Abstract:

Our team was tasked with building a small-scale pecan cleaner for our client. The objective was to create a mobile cleaner that would make the cleaning process easier. It was to be able to fit within a small shop, be run off 240V 50A power, and include a variable frequency drive to adjust fan speed and conveyer speed of the cleaner. Research and testing were done on pecan cleaning and pneumatic separation. The design consists of a portable trailer/skid that includes a 3-step cleaning process. The first part of the machine is the elevator belt that dumps the pecans and debris into a rotary trommel. The trommel removes small debris and breaks loose clods. The second is pneumatic separation using a blower fan and ductwork. Pneumatic separation uses the materials' terminal velocity to blow lightweight debris and bad pecans out the top. The third step is a conveyor belt where the operator can hand pick through the rest of the pecans and short them. Our team was able to complete all the objectives with our work throughout the year. We were happy to present a complete final product to the client.

Acknowledgments:

The senior design team consisted of Stephen Fuhrmann, Garrett Seger, and Gavin McCullough. The team has put lots of time and effort into realizing the potential that this project has. Despite all the hard work that we have put in, none of this would have been possible without the help of several different people. We would first like to thank Dr. Paul Weckler and Dr. Kevin Moore for their guidance and support from the beginning. We would also like to thank our client, Robert "Rocky" Harrington, who gave our team the opportunity to build this great project for him. A big thank you is extended to each of the BAE Lab technicians who helped us with the fabrication and were always there to help when we had questions.

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Introduction:

Our client wanted a small-scale custom pecan cleaner. He owns a pecan orchard North of Stillwater, Oklahoma and was searching for a more efficient cleaning method than sorting the pecans by hand.

Our project deliverable is a custom-designed pecan cleaner. The current post-harvest cleaners on the commercial market do not meet the needs/wants of our project. This cleaner was not designed to be used in an industrial setting. The cleaner is design for a small-scale pecan cleaning operation. With this market focus in mind, the team analyzed three different options for solutions to the project. The options included designing and developing a new machine, retrofitting a current model of cleaner, or finding a cleaner on the market that would fit the client's needs. When going through the options, designing our own version of a cleaner was more cost-effective. Cleaners on the marker were around $10,000 used before anything was retrofitted on the machines. Cleaning and sorting the pecans by hand is not a long-term solution to the issue at hand. An average yield of 3,000 pounds of pecans a year to clean by hand is inefficient.

Our project came with specifics for the pecan cleaner that our group is designing and developing. Our budget for the entire project is $15,000. There are three different categories that the requirements or “wishes” are categorized as. The “must haves” of the project are the items that must be included within the project or criteria that must be met with our design of the pecan cleaner. Below is all the information we have for our sponsor requirements.

The “must haves” of the project are:

- Must fit within a portable garage sized 20x12x7 ft.
- Run off 240V 50A power.

- Include a variable frequency drive to adjust fan speed and conveyor speed of the cleaner.
- Must be able to pull behind a 50 hp tractor.
- No hydraulics anywhere on the cleaner.

The “very desirable” wishes of the project include:

- Able to plug into a generator and stay under 12,000 W power.
- Cleaner includes a pre-cleaning mechanism.
- The output of the cleaner includes a conveyor belt for sorting good and bad pecans.

The “It would be nice” to have include:

- Foldable tongue on the trailer.
- Includes a rotary trommel.

As you can see, there were a lot of sponsor requirements for this project. Our team's challenge was incorporating those requirements into our design in a way that was efficient and productive at the end of the design and build process.

The motivation behind this project was to create a project that matches our clients’ wishes. While this is a one-of-a-kind project, we also wanted to ensure that it could be reproduced again if necessary.

Background:

Pecans can greatly vary in size depending on many factors, including weather patterns, drought conditions, temperature, and variety. These sizes play a major role in our project design. When pecans are harvested, they are collected off the ground. During this harvesting, debris such as sticks, leaves, dirt, and small gravel are also collected. The cleaning process is intended to separate all the debris from the clean pecans. With this in mind, we intend to design and

implement a rotary trommel. The pecans will roll through this trommel, and many of the rocks and debris smaller than the grate will fall out, aiding in the cleaning process. To design this trammel, we need to know the sizes of pecans that we will be running through the machine to properly size the grate so that minimal pecans get discarded. To properly size pecans based on the diameter, which is the dimension that we need to know for our design process, 200-300 pecans are selected and measured, and the percentage is taken from each size bracket. These brackets normally range from 10/16 to 16/16. According to Becky Carroll, (Senior Extension Specialist, Fruit and Pecans Horticulture & Landscape Architecture, Oklahoma State University), for native pecans, which are generally the smallest variety, we should expect the smallest pecans to be 9/16 of an inch.

Pecan Varieties:

To determine the size of pecans we will be dealing with, we need to know the varieties that are common in Oklahoma, and that could be run through the system. These varieties vary greatly in size, from half an inch in diameter to over an inch. This constrains a lot of our designs and ultimately needs to be where we design from on several different parts of the machine. An article titled “Pecan Varieties of Oklahoma” from Oklahoma State University article discusses the pecan varieties that are common in Oklahoma. This article goes over not only varieties but also nuts/lb. and maturity dates for the varieties. The background information found in this section is important to understand the material that we will be working with. The information will help determine the constraints that we have in building our project.

Managing Pecan Groves:

The number of pounds per hour plays a major role in our design. Yields for pecans are recorded by the pound per acre, which correlates to the number of trees per acre. Our machine needs to be properly sized to have the capacity to clean all of our sponsors' pecans given its timeframe. Our sponsor wants to be able to clean 200-300 lbs./hr. and usually has a yield of 3000 pounds from his orchard. To get the best yield possible from an orchard many aspects must be considered. Tree spacing plays a big role in crop yield, not overcrowding the orchard, but also not under populating the orchard, both of which would result in poor yields. Disease control and thinning contribute to a healthy tree as well. These procedures help to keep the tree as healthy and productive as possible. A properly managed orchard maximizes the yield potential and knowing the number of acres that the orchard consists of a yield can be estimated. With this yield in mind as well as how many pounds per hour need to be run through the machine, we can size the components accordingly.

Standards:

Shielding Standards:

This project will incorporate several different types of moving parts. We plan to input several belts, rollers, a conveyer belt, and an auger. Any one of these mechanisms provides a potential risk for injury. With moving equipment and the fast-paced process of trying to clean the pecans on the sorting table while simultaneously making sure the machine is cleaning to the desired standard, it can be easy to not be paying attention and get hung up in any number of moving parts. This is especially the case for our client who generally works by himself while cleaning his pecans. Being able to provide proper shielding to cover belts and any potential risk area is a very important aspect of our project. The standards provided by OSHA, ASABE, and

ASME provide a good starting point to at least see what the standard practice is that we need to work from to provide the safest project that we can. OSHA Standard 1910.219 outlines the different needs for shielding that were required by the cleaning system. The shields that were put in place would be the largest part of the project safety.

Electrical Standards:

To power our pecan cleaner, we are going to use 220V 50A service. This will either be powered by plugging it into our client's shop or by a generator that will be an option for purchase for this project. All our moving pieces will be powered by electrical motors. This includes the fan, trommel, conveyer belts, and stick cleaner. There will be a lot of wires throughout the cleaner providing a lot of risk for electrical issues. If anything is wired wrong or wired in a place where it might wear down and become exposed, becoming a hazard. Knowing how to avoid dangerous situations and how to install all of the electrical components properly is essential for safety purposes. OSHAs electrical safety standards guide provides good insight to what standards we need to follow to make our project as safe as possible. (OSHA Design Standard 29 CFR 1910.302-308).

