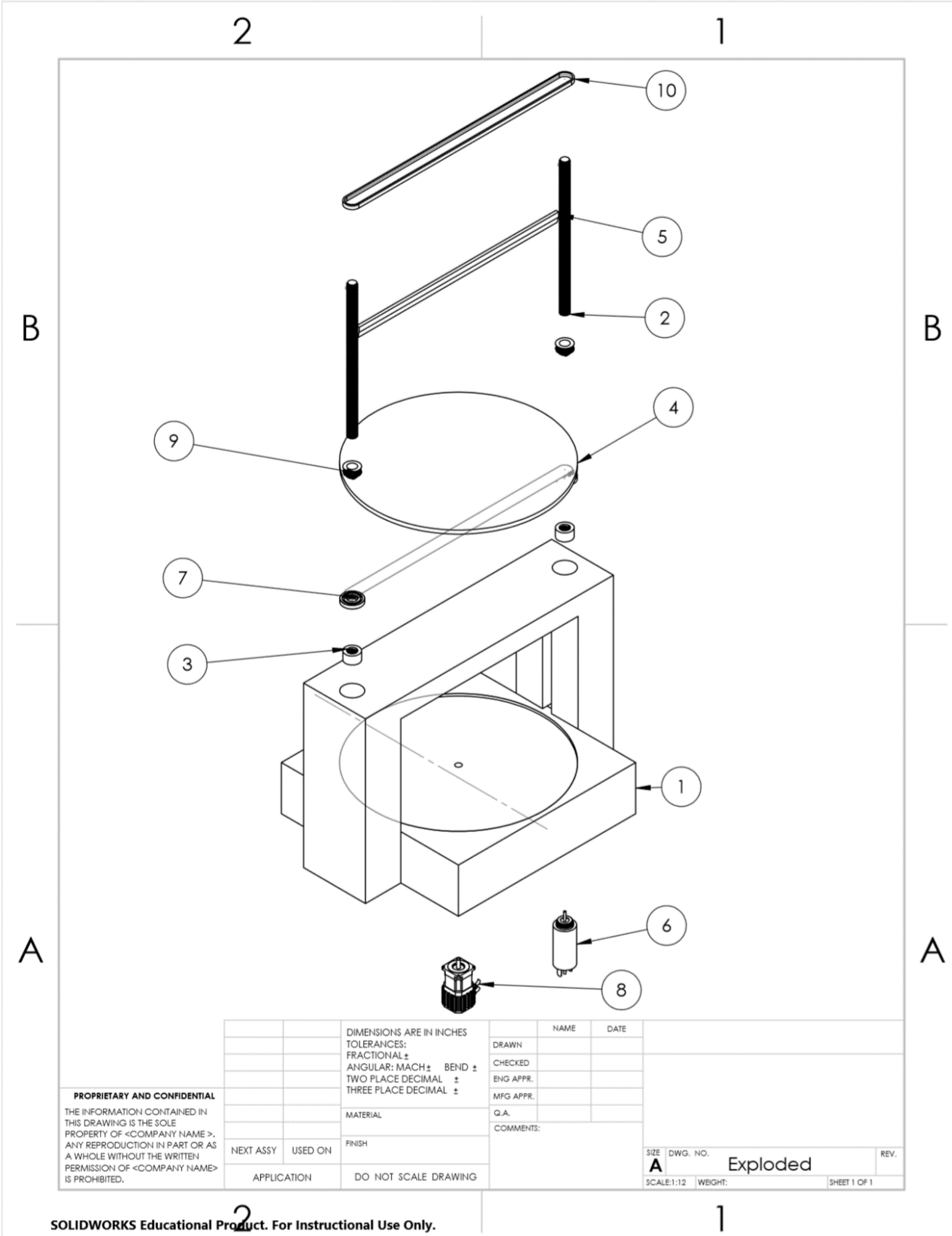


Figure 14: Exploded view of CAD embodiment of Automatic Pizza Cutter with balloon callout

Figure 15 shows the remaining views of the model, along with corresponding dimensions.

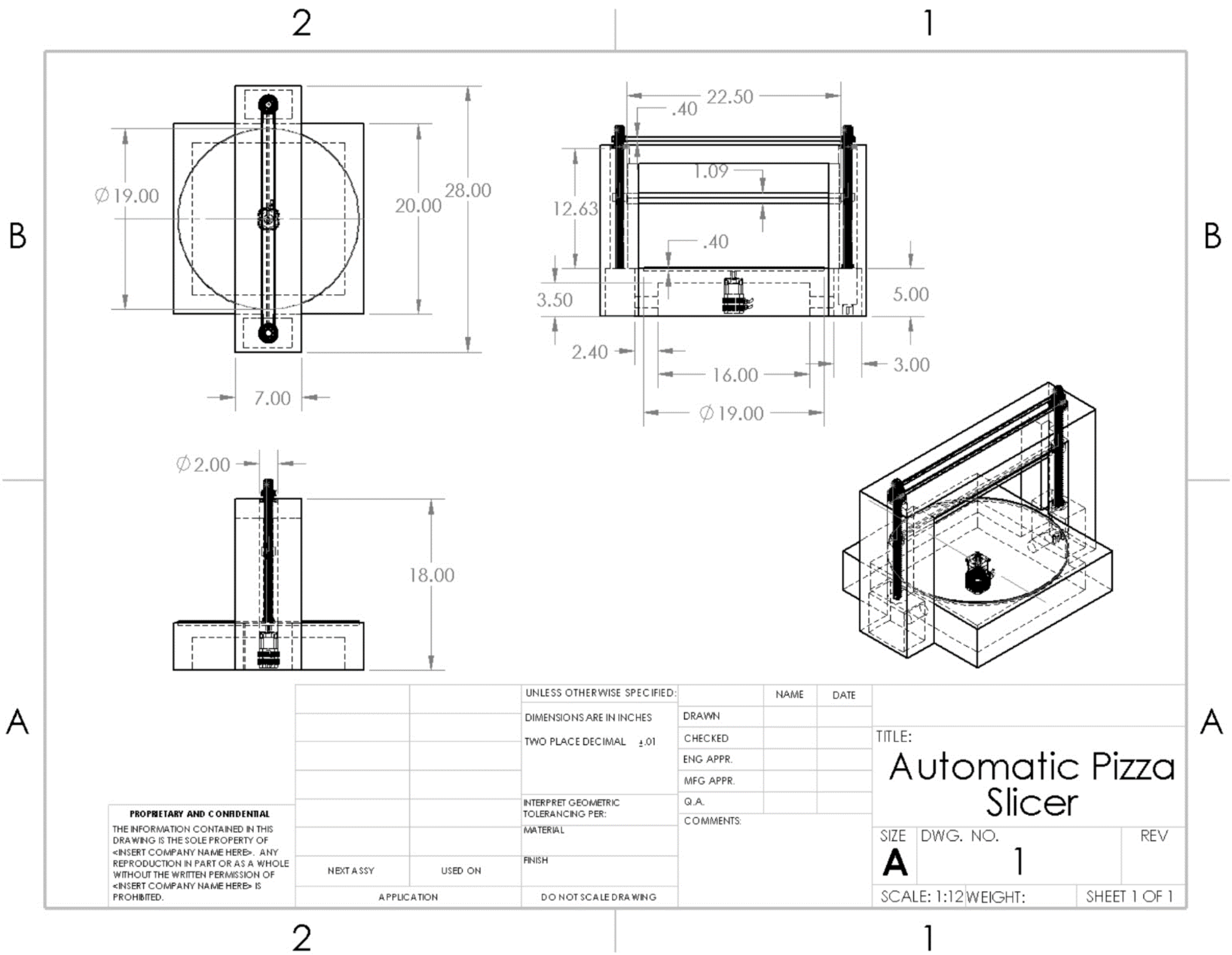


Figure 15: CAD drawing showing top, right, side, and isometric view as well as overall dimensions

The parts used in for prototype along with corresponding part information and prices are shown in Table 5 below.

