6-2022

AVA: The Roving Vending Machine

Nicholas Elwell

Jordan Hibbs

Jagos Jovanovic

Alec Lindeman

Antonio Matusich

SANTA CLARA UNIVERSITY

Department of Mechanical Engineering

I HEREBY RECOMMEND THAT THE THESIS PREPARED
UNDER MY SUPERVISION BY

Nicholas Elwell, Jordan Hibbs, Jagos Jovanovic,
Alec Lindeman, and Antonio Matusich

ENTITLED

AVA: THE ROVING VENDING MACHINE

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

9-June-2022

Thesis Advisor, Dr. Godfrey Mungal date

06/10/22

Department Chair, Dr. Hohyun Lee date

AVA: THE ROVING VENDING MACHINE

By

Nicholas Elwell, Jordan Hibbs, Jagos Jovanovic,

Alec Lindeman, and Antonio Matusich

SENIOR DESIGN PROJECT REPORT

Submitted to
The Department of Mechanical Engineering
of

SANTA CLARA UNIVERSITY

In partial fulfillment of the Requirements
For the degree of
Bachelor of Science in Mechanical Engineering

Santa Clara, California

June 2022

AVA: THE ROVING VENDING MACHINE

Nicholas Elwell, Jordan Hibbs, Jagos Jovanovic,

Alec Lindeman, and Antonio Matusich

ABSTRACT

AVA is an undergraduate engineering senior project that focuses on the design and integration of a roving vending machine. Such a product looks to utilize passing period foot traffic on college campuses when students and faculty do not have time to walk to a dining hall. In an effort to showcase a proof of concept, the team built a working prototype that consists of multiple subsystems. The vehicle has the ability to move with the use of remote control, autonomously sense obstacles and stop on its own, quickly dispense chilled beverages at a convenient customer location, and power itself with the use of a solar panel and a redundant battery supply.

ACKNOWLEDGEMENTS

We would like to thank the Santa Clara University School of Engineering for providing the funding, facilities, and resources to make this effort possible. We would also like to thank our advisor, Dr. Mungal, our Advanced Design Professors Dr. Restivo and Dr. Tszeng, and the Machine Shop Manager, Rodney Broome, for their support throughout our design and development process.

TABLE OF CONTENTS

Table of Figures

Table of Tables

Chapter 1 - Introduction

1.1 Problem Statement and Project Objectives

SCU students, faculty, and staff commonly experience the sinking feeling of needing a caffeinated beverage but finding Benson to have long lines at both the Mission Bakery and the Cellar or simply just not having enough time to stop before class starts. To combat this issue, our team decided to design and build an autonomous vending automobile (AVA) that would take caffeinated beverages on the go to provide the SCU community with the ability to purchase caffeinated beverages on their walk to class. In addition to providing a convenient alternative to Benson, AVA would help to reduce the endless lines that accumulate at Benson during the peak times in between classes. AVA is essentially combining the convenience of vending machines with the mobility of beverage transport devices into a single product.

1.2 Benchmarking Results

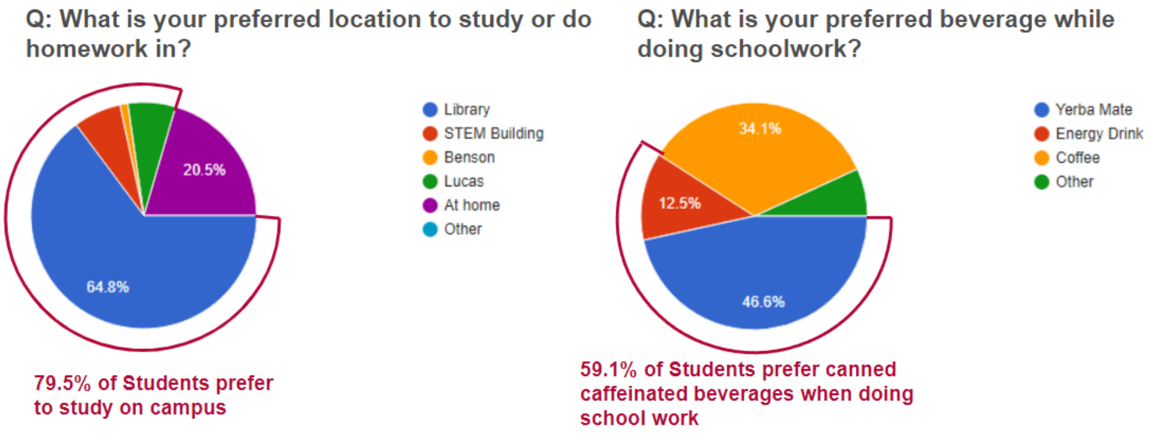
To get a better understanding of the feasibility of a roving vending machine, similar products were researched. However, it was found that a roving vending machine is a unique and fairly unattempted concept. There is no product that hits all of the desired requirements of the roving vending machine. There exist autonomous delivery robots, such as the Kiwibot 4.0, however, the critical difference between AVA and autonomous delivery robots is that the autonomous robots only serve the function of delivering pre-ordered items. There is no capability to interact with the robot and order directly from it, as one would a vending machine. Thus the roving vending machine design will essentially combine the functionality of existing vending machines, such as the Seaga INF5B, with existing autonomous delivery robots, such as the Kiwibot 4.0 (Figure 1.1).

Figure 1.1: Kiwibot 4.0: Food delivery bot.

Looking at existing vending machines helped develop the dispensing system discussed in Chapter 3, as both AVA and typical vending machines must dispense cans reliably on demand. Looking at existing food delivery bots helped determine design requirements for an autonomous robot that drives on sidewalks alongside people.

1.3 Market Survey

To get a better understanding of how AVA could better provide value to students across campus and drive design choices, a preliminary market study was conducted. The survey was sent out to Santa Clara University students and we received 88 responses.



Q: What is your preferred location to study or do homework in?

Q: What is your preferred beverage while doing schoolwork?

79.5% of Students prefer to study on campus

59.1% of Students prefer canned caffeinated beverages when doing school work

Figure 1.2: Market Survey Results For 2 Significant Findings

Figure 1.2 shows 2 significant findings from the survey. First, when asked “What is your preferred location to study or do homework in?”, approximately 80% of students responded that they prefer to study in buildings across the campus. This informed us that students will be on campus more frequently than just for class. This information becomes more relevant following the next finding. When asked “What is your preferred beverage while doing schoolwork?” approximately 60% of students responded that they prefer some kind of canned caffeinated beverage. This shows us that there is a large demand for canned caffeinated beverages amongst students. Combining this with the previous finding, it can be deduced that students traveling through campus are highly receptive to purchasing canned caffeinated beverages. This provides validation for the general concept of a roving vending machine that dispenses canned caffeinated beverages throughout a campus. Additionally, it can be noted that Yerba Mate is the most preferred beverage while studying.

Another question asked students what time of the day they would most likely purchase a caffeinated drink. The result found that a vast majority of students would purchase caffeinated beverages between 7 am and 2 pm, a 7-hour window. This informed us when and for how long AVA should run.

1.4 Literature Review

As there is no standalone product that accomplishes all of the desired functionality of AVA, in order to better inform our design process we reviewed the current technology used in vending machines found in the following three patents.

1.3.1. Helical Coil Dispenser for Vending Machines [1]

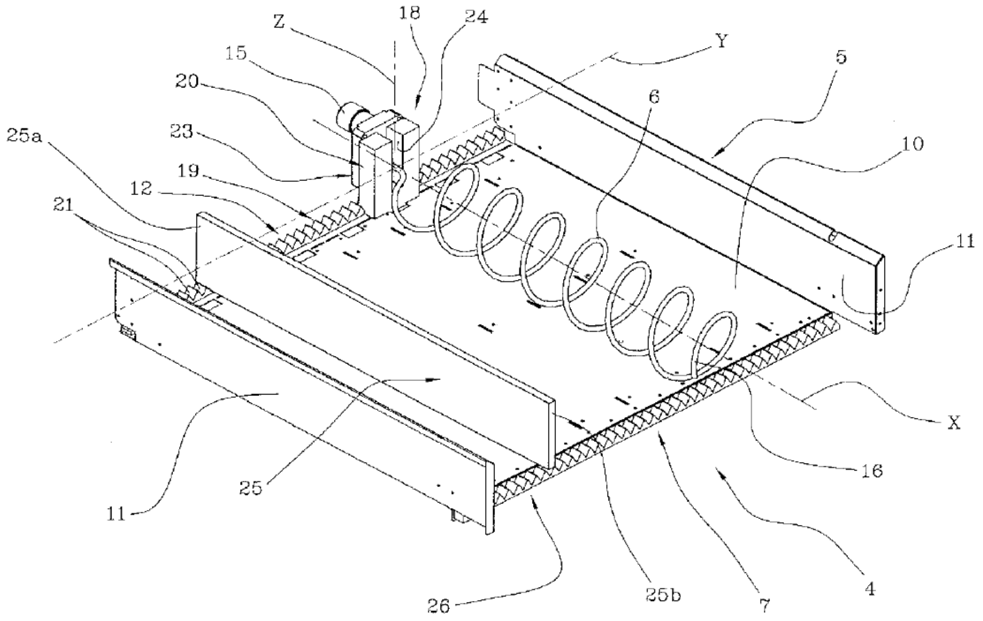


Figure 1.3: Helical Coil Dispenser Schematic [1]

To begin our research, we analyzed the most common vending machine design, the helical coil method. The helical coil is used by placing individual items within the openings of the helical shape such that as the coil is rotated, the products are consistently moved along the x-axis until they are ultimately dispensed out of the coil. The helical coil is driven by a motor, labeled as (15) in Figure 1.3, and the two components are mounted to the supporting frame along an adjustable track, (19) in Figure 1.3, such that the coil and motor can be adjusted along the y-axis to accommodate products of differing sizes.

1.3.2 Extraction Mechanism for Automatic Vending Machines [2]

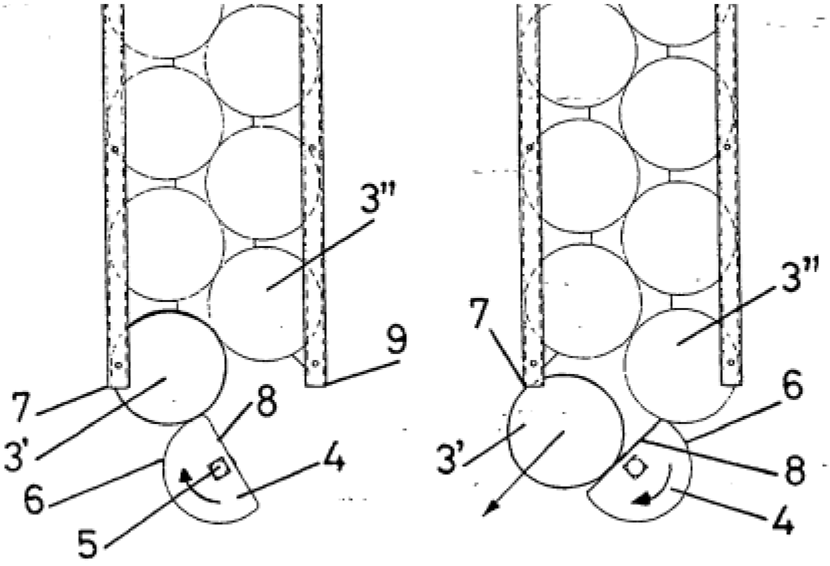


Figure 1.4: Vertical Stack and Extraction Mechanism Schematic [2]

The second patent that was reviewed was a vertical stack storage method with a rotating extraction mechanism to dispense the cans. The focus of the patent is on the extraction mechanism assuming a vertically stacked storage track. The cans are assumed to be positioned within the track such that they are arranged in repeating quincunxes as shown in Figure 1.4. This specific can arrangement forces the cans into two columns within a single track such that the column with the bottom can is alternating as the cans are dispensed. As for the dispensing action of the mechanism, a rotating retainer, (4) in Figure 1.4, is positioned underneath the stack of cans and is rotated along the axis parallel to the center axis of the cans. As the retainer is rotated, the lowermost can is released while the remaining cans are held in place. Once a can has been dispensed, the retainer further rotates to allow the remaining cans to fall back into the intended arrangement.

1.3.3 Tandem Gate Release Mechanism for a Vending Machine [3]

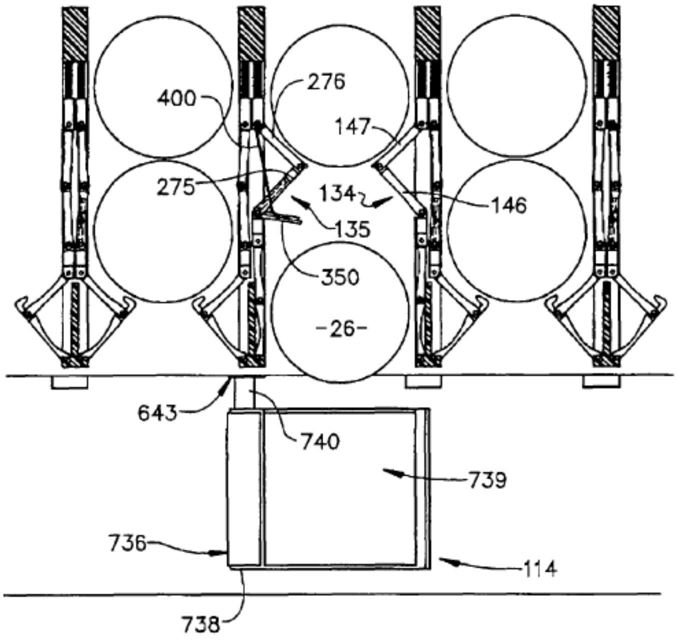


Figure 1.5: Tandem Gate Release Mechanism Schematic [3]

The third patent we reviewed was a mechanism to release an individual can from the storage track. There are two mirrored mechanisms for each track of cans to facilitate the movement of the primary can, (26) in Figure 1.5, from both sides. The individual mechanisms are six-bar linkages that are mechanically activated by the product delivery cup, (114) in Figure 1.5. When a purchase is made, the product delivery cup moves in front of the row containing the desired product, and the plunger, (740), engages with the activation member, (643). When the activation member is engaged, the six-bar linkage is moved from its product retention position to the product release position and the purchased product is released into the product delivery cup to be delivered to the customer.

Chapter 2 - System-Level Analysis

2.1 Project overview

2.1.1 Customer needs

The customer needs were selected through a combination of interviews with individuals, a market survey, and conversations with advisors. In this part of the design process, the "customer needs" aim to serve an ideal market-ready AVA. This means that not all the customer needs would be addressed in the prototype build of AVA conducted throughout the school year.

The highest priority need that was identified for AVA is safety. Since AVA would be driving autonomously throughout campus, it cannot hit people or obstacles. In addition to having autonomous stopping and obstacle avoidance, AVA's center of gravity should be low to minimize the risk of tipping. Further, a top speed for AVA will be set around walking speed to minimize the probability of an injury if a collision does occur.

Another primary customer need identified was an easy-to-understand user interface. Since a roving vending machine would be an unfamiliar concept to most, it would need to be easy to understand for new users. Thus it should feature a familiar user interface, preferably one similar to standard vending machines.

In order to provide a good experience to customers and be competitive with conventional drink sales, AVA needs to keep drinks cold throughout the duration of the day. In addition, it should accept any form of payment for customer convenience. Lastly, as AVA is intended to provide utmost convenience for someone in a hurry to go from one place to another, the dispensing system should operate quickly and release the drink at a location that is easily accessible for any regardless of physical ability.

2.1.2 User Scenario

Our target customers are users on campus, in a mall, or in other such enclosed high foot traffic areas. AVA would run in a predetermined route around the campus, reaching high traffic areas during ideal times, such as between classes for a school. Operating in such an area simplifies operational procedures as the roving vending machine will have a fairly consistent route to run. This also minimizes the risk of unforeseen path conditions and eliminates the risk of vehicular traffic collisions. Further, since campuses typically have some security infrastructure in place, this reduces the risk of theft or vandalism occurring to the roving vending machine.

If a user encounters AVA and chooses to interact with it, they can simply walk in front of it and the robot will stop moving, additionally, if they press any button on the top face the robot will stop moving. From here they can select a beverage and pay for it, just as a typical vending machine would work. When the beverage is dispensed and the can is detected to have been picked up, AVA will continue on its route until another user is encountered.

The operator of AVA would fill it up with refrigerated cans in the morning and unplug the charging cable. AVA would then begin on its predetermined route around the campus. Operating during selected high traffic hours. For example, at a college campus, this would be between around 7 am and 2 pm.

2.1.3 Functional Analysis

The finalized, market-ready version of AVA will have the following five features:

1. **Fully Autonomous Movement:** AVA will autonomously move along a predetermined path that will direct AVA to high traffic areas during optimal times such as passing periods between classes. In addition, AVA will have an autonomous stopping and obstacle avoidance system to decrease any potential safety concerns as AVA is navigating through crowded areas and around obstacles along its predetermined path.
2. **Refrigerated Drinks:** The refrigeration system will maintain an internal temperature of 37° F to keep the drinks at a refreshing temperature throughout AVA's daily operation.
3. **Payment System:** AVA will have a multipurpose point of sale system that will allow customers to purchase drinks through a variety of payment methods such as credit, debit, or access cards.

4. **Convenient Dispensing:** AVA will have an internal dispensing system, positioned inside the refrigerated volume, that dispenses the purchased beverage quickly and reliably. In addition, to improve upon the dispensing process of a regular vending machine, AVA will dispense the can at a convenient location such that the customer does not have to reach to the ground to receive their purchased beverage.

5. **Ease of Use and Operation:** As AVA will have autonomous movement capabilities there is limited required interaction from the operator. The requirements of the operator are to stock AVA in the morning and to plug AVA in to charge when not in operation. As for the customer, the automatic stopping system allows the customer to stop AVA simply by walking in front of it or pushing one of the flavor selection buttons. AVA will have a display screen above the flavor selection buttons to direct the customer through the payment and dispensing process.

2.1.4 Project Scope Decisions

The previous section outlined the five main objectives of a market-ready AVA. Given we are a group of five mechanical engineers with a 30-week timeframe, we needed to evaluate the desired functionality to set a realistic scope for the project. We decided to focus on the main functions of AVA identified as the dispensing, refrigeration, and movement systems. To limit the scope of the project, we chose to replace the autonomous movement with a remote-controlled movement that is assisted by the automatic stopping and obstacle avoidance system. In addition, we decided to remove the payment system as it would not provide significant value to the functionality of the prototype and could be easily integrated into a beta version of AVA.

2.1.5 Subsystem Overview

To organize the design process of AVA, the design was split into the following five subsystems.

1. Dispensing Subsystem: Consists of a storage track(s), release mechanism, and delivery mechanism to facilitate the movement of the can from inside the refrigerated volume and into the customer's hand.

2. Refrigeration Subsystem: An insulated refrigerated volume containing the dispensing subsystem and equipped with thermoelectric cooling modules to maintain an internal temperature of 37° F.

3. Control Subsystem: As the brains of the operation, the control subsystem will control the movement and automated safety stopping system of AVA. In addition, the control subsystem will integrate the dispensing system with the movement control such that AVA will remain stationary throughout the dispensing process.

4. Structural Integration Subsystem: Provides a lightweight frame for other subsystems with convenient mounting locations for components such as the refrigeration system, dispensing mechanisms and electrical components and a shell to protect the internal components.

5. Power Integration Subsystem: Provides power for other subsystems with redundant safety measures. Utilizes a battery, a solar panel, a fuse box and other components. Allows continuous running of AVA remotely for long periods of time.

2.2 Team and Project Management

2.2.1 Team Management

In order to organize the progress of the project as a whole, each team member was designated as the lead for one of the five subsystems.

1. Dispensing Subsystem Lead: Jordan Hibbs
2. Refrigeration Subsystem Lead: Nick Elwell
3. Control Subsystem Lead: Antonio Matusich
4. Structural Integration Subsystem: Alec Lindeman
5. Power Integration Subsystem: Jagos Jovanovic

While each subsystem had a designated lead member, all decisions and progress was presented to and discussed with the entire team in order to mitigate knowledge fragmentation between team members. In addition, the team utilized a Gantt chart to illustrate the progress and timeline of specific subsystem goals.

2.2.2 Budget

As there are five team members, we received a total of $2,500 from Santa Clara University to fund our project. The breakdown of how our budget was spent can be found in Appendix C.

2.2.3 Timeline

This project was to be completed over the course of a school year (Sep-Jun). The progress marks were broken up into the 3 quarters of a school year as such:

- Fall Quarter
    - Concept Selection
    - Project management planning
    - Market research and benchmarking
    - Budget development and approval
    - Initial Design
- Winter Quarter
    - Design Analysis
    - Testing/prototyping
    - Structural Assembly
- Spring Quarter
    - Build final product
    - Testing/iterating final build
    - Presentation/Thesis

We were able to keep up with the schedule throughout the course of the school year. The most significant challenge in maintaining the schedule stemmed from the interdependence of the subsystems. Some systems would get backlogged as other subsystems needed to be completed first. This caused much of the building to be pushed to the spring quarter, however, we were still able to complete our build prior to the presentation date.

2.2.4 Safety and Risk Management

The safety of all team members was of utmost importance during the construction of AVA as our project posed a variety of safety hazards. The manufacturing process required extensive use of both machine shop equipment such as mills, lathes, and bandsaws as well as handheld power tools such as drills and circular saws. All operation of this equipment was done with proper safety equipment such as close-toed shoes, long pants, and safety glasses as well as with appropriate supervision when needed. In addition, our project presented electrical safety hazards in the use of a battery to power all of the individual components. The chosen battery was a LifePO4 battery that has a built-in smart BMS (Battery Management System) to protect from overcharge, over-discharge, overcurrent, and short circuits. To further mitigate any potential electrical safety hazards a fuse box was used to protect the entire system from excessive current.

Chapter 3 - Dispensing Subsystem

The objective of the dispensing subsystem is to reliably deliver the purchased beverage to the customer at a convenient location and with an efficient speed. The dispensing process has three main steps identified as can storage, a release mechanism, and a transportation mechanism to deliver the can at a convenient dispensing location. To provide context to the following explanation, the final design of the dispensing subsystem is shown below in Figure 3.1. The final design consists of three storage tracks, a release mechanism for each track, a conveyor assembly, and a lead screw.

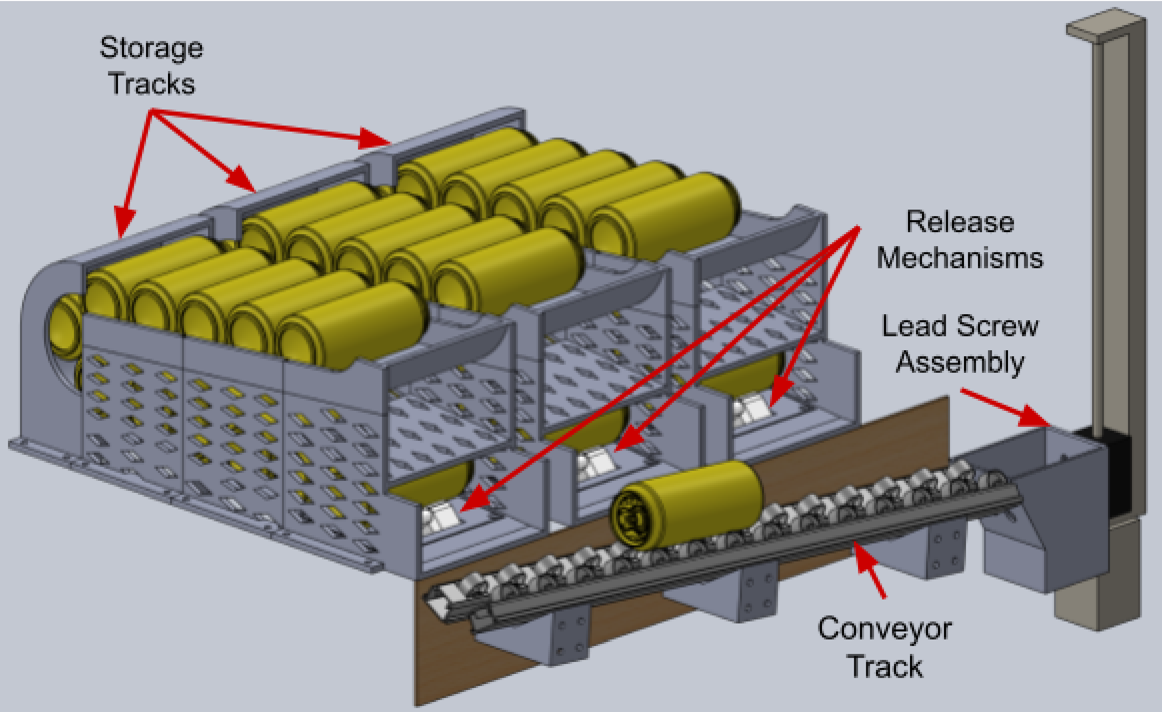


Figure 3.1: Final Dispensing Subsystem Design

3.1 Can Storage

3.1.1 Design Requirements and Background

The first step in designing the dispensing system was to design the can storage tracks that would sit within the refrigerated volume. As seen in Section 1.3, we researched and analyzed existing vending machine technology and mechanisms to provide a foundation for our design process.