Patent Research:

With our project lots of attention must be given to the cleaners that are already on the commercial market. Not only commercial cleaners but patents for the individual pieces that we are considering using in our design process. The patents below are broken down into commercial cleaners and individual parts that we will be using.

Commercial Cleaners:

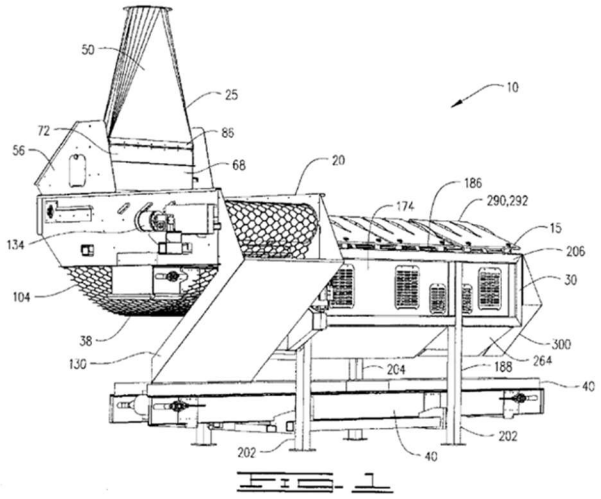

Figure 1: Savage Nut Processing Apparatus (PCT Patent No. WO 2019/060449A1)

In Figure 1, you can see a sketch of the Savage Equipment Nut Processing Apparatus. This patent was filed in November of 2019. This machine is one of their all-inclusive nut cleaners. It includes an intake end for the pecans that drops onto a stick remover. The stick remover is a chain-link belt that removes any large sticks from the pecans as the pecans will fall through the chain while the sticks stay on top of the chain. This piece of the machine is relevant to our design as our client wants a prescreen for large foreign objects that are collected with the pecans during the harvesting process. The pecans that drop through the chain-link belt are then sorted into different sizes by a nut sizer using a rotatable nut sizer reel. There are 17 different varieties of pecans that are grown, and it is pertinent to sort them by different sizes for sale purposes. The other key part of this machine is the rotary trommel section of the cleaner. Our group wants to incorporate a rotary trommel into our design as it is a wish of our client. This rotary trommel would shuffle out rocks and other debris that make it through the stick cleaner before the pecans drop over the squirrel fan. The rotary trommel design of this piece of Savage Equipment is something that we plan to draw from for our design.

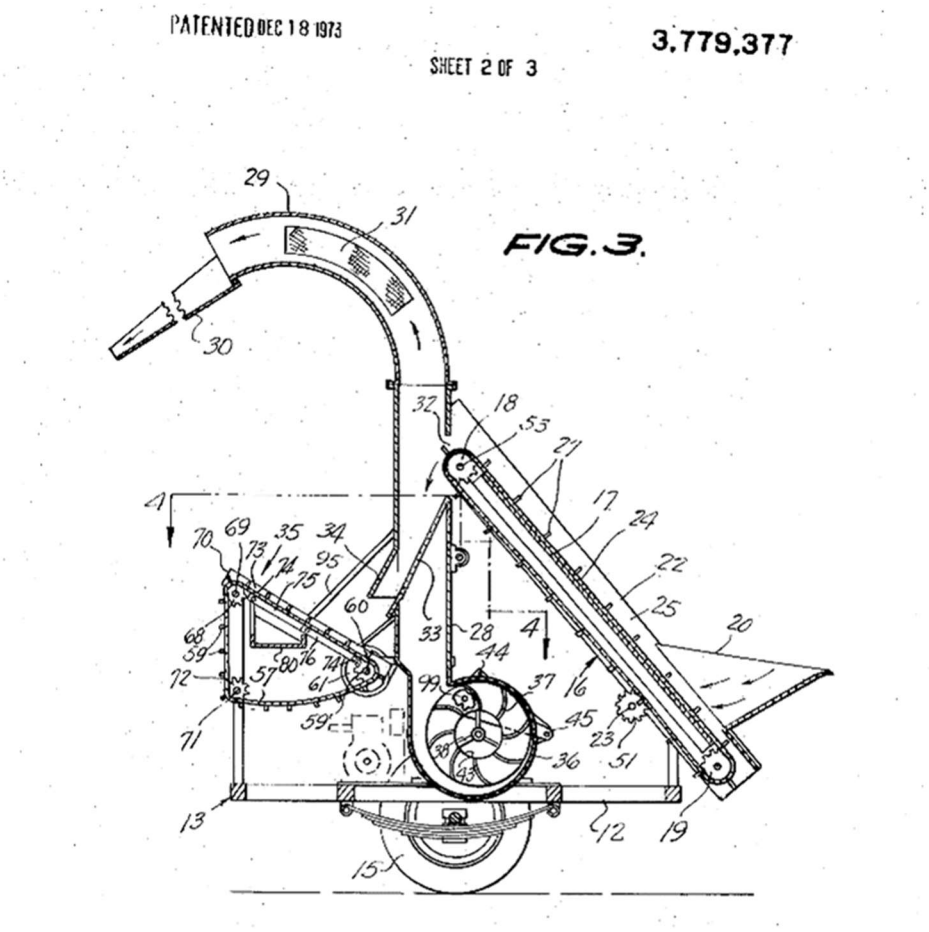

Figure 2: Pecan Cleaner Patent (US Patent No. 3,779,377, 1973)

One of the most important requirements for this pecan cleaning system is a debris removal system using high-velocity air. The patent shown in Figure 2 covers a pecan separator and cleaner using an infeed-cleated conveyor with a vertical air duct. The air is supplied by a blower with a manually adjustable air intake port. As the pecans and debris enter the air stream, the lightweight debris gets forced out of the top as the pecans fall down and out the other end. The apparatus in Figure 3 and Figure 4 are also readily portable to a desired location for use, which greatly facilitates the process of separating acceptable pecans from accompanying trash, debris, and faulty unacceptable pecans.

The portable pecan cleaning machine, shown in Figure 3, incorporates a first chamber in which pecans are subjected to drum-mounted resilient flails which cooperate with a roughened chamber portion in effecting a separation of the husks or hulls of the pecans. This first chamber shows a way of breaking up debris and removing some of the husk from the pecans while also not taking up very much room. The first chamber utilizes a rubber tooth the scrapes the pecans against the stationary barrel shown in Figure 4. The team is planning on using a rotary trommel to accomplish this task because it also allows small heavy debris like gravel to fall out, but a rotary trommel takes up more room.