	Part	Source Link/store	Supply part number	Color, TPI, other part IDs	Unit Price	Quantity	Total Price
1	UNO breadboard kit	Micro Center in St. Louis	341966SKU	Blue, multiple wires, casing	17.99	1	17.99
2	Servo Metal Gear Digital	Micro Center in St. Louis	LS8101F	Black, multiple input wires, 172 oz-in	25.99	1	25.99
3	6v DC Motor	Micro Center in St. Louis	OSEPP R540	Silver, 10,000 RPM	14.99	1	25.99
4	wood	Home Depot	For Home Depot: 2014	Oak, ¾ ft. x 2 ft. X 4 ft., dense	19.00	1	19.00
5	Lead screws	https://www.mcmaster.com/98935a838	98935A838	¾"-6, 3ft. Long. Carbon steel ACME lead Screw	10.10	2	20.20
6	BLADE						

Table 5: Initial parts list of prototype components

5.2 ROOF-OF-CONCEPT

5.2.1 Prototype Performance Goals

1. Automatic Pizza Cutter can cut 10" diameter, regular crust, pepperoni pizza from Domino's (request uncut) into 12 slices in under 60 seconds
2. Automatic Pizza Cutter can cut 16" diameter, regular crust, sausage and mushroom pizza from Domino's into 8 slices in under 60 seconds
3. Automatic Pizza Cutter will stop operation/motion at any point in the cutting procedure if the door is open, and resume when the door is closed again

5.2.2 Design rationale for PoC Components

The main calculations needed for this project were the lead screw pitch needed to lower the blade, torque of the dc motor used to rotate the lead screws, and the torque of servo used to rotate the base. First, the lead screw size and motor specs were determined at the same time. Before any calculations, the initial height of the blade above the pizza was determined, as well as the vertical distance the blade travels above the pizza after each cut. These were determined to be 5" and 2" respectively. The average distance the blade needed to travel in-between cuts was then determined for a pizza with 12 slices. This was used because one of the performance goals was to cut a pizza into 12 different slices in under 60 seconds. This value was 4.5" per cut, with a total of 27 inches for all 6 cuts (only needs 6 cuts to get 12 slices).

Another determining factor for our calculations was how fast each task needed to be performed. There are two tasks to consider: The travel distance of the blade and the time it takes to rotate the pizza 180 degrees. For the calculations, the blade had to finish cutting the 12 sliced pizza in 30 seconds and the rotation of the base 180 degrees needed to be finished in 10 seconds. This allows extra time for any errors in our calculations.

Next, the lead screws needed to be determined. The lead screws are used for linear displacement of the blade up and down above the pizza. Since a twelve sliced pizza needed to be cut in under 60 seconds, a lead screw with a larger linear distance per rotation was chosen. This led to a lead screw with a linear travel distanced per rotation of 0.167" to be chosen.

Using this linear distance, we can find the rpm needed from the motor to achieve the desired time. This was calculated using the following equation [3]

$$rpm = \frac{linear\ velocity\ \left[\frac{in}{min}\right]}{lead\ \left[\frac{in}{rev}\right]} = \frac{(27[in]/.5[min]}{0.167\left[\frac{in}{rev}\right]} = 325rpm$$

Next, the torque needed to raise and lower the blade with an applied load was calculated (an assumption was the torque needed to lower the blade and cut the pizza was higher than the torque needed to raise the pizza, so we focused on the lowering torque). The torque needed to be high enough to apply enough force to completely cut a pizza. The force to cut a pizza was assumed to be 10 lbs. The equation for lowering torque is [1]

$$T_R = F \cdot \frac{d_m}{2}\left(\frac{-l + \pi\, f\, d_m \sec\alpha}{\pi d_m + fl\sec\alpha}\right) + T_c$$

Where d_m is the mean diameter [in], 2α is the thread angle [degrees], l is the lead [in/revolution], F is the load [lbs], and f is the coefficient of thread friction. The coefficient of thread friction was assumed to be 0 for ease of calculation. The magnitude of the torque was calculated to be 2.40 [lb*in].

The final calculation was the torque required of the servo motor. The servo had to complete 180 degrees in 10 seconds, which was the basis for our calculations. The equation used was

$$T = I\alpha$$

Where T is the torque [lb*in], I is the inertia [lbf·ft·s^2], and α is the angular acceleration [rad/sec^2] [2]. First, I was calculated using the following equation [2]

$$I = \frac{1}{2}mr^2$$

Where m is the mass [kg] and r is the radius [in]. The mass of a large pizza was assumed to be 3 lbs., and the mass of the turn table was assumed to be 10 pounds for ease of calculations. (density of wood was used with a volume of Pi*(9.5^2*.5)). Next, α needed to be determined. We wanted the pizza to make a 180 degree turn in 10 seconds. This led to our angular acceleration to be Pi/100. Once I and α were determined, they were plugged into the torque equation, and a needed torque by the servo was calculated to be approximately 19 lb*in.

5.2.2 PoC Prototype in Current State

Most of the work currently being done is focused on the servo motor that will rotate the base, as well as the motor that will turn the lead screw needed to raise and lower the blade. Figure 16 shows the servo motor along with some of the wiring equipment being used.

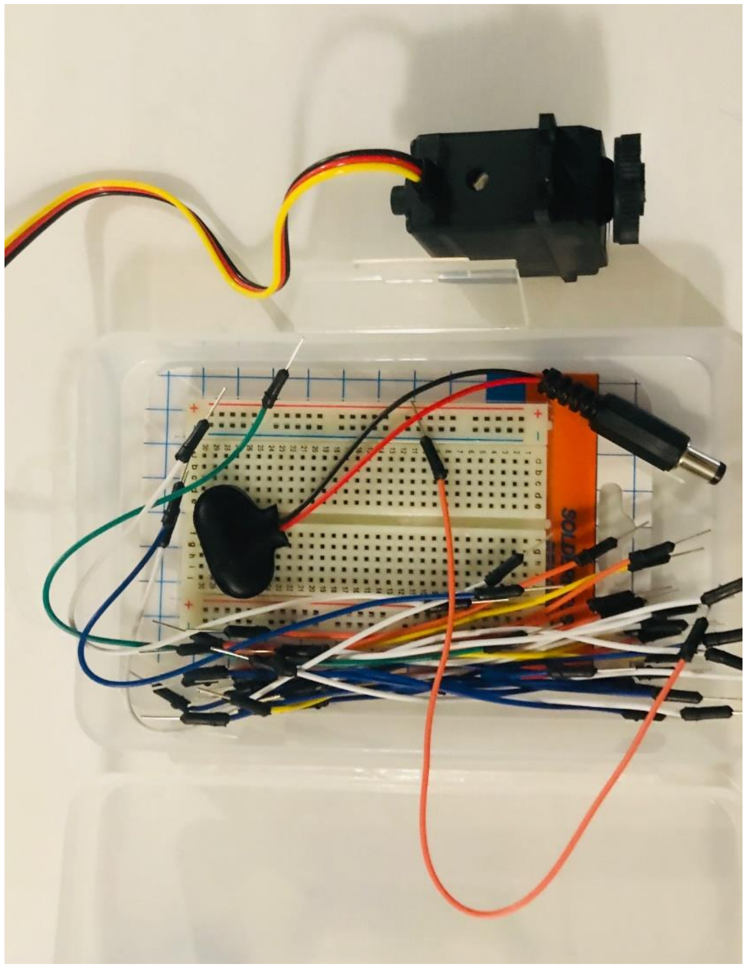


Figure 16: Arduino kit connecting to servo

Since timing and coordination is such an important factor to this project, an Arduino controller is being used to control the functions of the rotation of the pizza base as well as the cutting function of the blade. Below is a picture of Arduino UNO controller wired to run one of the motors.