Using the information provided by the literature review and the restraints of AVA's desired functionality, we identified the design requirements necessary to perform the desired functions. The design requirements are as follows:

1. Reliable can movement
2. Minimize height requirement
3. A minimum capacity of 36 cans

In order to determine the optimal design from an accurate comparison, the options for the storage tracks were placed into a selection matrix, shown in Appendix C, Section C1. As seen in the matrix, the existing methods of the helical coil and vertical stack had significant downsides and thus the proprietary design of the zig-zag track proved to be the most viable option. The ways in which the zig-zag design improves on the existing methods are discussed in the following sections.

3.1.2 Initial Design

The first design requirement was to ensure reliable can movement within the storage track. While the helical coil method has the highest reliability, it does so with the use of a motor which would further complicate the refrigerated volume. The motor would be positioned either inside the volume, thus creating unwanted heat generation, or outside the volume and extend through the refrigerated volume wall creating additional areas for the cooled air to escape. As for the vertical stack method, the gravity feeding provides consistent movement within the track but the freedom of the cans to arbitrarily move amongst each other poses a potential concern for unreliability.

In order to achieve reliable can movement, minimize the potential for cans to get stuck with minimal electrical components, we decided to utilize a similar feeding mechanism as the vertical stack method. The vertical stack design was altered to orient the cans such that they roll down a 5° declined plane, shown in Figure 3.2. The 5° decline capitalizes on the reliable feeding provided by gravity but significantly reduces the gravitational force experienced at the end of the track, which will become an important factor in the release mechanism design.

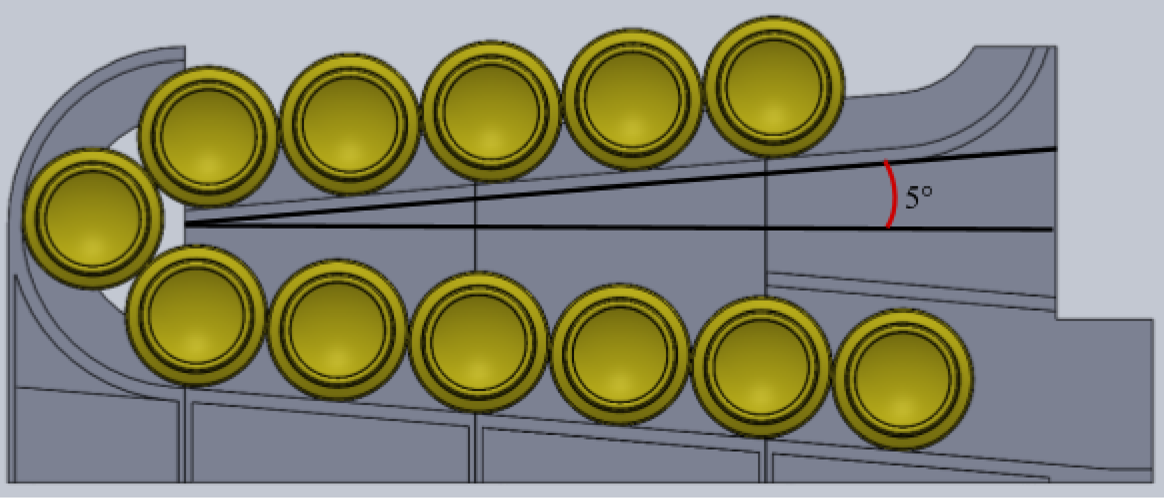


Figure 3.2: Storage Track Design

In addition to ensuring reliable and continuous can movement throughout the track, the 5° decline decreased the height requirement of the refrigerated volume in exchange for increasing the horizontal dimensions. As AVA will be in motion and navigating through a crowd during it's daily operation, we identified a potential safety issue of lateral instability. As a result, the decision to favor an increase in the horizontal dimensions was in order to maximize the stability of the robot while in operation.

The last design requirement of the tracks is to have a maximum capacity of 36 cans. Given that AVA was to have multiple flavor options, and that Yerba Mate is commonly sold in packs of 12, it was determined that there would be three separate tracks positioned side by side within the refrigerated volume, each with a capacity of 12 cans. In order to achieve this capacity per track, the declined plane needed to be split into two conjoining declined planes, as shown in Figure 3.2. The conjoining tracks that create the zig-zag pattern balance both the can capacity need and height requirement issue.

3.1.3 Prototyping & Testing

As the zig-zag method was a proprietary design, there would inherently need to be multiple design iterations to produce the optimal design. The tracks were designed as a complete unit and split into a total of seven pieces, as shown by the red dotted lines in Figure 3.3, that can be printed individually by a basic 3D printer to allow for efficient design iteration and manufacturing.

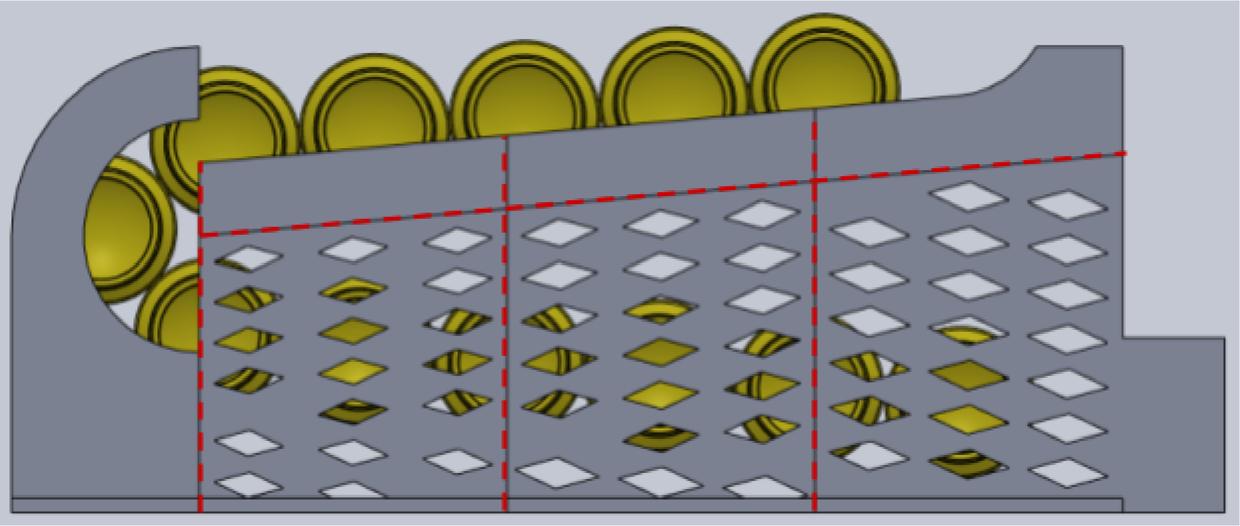


Figure 3.3: Storage Track Pieces

The bottom four pieces are designed to be aligned and bolted to the base plate of the refrigerated volume. The three top layer pieces connect with dovetail joints to restrict any lateral movement and connect to the bottom section with the tabs and slots shown in Figure 3.4. The connection between the bottom and top layers allows the top layer to be removed if needed but maintains a secure connection such that the top layer will not vibrate out of place if AVA navigates over any significant bumps in the terrain.

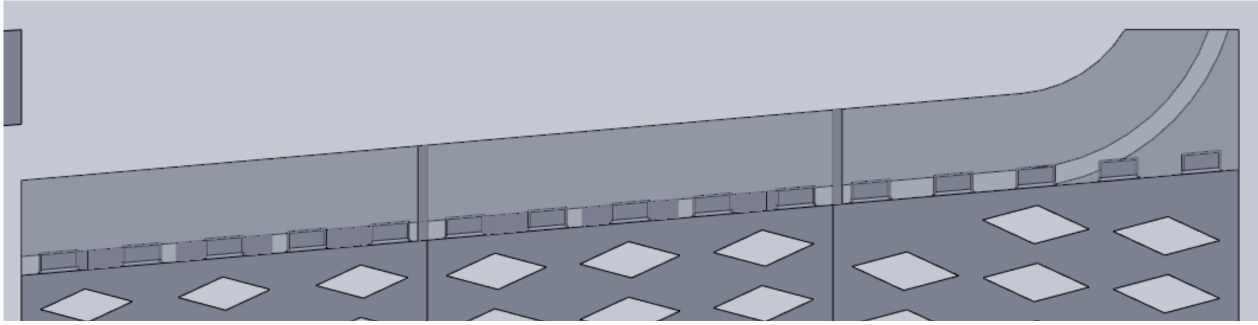


Figure 3.4: Dispensing Track Connections

3.1.4 Design Iterations

When testing AVA's refrigeration capabilities, discussed in further detail in Section 4.5, it was determined that the storage tracks needed to allow for maximum airflow throughout the refrigerated volume. To facilitate improved air circulation, airflow holes were added to the surfaces of the storage track. Given that the storage tracks are designed to be 3D printed, the airflow holes were chosen to be a diagonal shape, shown in Figure 3.3, in order to minimize the amount of support material needed when printing.

3.2 Release Mechanism

3.2.1 Design Requirements and Background

The second step in designing the dispensing subsystem was to determine how the can would be released from the storage track once a flavor is selected. The primary design requirement was to release a single can while maintaining the seal on the refrigerated volume in order to minimize heat loss during the dispensing process. For the mechanism itself, we took inspiration from both the vertical stack and mechanical gate methods shown in Section 1.3 to create two different design options. Once again, the two options were placed into a selection matrix for accurate comparison and it was found that the two options had offsetting strengths and weaknesses. As a result, the rotating mechanism was chosen to be the initial prototype as the motors would be mounted externally to the refrigerated volume as the performance of the refrigeration system was a high priority.

3.2.2 Initial Design

3.2.2.1 Rotating Mechanism

Figure 3.4: Rotating Mechanism Assembly

The first design option is the rotating mechanism shown in Figure 3.4. The rotating mechanism is driven by a stepper motor attached to the can holder with a flange. The can holder is supported on the side opposite the motor with a dowel pin and bushing that is press-fit into the can holder. When a flavor is selected, the corresponding motor turns the can holder 360°. As the opening on the can holder passes in front of the initial can, the can rolls into the holder positioned such that the center axis of the can is aligned with the motor shaft. As the holder continues to rotate, the outer shell of the holder fills the opening to the refrigerated volume to limit heat loss. When the can holder reaches the end of its rotation, the can falls out of the opening and moves to the next stage of the dispensing process which will be discussed in Section 3.3. The entirety of the rotating mechanism components are to be mounted externally to the refrigerated volume in order to limit the amount of potential heat generation or loss induced by motors or wiring holes.

3.2.2.2 Linkage Mechanism

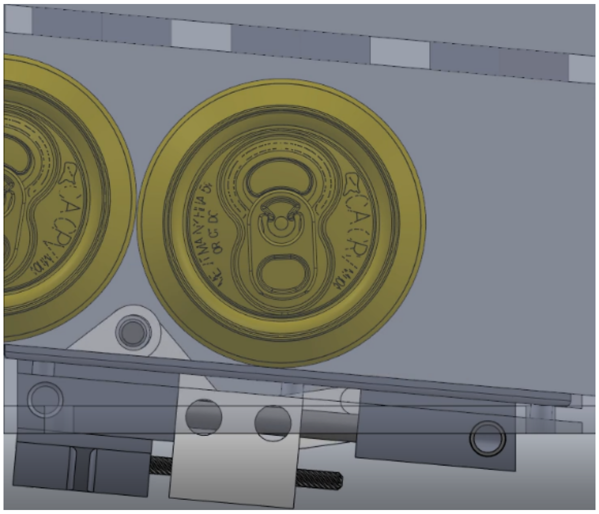


Figure 3.5: Release Mechanism Left Limit

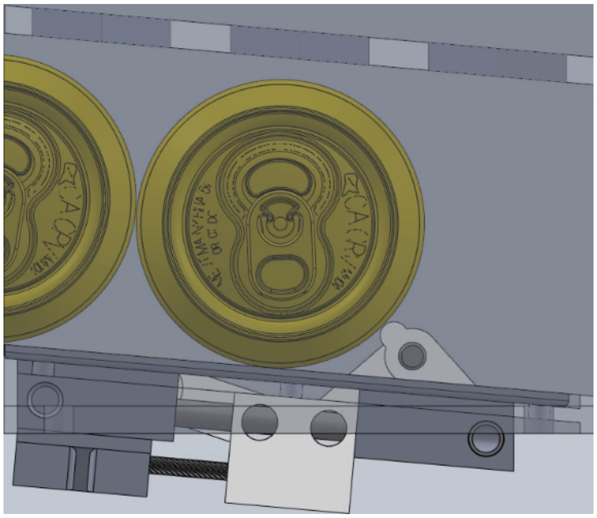


Figure 3.6: Release Mechanism Right Limit

The second design option is the linkage mechanism shown in Figures 3.5 and 3.6. The mechanism is a 6-bar linkage driven by a lead screw with an M4 nut recessed into the center of the slider. The default position of the mechanism, shown in Figure 3.6, is the right limiting position that holds all of the cans in place until a purchase is made. Once the flavor has been selected, the lead screw rotates to move the slider to the left until it reaches its left limiting position, Figure 3.5, where the front linkages have dipped below the bottom plane and the front can is free to roll forward. Once the first can has passed over the front link, the lead screw reverses direction to return to its default position. In order to control the reverse direction and stop the lead screw once the process had finished, the linkage mechanism was equipped with a limit switch at either extreme and connected to the Arduino microcontroller to be integrated into the control code. Differing from the rotating mechanism, the frame of the linkages is recessed into the bottom plane of the storage track meaning all of the components are mounted inside of the refrigerated volume. Further detail for the design of the release mechanism can be found in Appendix G Section 1.

3.2.3 Prototyping and Testing

Figure 3.7: Rotating Mechanism Prototype

As mentioned above, the rotating mechanism is to be mounted externally to the refrigerated volume thus our first course of action was to prototype with the rotating mechanism. In our original mockup and proof of concept stage, shown in Figure 3.7, the rotating mechanism proved to be a viable option. When scaling up the design to include 12 cans on the track, it was found that there was a significant difficulty in ensuring sufficient alignment between the motor shaft, flange coupling, and dowel pin. As a result, the efficiency of the motor was restricted such that it was unable to overcome the gravitational force placed on the can holder by the cans themselves. To combat this issue, the design was altered to begin prototyping the linkage mechanism option. The linkage mechanism was designed to remove the gravitational force of the cans from the dispensing process as the retaining linkages hold the cans in place before any movement of the cans occurs, thus the driving motor did not need to overcome the gravitational force in order to release the can. By removing the issue resulting from the gravitational force of the cans, the linkage mechanism was able to work consistently regardless of the number of cans on the track.

3.2.4 Design Iteration: Refrigeration Door Mechanism

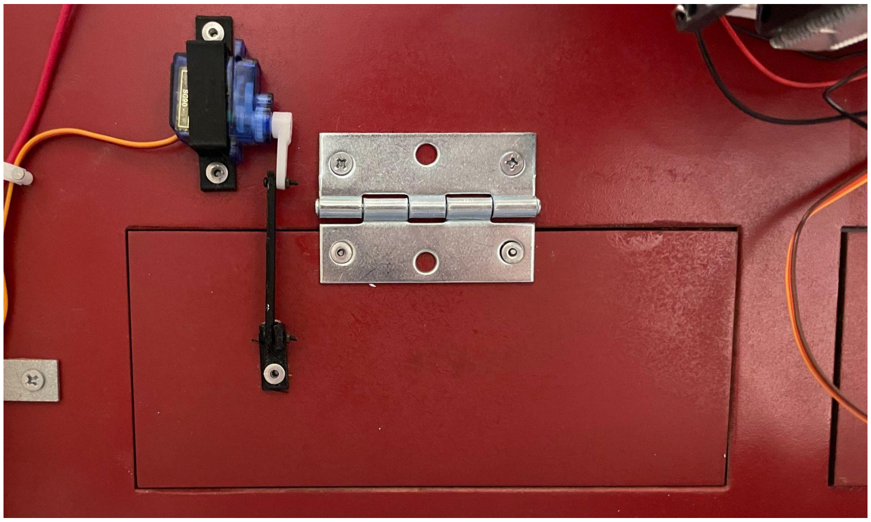


Figure 3.8: Refrigeration Door Mechanism

The decision to continue with the linkage method as our release mechanism resulted in an additional design requirement of a door to the refrigerated volume that maintains the seal of the volume unless actively dispensing a can. Our simple door design, shown in Figure 3.8, consists of a servo motor attached to the door with two linkages and operates in conjunction with the linkage mechanism inside the refrigerated volume. The door functions by opening once the linkage mechanism hits its left limiting point where a can is released and closes once the can has exited the refrigerated volume.

3.3 Convenient Dispensing Location

3.3.1 Design Requirements and Background

As mentioned in Section 2.1.5, the main goal of the dispensing system is to deliver the drink to the customer at a location that is easily accessible to anyone regardless of physical ability. We identified the most convenient dispensing location to be on the front section of the top face of AVA and given that the storage track releases the can at the bottom of the refrigerated volume, a lifting mechanism was required.

3.3.2 Design

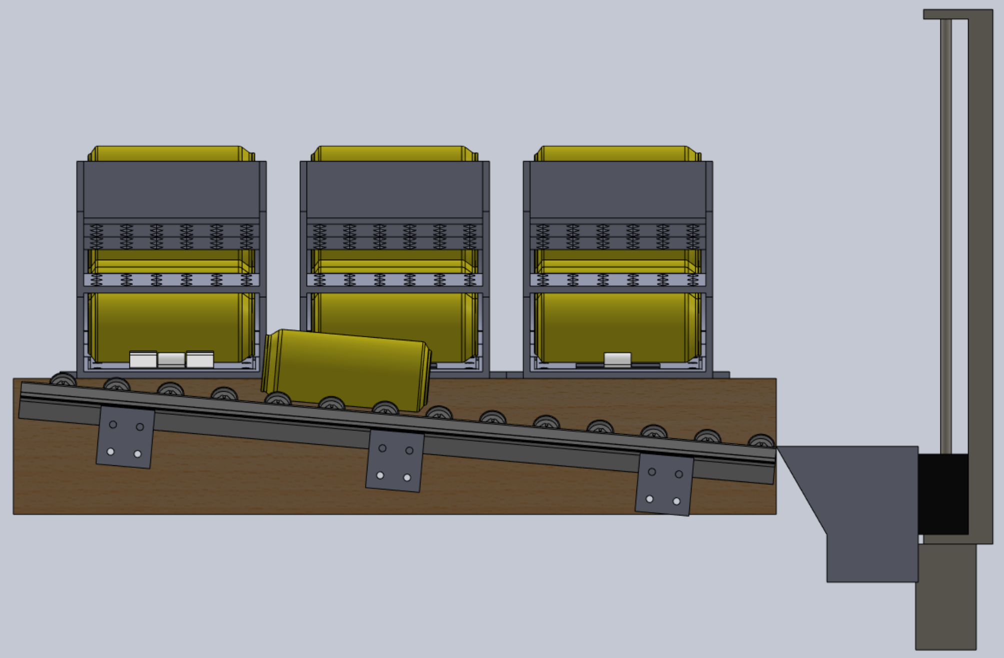


Figure 3.9: Conveyor Track and Lead Screw Layout

The refrigerated volume contains three storage tracks situated side by side across the front face of AVA, shown in Figure 3.9. As there will be only one dispensing location but three separate release locations for the flavors, the lifting mechanism is required to have two axes of movement, both horizontal and vertical. To simplify the lifting mechanism, we implemented a conveyor track constructed of two flow rails mounted such that both rails support the can and are set at a 5° decline. The conveyor track creates the horizontal movement of the can regardless of which flavor is selected. At the bottom of the conveyor track is a bucket mounted to a lead screw that meets the end of the conveyor track such that the can smoothly slides into the bucket. Once the can has entered the bucket, the lead screw assembly accomplishes the vertical movement of the can to the final dispensing location at the top face of AVA.

3.4 Final Dispensing Subsystem Design

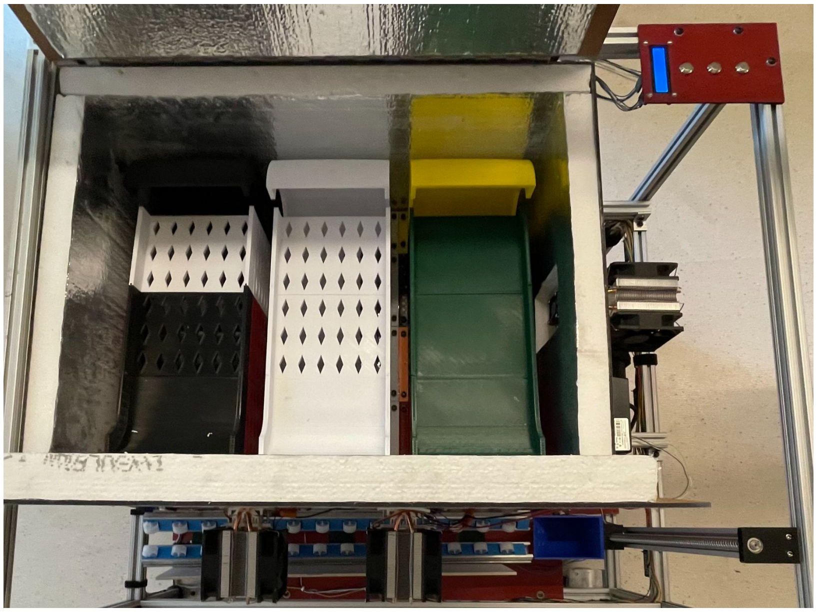


Figure 3.10: Final Dispensing Design Top View

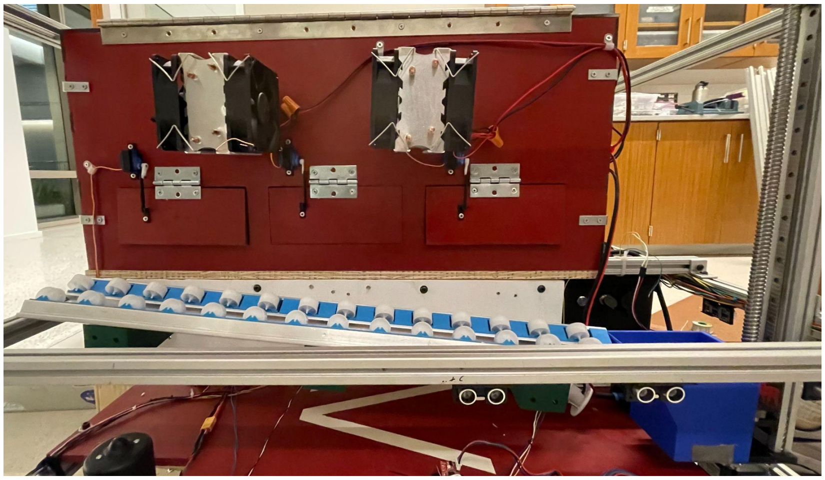


Figure 3.11: Final Dispensing Design Front View

Figures 3.10 and 3.11 show the top and front views of the fully assembled dispensing subsystem. In Figure 3.1, the three storage tracks are positioned next to one another inside of the refrigerated volume. Not shown in the picture are the release mechanisms mounted to the bottom of each storage track. Figure 3.11 highlights the refrigeration doors, the angle of the conveyor track, and the lead screw assembly located to the right of the conveyor track.

Chapter 4 - Refrigeration Subsystem

4.1 Background

The refrigeration subsystem consists of the cooling system and the enclosure for the cooled beverages. Based on real-world vending machines, we set a goal to store drinks in a refrigerated volume maintained at around 37 °F. The system must also be lightweight, electrically efficient, and work in conjunction with the dispensing system. The type of refrigeration system will be explored later in this report. The beverage storage container must be able to fit our goal of at least 36 cans, work in conjunction with the dispensing system, and be well insulated. In order to keep the power consumption of the refrigeration system to a minimum, we agreed that AVA would be stocked with beverages which have already been chilled. This also allows AVA to be restocked during the day without the need to spend additional time waiting for newly stocked drinks to cool.

4.2 Thermal Analysis

4.2.1 Hand Calculations

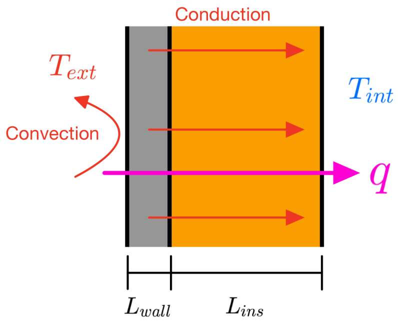


Figure 4.1: Heat Transfer Diagram of 2-layer Wall Cross Section

Thermal analysis using established heat transfer equations were used in order to determine a reasonable estimate of the cooling power requirements. Figure 4.1 shows the cross section of the wall with heat transfer occurring via conduction and convection from the hot side. Equation 1 is derived from this model where T_{ext} is the external temperature, T_{int} is the internal temperature,

L_{wall} is the wall thickness (0.318 cm), and L_{ins} is the insulation thickness (3.81 cm). K_{ins} (0.02 W/mK) and K_{wall} (0.25 W/mK) are thermal conductivity values for the insulation and wall respectively. H is the convection coefficient which was selected to be 5 W/m^{2}K. Lasty, A is the total surface area of the approximated six sided rectangular volume which is 1.67 m^2. The resulting q is the total heat transfer of the system in Watts which is equivalent to the power requirement of the cooling system.

$$q = \frac{Text - Tint}{\frac{Lins}{Kins} + \frac{Lwall}{Kwall} + \frac{1}{H}} \cdot A \qquad \text{(eq. 1)}$$

This approach assumes constant material properties, steady state, one dimensional conduction, no work, and no radiation. Equation 1 also ignores thermal contact resistance between the two walls and reflects a perfectly enclosed volume that does not account for the three doors for dispensing. The stated material property values for the selected materials reflect known values. The convection coefficient of 5 W/m^{2}K was selected to reflect natural convection as the refrigeration system will be enclosed within AVA thus theoretically not susceptible to forced convection due to wind.