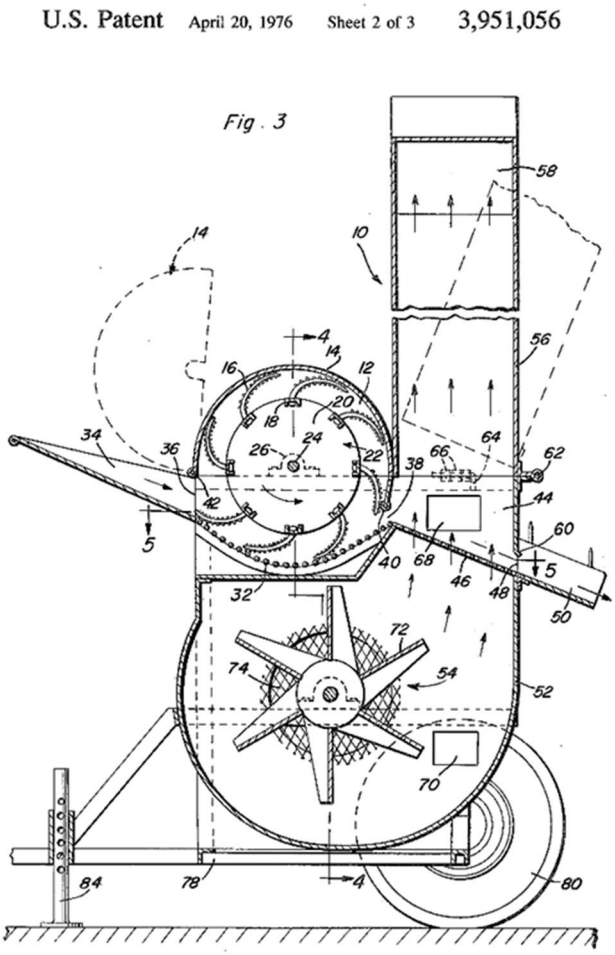

Figure 3: Portable Pecan Cleaner Patent

A second chamber located outward of the first chamber receives the pecans, hulls, and other vegetation that might have been gathered with the pecans, with all the materials in the second chamber being subjected to a separating flow of air whereby the normally heavier pecans are allowed to pass there through with the lighter hulls and other materials being air separated from the pecans. This air stream process would work for our project, but we are also planning to incorporate a debris trap at the bottom of the ductwork with the blower fan being mounted past a bend. This should allow heavy debris to fall down and collect and be dumped out instead of falling into the fan blades.

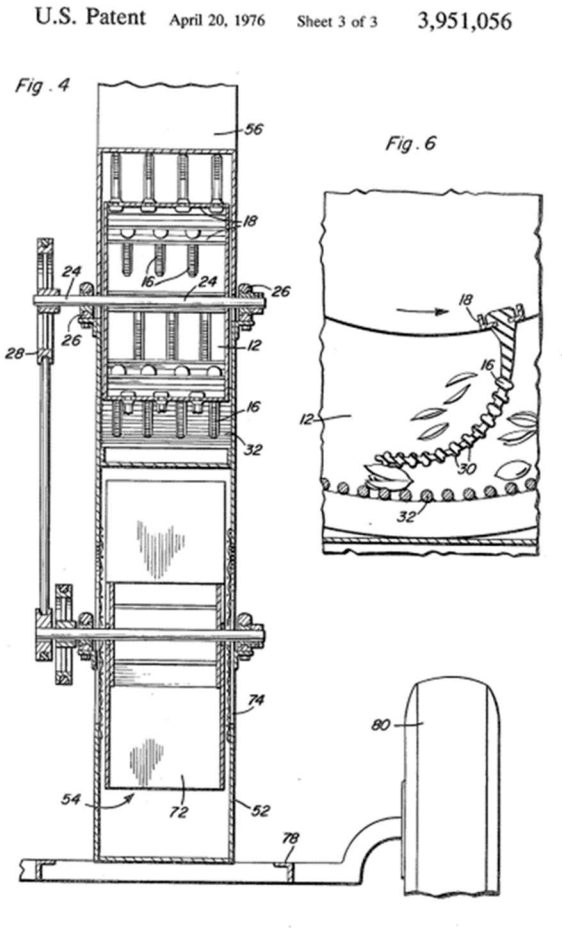

Figure 4: Portable Pecan Cleaner Patent

Rotary Trommels:

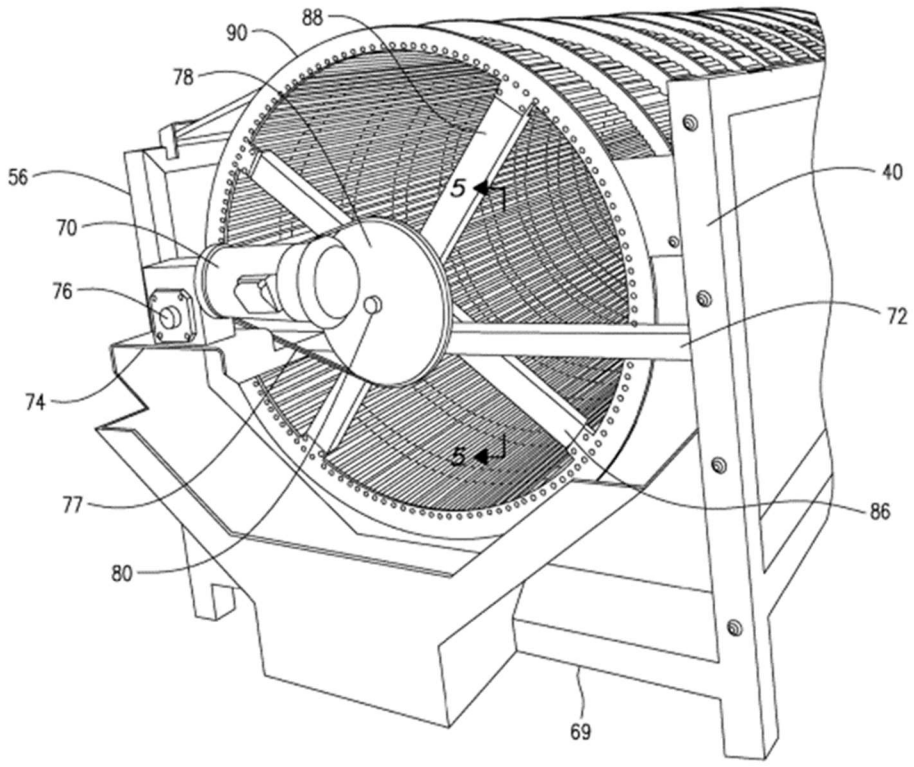

Figure 5: Nut Sorter (US Patent No. 11,020,769, 2021)

A nut sorter shown in Figure 5 includes a support frame with a rotatable cage. The rotatable cage is comprised of support rings with a plurality of longitudinally extending rods. Although the project will not sort the nuts into sizes, the rotating cage will help break up debris and husks. The outer periphery of the longitudinally extending rods extends inwardly into a center space defined by the inner diameter of the support rings. The nut sorter also has a plurality of scrapers utilized to dislodge stuck debris and nuts as the cage rotates under the scrapers. Using a scraper on the inside will help keep the debris and pecans from getting stuck in between the rods.

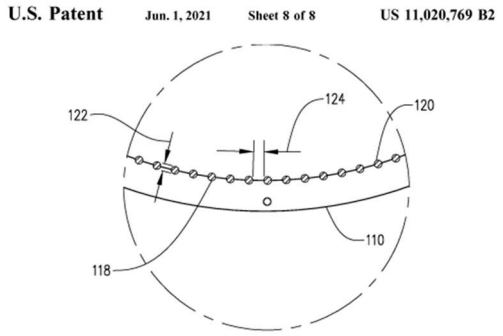

Figure 6: Nut Sorter

Figure 6 shows the size of the rods and the gap between each rod. The size or space between longitudinal rods, which will be a general uniform space, will be determined based on the smallest diameter of the desired nut. Debris and nuts that are below a specified size will fall through the spaces.