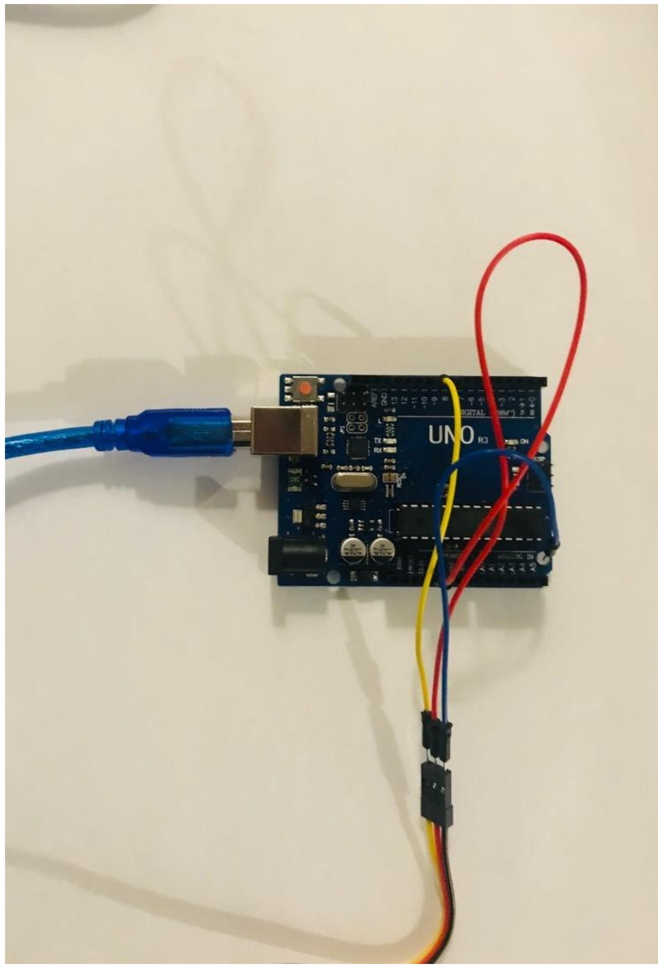


Figure 17: Arduino board used to control motors

A key component for this design is a motor that will be powerful enough to lift and lower the blade, while fast enough to complete the cutting in a reasonable amount of time. Picture below is the motor currently being used to fulfill this functionality.

Figure 18: DC motor that will be used to turn the lead screw

Figure 19: Front view of POC prototype

Figure 20: Servo motor mounting to turn rotating base

Figure 21: Overhead angle of POC

6 WORKING PROTOTYPE

6.1 OVERVIEW

A few notable design changes were made. The most notable is changing from a DC motor turning a threaded rod to a large stepper motor turning a ball-screw. This provided much more power, allowed the bracket holding blade to move more quickly, and provide a much higher degree of precision when moving the blade. Additionally, a new base was designed, to house all components and support the cutting surface and machinery. A more powerful servo motor was used to turn the heavier base, and clear-acrylic walls and a door encasing the entire cutting area were designed and made. For the final model a custom 3D printed piece had to made to connect the pizza cutting wheel to the ball-screw and linear bearing on the guide-rod. Finally, a control panel housing both of the buttons was made as well.

6.2 DEMONSTRATION DOCUMENTATION

Figure 22 below depicts a frontal view of the final working model. In the front, a control panel controlling the two cut options can be seen where 12 represents the button for the 12-slice sequence, and 8 for the 8-slice sequence. The new and improved linear motion system can be seen as well, with the stepper motor (on the left of the picture), and the ball-screw across the top.

Figure 22: Frontal view of working prototype

Figure 23 provides a better view of the cutting surface, where the blade moves across.

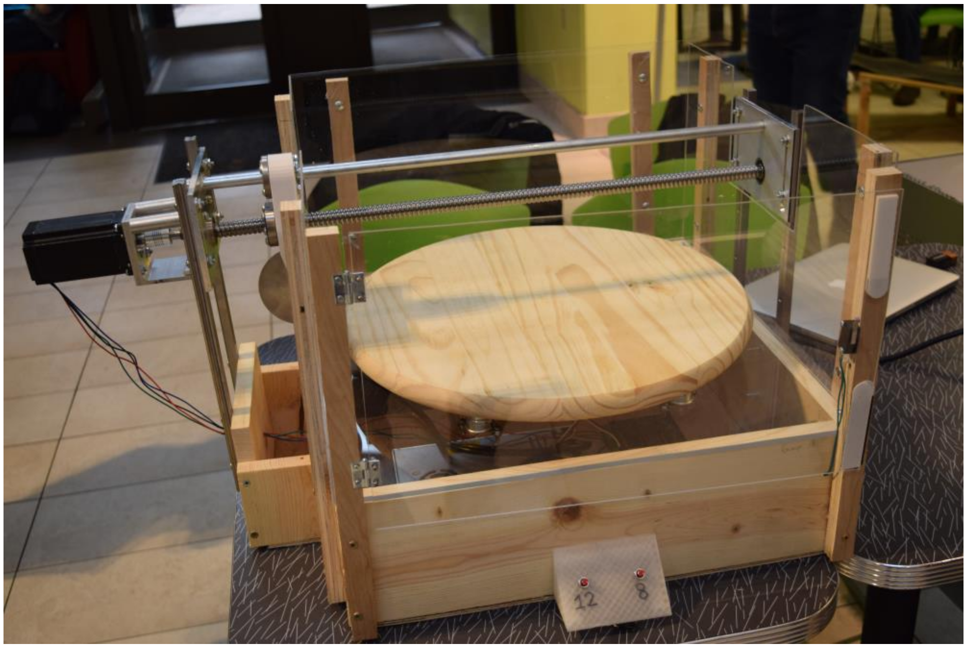


Figure 23: Isometric view of working prototype

Figure 24 shows a snap-shot of the cutting sequence in motion for a large sized pizza.

Figure 24: Overhead view of Prototype in operation

6.3 EXPERIMENTAL RESULTS

The first performance goal for the Automatic Pizza Cutter was to cut a 10" diameter, regular crust, pizza into 12 slices in under 60 seconds. Our working prototype was successful in meeting our design goal because it could cut a large, 16" pizza into 12 slices in about 56-61 seconds. The prototype could have cut the pizza faster, but the speed of the stepper motor driving the lead screw was not maxed. An increase in speed would have needed additional programming, so the speed was left at a lower speed. The pizza cutter was able to cut all sized pizzas into 12 slices in the same time frame.

The second performance goal was for the Automatic Pizza Cutter to cut a 16” diameter, large, regular crust pizza into 8 slices in under 60 seconds. Our prototype was successful in accomplishing this task. The automatic pizza cutter was able to cut one pizza into 8 slices in 40 seconds. The slices were even and cut all the way through. It was tested with large pizzas from different pizza franchises with different number of toppings with no issue. The pizza cutter could cut multiple pizzas in a row without any maintenance. Each of the pizzas were cut in 40 seconds.

The third performance goal was that the Automatic Pizza Cutter will stop operation/motion at any point in the cutting procedure if the door is open, and will resume when the door is closed again. This goal was met. The integration of the limit switch into the design ensured that the blade would never be in motion when the limit switch was not closed. This was done by programming this into the Arduino code, since both the stepper motor and limit switch were directly connected programmatically through the Arduino. The main drawback of this design approach was that the limit switch could be manually closed by hand, and would allow the cutter to resume motion if this was done (even if the door was open). But since this is something that would have to be intentionally done, (I.e. the switch would have to be intentionally closed this way), the primary safety concern of preventing unintentional accidents was achieved.