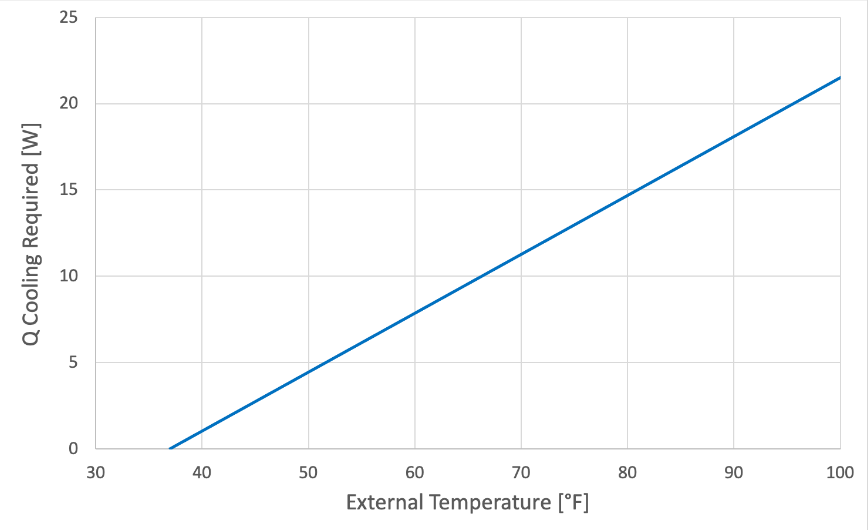


Figure 4.2. Q Cooling Power Required [W] vs. External Temperature [°F]

After plugging in the selected material properties and assuming the internal temperature is precooled to the desired 37 °F, the cooling power required can be compared to varying external temperatures, as shown in Figure 4.2. As expected, there is a linear relationship between the cooling power requirement and the external temperature. We estimate that on warm days in Santa Clara and with proper internal ventilation within AVA, the external temperature would rarely be over 90 to 95 °F. At these temperatures, the theoretical cooling power requirement is about 20 W.

4.2.2 FEA

The goal of the refrigeration FEA is to compare FEA results of a more detailed model to the equation used in hand calculation. The FEA was modeled after the most current iteration of the refrigerated space which had the internal dimensions of 12” x 15.34” x 26”. The walls consist of 1.5” thick phenolic foam insulation (k = 0.02 W/mK) between ⅛” thick ABS plastic as the inner and outer shell (k = 0.25 W/mK). The inside walls were set to a constant temperature of 37 °F (275 K), and the outside walls experienced convection with a coefficient of 2.31 W/(m^2K) at a temperature of 90 °F (305 K). The drink dispensing portion is modeled as a 0.5” thick rectangular section of ABS plastic.

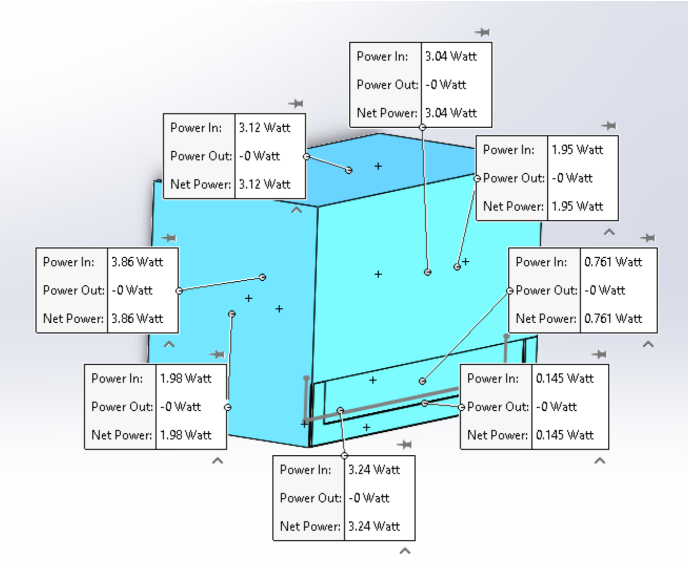


Figure 4.3: SOLIDWORKS Thermal FEA Results of Refrigerated Volume, Heat Flux Plot

Figure 4.3 shows the result of the thermal analysis, with the overall heat flux shown for each face. The total heat flux of all the faces combined is 18.096 W. The FEA was run again, except with the door being modeled as 0.5” of phenolic insulation (k = 0.02 W/m*K). In this case, the total heat flux was 17.936 W. Surprisingly, this showed that increasing the insulation in the door will not make a significant difference in heat loss. For this reason, we will not focus much effort on adding additional insulation to the door mechanism. We also repeated the FEA without the usage of an internal ABS wall to match the model used in Section 4.2.1 and observed a very minor increase to the total heat flux. Lastly, it is clear that the results of the FEA align with the hand calculations. Using these results, we set an estimated need of 20 W of cooling for our refrigeration system. We chose a value that is slightly greater than the calculated and FEA results to account for additional sources of heat gain which have been neglected.

4.3 Refrigeration Options

Several different refrigeration technologies exist and were considered for their application to this project. Vapor compression refrigeration is commonly used in household refrigerators but reveals some drawbacks for this project. Most notably, compressor systems can be noisy, heavy, bulky, and use compressed refrigerant fluids. Compressors also tend to operate on 120V AC whereas our power system will be 12V DC. Upon researching portable electric coolers often used for camping we discovered that the vast majority used thermoelectric cooling. Thermoelectric cooling operates on DC power, uses no moving parts or compressed refrigerant, and is compact. The only substantial drawback of thermoelectric cooling is that they tend to be very inefficient. However, we decided to pursue thermoelectric cooling and devote additional time to testing and optimizing the efficiency.

4.4 Thermoelectric Cooling

Thermoelectric coolers make use of Peltier modules. A Peltier module uses the Peltier Effect which takes advantage of current flow across two different semiconductors to create a temperature difference. The semiconductors are sandwiched between two ceramic plates which allows one plate to get very hot and the other to get very cold. Peltier modules are limited by their theoretical maximum temperature difference (ΔTmax). Therefore, proper heat sinks are essential on both sides of the module in order to dissipate heat and cold air to the surroundings.

With the decision to use thermoelectric cooling, there are three different methods we could use to build the refrigerated volume. The first method would be to buy thermoelectric cooling units available on the market and mount them to a custom-built insulated box. The second method would be to buy a portable electric cooler that uses thermoelectric technology and modify the volume to work with the dispensing system. Lastly, a cooler could be purchased from which we could extract the necessary parts and configure them to a custom build volume. These three options were assessed in a decision matrix (see Appendix D, Section D2) and the first option was shown to be superior. This option gives us the freedom to build our own insulated volume to the exact size we need, rather than being restricted to the dimensions of a purchased cooler. It also gives us the option to buy and test multiple thermoelectric coolers and determine which performs the best.

4.5 Purchased Cooling Units Testing

Expensive, high-efficiency thermoelectric cooling units do exist on the market from companies like the Thermoelectric Cooling America Corporation and Seifert. Unfortunately, the units we would need for our project are too expensive so cheaper models available on Amazon were purchased. These cheaper units tend to have little to no technical data sheets and therefore had to be tested ourselves. Two different TE cooling units were purchased and tested for evaluation of their performance and usability in the final build. For testing, a mockup of the refrigerated volume was built out of a 1.5” thick insulation foam board to which the units could be temporarily affixed. While the units were running, data was collected from thermocouples placed inside the foam box. Data was collected until there was a clear minimum internal temperature.

4.5.1 Single Peltier Module Cooling Unit

Figure 4.4: Single Peltier Module Cooling Unit

The first cooling unit, pictured in Figure 4.4, tested is a single Peltier module design (Amazon part number: Wal frontprgbad3y45) and runs on a maximum of 60 W. We found this unit cooled the insulated volume to about 50 °F and the cold side heat sink nearly reached freezing temperature at about 33 °F. While the 50 °F result is far off from our desired temperature, we did notice that this unit's design dissipated heat on the hot side very well as the heated air coming out of the ventilation fans barely rose above ambient temperature. This is likely due to this design's hot side heat sink which features a large amount of thin aluminum fins creating a massive surface area for convection. We also noticed that this unit uses four copper heat pipes, which use vapor to pull heat away from the peltier module to the heat sink.

4.5.2 Dual Peltier Module Cooling Unit

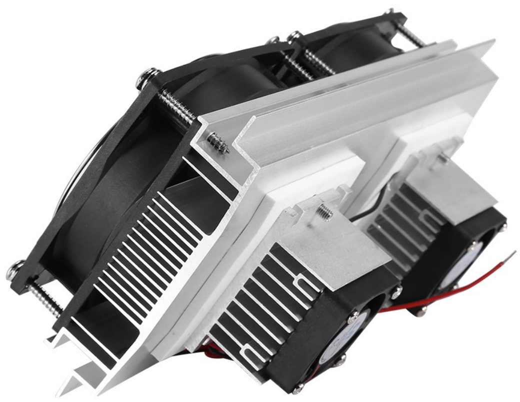


Figure 4.5: Dual Peltier Module Cooling Unit

The second cooling unit (Figure 4.5) we purchased is a dual Peltier module design (Amazon part number: 43307-6836) powered on 144 W. While we expected to see far superior cooling abilities from this design, the results actually showed internal temperature only reached about 55 °F at best. There are several reasons why this may be the case. Firstly, both Peltier modules share the same hot side heat sink which got very hot in testing and therefore did not dissipate heat very effectively. The hot side heat sink of this unit also had less surface area than the first unit tested and lacked the usage of heat pipes.

4.6 Single Peltier Module Cooling Unit Optimization

Based upon the preliminary test results the single Peltier module cooling unit was selected for further evaluation and usage in the final design. Because this unit uses heat pipes as its primary means of heat dissipation on the hot side, we wanted to test whether the orientation of the cooler impacts the maximum temperature difference. The unit was tested with the cold side facing up and the cold side facing down at various power levels. Thermocouples on the cold side were used to observe the maximum temperature difference. The results of this test showed very little impact of the orientation on the maximum temperature difference which therefore granted us the freedom to mount the unit however we deemed ideal within the robot.

These results also led to the discovery that the ΔTmax was still reached when the unit was only powered at 3A, far less than its 6A maximum which we used in preliminary testing.

Lastly, we wanted to determine the efficiency of the cooling unit by evaluating the 50 °F test result and comparing it to theoretical calculations. Figure 4.6 uses Equation 1 from Section 4.2.1 but instead compares cooling power required to the temperature difference (T_{ext}-T_{int}) as opposed to external temperature.

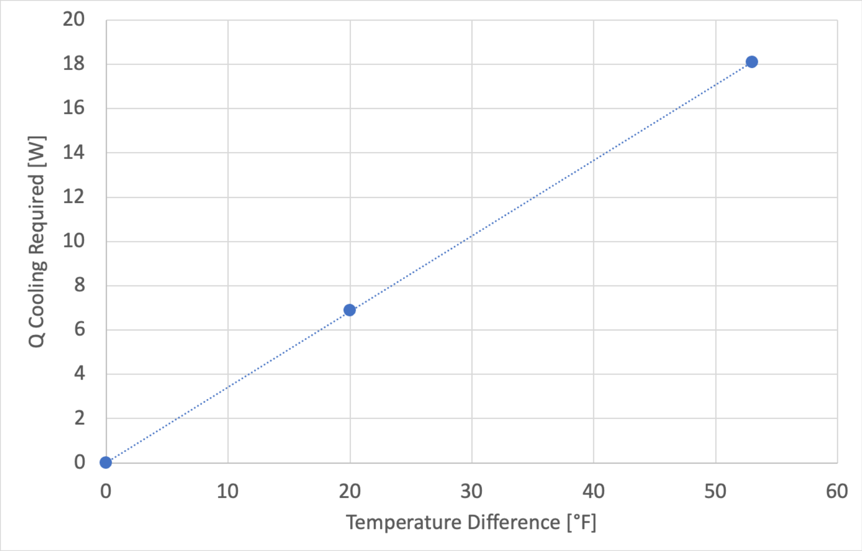


Figure 4.6: Q Cooling Power Required [W] vs. Temperature Difference [°F]

A point on the line is placed at a temperature difference of 20 °F representing the results of the preliminary test. This indicates a Q value of about 6.5 W which means the unit was only about 11% efficient. To reach our previously estimated requirement of 20 W of cooling we decided to use three of these cooling units. Additionally, with the observation that this cooler only needs 3 A to reach its ΔTmax, we will be able to run the coolers at 108 W and still achieve the theoretical cooling requirements.

4.7 Final Design Construction and Conclusions

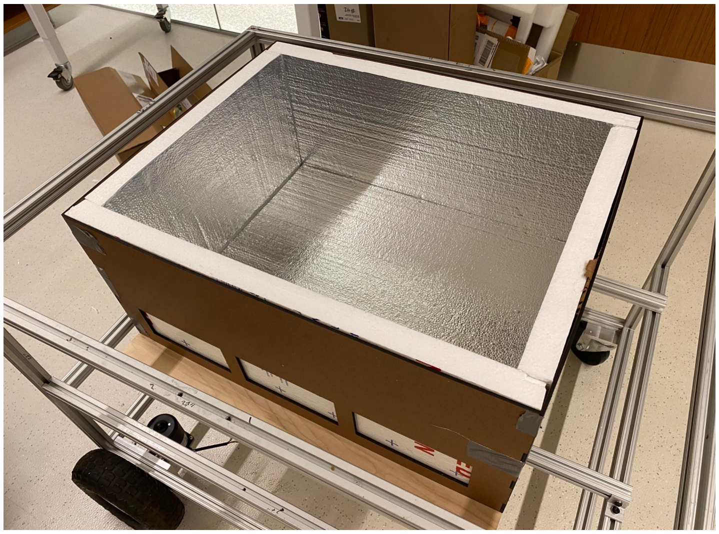


Figure 4.7: Refrigerated Volume Construction

Figure 4.7 depicts a preliminary assembly of the internal and external walls. Using the dimensions from the CAD model, the six internal 1.5” insulation foam board was cut to size using a straightedge and a long, sharp knife. Originally we had planned to build the external walls out of ⅛” ABS plastic sheeting, however here the external sides and lids were made out of 3/16” hardboard. Compared to ABS, hardboard is cheaper and has better insulative properties. The hardboard was cut using a laser cutter which allowed for precise parts made directly from the SOLIDWORKS drawings. The design specifications of the hardboard and insulation foam walls can be seen in Appendix G, Section G4. The bottom piece is made of ½” plywood to create a strong base on which to mount the dispensing system track. Each foam piece is securely attached to their respective walls with aerosol contact cement.

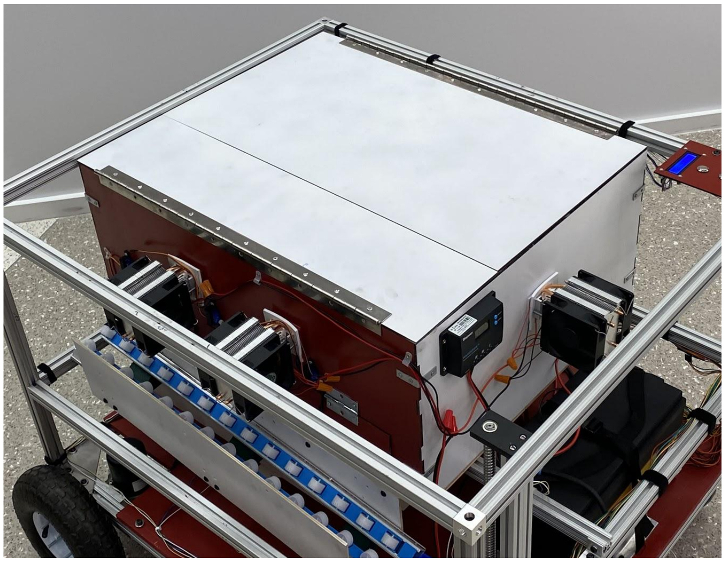


Figure 4.8: Final Refrigeration System Assembly

The completed assembly shown in Figure 4.8 shows the addition of two separate lids on the refrigerated volume. The smaller lid section allows for access to the can storage tracks for refilling beverages without opening the entire volume and losing a lot of cooled air. The larger lid allows for full access to the refrigerated volume for access to the full dispensing system and any maintenance that may be needed to the inside of the thermoelectric coolers. The three coolers are mounted as shown using bolts and the included mounting bracket which keeps the coolers firmly in place with a good seal. They are positioned to provide airflow from two of the four walls, allowing cooled air to reach all three of the can storage tracks. The three coolers are wired in parallel and connected to a separate switch for on/off control of the cooling system. Despite the theoretical calculations suggesting that this system would achieve the 37° F goal, the internal temperature was only seen to reach about 46° F. Discussions of this shortcoming are presented in Chapter 9.

Chapter 5 - Control Subsystem

The purpose of the control subsystem is to effectively command AVA's movement in both speed and direction, provide safety to potential customers with the use of autonomous stopping, and to communicate with the dispensing subsystem when a purchase is initiated. The following section begins with a background outlining the initial design requirements and updates made throughout the design process. Following that, an in-depth description of each control process will be presented. Finally, the final integration and performance testing techniques used will be explained. It should also be noted that the respective code used to carry out all of these control capabilities is located in Appendix E.

Shown in Figure 5.1 is a communication diagram outlining the final design for the control subsystem. The objective of this diagram is to show the relationship and interactions between movement, dispensing, and autonomous stopping components of the vehicle.

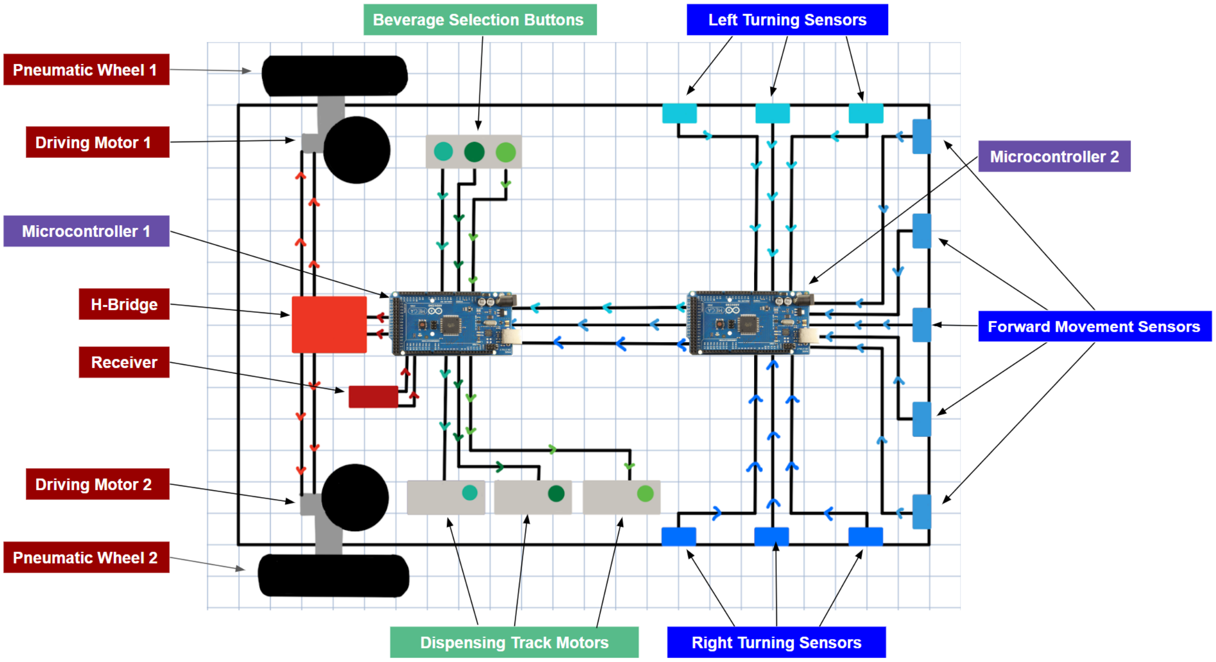


Figure 5.1: Control Subsystem Communication Diagram

5.1 Design Requirements

The initial design requirements for AVA consisted of autonomous movement, autonomous stopping, and effective dispensing integration. These goals were created in an effort to ensure AVA can travel in a fixed loop around any given college campus. However, the team discovered early on in the design process that autonomous movement was out of scope for this particular project. Therefore, the use of a manual remote control was the next best alternative. The revised design requirements for AVA became as follows:

1. Remote movement control
2. Efficient communication between the movement control microcontroller and the autonomous stopping microcontroller
3. Effective autonomous stopping
4. Simple integration between the movement control, autonomous stopping, and dispensing components
5. Safety to all potential customers and nearby pedestrians

5.2 Movement Control

5.2.1 General Movement Control Options

The initial design of AVA's movement control system consisted of the use of an onboard Raspberry Pi 4B microcomputer. The thought process revolving around this decision was that the team could connect the microcomputer to the on-campus Wifi network, eduroam. From there, one could manually access the Raspberry Pi from the team's Dell XPS 15 laptop through the use of virtual network computing (VNC.) This communication effort was successful. Then, the team looked to incorporate various keyboard commands that would be sent to the microcomputer. When performing simple maneuvers and tests inside of the design space, this method was incredibly effective. However, when attempting to produce the same results outside of the building, there were numerous delays in communication. This was due to the need for both the microcomputer and the laptop to maintain strong Wifi connections. Unfortunately, the university's network is split amongst various routers, meaning that if AVA were to travel across one of those regimes, communication would be lost momentarily. This finding was incredibly unideal, especially since the safety of nearby pedestrians could not be ensured. Therefore, the team decided on an alternative option. With the use of radio frequency communication, a user could send both speed and direction input signals from a remote control to an onboard receiver. Due to its ease of use and simple integration, the team decided this method best fit the needs of the prototype.

5.2.2 Radio Frequency (RF) Remote Control

RF remote control is commonly used for a variety of applications, including, but not limited to, remotely controlling a TV, car locking systems, or even a stereo. Due to the method's convenience, this type of control was appealing to the team and its application to AVA's movement capability. Shown in Figure 5.2 is a communication diagram for the movement control system. This diagram will help to better one's understanding of the following explanation.

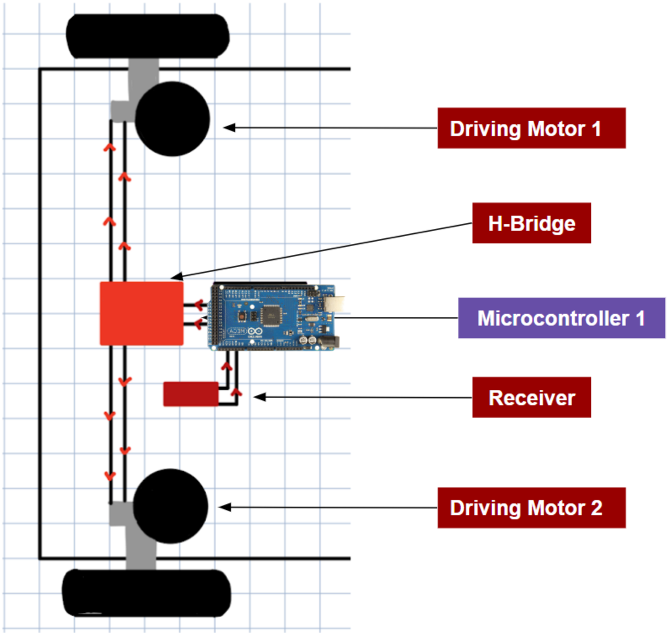


Figure 5.2: Movement Control Communication Diagram

Essentially, with the use of radio frequencies, a user can send nearly instantaneous speed and direction input signals to the onboard receiver. Then, this information is passed on to microcontroller 1, as shown in Figure 5.2. The consensus was to use an Arduino MEGA 2560 due to the large amount of input and output pins, effective processing speed, and simple programmability. Microcontroller 1 then converts the two input frequencies into four outputs. These outputs are then sent to the H-bridge, which provides the respective speed and direction for each driving motor. The reasoning for this is that AVA utilizes differential steering. This means applying more driving torque to one motor with respect to the other in order for the vehicle to turn. That is why each driving motor needs both a speed and direction to turn. Two motor-wheel assemblies are located towards the back of AVA and we used mounted casters towards the front to provide controllable 360° movement. The motor-wheel assemblies are described in greater detail in Chapter 6.1: Structural Integration.

5.2.3 Motor Selection

The driving motor selection assumed a 100 lb maximum load with a full capacity refrigerated volume. After conducting research on a variety of motors, the team determined that the following two motors listed in the table below would be most suitable for this application.

Table 5.1: Driver Motor Selection Matrix

Criteria	Importance	DC Electric Gear Motor	Brushless DC Motor
Low Cost	3	1	1
Performance at Low Voltage Inputs	5	1	0
High Torque Output	4	1	1
Safety	4	1	1
Simple Integration	5	1	0
Total		21	11

After examining the benefits of using both motors, the team decided to use two DC electric gear motors that provide 3 N-m of torque with a maximum speed of 100 RPM.