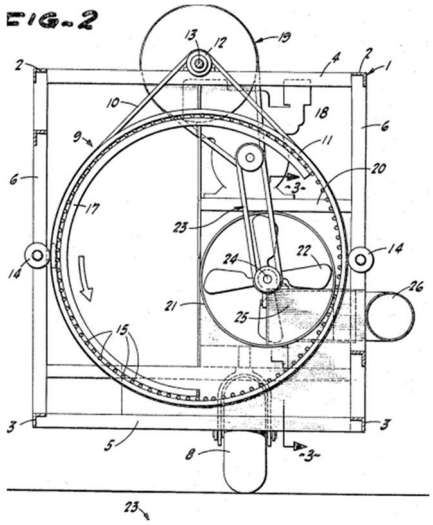

Figure 7: Trommel-Type Produce Cleaning Machine (US Patent No. 3,341,877, 1967)

The patent in Figure 7 has a rotary trommel used for pre-cleaning walnuts before hulling. Unlike some other cleaning systems, this utilizes a fan to blow through the trommel barrel to clean debris as the trommel breaks it free. The barrel has sectional flighting, shown in Figure 8, that allows control of the speed and route the nuts take through the barrel as it turns. This also

should reduce the chances of nuts bundling up in certain areas. This trommel is powered using a rubber belt, shown in Figure 7, that is tensioned around the barrel like a washing machine or drier instead of trying to add a cross to the middle to add gears or fabricating a large ring gear. This may allow easier service and decrease production costs. The fan and the trommel both run off separate motors using variable frequency drives.

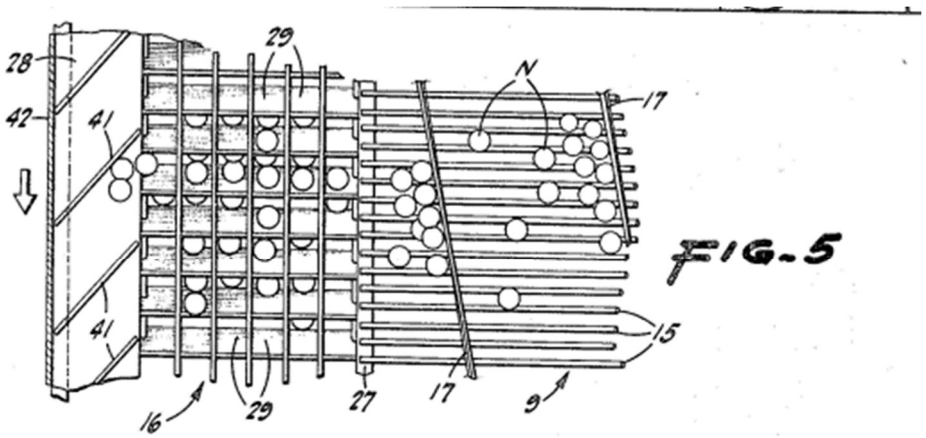

Figure 8: Trommel-Type Produce Cleaning Machine Sectional Flighting

Based on the background research that we collected during the fall, we were able to determine what the best options would be for a custom design cleaner. The most obvious option is to include a rotary trommel. The trommel separated most of the leaves, dirt, and sticks from the pecans. The next option that needed to be included was a blower system. This system would separate any remaining debris from the pecans and blow some bad pecans out of the cleaning operation. The sorting table was an option requested by our client, and the elevator was required to begin the cleaning operation. Using our research and clients' requests, we started piecing together what the project's final design would be.

Statement of work:

The custom pecan cleaner is a designed and fabricated cleaner intended for use by small commercial farmers. Many of the current commercial options are not appropriately sized for use by small pecan farmers or do not include desirable features. The pecan cleaner that is being designed will be able to run off 220V 50A power. The cleaner can be stored in a small mobile garage 20x12x7ft in measurement. The Senior Design Team intends to create a small-scale, economic, post-harvest pecan cleaner by the conclusion of the 2024 spring semester.

The Custom Pecan Cleaner will need to compete with similar products on the commercial market, if not exceed them. The cleaner will also need to remain economical for small-time producers in the pecan market. Components that cannot be purchased have been fabricated in the BAE Fabrication Lab. The fabricated parts will include a rotary trommel, a cleaner frame and axle, supports for other components, and a bagging apparatus. The information about pecans came from the Oklahoma Extension office and the client. Testing occurred at the BAE Lab by the Senior Design Team. Funding was provided through the client for the entire project.

Design:

The overall design combined several different ideas mentioned above in patent research. The idea was to combine several aspects that worked well in other designs into one working system. The design that will be described below includes a hopper attached to an elevator, a rotary trommel, an air duct, and a sorting conveyor. The first step in the process is to dump the “dirty pecans”, pecans that are intermixed with leaves, sticks, rocks, and other debris, into the hopper. From there, the pecans are transported to the rotary trommel using the cleated elevator. The rotary trommel is sized to allow smaller debris to drop into 17-gallon holding totes that can

be emptied as needed while allowing the pecans and larger debris to continue into the air duct. In the air duct, the good pecans are allowed to fall out of the bottom onto the conveyer by using air to pneumatically septate the heavier pecans from the lighter trash, such as sticks and empty pecan shells. The conveyor is the final step in the process. Here, the user sifts through the pecans to get rid of any items that the cleaner missed, as well as any defective pecans.

Overall CAD Model:

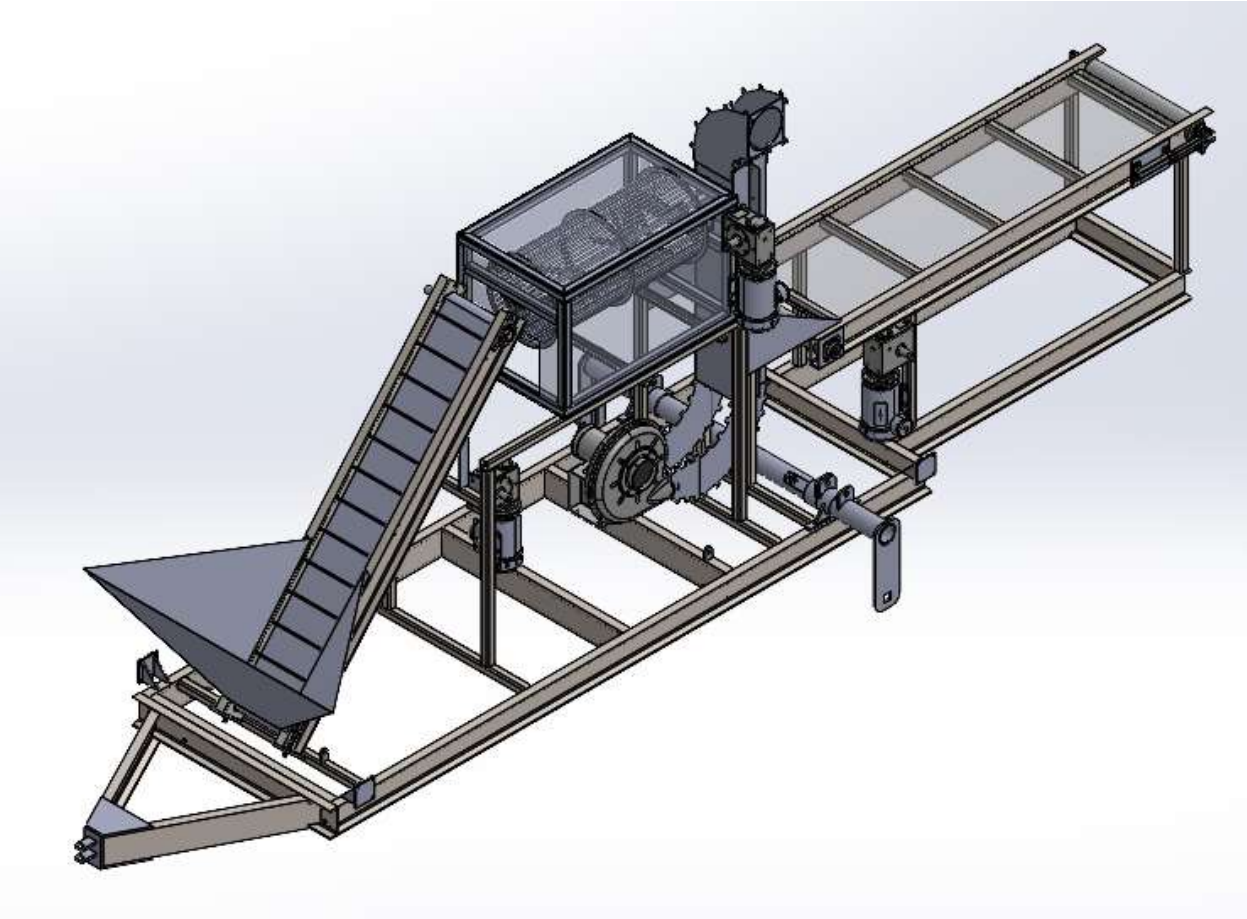

Figure 9: Overall CAD Model

The flow of this design begins with the hopper on the far-left side of Figure 9. This is where the pecans will be held before being input into the cleaning process. From the hopper, they are transported on the first conveyor, which is at approximately a 60-degree angle. This conveyor

then drops the pecans along with the rest of the trash into the rotary trommel. The trommel is where a majority of the small rocks, dirt clods, and other debris will drop out into a holding bin for later disposal. The pecans will then be dropped into the air duct, where the rest of the leaves, sticks, and lighter pecans will be blown out. The good pecans will fall out of the air duct and then onto the final conveyor. This is where our client will be able to sift through the pecans by hand and sort out the rejects from the good pecans. The conveyor overhangs the frame of the trailer just enough that a bin can sit underneath for the good pecans to fall into. All of this sits on a trailer. The trailer is designed so that the axles can be pulled out from underneath it by utilizing a hand pump hydraulic jack. This allows the trailer to sit flat on the ground. The hitch can also be removed to make for a shorter design. The designs will be discussed in further detail below according to their appropriate sub-assemblies.

Axle and Frame CAD Model:

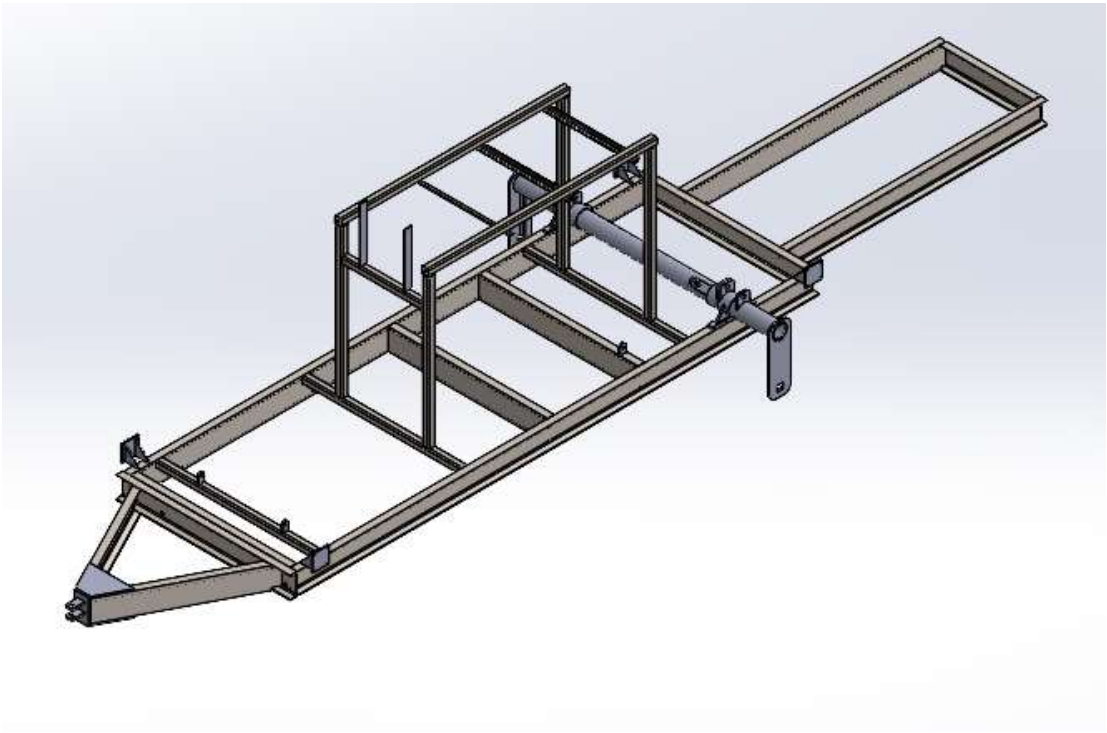

Figure10: Axle and Frame CAD Model

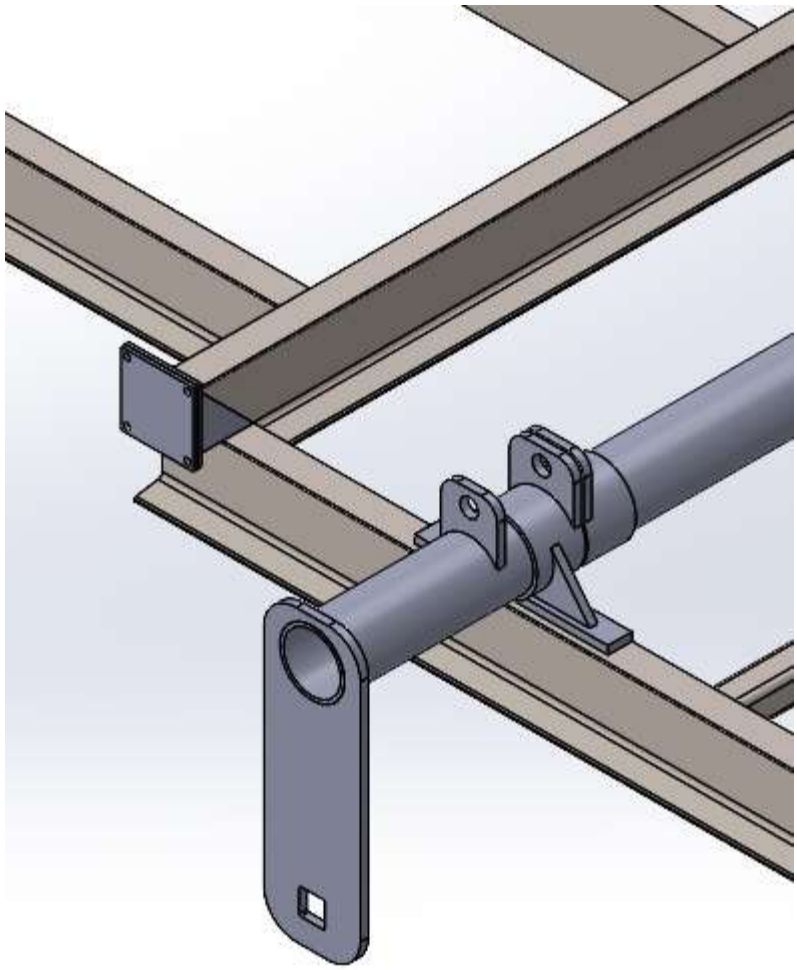

Figure 11: Axle Pin System

The trailer is designed to be pulled by either a truck or a 50-horsepower tractor attached to the hitch with a standard pin. The trailer is 4 feet wide and 20 feet long with the hitch attached. The trailer is approximately 600 pounds. The hitch is designed to be removable with 8 5/8-inch bolts to make the overall length 16ft. This will allow the trailer to fit better in the client's building. The trailer is made of 6x8.2 C channel. The axle assembly is made to rotate out from underneath the trailer, this will allow the trailer to sit flat on the floor of the building. The cleaner is more stable this way. When the axle is fully rotated down, the trailer roughly has an 18-inch