7 DESIGN REFINEMENT

7.1 FEM STRESS/DEFLECTION ANALYSIS

The mesh utilized in the analysis was a medium mesh, halfway between coarse and fine. The reason being is that the material to be used will be PLA, which we do not intend to use a high infill density on. The coarser the mesh represents a lower infill density for the PLA printed part. The loads were applied inside the two holes where the pizza cutting blade will be inserted. The loads applied were 5lbf. There were no von mises stresses that were approaching the failure or red zone. The boundary condition utilized was fixing the inner diameter of the attachment that would be rotating along the lead screw. The loads utilized mimic the real-world machine's expected conditions because we do not expect there to be any forces much larger than 5lbf when using the pizza cutter.

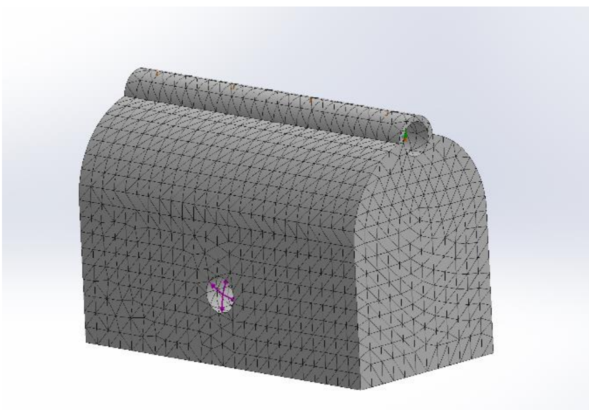


Figure 22: Mesh of Blade Holder

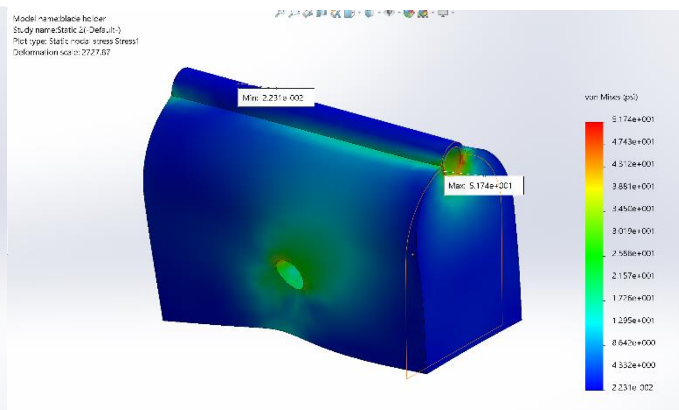


Figure 23: Stress Analysis of Blade Holder

Based on the FEM, the maximum projected stress would be about 51.74 psi, which is fairly small. The material used in this simulation was ABS, which has a yield strength of about 2,000 psi, which varies depending on the formulation. Based upon these results, the factor of safety would be 42.3. This means that this part should easily withstand the forces that it will experience under normal circumstances.

The maximum deflection calculated is 2.141e-006m. For our design, a deflection of approximately 1mm may cause the pizza cutter to be too low to the cutting board, causing the part to break. This predicted deflection should be acceptable because our cutting board will have a slight separation between the cutting board and the pizza cutter blade. This is because of the groves being added to the cutting board during the final prototype.

7.2 DESIGN FOR SAFETY

Risk Name: Limit Switch Malfunction

Description: The limit switch fails to work properly, and the pizza slicer continues moving past its set stopping point. This would only happen if the limit switch failed to trigger or was somehow damaged so that it could not trigger to begin with.

Impact: 3. The reason 5 was chosen for the impact of this risk was because would likely have little impact on the overall operation of the device or those operating it. The slicer it contained on both sides by vertical walls that will be made of medal or wood, and as such will not be able to cut beyond the bounds of the device. The biggest concern with this malfunction would be damage to the device itself that would potentially occur if the slicer attempted to keep moving into the wall, or if the motor was attempting to turn the lead screw when it would no longer move.

Likelihood: 1. The possibility of this happening is slim to none. Limit switches are fairly basic and durable components, so the likelihood that one would fail is fairly low. Additionally, the switch will be positioned in an area where it will not be easily moved or damaged.

Risk Name: Cut by Blade

Description: Someone's cuts their finger on the slicing blade while using the machine. This would most likely occur when the machine is in motion and someone has their hand in the cutting space. While it is unlikely that someone's finger would get cut off completely by this, it is still serious of an injuring to cause a deep cut with lots of bleeding.

Impact: 4. The impact could potentially be very dangerous. It is difficult to say how bad of a cut this could inflict but it as of now it is the primary safety concern with this device.

Likelihood: 2. Since this is such a large concern, the entire device will be designed around avoiding this outcome, whether that means including guards around the blade or extra safety measures to keep hands out of the cutting area while it is operating.

Risk Name: Electrical Shock

Description: The risk of getting an electrical shock while operating the machine, or being around the components.

Impact: 2. Since the components will be running on very low amperage and fairly low voltage, so any shock off of this device will be relatively minor.

Likelihood: 1. All of the electrical components will be well insulated and shielded from access while in use. This is of particular importance for this project considering that there may be times when the outside surface is near other food or drink and as such may be in contact with conductive fluids.

Risk Name: Food Poisoning

Description: Food particulate from a pizza gets stuck in some part of the device, is able to go bad, and gets transferred to another pizza being cut in the future, potentially causing food poisoning.

Impact: 4. Food poisoning can have serious implications, and as such it should be

Likelihood: 1. It is not very likely that this could happen. The base and wheel will be designed so there are no large nooks that food gets easily trapped in. Additionally, each piece will be easy to clean, which sill minimize the probably the food scraps are left on the device between uses. Even if small amount of food is transferred from one pizza to another between uses, the likelihood this will be enough to cause any kind of food poisoning is small.

Risk Name: Rust Getting on Food

Description: Rust or corrosion from metal components ending up in on the pizza.

Impact: 1. It is difficult to say the exact impact this could potentially have. However, since each component will be made from food-safe materials, the risk of any kind of toxicity occurring is fairly small. Regardless this is something that should be completely avoided.

Likelihood: 1. The components will be designed out of stainless steel or other corrosion and rust resistant materials, so this should be very unlikely to occur.