5.3 Autonomous Sensing and Stopping

The following section outlines the autonomous sensing system used for AVA. Although the autonomous movement was out of scope for this project, the ability of AVA to stop on its own and override a user's movement commands became one of the top priorities for the project. Figure 5.3 outlines the autonomous sensing and stopping system, as well as how it communicates with the movement control microcontroller.

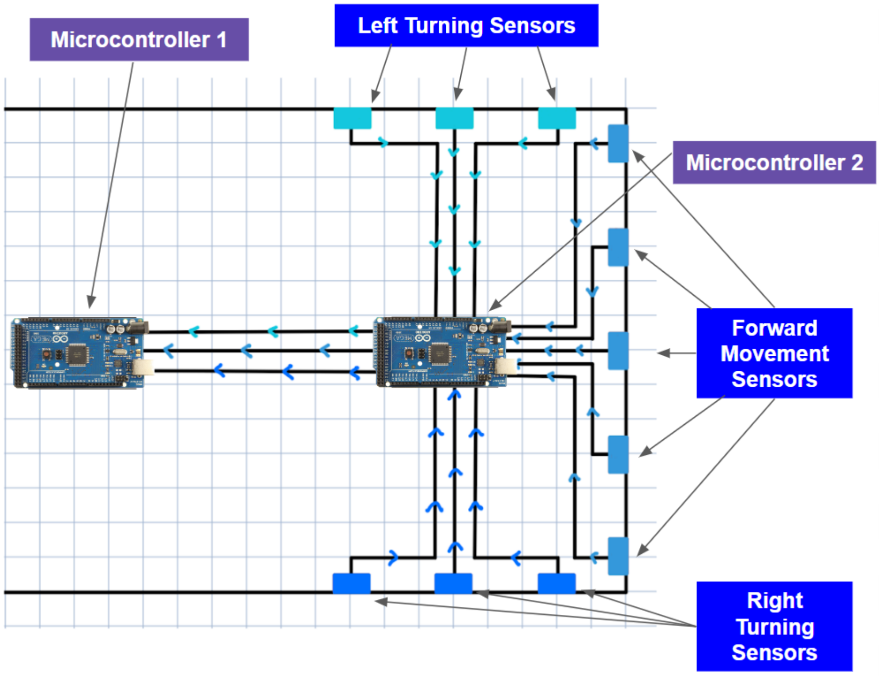


Figure 5.3: Movement Control and Autonomous Stopping Communication Diagram

As described in the previous section, microcontroller 1 plays an important role in AVA's steering and movement, but that is not its only purpose. It is also connected to the sensor system's microcontroller 2, as depicted in Figure 5.3. The communication between the two controllers is vital for AVA's success and safety. The following process occurs. There are a total of eleven ultrasonic sensors, all of which are spaced 6.5 inches apart and have a measuring angle of 30 degrees. When an object or individual is within 1 foot of any sensor, that sensor will be triggered and will send a signal to microcontroller 2. Now, it is important to note that a sensor will only be triggered for its respective type of movement. For example, a left-turning sensor will not invoke a stopping command unless it is actually turning left. The same goes for the right turning and forward movement sensors. That is why there are three separate possible control signals that can be sent from microcontroller 2 to microcontroller 1. Once a sensor is triggered, microcontroller 2 relays that message to microcontroller 1 in order to automatically stop the driving motors and motion entirely. After an event like this occurs, AVA's movement will be restricted to movement in any other direction other than the one it was stopped in. This is a safety feature the team implemented in order to avoid accidentally driving into individuals or obstacles after AVA automatically stops.

5.4 Dispensing Control

Similar to the AVA's sensing and autonomous stopping capability, an additional design requirement was to ensure the vehicle would stop and movement control would be disabled when a dispensing action is initiated. As shown in Figure 5.1, one can see how three distinct push buttons are connected to microcontroller 1. If any of these buttons are pressed, the vehicle's motion will be stopped and disabled until the dispensing process is complete. For the case of a potential future version of AVA, the team would recommend incorporating a payment system in addition to the push buttons. However, for the scope of this senior design project, the goal was simply to show a proof of concept of how that idea would be implemented.

5.5 Refrigeration Control

After initial performance testing of the thermoelectric coolers, it was found that even with a 100% duty cycle, the refrigerated volume could not reach our ambitious target temperature. Therefore, the team decided to opt out from building and designing a refrigeration control system. However, it was still incredibly important to consider the energy needed to power these devices, as the control system uses the same power supply as the refrigeration system. This analysis and decision making process is discussed in Chapter 6.2: Power Integration.

5.6 Control Performance Testing and System Integration

The performance testing and system integration consisted of first writing preliminary code for each control capability. From there, the team tested each program and conducted respective hardware integration simultaneously. That way, any hardware and software anomalies could be found and addressed immediately. Once a specific control capability was deemed effective and efficient, the team moved on to the next one. Once all of these capabilities were completed individually, the entire control system was integrated together, one capability and component at a time. This turned out to be a very effective strategy as the team could find solutions to problems more efficiently when working on one task at a time. Although the general process is described above, an explicit step by step outline is shown below.

1. Movement control capability programmed in Arduino C++ ‘dialect’
2. Motor wheel assemblies and casters integrated to the structural frame
3. H-bridge wired to the respective driving motors
4. Movement control capability tested, necessary changes in the code were made, and the system was approved
5. Sensing and autonomous stopping capability programmed in Arduino C++ ‘dialect’
6. Ultrasonic sensors integrated and wired completely to microcontroller 2
7. Sensing and autonomous stopping capability tested, necessary changes in the code were made, and the system was approved
8. Dispensing capability programmed in Arduino C++ ‘dialect’
9. Dispensing capability tested, necessary changes in the code were made, and the system was approved
10. Microcontroller 1 wired to microcontroller 2
11. Dispensing system integrated with the movement system
12. Movement control, sensing and autonomous stopping, and dispensing system full integration and testing

Chapter 6 - Integration

This chapter covers the design of the structural integration subsystem and the power integration subsystem. These subsystems are grouped in this chapter because they act as supporting subsystems to the dispensing, refrigeration, and control subsystems.

6.1 Structural Integration

The primary objective of the structural subsystem is to provide a rigid structure for all other subsystems to mount to. This was achieved through the combination of a metal frame with a wooden base plate to allow for the easy mounting of all subsystems. Additionally, this subsystem is responsible for a protective and waterproof outer shell. This section will cover the design requirements for the subsystem, a structural analysis, material selection, prototype and testing, and the finalized design.

6.1.1 Background

The structural subsystem has a number of design requirements that were determined through customer research. These design requirements were adapted to better align with the revised goals for the project. The revised design requirements for the structural subsystem are listed below.

1. Frame supports loads of 100 lbs
2. Frame provides mounting locations for other subsystems
3. Protective outer shell
4. Lightweight

6.1.2 Materials Selection

To best meet the requirements listed above, pros and cons for different frame and shell materials are tabulated in Appendix D, Section D3.

A selection matrix was created to assist with choosing the best material for the frame. Each material was ranked based on how it performs in the following categories. The categories are listed in order from most important to least: Subsystem Mounting, Rigidity, Cost, Durability, Water Resistance, Lightweight, Aesthetics. The selection matrix indicates that the ideal frame material for the RVM is extruded T-slotted aluminum [see Appendix D, Section D3]. This material excelled due to the abundance of mounting positions it provides for all other subsystems. Additionally, it provides a good balance of strength and weight. These positives are able to make it the ideal frame material despite the higher price when compared to other materials.

A second selection matrix was created to determine which shell material was best suited for the RVM. The shell materials were graded by the following criteria: Water Resistance, Formability, Cost, Durability, Aesthetics, Lightweight. Based on the results from the selection matrix, the best material for the outer shell of the RVM is fiberglass followed closely by plywood with epoxy resin [see Appendix D, Section D3]. Both materials excel in most of the categories but fiberglass gains a slight advantage over plywood when it comes to creating a weather resistant shell.

6.1.3 Structural Analysis

To reduce the structural complexity and the amount of time doing structural analysis, we made the decision to only use one type of frame material (cross-section and material). By making this assumption, the analysis can be performed only on the frame members that would experience the highest stress and deformation.

To perform the analysis, basic dimensions for the frame were needed to determine how the frame would be loaded. The dimensions of the frame were approximated based on the spatial requirements of the other subsystems. The dimensions of the final frame differ from the dimensions used in the structural analysis and will be explained in Section 6.1.4.

The structural analysis was performed on the refrigerated volume supports. It was anticipated that these members would experience the most stress due to bending from the weight of the refrigerated volume and its contents. The load used for the calculations assumed 36 - 16oz. cans, refrigerated volume and dispensing system for a total load of 50lbs. This load was to be supported by two members resulting in a load of 25lbs per member. The load on each member was assumed to be a distributed load at the center of the member with a width of 20 inches. The estimation of 20 inches was based on the idea of 3- 5inch tall cans stacked end to end with an additional 5 inches for the dispensing and refrigeration system.

After outlining the assumptions for the loading conditions, a factor of safety of 3 was used when performing the calculations. A maximum deformation of 2mm was set as a goal to make sure the frame did not deform significantly under load. Stress and deformation calculations require material properties which correlate to the properties of T-slotted aluminum which was chosen in the previous section. After performing calculations, it was found that 1”x1” t-slotted aluminum is sufficient to meet the requirements. This size was chosen because of the leftover material available in the machine shop.

6.1.4 Prototype Design and Testing

The design of the frame is highly dependent on the spatial requirements of the other subsystems. The frame needs to be large enough to house the refrigerated volume, dispensing components, and power components. However, the frame dictates the overall size of AVA and therefore should be kept as small as possible.

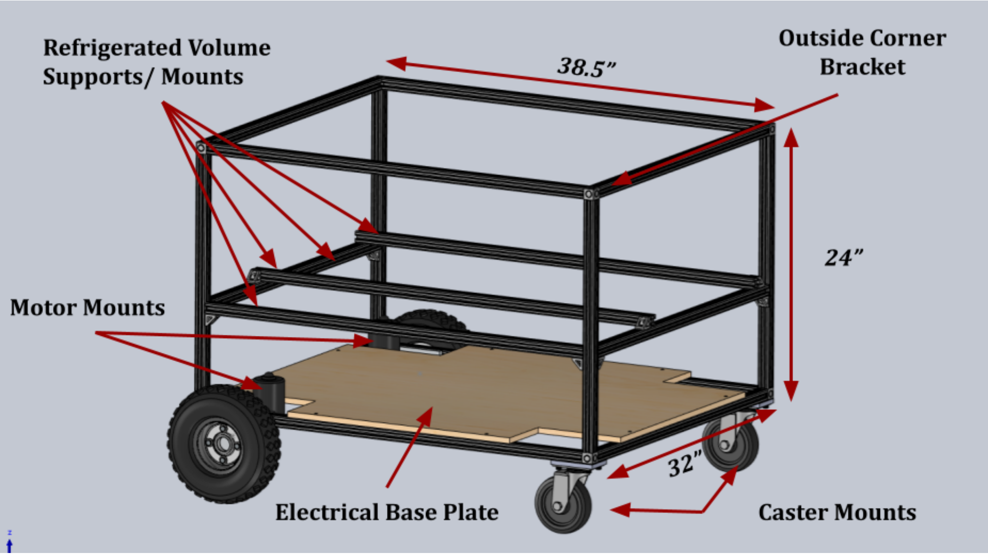


Figure 6.1: Structural Subsystem Preliminary Design

The dispensing subsystem was the driving force behind the overall design of the frame. In order for the dispensing system to work as designed, the refrigerated volume, conveyor track and vertical lift mechanism need to be mounted securely with specific relations to one another. The height, width, and depth of the frame were determined by the minimal amount of space required to hold these components in relation to one another. The refrigerated volume supports shown in Figure 6.1 were added to support the refrigerated volume itself along with the conveyor track.

The refrigerated volume supports also serve as a convenient mounting location for the ultrasonic sensors utilized by the control subsystem for autonomous stopping. The mounts for the ultrasonic system shown in Figure 6.2 were designed to be 3D printed and bolted to the underside of the refrigerated volume supports. The sensor mount includes a clearance hole to allow for it to be bolted to the frame. Two locating tabs were added to prevent the sensor mounts from rotating about the bolt and ensuring that all of the mounts were parallel to one another.

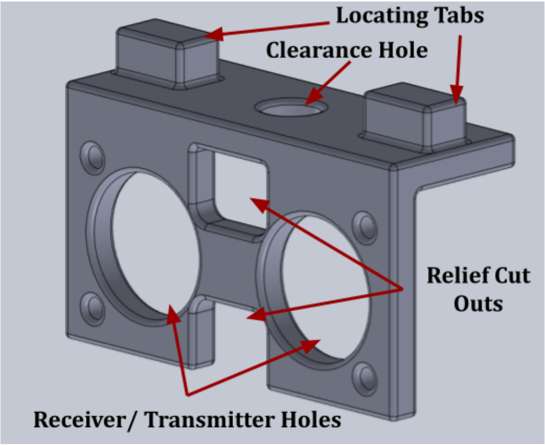


Figure 6.2: Ultrasonic Sensor Mount

Once the sensor mount is securely bolted to the frame in its desired position, an ultrasonic sensor can be slid into the mount starting with the transmitter and receiver. Relief cut outs were added to the sensor mounts so that the header pins and other components on the board did not interfere with the sensor from sitting flush to the mount. The sensor is secured to the mount using four 0-80 nuts and bolts.

In an effort to save space, all of the power components were designed to be mounted under the refrigerated volume. As seen in Figure 6.1, a wooden base plate was designed to protect the underside of AVA while also providing adjustable mounting locations for all electrical components. The cutouts in the corner of the base plate serve as clearance holes for the motors and casters. The electrical base plate must be strong enough to support all of the electrical components (primarily the battery), be nonconductive to prevent short circuits, and provide convenient mounting for all of the electrical components. To serve all these requirements, ½” plywood was selected. Plywood is naturally nonconductive and allows components to be easily mounted with wood screws.

To connect all of the exterior frame components together while taking up the least amount of space inside AVA, three-way outside corner brackets were selected for their minimal footprint. Our frame is designed to be fastened with 8, three-way outside corner brackets shown in Figure 6.3. After shipping and tax, the total for 8 corner brackets comes out to $115 at the time of writing this paper. In an effort to reduce costs, these brackets were reverse engineered and machined in the SCU machine shop.

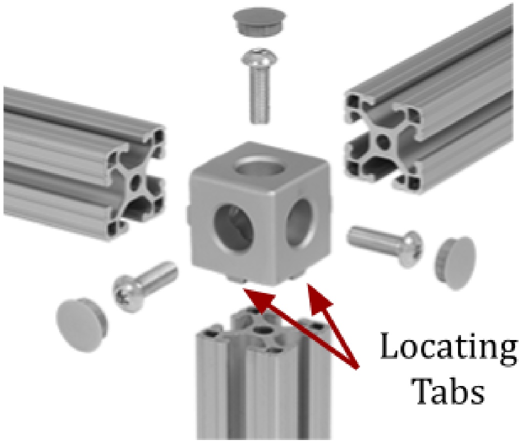


Figure 6.3: Three-Way Outside Corner Bracket

Figure 6.4: Fabricated Three-Way Outside Corner Bracket

The reverse-engineered brackets shown in Figure 6.4 were designed and fabricated without the locating tabs that are part of the commercially available version shown in Figure 6.3. This choice was made to reduce the complexity of the part and the time required to manufacture the part. As a result of not having locating tabs, the frame members had to be held square to the bracket when tightening the bolts. Once tightened the frame members did not rotate about the bolt securing it to the bracket.

The motor mount shown in Figure 6.5 is designed to mount to the inside of the frame and hold the drive motor securely to the frame. The motor mount is bolted to the frame using three, ¼”-20 bolts at the top of the mount. The motor is secured to the mount using three M6 bolts that are spaced 120° apart on a 1” radius circle. A large clearance hole in the center of the motor mount allows the drive shaft to connect the 10” pneumatic wheel to the drive motor.

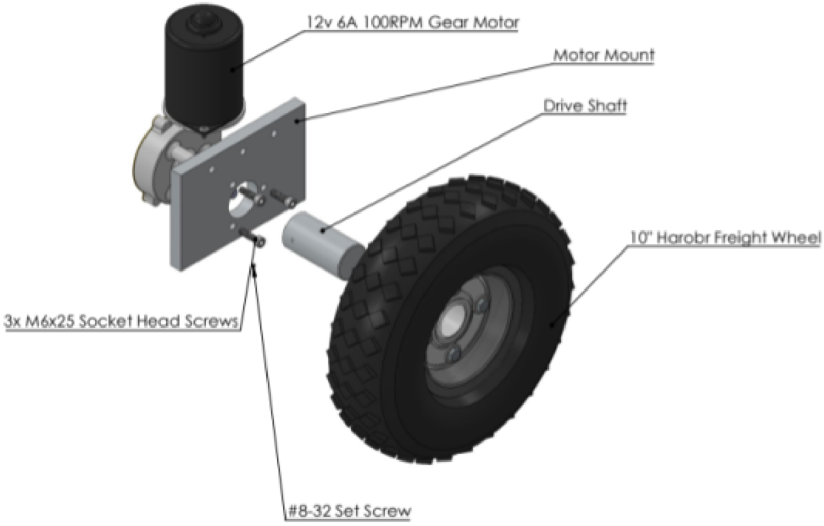


Figure 6.5: Motor Wheel Assembly - Exploded View

The drive shaft shown in Figure 6.5 is designed to fit over the output shaft of the drive motor and inside the hub of the 10” pneumatic tire. Using one 8-32 set screw, the drive shaft is secured to the motor by tightening the set screw to the flat part of the d-shaped output shaft. The wheel is secured to the drive shaft using two set screws spaced 180° apart.

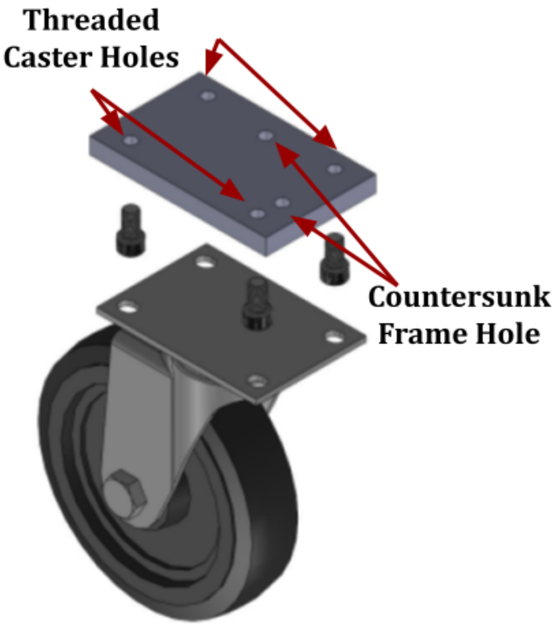


Figure 6.6: Caster Assembly - Exploded View

The caster mount shown in Figure 6.6 is designed to provide additional rigidity to the frame as well as provide mounting holes for the casters. The caster mount is secured to the frame using two ¼”-20 crews. The holes for securing the mount to the frame are countersunk so that when the screws are tightened down, the heads are recessed into the mount and allow the caster mounting plate to sit flush with the caster mount. The caster is then secured to the caster mount using four ⅜” -16 screws screwed into the threaded holes in the caster mount.

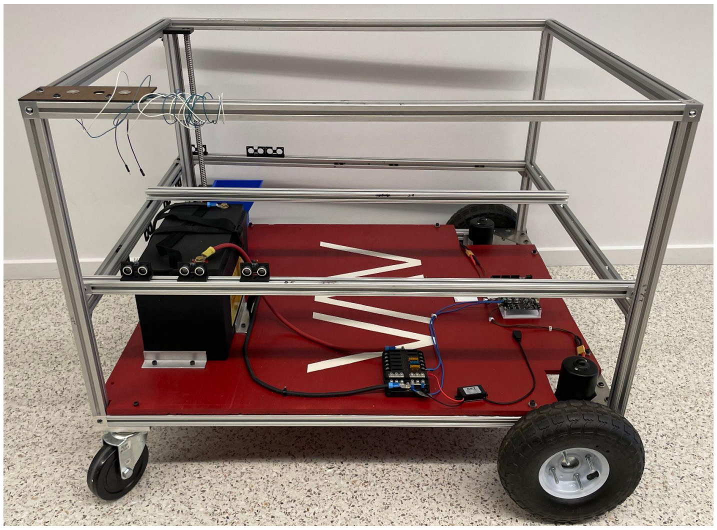


Figure 6.7: Assembled Frame

Figure 6.7 shows the fully assembled frame with a few electrical components mounted to the base plate. The frame was loaded with approximately 70 pounds of scrap steel along with the 30 pounds frame totalling a 100 pound load with no visible deflection seen in any of the members. The casters worked as expected and allowed AVA to turn using differential steering.

6.1.5 Finalized design

As mentioned in the section above, the frame met the requirements of withstanding the 100lb load, providing mounting points and remaining lightweight. However, in test driving AVA, a few problems arose causing AVA to stop driving.

The team noticed that despite the motors continuing to spin, the wheels would not turn and AVA could not move. The cause was identified as the set screws that lock the wheels to the aluminum drive shaft would back out the more that AVA was driven. This problem became worse especially when going over bumpy terrain such as the pavers all around campus. To mitigate the issue of the set screws slipping, shallow holes were drilled into the drive shaft for the set screws to seat into. Additionally, the set screws were coated in a medium strength thread locker so that the vibrations would not cause them to back out.

These measures helped AVA drive for longer periods of time, however, AVA would occasionally still come to a stop. The team noticed that the longer AVA was driven, the camber of the wheels would increase in the negative direction. The camber increased to the point where there was no gap between the wheels and the frame shown in Figure 6.8 resulting in the wheels rubbing against the frame, causing AVA to slow to a stop.

Figure 6.8: Wheel Frame Spacing

Figure 6.9: Frame Support Bracket

This issue was caused by the frame twisting about the bolt that holds the frame together at the corner bracket. This rotation is the result of a torque being applied to the frame member from the weight of the vehicle being supported away from the axis of rotation of the frame member. The only thing preventing the frame members from rotating freely about the bolted axis is the preload in the bolts. When the bolts are tightened during assembly, friction is created between the frame member and the corner bracket which prevents the member from rotating freely. This friction was enough to prevent the members rotating under the weight of the vehicle when it was being statically loaded. However, when the AVA drove over bumps, the torque applied to these members would fluctuate, occasionally reaching enough torque to overcome the preload, causing the member to rotate.

This is not normally an issue for T-slotted aluminum frames that use three way corner brackets. The reason most T-slotted frames do not have this issue is because the commercially available three way corner brackets have locating tabs that provide a torque in the opposite direction of any torque applied to the member preventing any rotation.

By the time the team discovered the issue with the rotating members, it was essentially too late to remove the three way corner brackets to add locating tabs because doing so would require the complete disassembly of AVA. To prevent the members from rotating, the brackets shown in Figure 6.9 were designed, fabricated out of ⅛ in aluminum and are shown more specifically in Appendix G, Section G5. The brackets prevent the rotation of the frame member by linking it in a bolted connection to a perpendicular frame member. After implementing the brackets, there was no longer an issue with the frame member rotating.

When it came time to build the protective outer shell, the team decided that doing so was not a valuable use of time in the minimal time remaining before the project presentation. The main functionality that the shell adds is protecting all of the components from the elements as well as preventing people from tampering with the robot. Since the scope of this project was to build a prototype intended to only interact with a few customers, the need for a protective shell is not as important as it is for the market ready version.

6.2 Power Integration

The Power Integration subsystem covers the electrical power supply for all onboard systems. The primary objective is to safely provide power to the various systems for the desired daily operation time. The power system utilizes solar panels and plug-in charging to power a lithium ion battery which distributes power to the subsystems. To meet the design criteria, accurate estimations of the power requirements were necessary. Analysis of other subsystem power requirements was performed. This allowed for the proper selection of wiring and other components. The power system integrated with the other subsystems as they were finalized, allowing for onboard testing to be performed.

6.2.1 Background (design requirements)

The first step in designing the Power subsystem was to determine the system-level design requirements that must be met. Market research and interviews guided the considerations of the Power subsystem. Additionally, since AVA is a prototype, the wiring needed to be easily altered and accessible throughout the testing process. The key requirements are as follows:

- Safety measures to prevent overdrawn current
- Minimum runtime of 8 hours
- A method for turning off the power
- Easily adaptive wiring

Safety measures mitigate risk to operators and customers who interact with the AVA. The runtime was selected using market survey data. As discussed previously in Section 1.5, the highest demand for caffeinated beverages occurs between 7 am and 2 pm. Accounting for additional time to set up and retrieve AVA, a minimum daily runtime of 8 hours was selected. The battery cut-off switch is necessary to minimize wasted energy and mitigate the risk of a battery short while prototyping. Lastly, the adaptive wiring allows for prototyping simply to go through iterations.

6.2.2 Power requirements

To meet the 8-hour minimum runtime goal, the power usage of the subsystems were calculated. All the components that draw power were itemized and their respective power requirements were analyzed. Since the power system was developed simultaneously with the other subsystems, an initial power estimate was conducted during the winter quarter based on the information available at the time.