ground clearance. The axle rotates using a hand-pump hydraulic jack that is attached on one end to the axle and the other to the frame. There are pin holes through 3 half-inch plates located on either side of the jack (*Figure 11*). These are used during transport mode. When the axle is fully rotated down, a pin is put through these holes on either side to allow the user to let the pressure off the jack. The area at the rear of the trailer that holds the rear conveyor was an area of concern. Since the C-Channel for that rear frame was just butt-welded to the main frame, there was concern for weld/material weakness. The calculation for this is done in Appendix- Calc 1. This confirms that we have a material factor of safety of 1.79 for the material, which, in this case, is weaker than the weld itself. Once the conveyer was added on to the rear of the trailer, ¼" gussets were added between the conveyer and the frame that the trommel sits on. This greatly increased the stiffness of the system. Leveling jacks were added to the four corners of the trailer. One plate is welded to the jack itself, and another is welded to the trailer using two ribs to offset it away from the trailer frame. These two plates are bolted together using four 3/8" bolts for easy removal. The bracket can be seen on the left side of Figure 11.

A square tubing frame is welded onto the main trailer frame. This frame is what the trommel and elevator sit on. Four pieces of 1.25"x1.25" angle iron are welded on the underside of the trommel. These act as rails for the catchment tubs to sit on to catch the debris exiting the trommel.

Elevator:

Figure 12: Elevator

The elevator is used to transport the pecans, along with the debris, from the holding hopper, located at the bottom of the elevator, into the rotary trommel, where the cleaning process will begin. The hopper is designed to roughly hold the 30 gallons of debris contained in one of our clients' gunnysacks. The belting that transports the debris from the hopper into the trommel, located at the top of the elevator, is ribbed with 2” ribs. These ribs allow for the debris to ride up the elevator; without them, everything would slide down the belting back into the hopper. The

elevator is powered using a 1 HP 3-phase motor that is hooked into a variable frequency drive to control the speed of the belt. The elevator used is a modified Savage elevator that the client had previously purchased. The elevator was cut down to fit the requirements of the project and a new motor and gearbox were installed to meet the variable speed requirement that the client had.

Rotary Trommel CAD Model:

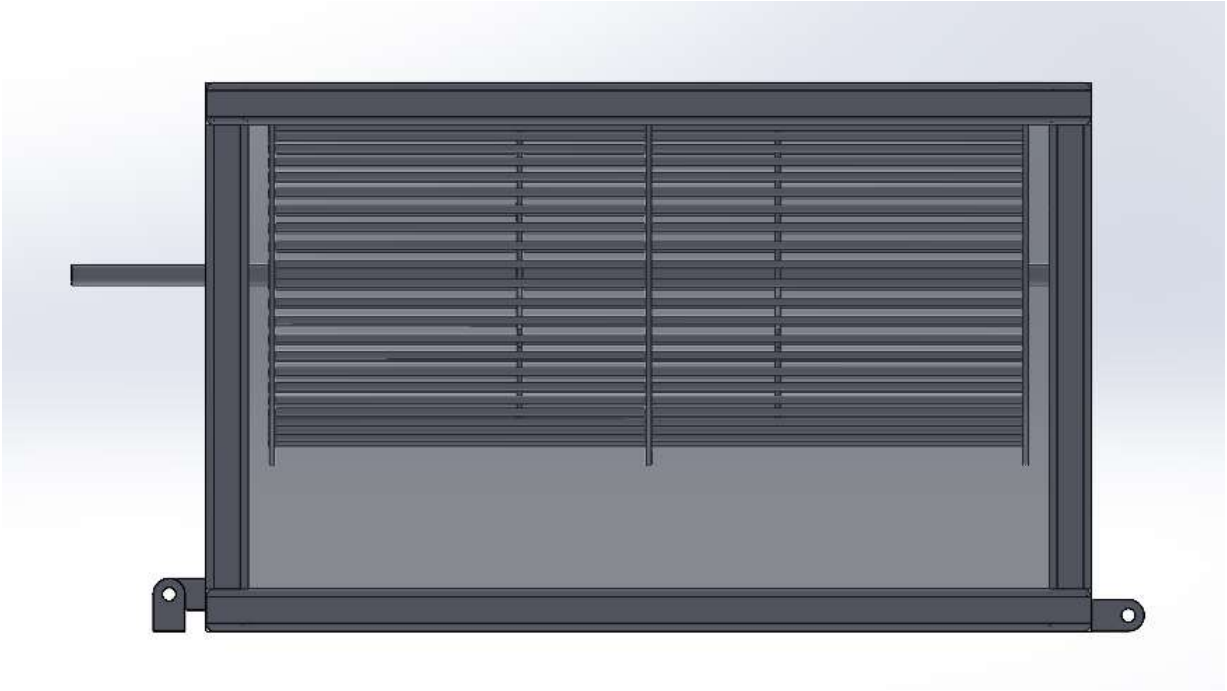

Figure 13: Rotary Trommel CAD Model

The rotary trommel is used in the cleaning process to stir up all the debris and drop out any small particles. These particles could include small rocks, dirt clods, leaves, and sticks. The trommel is 3 feet long and 1-½ feet in diameter. The rings on either side are half circles that are welded together. The rings are cut to fit 3/8-inch rods so that they are perfectly spaced to be 9/16 of an inch apart. This number is from the acceptable size of pecans that most buyers prefer, according to Becky Carroll (Pecan Management OSU Extension). In the center of the trommel is a shaft that runs the length of the trommel. The trommel sits in a frame made of 2x2 inch square

tubing. On either side of the trommel, attached to the frame, are pillow blocks that the shaft runs through to support the trommel. A gear is on the long end of the shaft that is driven by a 50 tooth chain and attached to a 1 HP gear motor that is controlled by a 2 HP VFD. The debris that falls out from the bottom of the trommel is funneled down into a bin. When this bin fills it can be removed and later dumped. The trommel is shielded using 18-gauge sheet metal that is cut to fit onto the sides and top of the square tubing frame. This uses rivnuts that are riveted into the square tubing to bolt onto with 1/4x20 bolts. The angle of the trommel is adjusted using a hand pump hydraulic jack. One end of the trommel frame has bolts that run through tabs welded to the trailer frame; this allows the trommel to rotate. The other end is where the jack attaches to push the conveyor upward. The angle can be adjusted from 0 degrees to 4 degrees.