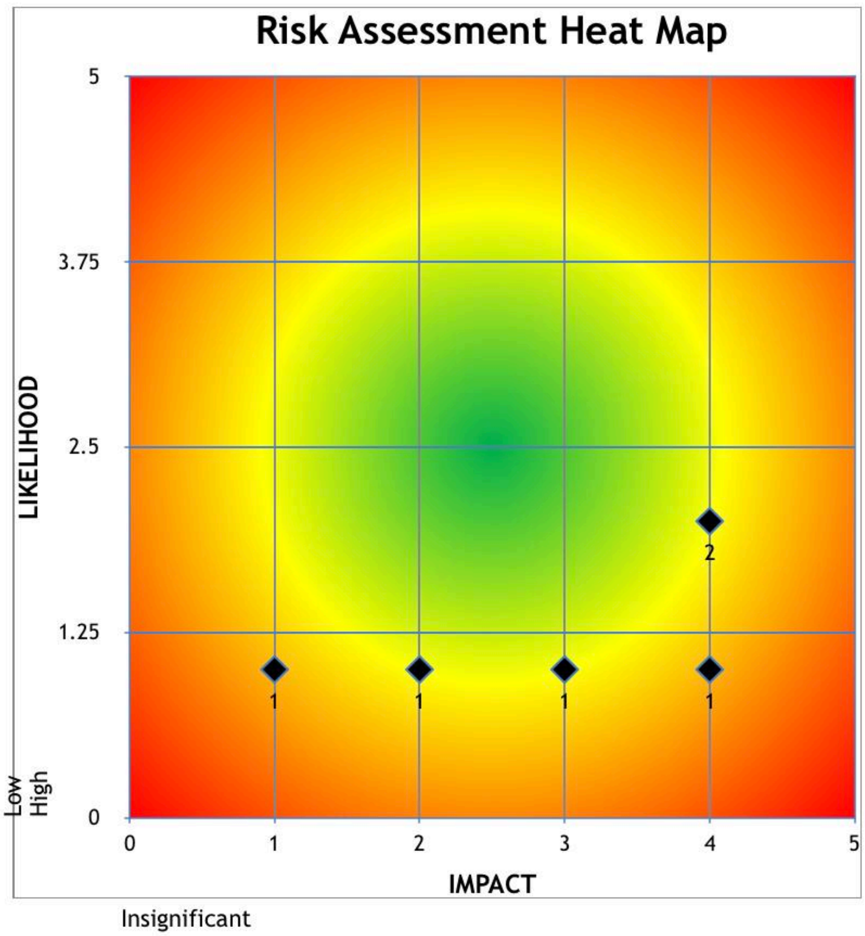


Figure 24: *Risk analysis heat-map.*

From the heat map it is clear that the most important risk to address was the risk of getting cut. This one had the highest likelihood occurring as well as the highest impact. The second most important risk in terms of priority was food poisoning. This should be fairly easy to address and avoid through material selection. The third highest priority risk was the risk of a limit switch failure. The damage this could do could be fairly significant, however the likelihood is relatively small, and should be avoidable through proper design practices. The fourth risk from this list was the risk of an electrical shock. The impact was low mainly because of the low voltage and current that will be used by the components limits the damage any shock could do. The final risk as the risk of rust being introduced to the food. This is very unlikely to happens and the impact would be relatively little even if it were to happen, and as such its position on the heat map makes sense.

7.3 DESIGN FOR MANUFACTURING

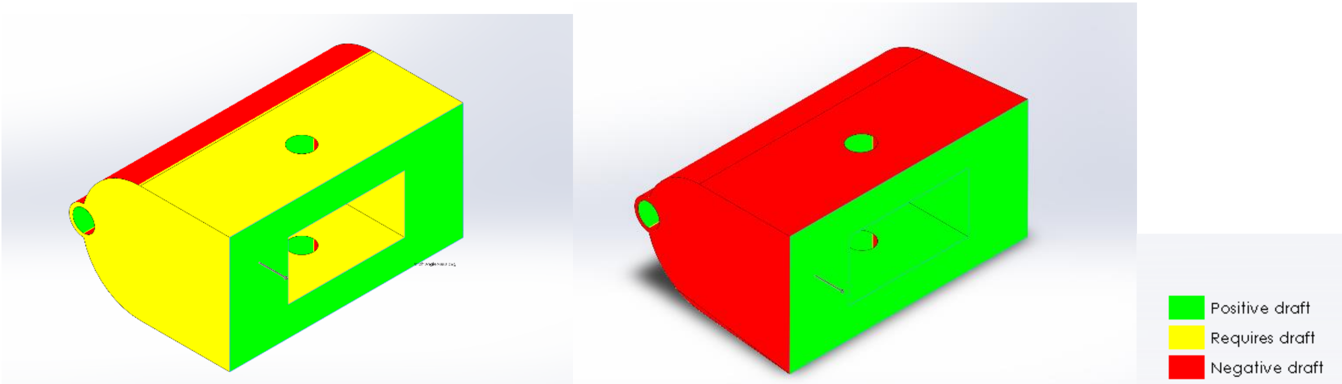


Figure 25: *Before (Left) and after (Right) Images from the pizza cutter sliding mechanism using SolidWorks "Draft Analysis"*

Figure 24 shows the changes made to the pizza cutter holder in order for it to be mass produced using injection molding. The outer surface had a 3-degree draft added to get a negative draft. The inside rectangle (where the pizza cutter attaches) also received a 30-degree draft angle to ease the injection molding process. Since there was an added fillet, only half the part needed a draft angle adjustment.

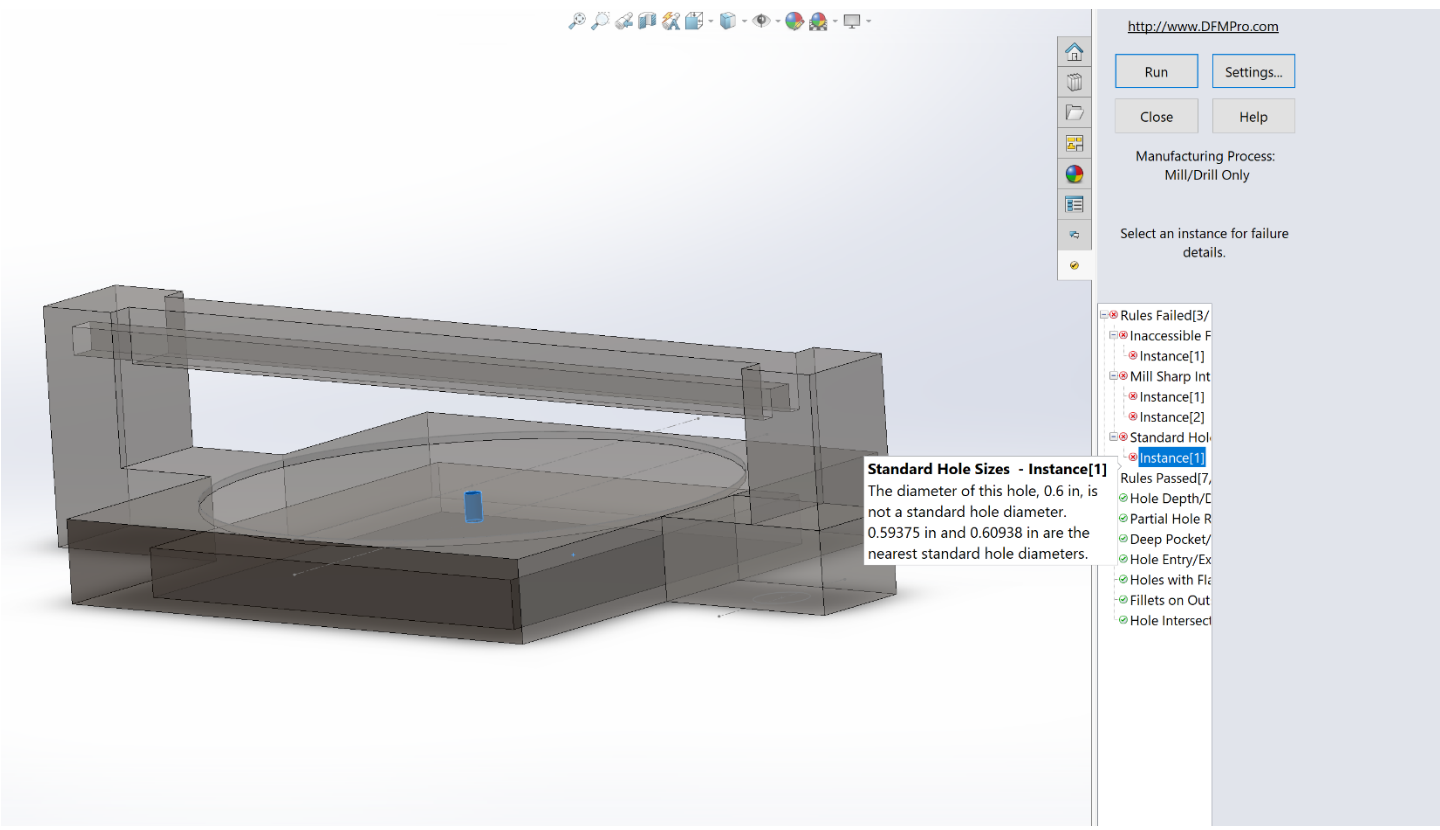


Figure 26: *DFMXpress analysis using a Mill/Drill only*

The part chosen for the DFM analysis was the entire base for the Pizza Cutter. The first analysis chosen was the Mill/Drill only option. The results showed 3 failed rules and 7 passed rules. The failed rules are as followed: Inaccessible features, Mill sharp internal corners, and Standard Hole Sizes. If we were to Mill/Drill the base, we would have to split the base into pieces and choose a standard sized hole for the drill.