Table 6.1: Initial Power Requirement Estimation Performed Winter Quarter

Component	Voltage (V)	Current (A)	Duty Cycle	Quantity	Average Power Consumption (W)
Driving Motor	12	2	95.00%	2	45.6
Thermoelectric Coolers	12	6	100.00%	1	72
Lead Screw	12	2	2.50%	1	0.60
Rotating Stepper Motors	12	1	0.20%	3	0.07
Raspberry Pi	5	0.885	100.00%	1	4.425
Total Average Power Consumption:					**123**

Table 6.1 shows the initial power requirement results. The table includes all components which draw power excluding the sensors. The sensor types and quantity were not yet known and we anticipated them to be negligible due to their low power consumption. The component current values were drawn from datasheets for components that were already selected. The driving motors were not yet selected, thus a calculation was done to estimate their power needs. The rotating stepper motors shown above drive the rotating dispensing mechanism described in Section 3.2. The duty cycle column accounts for the restricted use of various components. For example, the dispensing system is only operational while dispensing is occurring. With these values, we found that the average power consumption throughout a day of use would be approximately 123 W.

To reach the design requirement of 8 hours of runtime, this calls for approximately an 80Ah 12V battery. In order to give room for error in the power estimation, we purchased a 100Ah 12V battery.

Table 6.2: Power Usage of Final Design

Component	Voltage (V)	Current (A)	Duty Cycle	Quantity	Average Power Consumption (W)
Driving Motor	12	1.9	95.00%	2	43.32
Thermoelectric Coolers	12	3	100.00%	3	108
Lead Screw	12	2	2.50%	1	0.60
DC Dispensing Motors	12	0.335	0.20%	3	0.02
Arduino	5	0.132	100.00%	2	1.32
Ultrasonic Sensors	5	0.015	100.00%	11	0.825
Total Average Power Consumption:					**154**

Table 6.2 shows the actual power usage of the final build. This result is an average power consumption of 154 W, considerably higher than the initial estimate. This is largely due to the increased power demand of the finalized refrigeration system discussed in Chapter 4. The purchased 100Ah 12V battery allows for a single charge runtime of ~7.8 hours. More information on the battery can be found in the subsequent section.

6.2.3 Design

Power to AVA was distributed as provided in Figure 6.10

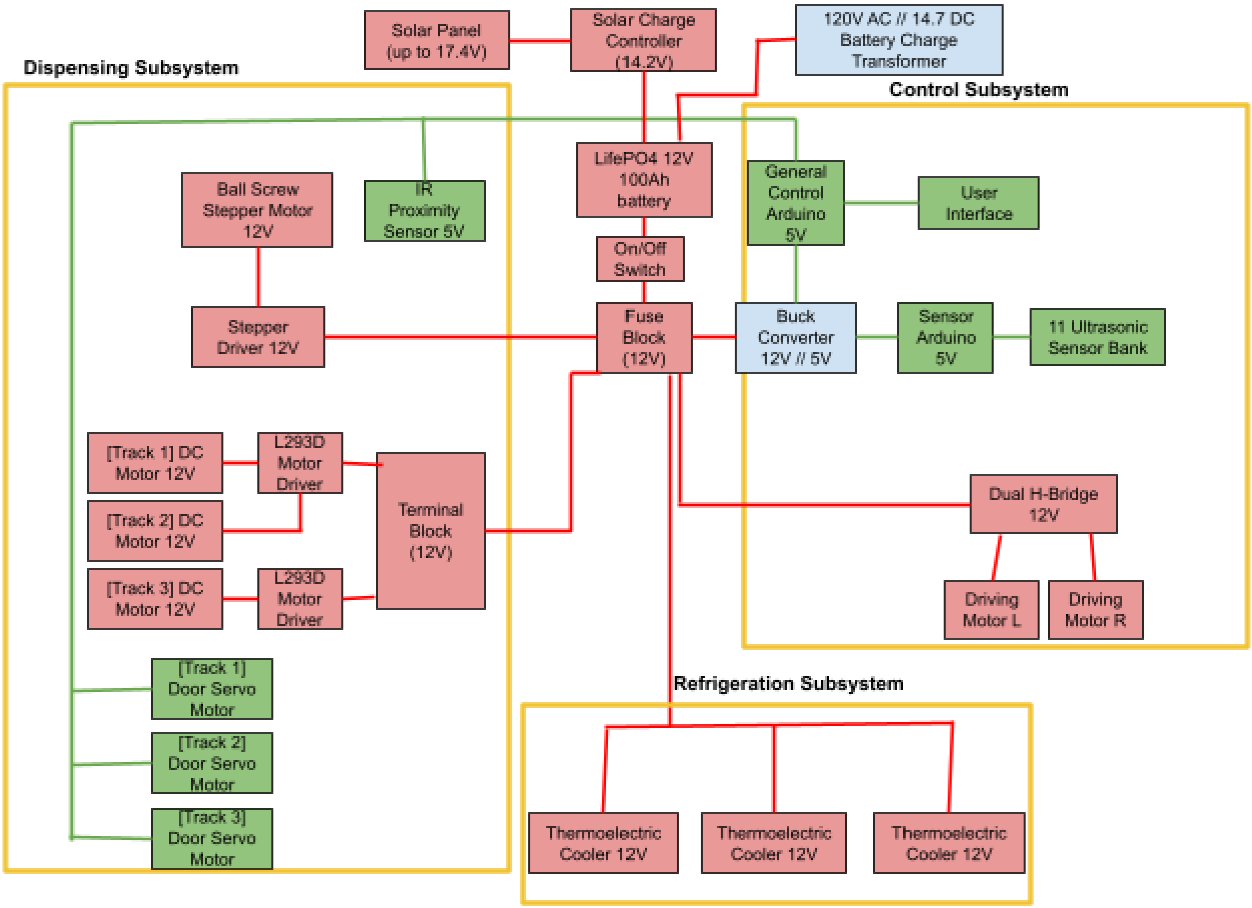


Figure 6.10: Electrical Component Block Diagram of AVA

Figure 6.10 shows the electrical component block diagram for power supply only and does not include control wiring. In the figure, red signifies an operating DC voltage of 12V or higher and green an operating DC voltage of 5V. Blue denotes the DC/DC buck converter which provides 5V power and the AC/DC transformer that charges the battery when plugged into a wall outlet. As shown, the power bus involves the dispensing, refrigeration, and control subsystems of AVA. The key components that make up the power system are shown outside of the yellow section boxes and are as follows:

- LifePO4 Battery
- Solar Panel and Solar Charge Controller
- Fuse Block

These components will be discussed in the following subsections.

6.2.3.1 LifePO4 Battery

The power supply of AVA needed to be able to power all system components simultaneously for a relatively long period of time. Thus it requires a battery that can hold a significant amount of power. Further, it has to reduce the risk of chemical related spilling as it can be subjected to adverse operating conditions. Additionally, it would be beneficial to require minimal maintenance for ease of use.

We initially considered lithium-ion, nickel-metal hydride, flood lead acid, gel, and AGM batteries, however all but lithium-ion and nickel-metal hydride (NiMH) were eliminated in an initial selection matrix shown in Appendix D, Section D4. The NiMH composition was considered as it offered a lower cost and a slightly higher safety rating compared to Lithium-Ion, however, proved less efficient and has a shorter lifespan. Lithium-Ion, more specifically lithium iron phosphate batteries offered high safety, long lifespan, and large depth of discharge with minimal impact on lifespan.

Thus, a Lithium Iron-Phosphate battery was selected to power AVA. The battery selected runs at 12V (the most common voltage requirement for components), stores 100Ah (1200Wh), can discharge at a rate up to 100A and has a lifecycle rating of 2000 cycles or more. The battery comes with a built-in smart BMS (Battery Management System) to protect from overcharge, over-discharge, overcurrent, and short circuits. Additionally, it has a temperature protection function and comes with an AC/DC charge transformer. The battery was mounted to the baseplate of AVA with 3 connections going to the fuse block, solar charge controller, and AC/DC charge transformer as shown in Figure 6.10. A battery mount was attached to the base plate including a strap to hold the battery securely in place.

6.2.3.2 Solar Panel and Solar Charge Controller

The solar panel aimed to provide additional power to the battery during AVA's operation. This would increase the duration AVA can operate in a given day and reduce AVA's carbon footprint. The solar panel needed to be highly efficient and fit within the available space on top of AVA. Thus a monocrystalline solar panel was chosen as it offers increased efficiency per area compared to polycrystalline panels. The selected solar panel is rated at 12V (actually runs up to 17.4V) and can output up to 100W in ideal conditions.

Solar panels require a charge controller to ensure that the battery can be safely and efficiently charged. The solar charge controller monitors battery voltage and adjusts how much current can be safely fed to it. As this is a relatively low power solar panel, it does not require a complex and costly solar charger. The Renogy PWM Wanderer 10A Charge Controller was selected due to its effectiveness at a low cost.

6.2.3.3 Fuse Block

As in many electric applications, fuses provide an effective and inexpensive method for protecting the system from excessive current. Since AVA's function is in many ways similar to that of a road vehicle, it was natural to utilize a fuse block that is commonly used in such vehicular applications. A 12-way fuse block with a shared ground was selected. The 12 different paths were not anticipated to be used, however, allowed for additional components to be added if necessary. Every component that required power was connected through the fuse block. This protects the battery and other components if any short circuit occurs, and proved exceptionally beneficial in the testing phase when the wiring was not securely mounted. Additionally, it was simple to have all components run in parallel through one block as a majority of components require the same voltage (12V). The fuse block has the added benefit of being easy to maintain for an operator with minimal technical experience.

The fuses for each component were selected using the UL 248-14 standard for low-voltage fuses. This calls for fuses to be operated at no more than 75% of the nominal current. Equation 2 shows how the fuse should be selected:

$$Fuse\ Rating\ =\ Operating\ Current/0.75 \qquad \text{(eq. 2)}$$

Thus the fuse for the driving motors (run up to 6A each when accelerating) should be 12A/0.75 = 16A fuse rating. Due to limited resources, fuses were rounded up to a 2.5A increment. Thus the driving motors are connected through a 17.5A fuse. More fuse information for the various components can be found in Appendix D, Section D4.

6.2.4 Integration and Final Design

The power system went through the following iterations of integration.

- Single subsystem testing with external power
- Single subsystem testing with battery
- Multiple subsystem testing and integration with battery

Initial benchtop testing was performed one system at a time utilizing a power supply unit. This was to minimize the issues introduced with integration. As systems began mounting to the frame, further testing was performed utilizing the battery. This allowed for more in depth testing of the dispensing and movement. Once individual systems proved to work as intended, multiple subsystems were tested together powered by the onboard battery. This continued until the final build was completed.

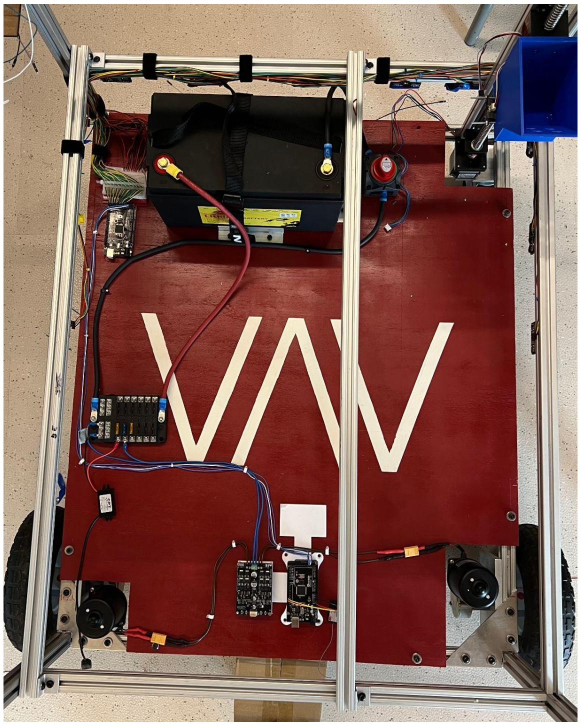


Figure 6.11 Baseplate with Partially Completed Power System For Onboard Testing

Figure 6.11 shows the baseplate with components to test the movement control system. Onboard mounting allowed for testing in a real application setting to occur, helping debug the movement control system.

As shown previously in Section 6.2.3, the average power consumption of the final build was found to be approximately 154 W. The 100Ah 12V battery is able to power AVA for 7.8 hours per charge. This falls short of the initial goal of 8 hours, however, is within a reasonable margin. Factoring in the power provided by the solar panel, AVA can run up to ~11 hours in ideal weather conditions.

Chapter 7 - Mass Production Cost analysis

Table 7.1: Production Cost Breakdown

	Prototype (1 Unit)	Mass Produced (1500 Units)
Dispensing	$513	~$ 220
Control	$266	~$180
Refrigeration	$252	~$150
Power	$664	~$350
Structural	$431	~$150
Total	$2,126	~$1,050 Per Unit

7.1 Prototype cost

Table 7.1 illustrates the cost comparison of our prototype and cost per unit of mass production of a similar model. As a disclaimer, the mass production cost does not account for the features yet to be implemented that are intended to be in a market ready version of AVA. In addition, we are assuming a total of 1,500 units would be produced per production batch.

The final cost for the prototype came to a total of $2,126. One of the biggest contributors to this cost is the dispensing subsystem, specifically the dispensing tracks. The storage tracks and release mechanisms were 3D printed for the prototype as it allowed for efficient design iteration and convenient manufacturing. In mass production 3D printing would not be a financially feasible option and injection molding would significantly decrease the production cost of the dispensing tracks. For the refrigeration subsystem, mass production would decrease the cost of the refrigeration box as it would be rotomolded instead of constructed from 3/16” hardboard. As for the remaining subsystems, a significant portion of the cost can be attributed to the fact that the components were purchased individually and at mass scale would inherently be significantly cheaper. Purchasing components such as the electrical components, battery, lead screws, and motors would provide bulk discounts to further decrease the production cost. Lastly, with a finalized layout and structure for AVA, the frame would be made with welded tube steel instead of the T-slotted aluminum needed in the prototype further decreasing the mass production cost.

Using our mass production assumptions, we found that the decrease in production cost would bring the price per unit down to about $1,050 which is much significantly more financially viable that the original prototype cost.

Chapter 8 - Economic Justification

8.1 Business Assumptions

To determine the capability for profit, a couple of assumptions are made. Note that these assumptions are based on usage at Santa Clara University.

Table 8.1 Profit Calculation Assumptions

Assumptions:
- Cans are only sold during the school year (33 weeks/year)
- Cans are only sold on weekdays
- Guayaki Yerba Mate Cans are sold
- Time required to maintain AVA is 45 minutes/day
- Cost of labor is $16.50 per hour

AVA is most effective when there is continuous foot traffic going past its location. On a school campus, consistent foot traffic can be seen on weekdays during the school year. To reduce cost and increase AVA lifespan, it would be most effective to use during this time. This means AVA will be selling cans 165 days out of the year. We chose Guayaki Yerba Mate as our primary product as our market survey in Section 1.5 showed that it is the most popular caffeinated beverage amongst students at Santa Clara University. The time required to maintain AVA accounts for retrieving AVA, refilling cans, and plugging in to charge. Lastly, the cost of labor is included to account for the price of maintaining AVA.

8.2 Profitability analysis

Guayaki Yerba Mate Cans can be purchased from Whole Foods Marketplace for $2.25 per can. These cans are sold for $4.29 at Santa Clara University dining places. This gives a gain of $2.04

per can. Assuming 50% of AVA's 36 cans are sold each day on average, the annual profits are $6059.

The profit above does not consider the cost of electricity or labor. In 2022, the cost of electricity in Santa Clara was $0.06461 per kWh for large businesses. Assuming the entirety of AVA's battery gets depleted each day of usage, the cost of electricity annually would be $12.38.

Through testing, it was found that an employee would take at most 45 minutes to replace the cans and plug the battery in to charge each day. Assuming the employee is paid $16.50 per hour, the annual labor cost is $2,042. Deducting the cost of electricity and labor from the initial profits it is determined that for a 50% selling rate, the annual profits are approximately $4017.

Assuming that AVA has a lifecycle of 2000 (a conservative estimate of battery life), a lifetime profit can be calculated. With the initial purchasing price of $5000 and all previous assumptions accounted for, AVA profits would cover the initial purchase cost after 1.25 years. Additionally AVA would bring a profit of ~$44,000 over its lifespan of 2000 cycles. This shows that AVA has high potential for being economically viable.

Calculations and further analysis of AVA profitability can be found in Appendix F.

Chapter 9 - Conclusion

9.1 Overall Evaluation of Design

We were able to build a functional prototype of a roving vending machine which can power itself for approximately 8 hours a day. The refrigeration system can cool up to 36 beverages to approximately 46°F. Beverages can be selected and dispensed one at a time in under 20 seconds. The movement system can be controlled remotely and features autonomous stopping detection through the use of ultrasonic sensors. The overall cost of the prototype was approximately $2100, and could be reduced to approximately $1050 when manufactured on a large scale. The project received 1st place during presentations in the second mechanical engineering section.

9.2 Suggestions for Improvement

There was a clear shortcoming in the refrigeration system as our refrigerated temperature did not achieve the 37° F goal. Further improvements to the thermoelectric system may still be possible by testing different designs of heat sink on the cold side of the module, and testing other Peltier modules available on the market that may have better performance for this application. These are areas of further research and testing we wanted to perform but became limited by time and money in the development of our prototype. In a final, mass produced design, compression cooling would be a superior option due to its vastly higher efficiency and ability to run on a low duty cycle. The usage of a compression cooling system would have some major design implications that were not necessary when using thermoelectric cooling. A compressor system may be susceptible to damage due to vibration, would take up more space and weigh more, and would require a complete redesign of the refrigerated volume.

Further the vehicle frame could be more efficiently designed to minimize size and increase lifespan. The prototype AVA is too wide to fit through a singular doorway and can only move through double doors. This limits the spaces AVA can access and thus reduces its potential market. In a final design, dimensions of the refrigeration and dispensing system could be modified giving space for the frame to be thinner. In addition, AVA was subject to significant vibrations when driving through rougher terrain such as brick roads. This causes more damage to the components and frame and reduces the overall lifespan of the vehicle. To address this, a future design should include damped suspensions for the wheels to minimize stress on the frame and components.

9.3 Next steps

As addressed in the project scope decisions, our AVA prototype does not feature autonomous movement, nor does it have the sensor banks required to allow for fully autonomous movement. Sensors such as cameras, lidar, radar, and ultrasonic can be added to AVA to allow for autonomous movement code to be implemented. This is an essential addition to making AVA a market ready product, as manual control would be too expensive to justify the usage of a roving vending machine.

Additionally, our prototype did not feature a payment system. Going forward, a payment system needs to be added to the user interface on the top of AVA. This also requires additional code to restrict dispensing to only function after a purchase has been made. For a campus such as SCU, it would be favorable to add a payment system which accepts student meal points.

9.4 Lessons Learned

Throughout any project an engineer will go through the iterative process of design, prototype, test, and redesign. However, one thing became painfully apparent throughout our senior design project which was the importance of performing analytical calculations and designing small scale tests that yield data that can be applied to final design. A few examples of this can be seen in our design of the rotating can mechanism, the refrigeration, and the frame rotation problem.

The rotating can mechanism initially appeared as a viable option for the dispensing subsystem as testing of the prototype was successful. Our mistake was proceeding with construction of components dependent on the dispensing system before we tested the mechanism with a fully loaded track which revealed alignment issues that rendered the mechanism unusable. Had we applied a force equivalent to a fully loaded track during the prototype phase, we could have decreased a few key dimensions of the frame that would have allowed for more efficient space usage and decreased wasted funds.

The refrigeration system was successfully able to maintain beverages around 46° F, which is not a horrible temperature for a beverage but it is a shortcoming compared to standard vending machines which typically chill to 37° F. Thermoelectric cooling appeared to be a good option due to its simplicity, operation on DC power, and compact size. While tests of the individual cooling units themselves appeared very promising, the results did not scale up to operate within the finished prototype as our calculations suggested. In hindsight, it would have been beneficial to purchase and test thermoelectric coolers earlier on in the design process as the decision was based entirely on research. Unfortunately, when thermoelectric cooling was clearly struggling to get to our desired temperature, we were too far along in the process to redesign the system. Regardless of the outcome, testing different thermoelectric coolers and learning how different variables impact their performance, and comparing this to theoretical data, was a valuable learning process as mechanical engineers.

The frame rotation problem resulted from an oversight in a modified design. When fabricating the three way corner brackets, the team opted to not implement the locating tabs as it would significantly increase the time required to make them. A fairly simple analytical calculation could have shown how important these tabs are in preventing the frame members from rotating. The time required to design and fabricate the frame support brackets could have been saved by performing a simple hand calculation. This was a relatively minor issue in terms of senior project because the frame support brackets only took about an hour to design and fabricate. However, when working for a company, time is money, so spending six hours fabricating corner brackets and another hour fixing a mistake just to avoid buying $115 in corner brackets might actually cost the company closer to $300 in the engineer’s wages.

References

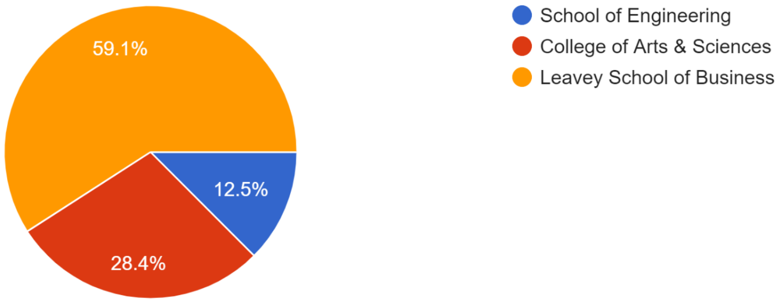
[1] Borra, P., 2011, “Helical Coil Dispenser for Vending Machines and Vending Machine Comprising Such Dispenser,” (US 8,052,010 B2).

[2] Lopez Ruiz, J. M., 2008, “Extraction Mechanism for Automatic Vending Machines,” (EP1028400B1).

[3] Albert, R., Bowen, D., Collins, B., Lewis, A., Miller, P., Percy, C., Robinson, J., Roe, W., and Watts, R., 2010, “Tandem Gate Release Mechanism for a Vending Machine,” (US 7,784,644 B2).

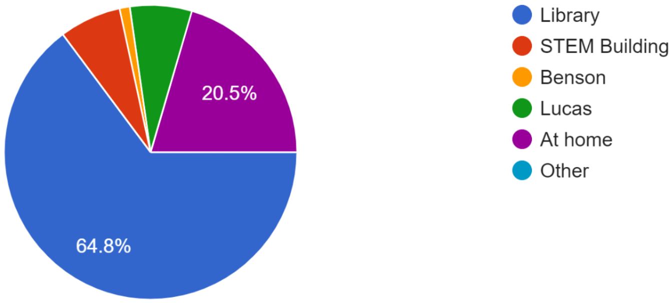
[4] 2014, *Selection Guide Fuse Characteristics, Terms and Consideration Factors*, Littelfuse.