Air Duct CAD Model:

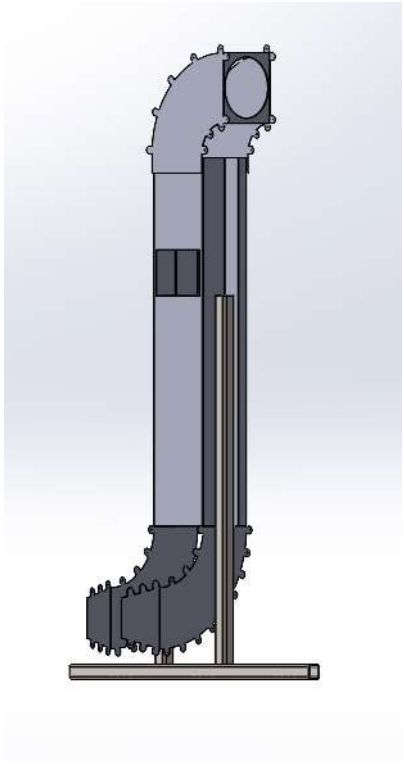

Figure 14: Air Duct CAD Model

The purpose of the air duct is to blow out excess sticks, leaves, pecan husks, and lighter pecans. Through experimenting, 20-30 mph is the appropriate wind velocity to blow out debris while letting good pecans fall out the bottom opening of the duct. To get this velocity using the pressure blower from the client a cross-sectional area of 72 square inches was required. The experimenting was done with plywood and a 3 HP New York Pressure blower rated for 1,000 CFM. With the calculation done in Appendix- Calc 2 we can see that the output of the pressure blower through the 72 square inch cross sectional area is 22.7 mph. This falls right within the range for terminal velocities of like sized nuts and confirmed with experimenting with an anemometer. The duct is made from 18-gauge steel sheet that is bent and riveted. The outlet is sheet metal that the pecans can roll down and onto the conveyer. The outlet duct is directed to the outside of the client's building where it will go into a trailer. The original 3HP motor was found to be bad so a new one was purchased. With testing during the spring semester with the sheet metal air duct and the new motor the top velocity exiting the duct was approximately 50 mph. Using the VFD it can be turned down to 25-30 mph. This is optimal speed. The design of the air duct sweep uses tabs that are located every 4-5 inches along the curves. These tabs are bent in and riveted to the curved top and bottom face plates. The outlet sweep transforms from a rectangular cross-sectional area to an 8” round hole. This is client specified so that he can utilize preexisting duct work to route debris out of the working area.

Conveyer CAD Model:

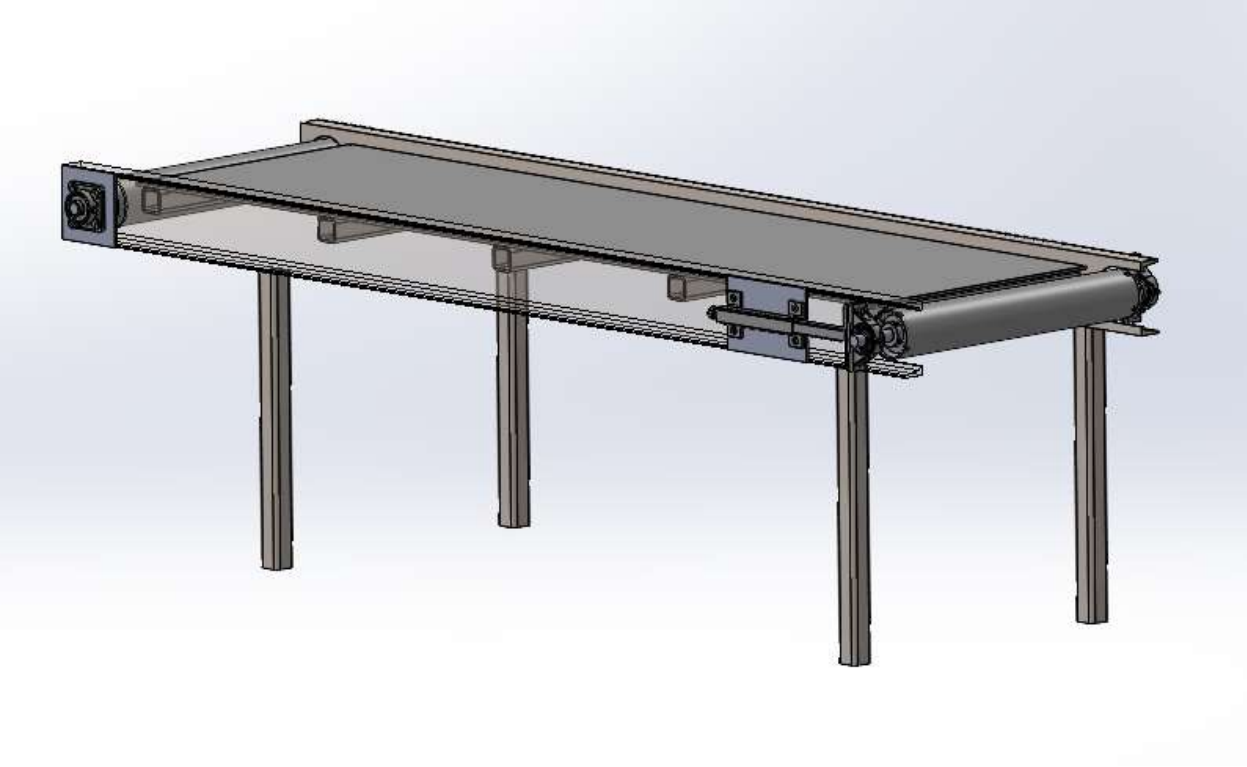

Figure 15: Conveyer CAD Model

The final conveyer is used as the final cleaning process in the system. It is designed to have a person stationed on either side to sift through the pecans exiting the air duct shown in Figure 15. This is done to determine “reject pecans”, which can consist of broken, diseased, or worm-infested pecans. The conveyor is 2 feet wide by 8 feet long and sits approximately 36 inches off the ground. This conveyor is variable speed to control the speed of the belt so that the client can sift through the pecans in as much detail as desired. This conveyor is powered with a 1 horsepower variable speed electric motor and driven using 50 chain. The electric motor is tied into a 50:1 gearbox, which gears down the motor to power the conveyor belt at a slower, desired speed. The conveyor belt is a flat belt. A slippery plastic sheet is riveted to the 5 square tubing supports, as shown in *Figure 15.* This ensures that the conveyor belt moves with ease and doesn’t have any sag in it.