1

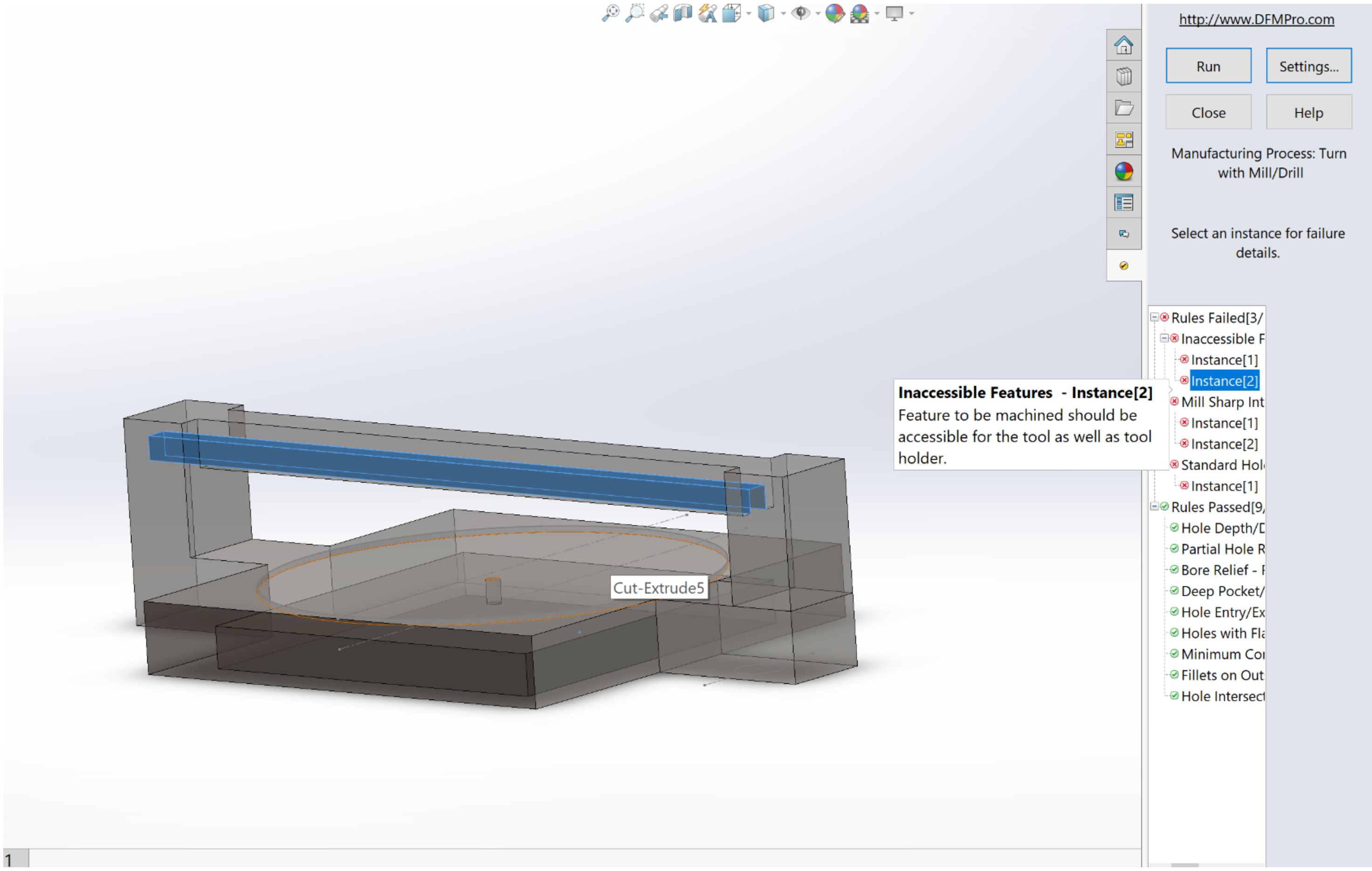


Figure 27: *DFMXpress analysis using a Turn with Mill/Drill*

The second analysis on the base was the turn with mill/drill. This DFM showed the same 3 failed rules with 9 passed rules. This means that the base has to be separated more in order for the part to be manufactured using a turn with mill/drill. In addition, the holes will have to be sized to a standard drill size and the corners will need to be rounded off.

7.4 DESIGN FOR USABILITY

1. **Vision:** There are very small vision influences that we need to take into account when designing our Pizza Cutter. This is because our pizza cutter has no current design implementations where color matters. The user pushes a button to activate the pizza cutter and does not do anything else until the pizza is finished cutting. The only implementation we have considered is adding a green light while the pizza cutter is in use and a red flashing light when the pizza cutter is not moving (This could mean blinking red light if emergency stop or a solid red light when the pizza is done cutting). This is not an essential part of our design, causing vision to not influence our design.
2. **Hearing:** A hearing impairment will not have a huge impact on our design, but will be more viable than vision. The user can hear when the machine is operating and when it is turned off. A way we can modify our design would

be, like vision, to add in indication lights that show when the machine is operating, if an emergency stop was activated, and when the machine has finished cutting the pizza.

3. **Physical:** A user with a physical impairment may have trouble carrying around the pizza cutter if it is too heavy. Our original design was to make the pizza cutter out of metal, however a modification could be made to make the pizza cutter out of wood. This would decrease the overall weight of our pizza cutter making it easier to lift. Another option would be to make the safety cage removeable. This would allow the user to detach the safety cage and reattach it to decrease the weight even more. The pizza cutter, however, would not operate unless the safety cage was attached correctly and securely.
4. **Language:** Speaking little to no English could cause issues mainly with the emergency stop button we will be implementing into our design. If the emergency stop was just a regular looking button with the word STOP on it, someone who did not know English could be having an issue with the pizza cutter and not know how to stop it even though there was an emergency stop switch. A way to combat this would be to make the emergency stop button either a big red button, or look like a stop sign. This is because a stop sign is mostly universal, so everyone knows that this button is an emergency stop.
5. **Control:** People who have a control impairment could be in risk of injury if they are not careful around the spinning blade. This led to the addition of a Plexi-Glass like casing to completely cover the Pizza and pizza cutter. The cutter will have a door that swings open so the pizza can be put in, and the machine will not operate until the door is fully closed. This allows for total protection from the blade with anyone who has a control impairment.

8 DISCUSSION

8.1 PROJECT DEVELOPMENT AND EVOLUTION

8.1.1 Does the final project result align with its initial project description?

The final project mostly aligned with the initial project description. The goal of cutting a pizza into differing numbers of slices was obtained, but the ability to control the exact number of slices was not part of the project. This was because we used two buttons with two slice-options as the input rather than an input panel where users could select a custom number of slices. This feature however would be something that could be integrated fairly easily.

8.1.2 Was the project more or less difficult than expected?

It was about what was expected. Certain aspects were more difficult, particularly everything involved with the linear motion system, including finding and ordering the rights parts, the coding and the machining of the supports, but other aspects were somewhat more-straight forward than expected, particularly the rotating base.

8.1.3 On which part(s) of the design process should your group have spent more time? Which parts required less time?

Designing the base. The actual wooden base was not perfectly squared up, which led to a few complications further along with mounting the linear motion system. The main part that could have required less time was the prototype model. There were aspects that were helpful in designing and building the final model, but most if not all was not very useful, and was not intended to be. Part of this however had to do with the limited budget and time constraints, because it did not make sense to spend too much time and effort on aspects of a model that would not be used in the final design.

8.1.4 Was there a component of the prototype that was significantly easier or harder to make/assemble than expected?

The linear motion system was by far the most difficult, and this had mostly to do with designing and mounting the stepper motor and lead screw. It took lots of time and effort to make sure everything was perfectly aligned and spaced out correctly. This included lots of time spent taking measurements and doing calculations to make sure all the machined parts would perfectly fit together.