Appendix A: Market Survey Data



Undergraduate Study

88 responses

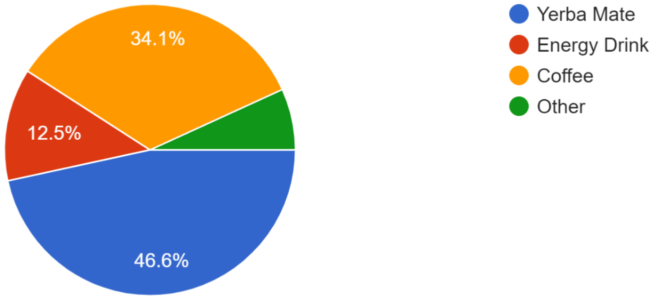


Preferred Location while studying/ doing homework

88 responses

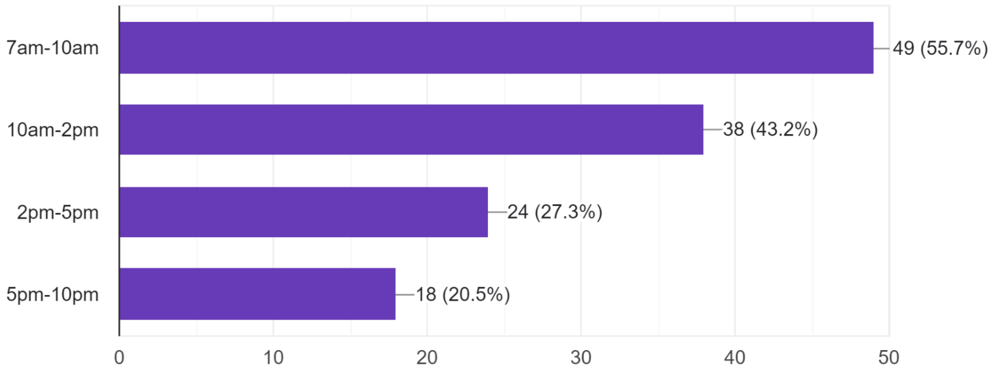
Preferred Beverage while studying

88 responses



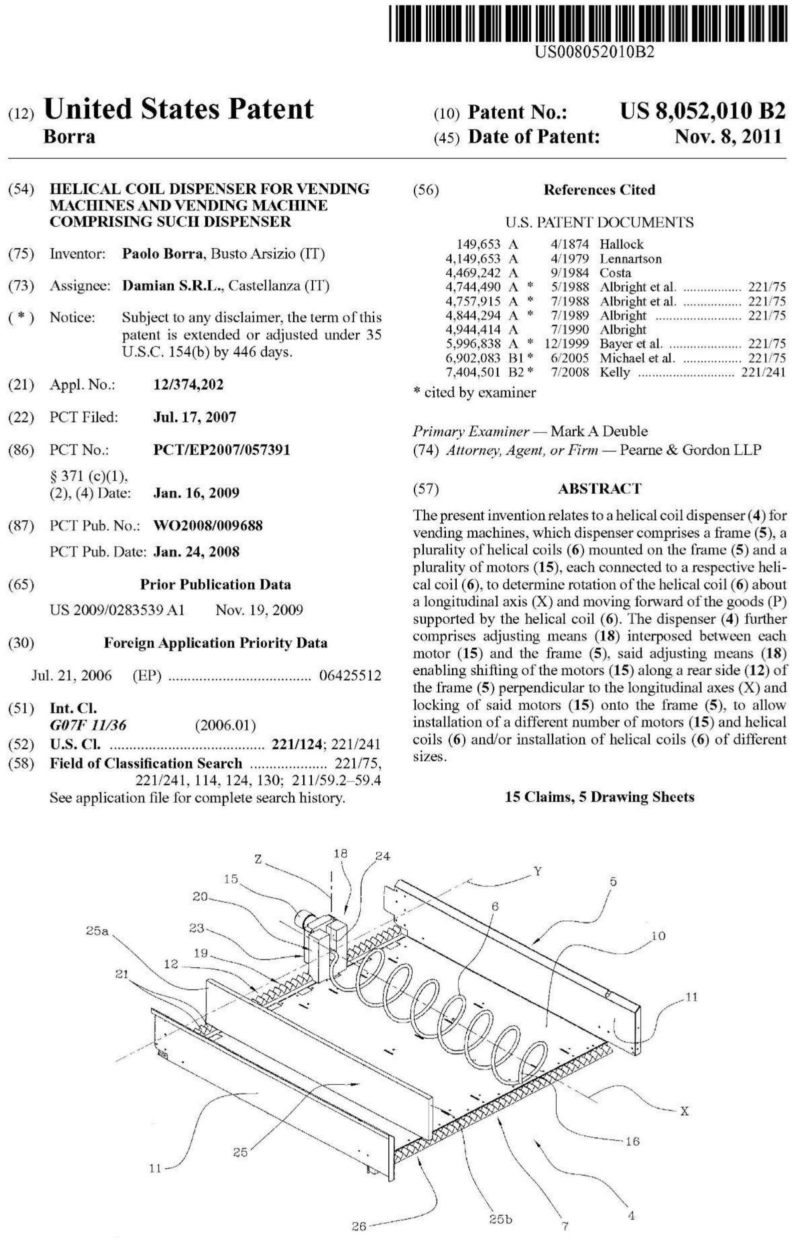
What time would you be most likely to buy a caffeinated drink?

88 responses



Appendix B: Prior Art

B1: Helical Coil Dispenser for Vending Machines [1]



US008052010B2

(12) **United States Patent**
Borra

(10) **Patent No.: US 8,052,010 B2**
(45) **Date of Patent: Nov. 8, 2011**

(54) **HELICAL COIL DISPENSER FOR VENDING MACHINES AND VENDING MACHINE COMPRISING SUCH DISPENSER**

(75) Inventor: **Paolo Borra**, Busto Arsizio (IT)

(73) Assignee: **Damian S.R.L.**, Castellanza (IT)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 446 days.

(21) Appl. No.: **12/374,202**

(22) PCT Filed: **Jul. 17, 2007**

(86) PCT No.: **PCT/EP2007/057391**
§ 371 (c)(1),
(2), (4) Date: **Jan. 16, 2009**

(87) PCT Pub. No.: **WO2008/009688**
PCT Pub. Date: **Jan. 24, 2008**

(65) **Prior Publication Data**

US 2009/0283539 A1 Nov. 19, 2009

(30) **Foreign Application Priority Data**

Jul. 21, 2006 (EP) 06425512

(51) **Int. Cl.**
G07F 11/36 (2006.01)
(52) **U.S. Cl.** **221/124**; 221/241
(58) **Field of Classification Search** 221/75, 221/241, 114, 124, 130; 211/59.2–59.4
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

149,653	A	4/1874	Hallock	
4,149,653	A	4/1979	Lennartson	
4,469,242	A	9/1984	Costa	
4,744,490	A *	5/1988	Albright et al.	221/75
4,757,915	A *	7/1988	Albright et al.	221/75
4,844,294	A *	7/1989	Albright	221/75
4,944,414	A	7/1990	Albright	
5,996,838	A *	12/1999	Bayer et al.	221/75
6,902,083	B1 *	6/2005	Michael et al.	221/75
7,404,501	B2 *	7/2008	Kelly	221/241

* cited by examiner

Primary Examiner — Mark A Deuble
(74) *Attorney, Agent, or Firm* — Pearne & Gordon LLP

(57) **ABSTRACT**

The present invention relates to a helical coil dispenser (**4**) for vending machines, which dispenser comprises a frame (**5**), a plurality of helical coils (**6**) mounted on the frame (**5**) and a plurality of motors (**15**), each connected to a respective helical coil (**6**), to determine rotation of the helical coil (**6**) about a longitudinal axis (X) and moving forward of the goods (P) supported by the helical coil (**6**). The dispenser (**4**) further comprises adjusting means (**18**) interposed between each motor (**15**) and the frame (**5**), said adjusting means (**18**) enabling shifting of the motors (**15**) along a rear side (**12**) of the frame (**5**) perpendicular to the longitudinal axes (X) and locking of said motors (**15**) onto the frame (**5**), to allow installation of a different number of motors (**15**) and helical coils (**6**) and/or installation of helical coils (**6**) of different sizes.

15 Claims, 5 Drawing Sheets

B2: *Extraction Mechanism for Automatic Vending Machines* [2]

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 019 393**
A1

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: **80301421.6**

(22) Date of filing: **30.04.80**

(51) Int. Cl.^{3}: **G 07 F 11/60**

(30) Priority: **02.05.79 US 35421**
14.04.80 US 139991

(43) Date of publication of application:
26.11.80 Bulletin 80/24

(84) Designated Contracting States:
DE GB NL

(71) Applicant: **D. O. V. E. EQUIPMENT CORPORATION**
P.O. Box 196
Winfield, Missouri 63389(US)

(72) Inventor: **Boettcher, William C.**
R.R.1,P.O.Box 95
Foley Missouri 63347(US)

(74) Representative: **Baillie, Iain Cameron**
c/o Ladas & Parry Blumenstrasse 48
D-8000 München 2(DE)

(54) **Vending machine item discharge unit.**

(57) This invention involves a vending machine having helix discharge units in which the rearmost convolution of the helix is retained by a clip (39) and held off the floor of the unit to reduce friction and prevent excessive side-to-side movement of the rear of the helix. The units are used to store and dispense packaged objects such as chip products, candy, mints, chewing gum, candy bars, cigarettes, cigars, etc. The unit preferably utilizes a rotatable helix dispensing spindle (23) having a central divider (24) within the convolutions of the helix which can be adjusted by rotation from horizontal to vertical and which divides the helix into separate side-by-side compartments which can be varied in any size to accomodate different size packages. The size of the compartments is determined by the position of the center divider (24), the two compartments being largest when the divider is vertical and smallest when it is horizontal.

EP 0 019 393 A1

./...

Croydon Printing Company Ltd.

B3: *Tandem Gate Release Mechanism for a Vending Machine* [3]

US007784644B2

(12) **United States Patent**
Albert et al.

(10) **Patent No.: US 7,784,644 B2**
(45) **Date of Patent: Aug. 31, 2010**

(54) **TANDEM GATE RELEASE MECHANISM FOR A VENDING MACHINE**

(75) Inventors: **Richard T. Albert**, Aiken, SC (US); **Dan Bowen**, Aiken, SC (US); **Bryan Alan Collins**, New Ellenton, SC (US); **Aron Phillip Lewis**, Aiken, SC (US); **Paul Miller**, Aiken, SC (US); **Charles Wayne Percy**, Aiken, SC (US); **John Robinson**, Aiken, SC (US); **William E. Roe**, Sanford, NC (US); **Russell Watts**, Aiken, SC (US)

(73) Assignee: **Dixie-Narco, Inc.**, Williston, SC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 647 days.

(21) Appl. No.: **11/249,376**

(22) Filed: **Oct. 14, 2005**

(65) **Prior Publication Data**

US 2007/0084877 A1 Apr. 19, 2007

(51) **Int. Cl.**
G07F 11/22 (2006.01)
B65G 59/00 (2006.01)
G07F 11/00 (2006.01)

(52) **U.S. Cl.** **221/274**; 221/226; 221/7; 221/124; 221/298; 221/279; 221/289; 221/299; 221/301; 221/250; 221/270; 221/251; 221/268; 221/133

(58) **Field of Classification Search** 221/274, 221/250, 270, 226, 298, 279, 289, 299, 301, 221/7, 92, 124, 133, 251, 268
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,423,828	A	1/1984	Tanaka et al.	
5,497,905	A *	3/1996	Vogelpohl et al.	221/226
5,511,688	A	4/1996	Duncan et al.	
5,651,476	A	7/1997	Percy et al.	
5,695,074	A	12/1997	Wiese	
5,799,823	A	9/1998	Feltrin	
6,012,604	A	1/2000	Takahashi et al.	
6,230,930	B1	5/2001	Sorensen et al.	
6,241,121	B1	6/2001	Yasaka	
6,253,954	B1	7/2001	Yasaka	
6,328,180	B1	12/2001	Sorensen et al.	

(Continued)

FOREIGN PATENT DOCUMENTS

EP	343505 A2	11/1989

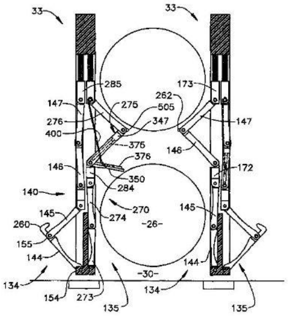
(Continued)

Primary Examiner—Gene O. Crawford
Assistant Examiner—Rakesh Kumar

(57) **ABSTRACT**

A vending machine includes first and second integrated dispensing systems mounted at front portions of adjacent product shelf dividers establishing at least first, second and third product queues. Each of the first and second dispensing systems includes first and second release mechanisms having a plurality of hinged plates supported by a frame. The plurality of hinged plates are selectively shifted into and out of corresponding ones of the first, second and third product queues, such that each product queue has associated therewith two opposing release mechanisms. Preferably, at least one of the first and second release mechanisms for each dispensing system includes a queue spacing member which is mounted to one of the hinged plates and projects into the product queue to establish a desired spacing between the release mechanisms.

20 Claims, 13 Drawing Sheets



Appendix C: Budget

Table C1: Expense Sheet

Expense Sheet					
Item	Source	Subsystem	Quantity	Price Per Item	Total
Bipolar Stepper Motor Driver Board	Amazon	Dispensing and Payment	1	$9.69	$10.59
5mm Flange Coupling Connector	Amazon	Dispensing and Payment	1	$7.99	$8.73
Momentary Switches	Amazon	Dispensing and Payment	1	$14.99	$16.38
Linear Guide Screw	Amazon	Dispensing and Payment	1	$182.00	$198.84
Nema 17HS08-1004S	Amazon	Dispensing and Payment	1	$11.99	$13.10
5 ft Flow Rail Frame	McMaster Carr	Dispensing and Payment	1	$17.46	$19.08
9/16 in Flow Rail Wheels	McMaster Carr	Dispensing and Payment	1	$12.76	$13.94
7/8 in Flow Rail Spacers	McMaster Carr	Dispensing and Payment	2	$4.22	$9.22
1" 1/4-20 Socket Head Screw	McMaster-Carr	Dispensing and Payment	1	$11.19	$12.23
0.5" 1/4-20 Rounded Head Screw	McMaster-Carr	Dispensing and Payment	1	$14.88	$16.26
10mm M4 Flat Head Screws	Home Depot	Dispensing and Payment	2	$0.96	$2.10
Dispensing Gate Hinge	Home Depot	Dispensing and Payment	2	$15.99	$34.94
Release Mechanism Lead Screw	Amazon	Dispensing and Payment	2	$11.09	$24.23
10mm Flange Coupling Connector	Amazon	GNC	1	$9.49	$10.37
Makermotor 12V DC 100 RPM Motor	Amazon	GNC	2	$76.00	$166.06
Raspberry Pi 4 - 2 GB RAM	Amazon	GNC	1	$108.95	$119.03
USB to USB cable	Amazon	GNC	1	$8.99	$9.82
USB-C Power Adapter	Amazon	GNC	1	$7.99	$8.73

Item	**Source**	**Subsystem**	**Quantity**	**Price Per Item**	**Total**
Ultrasonic Proximity Sensors (5 unit pack)	Amazon	GNC	2	$12.99	$28.38
Micro SD Card	Amazon	GNC	1	$9.99	$10.91
10A H-Bridge	Amazon	GNC	1	$26.90	$29.39
12V 100 Ah Lifepo4 Battery	Amazon	Power	1	$339.00	$370.36
12 Way Fuse Block	Amazon	Power	1	$15.99	$17.47
6 Terminal Bus Bar	Amazon	Power	2	$12.95	$28.30
Battery Holding Tray	Amazon	Power	1	$7.99	$8.73
12V to 5V Transformer	Amazon	Power	1	$11.99	$13.10
18 AWG wire	Amazon	Power	1	$16.95	$18.52
Relay 4 In-line	Amazon	Power	1	$7.39	$8.07
12 AWG wire	Amazon	Power	1	$17.99	$19.65
6 AWG Wire	Amazon	Power	1	$31.71	$34.64
MC-4 Connector Wires (Solar Panel Wires)	Amazon	Power	1	$14.69	$16.05
100 Watt 12V Monocrystalline Solar Panel	Amazon	Power	1	$119.00	$130.01
12V 10A Solar Charge Controller	Amazon	Power	1	$16.99	$18.56
Battery Cut Off Switch	Amazon	Power	1	$14.97	$16.35
72 Watt Thermoelectric Cooler	Amazon	Refrigeration	3	$53.49	$175.31
Adjustable DC Power Supply	Amazon	Refrigeration	1	74.99	$81.93
Dual TE Cooler	Amazon	Refrigeration	1	$42.09	$45.98
1/4-20 Nuts (100 pack)	McMaster Carr	Refrigeration	2	$5.56	$12.15
1/4" Rubber Washers (100 Pack)	McMaster Carr	Refrigeration	1	$10.81	$11.81
1/4"-20 x 2.5" Socket Head Screw	McMaster Carr	Refrigeration	2	$12.58	$27.49
1/4" Washers (100 Pack)	McMaster Carr	Refrigeration	2	$3.47	$7.58
1.5" Insulation Board	Home Depot	Refrigeration	1	$26.11	$28.53
3/16" Hardboard	Home Depot	Refrigeration	1	$25.98	$28.38
Spray Adhesive	Home Depot	Refrigeration	1	$14.98	$16.37

DeWalt Knife	Home Depot	Refrigeration	1	$8.97	$9.80
McMaster Carr Shipping		Refrigeration	1	$65.00	$71.01
Item	**Source**	**Subsystem**	**Quantity**	**Price Per Item**	**Total**
3-Way Outside Corner Bracket	McMaster Carr	Structural	8	$0.00	$0.00
5 inch Polyurethane Swivel Casters	Harbor Freight	Structural	2	$7.99	$17.46
T-Slotted Framing - 4ft Lengths	McMaster Carr	Structural	4	$22.87	$99.94
T-Slotted Framing - 3ft Lengths	McMaster Carr	Structural	6	$14.54	$95.31
T-Slotted Framing - 2ft Lengths	McMaster Carr	Structural	2	$10.72	$23.42
Corner Brace- Closed Gusset	McMaster Carr	Structural	10	$6.11	$66.75
5/16"-18 Thread Size, 1/2" Long	McMaster-Carr	Structural	1	$8.02	$8.76
10 Oz. Fiberglass Fabric	Fibreglast	Structural	4	$12.95	$56.59
Anti Fray Liquid	Fibreglast	Structural	1	$6.95	$7.59
Polyester Molding Resin	Fibreglast	Structural	1	$79.95	$87.35
PVA Release Film	Fibreglast	Structural	1	$10.95	$11.96
Bushings	McMaster-Carr	Dispensing and Payment	30	$0.61	$19.99
Item Total					$2,453.59
Budget Remaining					$46.41

Appendix D: Selection Matrices

D1: Dispensing Subsystem

Storage Tracks				
Criteria	Importance	Zig-Zag	Spiral	Lift
Convenient Dispensing Location	1	1	-1	0
Effective Use of Refrigerated Volume	2	-1	0	1
Dispensing Complexity	3	0	1	-1
Height Requirement	4	0	1	-1
Integration Complexity	5	1	-1	0
Total		4	1	-5

Release Mechanism			
Criteria	Importance	Rotation	Linkage
Cost	1	1	0
Integration Complexity	2	0	1
Reliability	3	0	1
Maintain Seal on Refrigerated Volume	4	1	0
Total		5	5

D2: Refrigeration Subsystem

Subsystem: Refrigeration				
Criteria	Importance	TE Cooling Unit	Modified Portable Cooler	Extract Parts from Portable Cooler
Cost	2	1	0	-1
Refrigerated Volume	4	0	1	1
Integration Complexity	3	1	0	-1
Power Consumption	4	0	1	1
Weight	2	1	-1	1
Total		7	6	5

D3: Structural Integration Subsystem

Structural Subsystem: Frame Material		
Material Option	Pros	Cons
Welded steel frame	• Easy to weld - MIG, TIG, or Stick • Easy to find - Local metal suppliers or online • Price - Relatively inexpensive when compared to aluminum • Strength	• Heavy • Low adaptability - Mounting locations are fairly final
Welded aluminum frame	• Easy to find - Local metal suppliers or online Price - Moderately priced • Strength • Lightweight • Easy to cut - can be cut using most woodworking tools	• Hard to weld - Requires lots of practice with tig welding • Low adaptability - Mounting locations are fairly final
Extruded T-Slotted Aluminum	• Very Adaptable - Slots allow for nearly endless adjustment. No welding means mounting locations and frame dimensions are easy to change • Lightweight • Easy to cut - Can be cut using most woodworking tools	• Expensive - 2x more expensive per linear foot • Strength • Difficult to find - Mostly online, not carried by most local metal suppliers
Glued and bolted wood frame	• Easy to find - All hardware stores and lumber yards • Price - Very Inexpensive • Easy to cut and assemble • Medium adaptability - Mounting locations are easy to change and components can be replaced	• Not dimensionally stable - prone to warping, shrinkage, and expansion • Especially susceptible when exposed to water • Not Isotropic - difficult to analyze • Susceptible to deterioration over time

Structural Subsystem: Shell Material		
Material Option	Pros	Cons
Wood and Epoxy Resin	• Easy to find - Available at all hardware stores and lumber yards • Price - Very Inexpensive • Easy to cut and assemble • Aesthetically appealing - Natural wood grain or painted	• Not dimensionally stable - prone to warping, shrinkage, and expansion • Especially susceptible when exposed to water • Difficult to waterproof • Difficult to form to complex shapes • Heavy
Acrylic / Polycarbonate	• Clear - Allows for easy presentation and diagnostic (Acrylic / Polycarbonate only) • Easy to find - Available online and specialty stores in the area. • Stores will custom cut any part	• Expensive - 3x more expensive than equivalent sheet of plywood • Difficult to waterproof - Requires rubber seals at every seam
Fiberglass	• Price - Very Inexpensive • Can be molded to almost any shape • Easy to find at hardware stores, auto part stores, and online • Aesthetics - wide range of possible designs and paint jobs • Waterproof - One completely sealed shell can block all water	• Difficult to work with - Glass shards and fumes from epoxy • Requires mold - can be provided by styrofoam insulation

Structural Subsystem: Frame Material					
Criteria	Importance	Steel Square	Aluminum Square	80/20 Extruded Aluminum	Wood
Rigidity	4	3	3	2	1
Cost	3	2	2	1	3
Subsystem Mounting	5	1	1	3	2
Durability	3	3	3	3	2
Water Resistance	2	2	3	3	1
Lightweight	1	2	3	3	3
Aesthetics	1	2	2	2	3
Total		40	43	46	37

Structural Subsystem: Shell Material				
Criteria	Importance	Wood and Epoxy Resin	Acrylic / Polycarbonate / Aluminum	Fiberglass
Formability	4	2	1	3
Cost	3	3	1	3
Ease of Assembly	2	2	3	1
Durability	3	3	3	2
Water Resistance	5	2	2	3
Lightweight	1	3	2	3
Aesthetics	2	3	3	3
Total		49	40	53

D4: Power Integration Subsystem

Power: Rough Battery Selection						
Criteria	Importance	Lithium Ion	Nickel Metal Hydride	Flooded Lead Acid	Gel Battery	AGM (Absorbant Gass Mat)
Cost	3	-1	0	1	0	0
Energy Density	1	1	1	0	0	0
Depth of Discharge	3	1	1	1	0	1
Discharge Rate	2	1	0	0	0	-1
Safety	5	1	1	-1	1	0
Maintenance	2	1	1	-1	0	1
Lifespan	3	1	0	1	1	0
Total		13	11	2	8	3

Power: Battery Selection			
Criteria	Importance	Nickel Metal Hydride	Lithium Ion
Cost	3	3	1
Energy Density	1	4	5
Depth of Discharge	3	5	5
Discharge Rate	2	3	5
Safety	5	5	5
Maintenance	2	5	5
Lifespan	3	4	5
Total		81	83

Appendix E: Software

E1: Movement and Dispensing

```
// Movement and Dispensing
#include <Servo.h>
#include <ServoInput.h>
#include <AccelStepper.h>

AccelStepper stepper(AccelStepper::DRIVER, 35, 34);
float prox; // Proximity Sensor

#define dirL 6 // Left Motor Control Pins
#define pwmL 5
#define dirR 12 // Right Motor Control Pins
#define pwmR 11

#define FRONT_SIGNAL 50
#define LEFT_SIGNAL 51
#define RIGHT_SIGNAL 52

#define EN1 26
#define IN1 28
#define IN2 31
#define BDir 44
#define BStop 46

#define servo_pin 40

// For Dispensing
Servo myservo;
int count;
int button_1_press = 0;
int button_2_press = 0;
int button_3_press = 0;

// For Movement
const int deadzone = 20; // Area where we count it as zero
ServoInputPin<2> ch1(1285,1732); // initializes input PWM signals
ServoInputPin<3> ch2(960,1960);



void setup() {
  // Lead Screw Raising Pins
  stepper.setMaxSpeed(6000);
  stepper.setAcceleration(550);
  pinMode(A1,INPUT);

  // Dispensing Pins
  myservo.attach(servo_pin);
  pinMode(EN1, OUTPUT);
  pinMode(IN1, OUTPUT);
  pinMode(IN2, OUTPUT);
  pinMode(BDir, INPUT);
  pinMode(BStop, INPUT);

  // Sensor Pins
  pinMode(FRONT_SIGNAL,INPUT);
  pinMode(LEFT_SIGNAL,INPUT);
  pinMode(RIGHT_SIGNAL,INPUT);
  pinMode(19,INPUT);
  pinMode(20,INPUT);
  pinMode(21,INPUT);
  attachInterrupt(digitalPinToInterrupt(19),DISPENSING_1_STOP,RISING);
  attachInterrupt(digitalPinToInterrupt(20),DISPENSING_2_STOP,RISING);
  attachInterrupt(digitalPinToInterrupt(21),DISPENSING_3_STOP,RISING);

  // Movement Pins
  pinMode(pwmL, OUTPUT);
  pinMode(pwmR, OUTPUT);
  pinMode(dirL, OUTPUT);
  pinMode(dirR, OUTPUT);
}
```

```
void loop() {
  MOVEMENT();
  if (button_1_press > 0){
    analogWrite(pwmL,0);
    analogWrite(pwmR,0);
    delay(50);
    DISPENSING();

    button_1_press = 0;
  }
  if (button_2_press > 0){
    analogWrite(pwmL,0);
    analogWrite(pwmR,0);
    delay(50);
    button_2_press = 0;
  }
  if (button_3_press > 0){
    analogWrite(pwmL,0);
    analogWrite(pwmR,0);
    delay(50);
    DISPENSING();
    button_3_press = 0;
  }
}

void DISPENSING_1_STOP(){
  button_1_press++;
}

void DISPENSING_2_STOP(){
  button_2_press++;
}

void DISPENSING_3_STOP(){
  button_3_press++;
}



void MOVEMENT() {
  int Lspeed;
  int Rspeed;
  float x = (ch1.getPercent()*2000);  // get percentage of servo (0 - 2000)
  float y = (ch2.getPercent()*2000);  // get angle of servo (0 - 2000)
  float yMod = (ch2.getPercent());  // For y on 0->1 scale (see turning for usage)

  x = map(x, 0, 2000, -255, 255);
  y = map(y, 0, 2000, -255, 255);

// DIRECTIONAL CONTROL ---------------
  if (y>(deadzone)){
    digitalWrite(dirL, LOW); // Makes positive y a forward direction (don't know if its high or low)
    digitalWrite(dirR, LOW);
    Lspeed = y;
    Rspeed = y;
  }
  else if (y<(-deadzone)){
    digitalWrite(dirL, HIGH); // Makes negative y a backward direction (don't know if its high or low)
    digitalWrite(dirR, HIGH);
    Lspeed = abs(y);
    Rspeed = abs(y);
  }
  else {
    Lspeed = 0;
    Rspeed = 0;
  }
```

```
// PWM/TURNING CONTROL ---------------
if(abs(y)>(deadzone)){ // Makes it so turning alone won't accelerate
  if(x>(deadzone)){       // For turning Right
    Lspeed = Lspeed+x*yMod;
    Rspeed = Rspeed-x*yMod;
    if (Lspeed>255){Lspeed = 255;}  // Upper limit
    if (Rspeed<0){Rspeed = 0;}      // Lower limit
  }
  if(x<(-deadzone)){       // For turning Left
    Lspeed = Lspeed+x*yMod;
    Rspeed = Rspeed-x*yMod;
    if (Rspeed>255){Rspeed = 255;}    // Upper limit
    if (Lspeed<0){Lspeed = 0;}        // Lower limit
  }
}

analogWrite(pwmL, Lspeed);
analogWrite(pwmR, Rspeed);

delay(50);

if ((digitalRead(FRONT_SIGNAL) == HIGH) && (y > deadzone)){ // forward movement stop
    analogWrite(pwmL,0);
    analogWrite(pwmR,0);
    delay(1000);}
if ((digitalRead(LEFT_SIGNAL) == HIGH) && (y > deadzone) && (x < (-deadzone))){ // left turn stop
    analogWrite(pwmL,0);
    analogWrite(pwmR,0);
    delay(1000);}
if ((digitalRead(RIGHT_SIGNAL) == HIGH) && (y > deadzone) && (x > deadzone)){ // right turn stop
    analogWrite(pwmL,0);
    analogWrite(pwmR,0);
    delay(1000);}
}
```

```
void DISPENSING() {
  digitalWrite(IN1,HIGH);
  digitalWrite(IN2,LOW);
  digitalWrite(EN1,HIGH);
  delay(250);

  while(digitalRead(BDir)==HIGH){     // runs to release can until hits stop button
    delay(100);
      }
    myservo.write(0);                 // opens servo door
    delay(1000);                      // delay allows can to fully pop out
    digitalWrite(EN1,LOW);            // stops can release mechanism

    delay(2000);        // lil extra time for can to fall out
    myservo.write(150);               // closes door

    leadScrew();

    digitalWrite(IN1,LOW);
    digitalWrite(IN2,HIGH);
    digitalWrite(EN1,HIGH);
    delay(250);

  while(digitalRead(BStop)==HIGH){
    delay(100);
    }
    digitalWrite(EN1,LOW);

}
```

```
void leadScrew(){
  prox = analogRead(A1);      // Proximity sensor data

  while(prox>500){          //waits for can to drop into cup
    prox = analogRead(A1);
    }

  stepper.moveTo(16100);      // sets distance (dont alter)
  while(stepper.distanceToGo()!=0){
    stepper.run(); }       // allows motor to run

  while(prox<550){          // waits for can to be removed from cup
    prox = analogRead(A1);
    delay(50);
    }

  stepper.moveTo(0);
  while(stepper.distanceToGo()!=0){
    stepper.run(); }       // allows motor to run

}
```