Electrical Design:

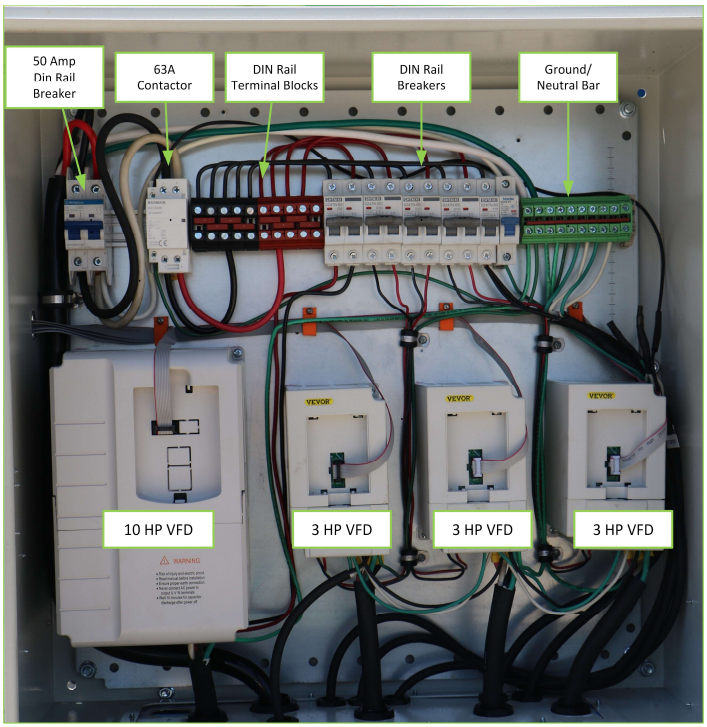

Figure 16: Nema 3r Electrical Enclosure

The cleaner features four 3 phase motors powered by VFDs to allow precise adjustments of speeds. The 3 HP motor on the blower is powered by a 10 HP VFD and the 1 HP motors are powered by 3 HP VFDs. When converting from single phase to three phase power in a VFD, generally a VFD rated at 1.5-2.0 times the motor's HP is selected.

The VFDs are supplied power from 2 pole DIN rail breakers. The 3 HP motor has a 25 AMP breaker, and the 1 HP motors have 10 AMP breakers. The breakers connect to DIN rail terminal blocks. The terminal blocks are supplied power from a 240V 60 AMP contactor. The contactor is a safety measure and is hooked up to three E-stops in series located on each side of the machine. Whenever an E-stop is engaged, all power to the machine and inside the Nema enclosure is shut off. The contactor is connected to a 2-pole 50 AMP DIN rail breaker that is

connected to the 6/3+8/1 incoming power cord. For versatility, a Nema 14-50 4-prong plug was selected. This opens up the ability to plug the machine up to any place with an RV outlet or adapter to another plug if needed.

Figure 17: Electrical control panel.

The control boards were relocated to the outside of the box to minimize the need to be inside the Nema enclosure. A waterproof clear face box was added for weatherproofing to keep the ability to run the machine outside. The start/stop buttons are wired into the digital inputs for the elevator belt, trommel, and conveyor belt VFDs. This allows the operator to pause the machine to catch up or load more pecans and debris in the hopper without shutting down the big blower. The two light switches were added to control the LED light above the conveyor belt and the 1HP dust collector for the trommel. One of the E-stops can be seen in Figure 19 above. A red LED indicator light was added that illuminates when an E-stop is engaged to let the operator know why the machine has no power. On the other side of the enclosure, a GFCI 120V outlet runs other accessories if needed.

FMEA:

FMEA stands for Failure Modes and Effects Analysis. This process allows the designers of a process to walk through potential failures of a system. During the walkthrough, steps can be worked out to prevent the failure from occurring. The other advantage of using FMEA is the ability to see what a failure can do to the operation. Will the effect of the failure shut down the entire operation for a lengthy period, or will it be a quick fix? Once the effects of the failure are realized, steps can be taken to decrease their severity.

Identify Steps	Potential Failure Mode	Potential Failure Effects	SEV	OCC	DET	RPN	Mitigation Strategy	Impact on RPN Score
What is the process step?	In what ways can the process step fail?	What is the impact if there is a failure?	How severe is the effect to the worker?	How likely is the failure to occur?	How likely is the problem detected prior to failure?	RPN = S X O X D	What are strategies for mitigating risk by reducing the occurrence or improving detection?	How much will mitigation reduce the RPN score? Is this acceptable?
Debris clogging between the elevator and the trommel.	The debris gets backed up so the system is no longer being fed material.	The cleaning process is halted and the clog has to be unplugged.	2	3	2	12	Slow the speed of the elevator to slow feed the trommel. This way it will not bakup. A better designof the enttry system between the elevator and trommel.	It could potentially reuce the score to 1.
Set screws back out.	The set screws for the conveyer, sprockets, and motors are what hold evrything in place. The release of this could shut down the system.	Shutting down the system. Causing damage to assemblies.	5	2	3	30	Use loctite on the set screws and periodically check the tighness.	5
Electrial Issue	Cut in the wire or bad wiring.	Casue electrification of the product or failure for systems to work.	5	1	5	25	Glance over the wires periodically and be alert for anything that looks off.	5
User Error	The system is run wrong, too fast or too slow. Could burn up one of the motors. Could have the system not level and bend something.	Cause damage and shutdown	5	1	5	25	Read the manual for how to operate the machine and understand how it works and what could go wrong.	10

Table 1: FMEA

Budget:

The total budget for the project was $15,000, including the materials that were provided to us. The total cost of the project was $12,250 once everything was totaled up. Now, if we had to purchase/build an elevator, that price would be much higher. The same can be said of the

blower, although the motor replacement was included in the final invoice. When comparing this finished product to other options on the market, we believe we can retail it for roughly $40,000. This accounts for increased labor prices and additional cost of materials. If the product was mass-produced, then the materials could be bought in bulk, which would lower the price of production. The retail price we suggest is in the same ballpark as the other commercial cleaners on the market.

Recommendations and future work:

While the project is complete and meets all the client requirements, there are a couple of recommendations that could be added on to the project. These recommendations are ease-of-life designs that will bring the project to its full potential.

Reject Divider-

A divider at the end of the rear conveyer was in the original scope, however it was determined that it was not a priority task for the project. This is something that should be added in the future to allow the client to sort the pecans into two different tubs. One tub for good pecans and the other for rejects that made it through the system.

Additional Hopper Capacity-

Since an off the market elevator was used, a full-sized hopper was not designed, the original hopper to the elevator was integrated instead. This hopper could be expanded using sheet metal or plywood to increase the storage capacity. This would help the client be able to work for longer on the sorting table and not have to pause production to reload the machine.

Conclusions:

Our team believes that this project is a success and meets all the client requirements. There are a few recommendations for future work that could be completed, but the project has a strong base. This is a unique custom cleaner that meets the client's wishes, unlike any other machine that was on the market. We would like to thank our client, BAE professors, and the lab technicians once again for all their help and hard work to make this project possible.

References:

- AMS, USDA 83 FR 50475
- Anna, G. (2015) US Patent No. US 9,027,319 B1
- ASME B18.2.8-1999
- Brumbaugh, B., Brumbaugh, E., and Riché, C. (1971) US Patent No. 3,591,948
- Donald E. Wilkinson. (1968). Pecans in the Shell. ucfoodsaftey.ucdavis.edu/sites/g/files/dgvnsk7366/files/inline-files/175739.pdf
- ("Improving Native Pecan Groves - Oklahoma State University," 2017)
- Ingalls, C. (1967) US Patent No. 3,341,877
- McGehee, R. (1976) US Patent No. 3,951,056
- OSHA CFR 19210.212 MAR2001
- OSHA CFR 1926.403 MAR2001
- OSHA CFR 1928.57 Subpart A MAR2001
- OSHA CFR 1928.57 Subpart C(5) MAR 2001
- ("Pecan Varieties for Oklahoma - Oklahoma State University," 2017)
- Phelps, W. (1973) US Patent No. 3,779,377
- Reiff, A., Pierce, C., and Knowles, A. (2009) US Patent No. US 2009/0293741 A1
- Savage, B. (2021) US Patent No. US 11,020,769 B2
- Savage, B., Savage, S., Wagonger, W. (2019) PCT No. WO 2019/060449 A