8.1.5 In hindsight, was there another design concept that might have been more successful than the chosen concept?

Probably not. The different design concepts centered around the mechanism through which the pizza was actually cut. And out of the available options, this one seems to be the option that works the best, is the lightest in weight, and provides the safest options of all. Even with this model however, weight primarily was still an issue, but this would have been much more of an issue had any of the other design concepts been chosen, due to the components involved.

8.2 DESIGN RESOURCES

8.2.1 How did your group decide which codes and standards were most relevant? Did they influence your design concepts?

The codes and Standards that were most relevant for this project dealt with the handling and preparation of food. Since our project involved cutting pizza, we had to abide by these food safety codes and standards to make sure the food did not get contaminated. This influenced our design because it influenced the type of material chosen for certain parts such as the wooden base, cutting wheel, and metal rod. The wooden base had to be a specific type of wood as given by the standard to be safe for the cutting of food, and the metal rood and blade had to be stainless steel to prevent rusting and further food contamination.

8.2.2 Was your group missing any critical information when it generated and evaluated concepts?

Our group was missing one critical piece of information when evaluating concepts. This was the force caused to the blade by the pizza while cutting. Our final design consisted of a 3-D printed part that connected the blade to the lead screw, which moved the blade across the table. Our first part did not have a high enough density, causing it to break and we had to 3-D print the part again with a higher fill density.

8.2.3 Were there additional engineering analyses that could have helped guide your design?

Our design was able to cut a pizza and met our design goals. However, one analysis that could have been done more in depth was the speed needed from the stepper motor. The stepper motor in our design had a higher torque and rpm than what was needed to meet our design goals. A motor with a lower rpm would have decreased the total cost of our final prototype while still meeting our design goals.

8.2.4 If you were able to redo the course, what would you have done differently the second time around?

If we could redo the course, we would order parts sooner and do more analyses for different parts. This would allow us to get the most efficient products for our specific design Specifically, we would look into analyzing different materials for different parts of the prototype. For example, looking for wood or metal that was lightweight for the base would be ideal because our final prototype was a lot heavier than expected. Finally, ordering the parts sooner meant they could be used in our first prototype and could have been tested versus testing only concepts.

8.2.5 Given more time and money, what upgrades could be made to the working prototype?

There are two main areas that could be upgraded. The first would be using different structural materials. Since the entire base and walls were constructed out of wood, the entire base was pretty heavy. This could be improved upon by using light weight extruded aluminum pieces (such as 80/20), covered with thin plastic or wooden panels. This would provide the same structural support at a fraction of the overall weight. The other improvement could be made in the door safety mechanism. The major concern with our model as of now is that if the limit switch is pressed by hand, the cutter sequence will continue even if the door is still opened. This could be improved by embedding the limit switch into the frame itself so it cannot as easily be pressed by hand, or by using another mechanism such as a photoelectric sensor to detect if a hand is in the cutting area.

8.3 TEAM ORGANIZATION

8.3.1 Were team members' skills complementary? Are there additional skills that would have benefitted this project?

The team member's skills were complimentary to each other. There were certain aspects of the project that one member's skillset was better fit for, and other aspects of the project that any of the members were capable of doing. As far as additional skills, some electrical expertise would have been beneficial for some of the electrical decisions.

8.3.2 Does this design experience inspire your group to attempt other design projects? If so, what type of projects?

This inspires us to take on additional projects as individuals. This opportunity provided us with lots of experience with the design process of a more complex project, which is something that is very beneficial and can be applied to future work. Future projects would most likely involve other mechanical processes or the automation of tasks.

APPENDIX A – COST ACCOUNTING WORKSHEET

	Part	Source Link	Supplier Part Number	Color, TPI, other part IDs	Unit price	Quantity	Total price
1	LewanSoul Standard Digital Servo High Torque	Amazon	48666K92	Black, Control angle 180, 6V, 278oz-in, 40x20x40.5mm	$16.99	1	$16.99
2	Nema 23 Stepper	Amazon	23HS45-4204S 57x100	425oz-in, 100mm Length, 4.2Amp	$38.09	1	$38.09
3	Stepper Motor Driver	Amazon	M542T	2/4 phase Name 23 driver, 24-50V DC, 1.5-4.5A, 256 Microstep Control	$38.99	1	$38.99
4	Uxcell Shaft Coupling	Amazon	a16121900ux0359	10mm to 10mm Stepper Motor Shaft Coupler, 25mm Length, 19mm Diameter	$6.21	1	$6.21
5	Uxcell 10mm Deep Groove Ball Bearing	Amazon	g18080100ux0005	10mm Inner Diameter, 30mm Outer Diameter, Double Sealed, Deep Grove Bearing	$5.54	1	$5.54
6	Uxcell 12mm Deep Groove Ball Bearing	Amazon	g18080100ux0005	12mm Inner Diameter, 32mm Outer Diameter, Double Sealed, Deep Grove Bearing	$6.24	1	$6.24
7	Mean Well Single Output Switchable Power Supply	Amazon	LRS-350-48	48V, 7.3 Amp Output Power Supply	$36.54	1	$36.54
8	Uno Breadboard Kit	Microcenter	426304	Arduino Controller with Breadboard, wires	$19.79	1	$19.79
9	Pine Rounds Laminated Panel	Home Depot	75684000252	1”x17-3/4”	$6.23	1	$6.23
10	Powertool Cord	Home Depot	812567011227	16/3 8’ Length, Black Cord	$12.07	1	$12.07
11	Pizza Cutter	Walmart	7675384360	Black, Large Wheel Cutter	$6.57	1	$6.57
12	Ball Casters	Amazon	B01MA6RZYD	5 ball casters	$9.29	1	$9.29
13	Lead Screw	Amazon	BO7DCVPRK5	Lead screw SFU1610-650MM and ballscrew	$42.99	1	42.99
14	Clear Acrylic Sheet	Home Depot	769125020712	20x32x.093 sheet and 18x24x.093 sheet	32.84	1	32.84
Total:							$278.38

APPENDIX B – FINAL DESIGN DOCUMENTATION

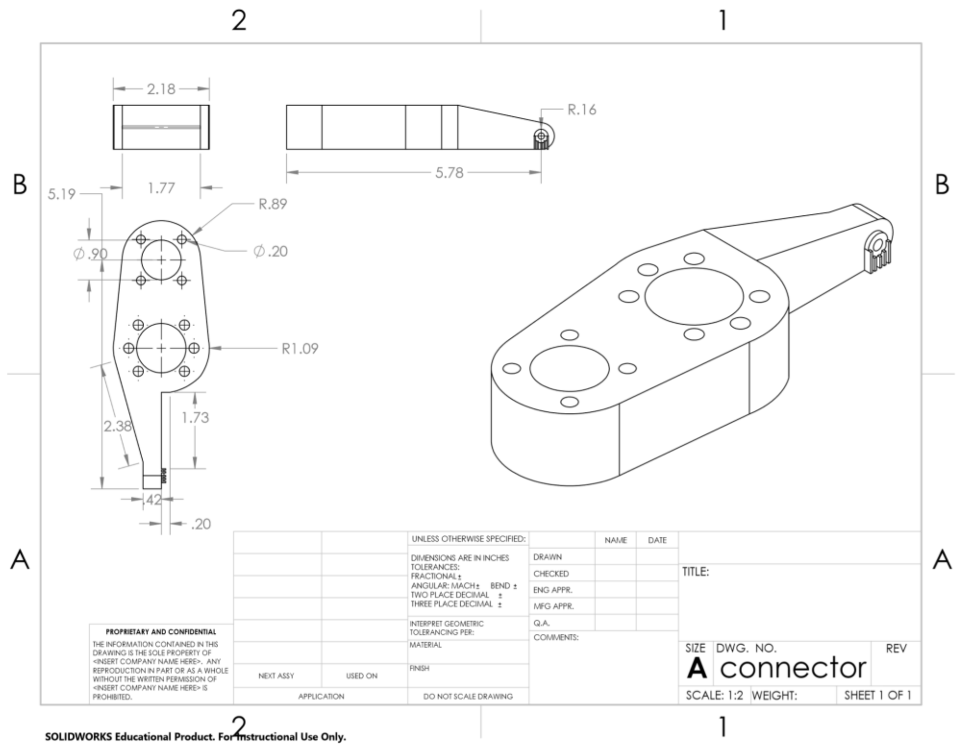


Figure 28: Solidworks Drawing of Pizza Connector

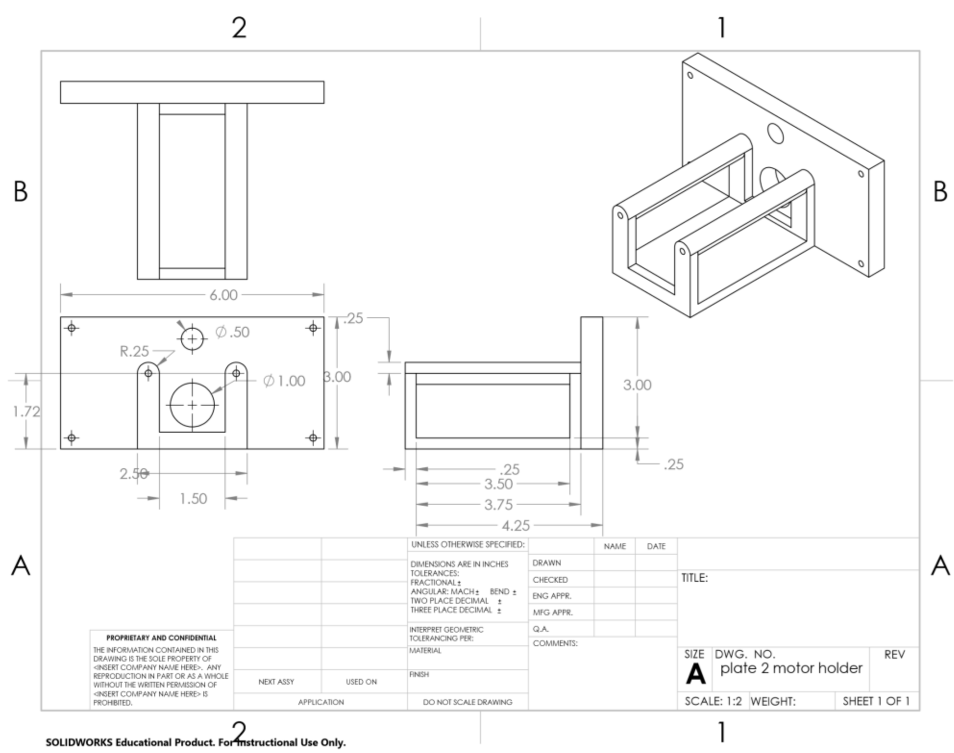


Figure 29: Solidworks Drawing of Motor Holder

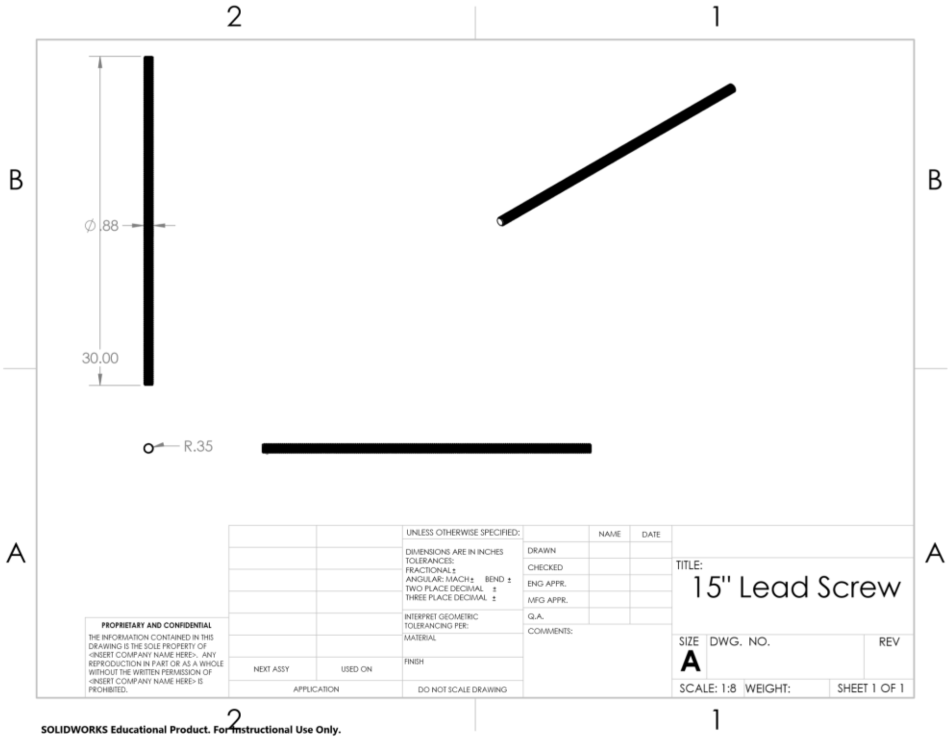


Figure 30: Solidworks Drawing of Lead Screw

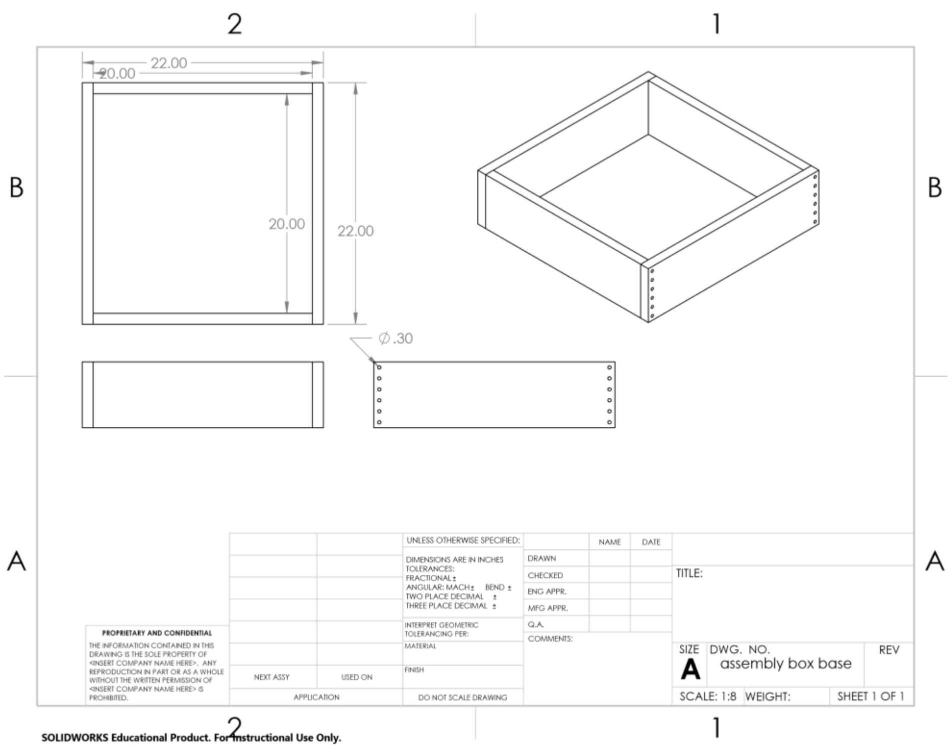


Figure 31: Solidworks Drawing of Box Base

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