E2: Autonomous Sensing and Stopping

```
// Autonomous Stopping and Sensing
#include <ServoInput.h>
#include <NewPing.h>
#define SONAR_NUM     11 // Number or sensors.
#define MAX_DISTANCE 45 // Max distance in cm.
#define PING_INTERVAL 33 // Milliseconds between pings.

#define FRONT_SENSING_SIGNAL 48
#define LEFT_SENSING_SIGNAL 49
#define RIGHT_SENSING_SIGNAL 52

unsigned long pingTimer[SONAR_NUM]; // When each pings.
unsigned int cm[SONAR_NUM]; // Store ping distances.
uint8_t currentSensor = 0; // Which sensor is active.

NewPing sonar[SONAR_NUM] = { // Sensor object array.(Order: Left 1-3, Front 1-5, Right 1-3)
  NewPing(23, 22, MAX_DISTANCE),
  NewPing(25, 24, MAX_DISTANCE),
  NewPing(27, 26, MAX_DISTANCE),
  NewPing(29, 28, MAX_DISTANCE),
  NewPing(31, 30, MAX_DISTANCE),
  NewPing(33, 32, MAX_DISTANCE),
  NewPing(35, 34, MAX_DISTANCE),
  NewPing(37, 36, MAX_DISTANCE),
  NewPing(39, 38, MAX_DISTANCE),
  NewPing(41, 40, MAX_DISTANCE),
  NewPing(43, 42, MAX_DISTANCE)
  };
```

```
void setup() {
  Serial.begin(115200);
  pinMode(FRONT_SENSING_SIGNAL,OUTPUT);
  pinMode(LEFT_SENSING_SIGNAL,OUTPUT);
  pinMode(RIGHT_SENSING_SIGNAL,OUTPUT);

  digitalWrite(FRONT_SENSING_SIGNAL,LOW);
  digitalWrite(LEFT_SENSING_SIGNAL,LOW);
  digitalWrite(RIGHT_SENSING_SIGNAL,LOW);

  pingTimer[0] = millis() + 75; // First ping start in ms.
  for (uint8_t i = 1; i < SONAR_NUM; i++)
    pingTimer[i] = pingTimer[i - 1] + PING_INTERVAL;
}

void loop() {
  for (uint8_t i = 0; i < SONAR_NUM; i++) {
    if (millis() >= pingTimer[i]) {
      pingTimer[i] += PING_INTERVAL * SONAR_NUM;
      if (i == 0 && currentSensor == SONAR_NUM - 1)
        oneSensorCycle(); // Do something with results.
      sonar[currentSensor].timer_stop();
      currentSensor = i;
      cm[currentSensor] = 0;
      sonar[currentSensor].ping_timer(echoCheck);
    }
  }
}



void echoCheck() { // If ping echo, set distance to array.
  if (sonar[currentSensor].check_timer())
    cm[currentSensor] = sonar[currentSensor].ping_result / US_ROUNDTRIP_CM;
}

void oneSensorCycle() { // Do something with the results.
  for (uint8_t i = 0; i < SONAR_NUM; i++) {
    Serial.print(i);
    Serial.print("=");
    Serial.print(cm[i]);
    Serial.print("cm ");
    if (((cm[0] > 0) && (cm[0] < MAX_DISTANCE))
    || ((cm[1]> 0) && (cm[1] < MAX_DISTANCE))
    || ((cm[2]> 0) && (cm[2] < MAX_DISTANCE))){
      digitalWrite(LEFT_SENSING_SIGNAL, HIGH);
      delay(50);
      digitalWrite(LEFT_SENSING_SIGNAL, LOW);
    }
    if (((cm[3] > 0) && (cm[3] < MAX_DISTANCE))
    || ((cm[4] > 0) && (cm[4] < MAX_DISTANCE))
    || ((cm[5] > 0) && (cm[5] < MAX_DISTANCE))
    || ((cm[6] > 0) && (cm[6] < MAX_DISTANCE))
    || ((cm[7] > 0) && (cm[7] < MAX_DISTANCE))){
      digitalWrite(FRONT_SENSING_SIGNAL, HIGH);
      delay(50);
      digitalWrite(FRONT_SENSING_SIGNAL, LOW);
    }
    if (((cm[8] > 0) && (cm[8] < MAX_DISTANCE))
    || ((cm[9] > 0) && (cm[9] < MAX_DISTANCE))
    || ((cm[10] > 0) && (cm[10] < MAX_DISTANCE))){
      digitalWrite(RIGHT_SENSING_SIGNAL, HIGH);
      delay(50);
      digitalWrite(RIGHT_SENSING_SIGNAL, LOW);}
  }
  Serial.println();
}
```

Appendix F: Business Considerations and Calculations

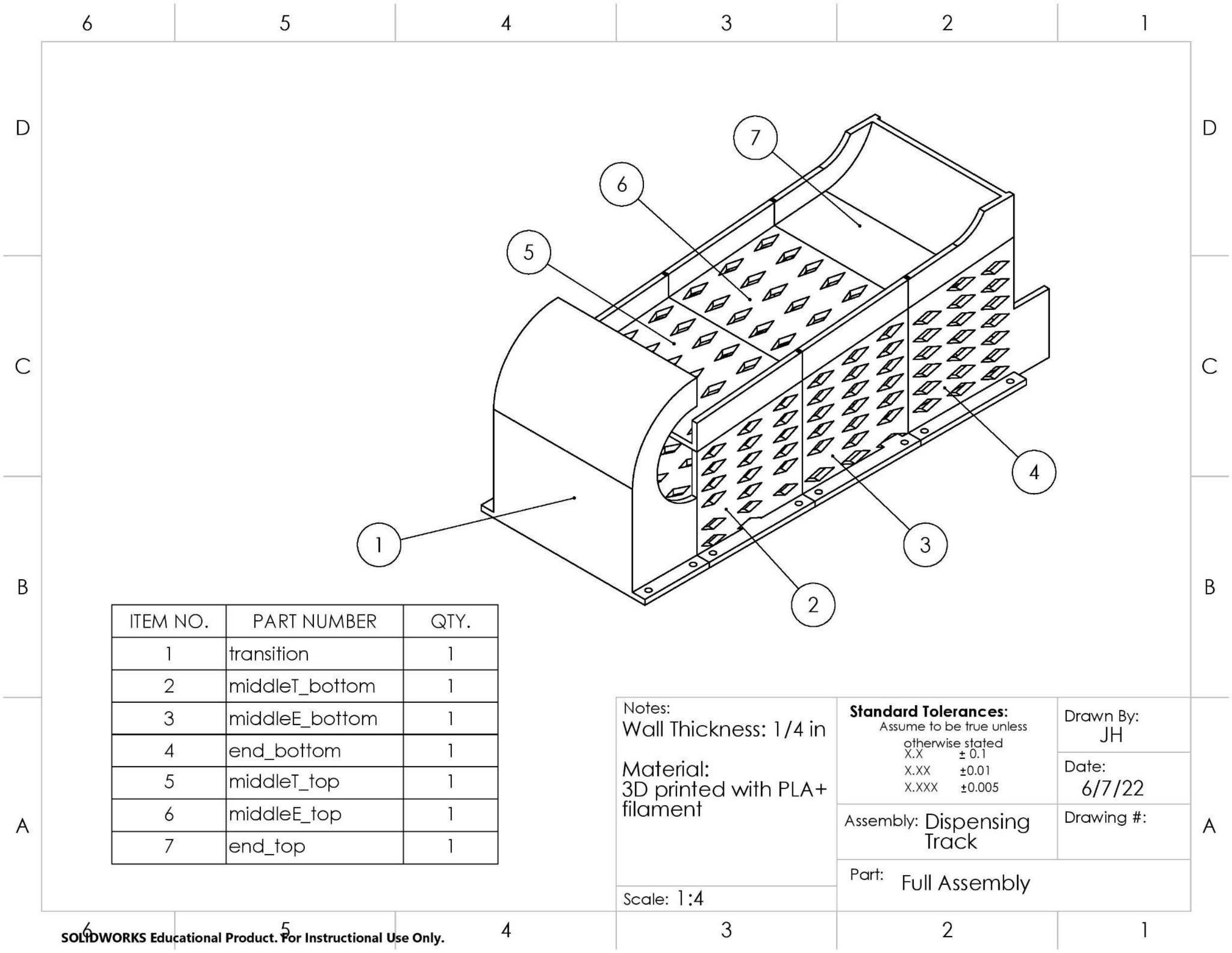
Purchase Cost:	$2.25					
Selling Price:	$4.29					
Profit Per can:	$2.04					
Cans that fit in AVA:	36					
Assumptions:						
Days per Week:	5	5	5	5	5	5
Weeks per Year:	33	33	33	33	33	33
Total Days Sold	165	165	165	165	165	165
Percent of cans sold/day:	**100%**	**75%**	**60%**	**50%**	**40%**	**30%**
Annual Profits from Cans:	$12,117.60	$9,088.20	$7,270.56	$6,058.80	$4,847.04	$3,635.28
Cost of Electricity:	$10.66	$10.66	$10.66	$10.66	$10.66	$10.66
Cost of Labor:	$2,041.88	$2,041.88	$2,041.88	$2,041.88	$2,041.88	$2,041.88
Total Annual Profits:	$10,075.67	$7,046.27	$5,228.63	$4,016.87	$2,805.11	$1,593.35
Assume: Cost to buy AVA is	$5,000.00					
Years until breaking even:	0.50	0.71	0.96	1.24	1.78	3.14
Assume: lifecycle is	2000					
Years until failure:	12.12121212					
Profits after 5 years:	$45,378.36	$30,231.36	$21,143.16	$15,084.36	$9,025.56	$2,966.76
Profits after 10 years:	$95,756.71	$65,462.71	$47,286.31	$35,168.71	$23,051.11	$10,933.51
Profits until failure:	$117,129.35	$80,409.35	$58,377.35	$43,689.35	$29,001.35	$14,313.35

Expenses:							

Electricity Cost:	Full battery Charge (kWh)	1.2	kWh	**Man Power Cost:**			
	Cost of Electricity in Santa Clara:	$0.05384	$/kWh		Time required per day:	0.75	hours
					Cost of Labor:	$16.50	per hour
	Electricity Cost per day:	$0.06461			Labor cost per day:	$12.38	
	Electricity Cost per Year:	$10.66			Labor cost per Year:	$2,041.88	

Appendix G: Part Drawings

G1: Dispensing Track Drawings



ITEM NO.	PART NUMBER	QTY.
1	transition	1
2	middleT_bottom	1
3	middleE_bottom	1
4	end_bottom	1
5	middleT_top	1
6	middleE_top	1
7	end_top	1

Notes:
Wall Thickness: 1/4 in

Material:
3D printed with PLA+
filament

Scale: 1:4

Standard Tolerances:
Assume to be true unless
otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

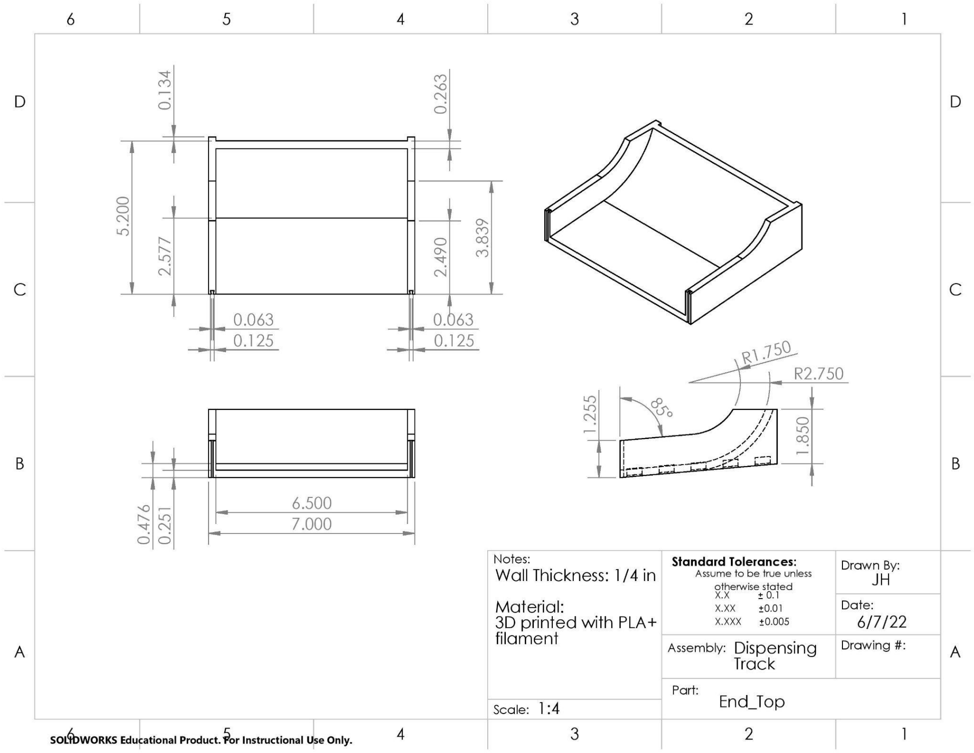
Assembly: Dispensing Track

Part: Full Assembly

Drawn By: JH

Date: 6/7/22

Drawing #:



Notes:
Wall Thickness: 1/4 in

Material:
3D printed with PLA+ filament

Scale: 1:4

Standard Tolerances:
Assume to be true unless otherwise stated

X.X	± 0.1
X.XX	±0.01
X.XXX	±0.005

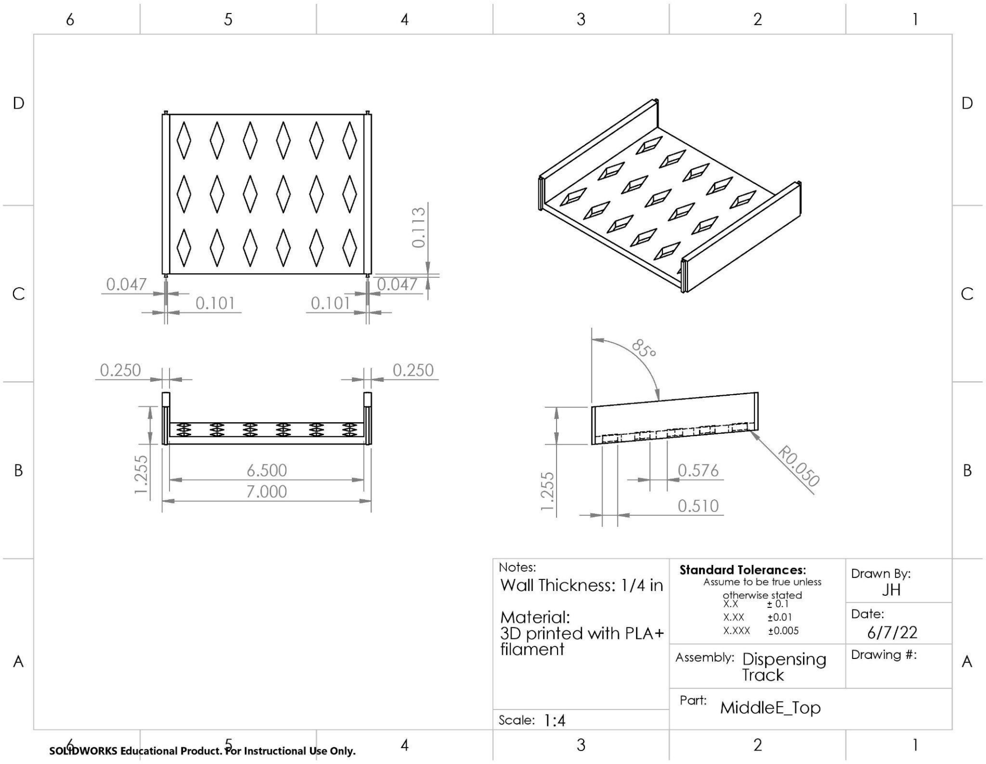
Assembly: Dispensing Track

Part: End_Top

Drawn By: JH

Date: 6/7/22

Drawing #:



Notes:
Wall Thickness: 1/4 in

Material:
3D printed with PLA+ filament

Scale: 1:4

Standard Tolerances:
Assume to be true unless otherwise stated

X.X	± 0.1
X.XX	±0.01
X.XXX	±0.005

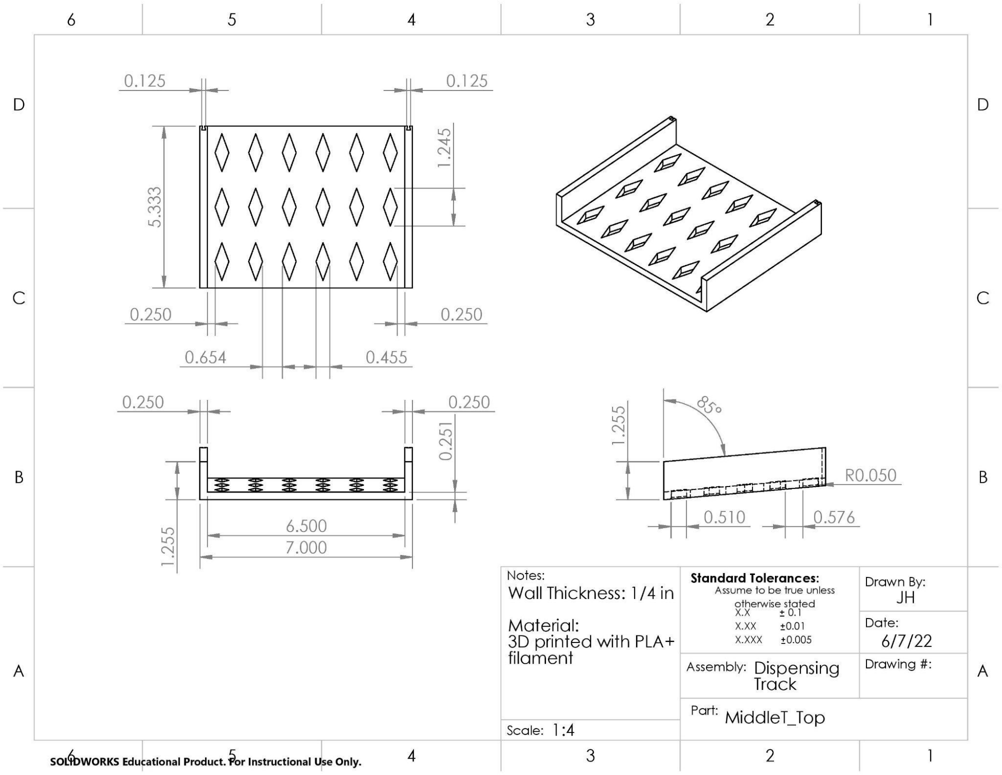
Assembly: Dispensing Track

Part: MiddleE_Top

Drawn By: JH

Date: 6/7/22

Drawing #:



Notes:
Wall Thickness: 1/4 in

Material:
3D printed with PLA+ filament

Scale: 1:4

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

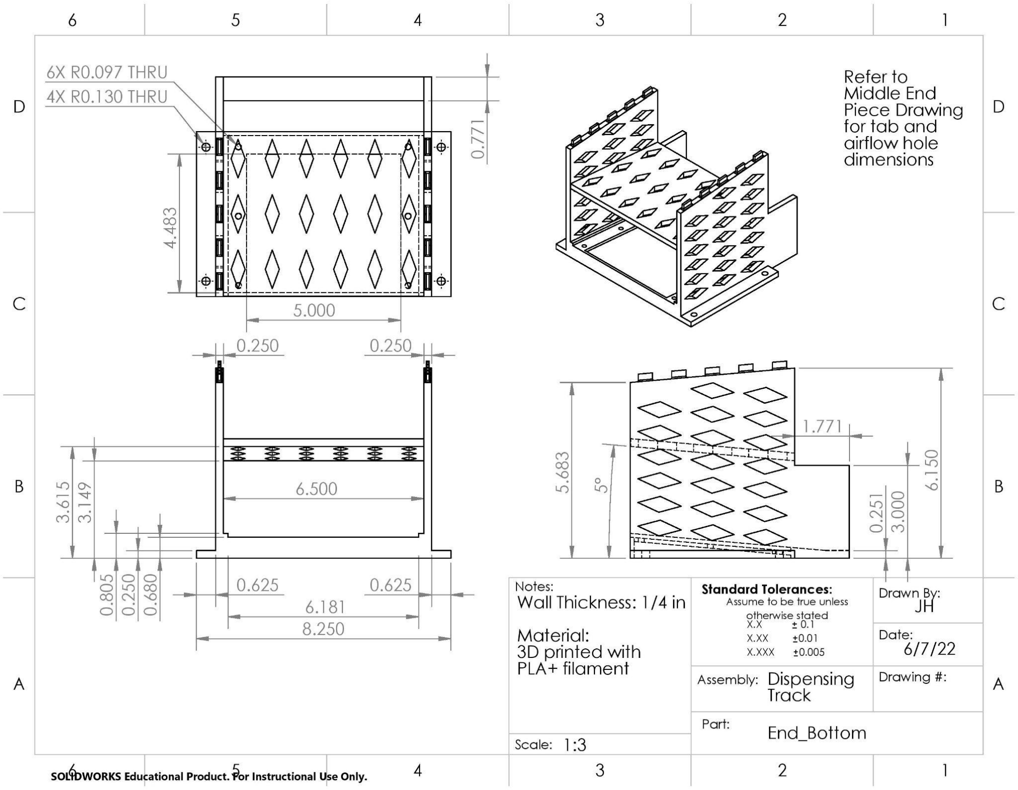
Assembly: Dispensing Track

Part: MiddleT_Top

Drawn By: JH

Date: 6/7/22

Drawing #:



Refer to Middle End Piece Drawing for tab and airflow hole dimensions

Notes:
Wall Thickness: 1/4 in

Material:
3D printed with PLA+ filament

Scale: 1:3

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

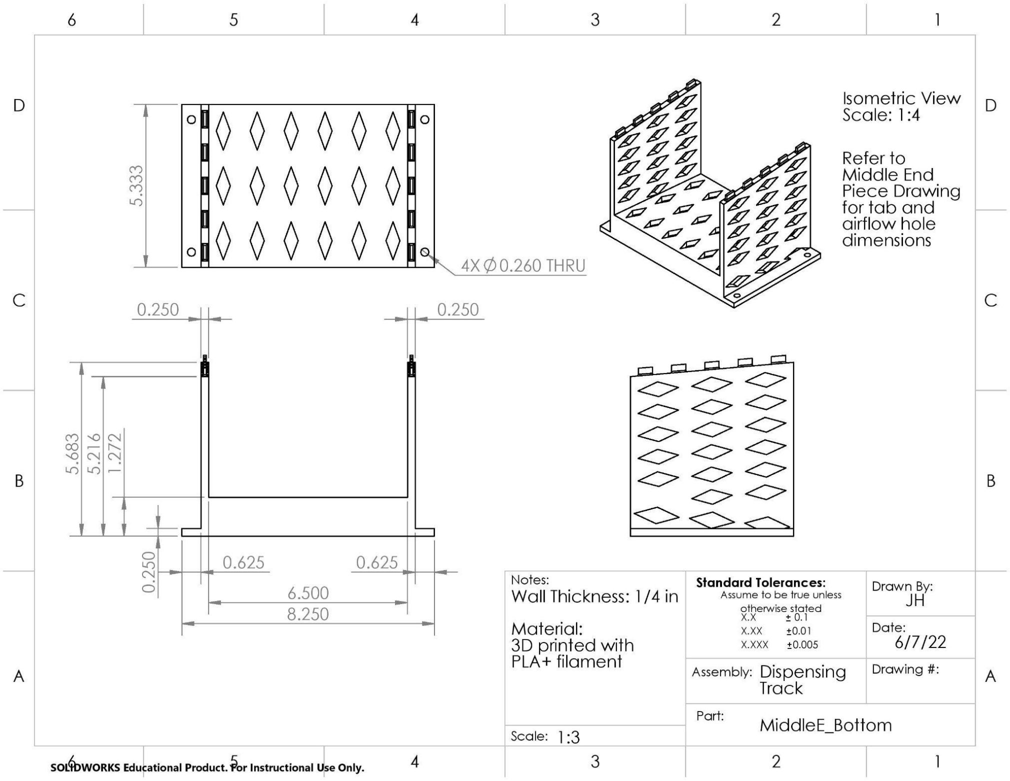
Assembly: Dispensing Track

Part: End_Bottom

Drawn By: JH

Date: 6/7/22

Drawing #:

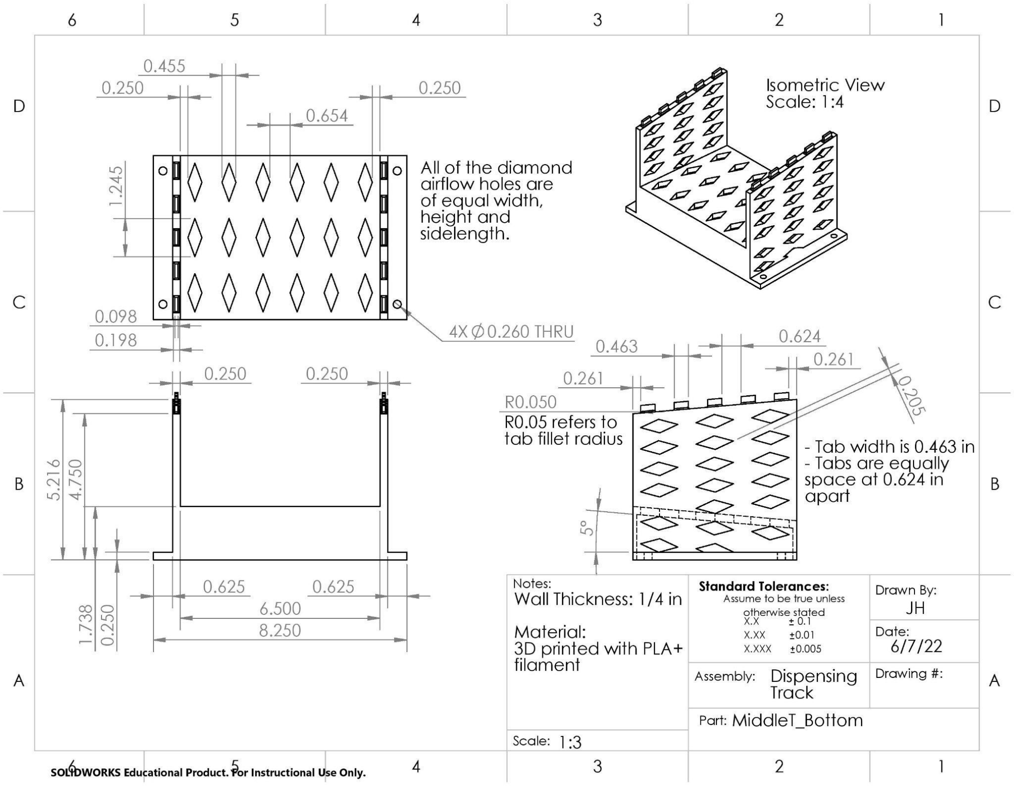


Notes:
Wall Thickness: 1/4 in

Material:
3D printed with PLA+ filament

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

Drawn By: JH
Date: 6/7/22
Assembly: Dispensing Track
Drawing #:
Part: MiddleE_Bottom
Scale: 1:3

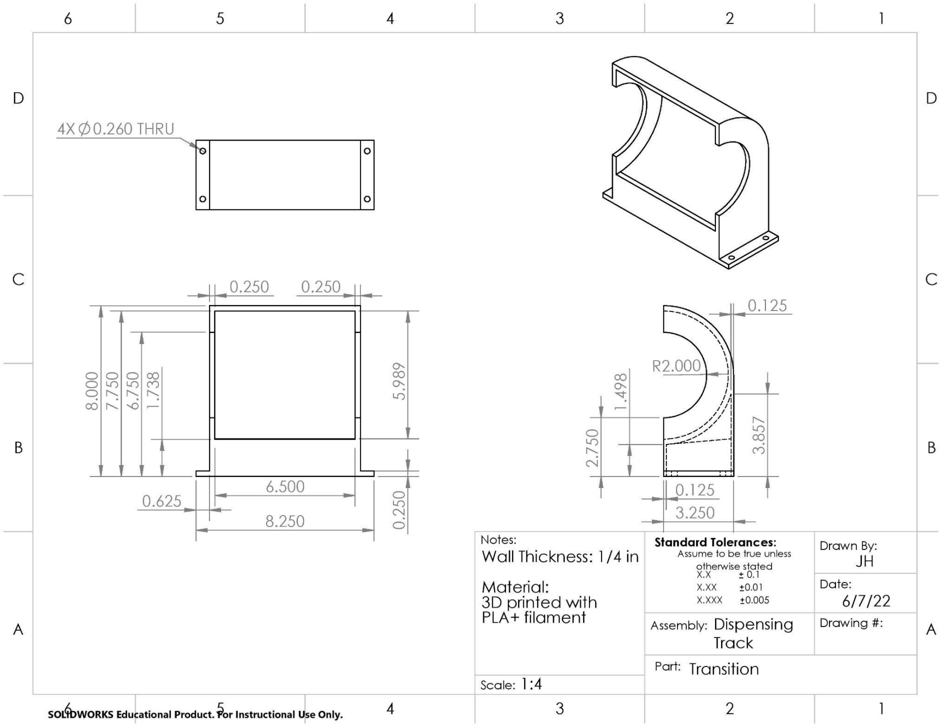


Notes:
Wall Thickness: 1/4 in

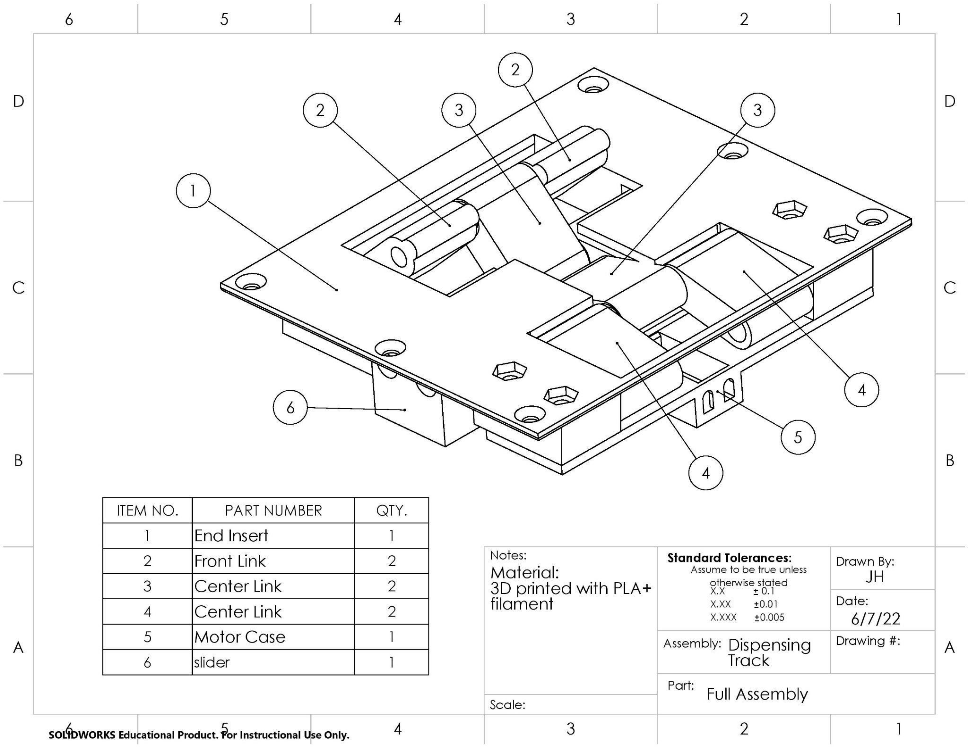
Material:
3D printed with PLA+ filament

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

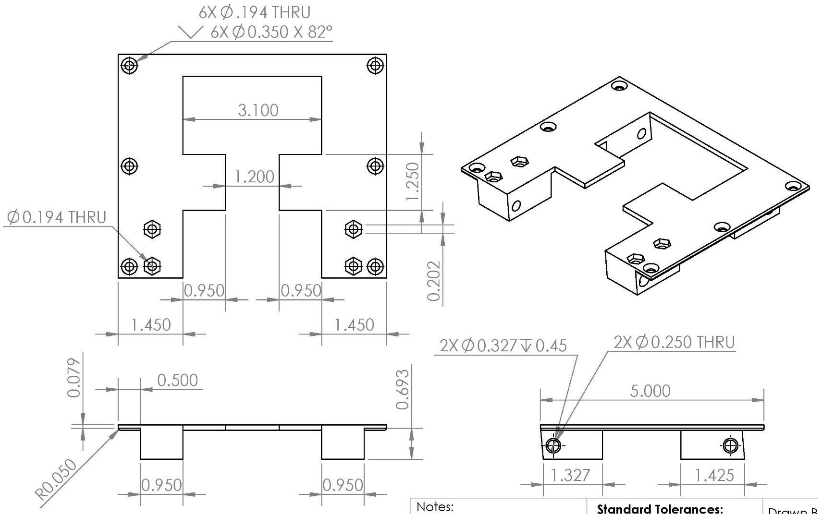
Drawn By: JH
Date: 6/7/22
Assembly: Dispensing Track
Drawing #:
Part: MiddleT_Bottom
Scale: 1:3



G2: Release Mechanism Drawings



ITEM NO.	PART NUMBER	QTY.
1	End Insert	1
2	Front Link	2
3	Center Link	2
4	Center Link	2
5	Motor Case	1
6	slider	1



Notes:
Material:
3D printed with PLA+ filament

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

Drawn By: JH

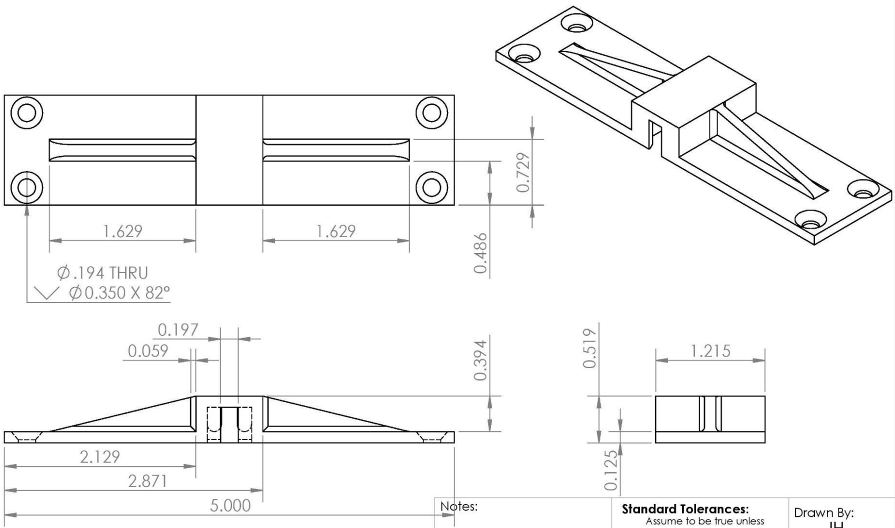
Date: 6/7/22

Drawing #:

Assembly: Dispensing Track

Part: End Insert

Scale:



Notes:
Material:
3D printed with PLA+ filament

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

Drawn By: JH

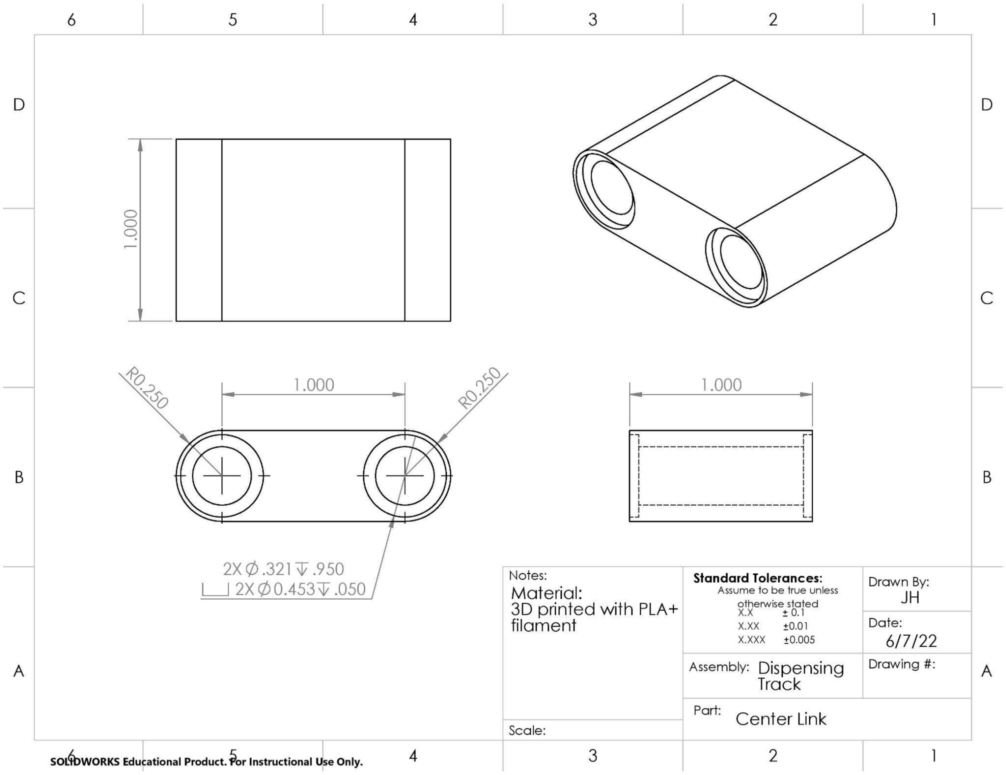
Date: 6/7/22

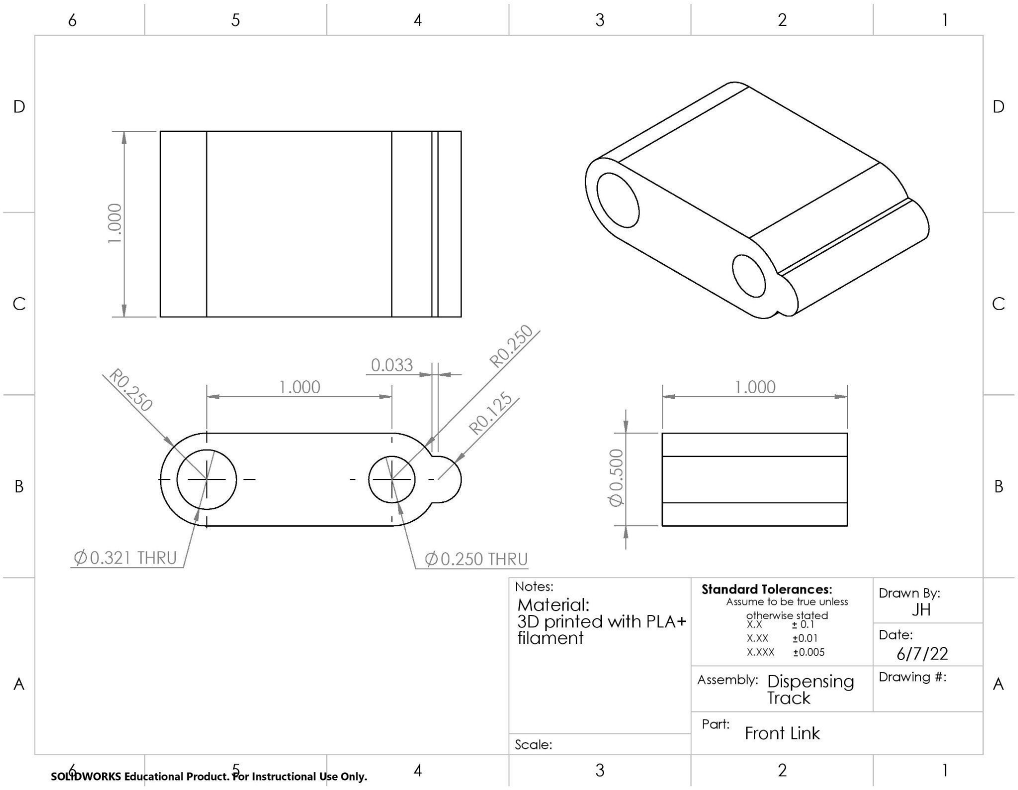
Drawing #:

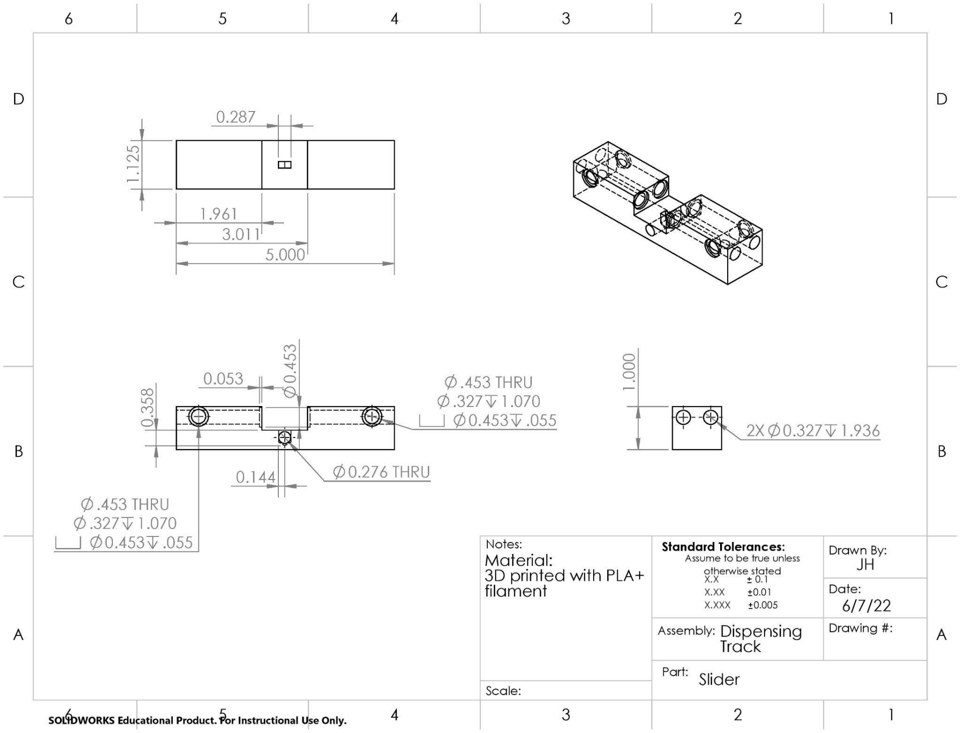
Assembly: Dispensing Track

Part: Motor Case

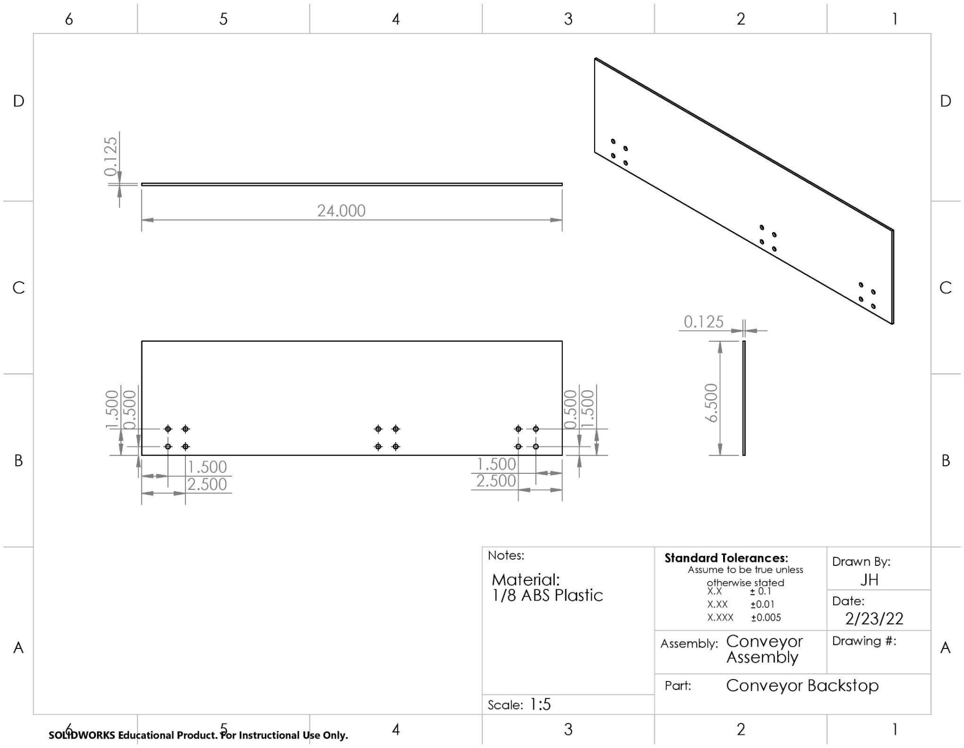
Scale:

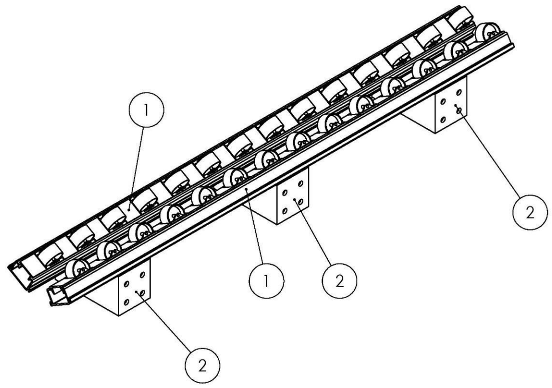

1.000
R0.250
1.000
R0.250
1.000
2X Ø .321 ↧ .950
⌴ 2X Ø 0.453 ↧ .050
Notes:
Material:
3D printed with PLA+ filament
Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005
Drawn By: JH
Date: 6/7/22
Drawing #:
Assembly: Dispensing Track
Part: Center Link
Scale:
SOLIDWORKS Educational Product. For Instructional Use Only.


1.000
0.033
R0.250
R0.250
1.000
R0.125
1.000
Ø 0.500
Ø 0.321 THRU
Ø 0.250 THRU
Notes:
Material:
3D printed with PLA+ filament
Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005
Drawn By: JH
Date: 6/7/22
Drawing #:
Assembly: Dispensing Track
Part: Front Link
Scale:
SOLIDWORKS Educational Product. For Instructional Use Only.



G3: Conveyor Assembly Drawings





ITEM NO.	PART NUMBER	QTY.
1	ConveyorAssembly	2
2	conveyorbracket	3

Notes:

Conveyor Assembly:
1. Wheels x28
2. Spacers x28
3. Brackets x3
4. Can

Scale: 1:6

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

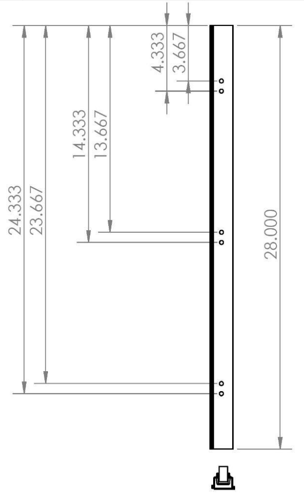
Assembly: Conveyor Assembly

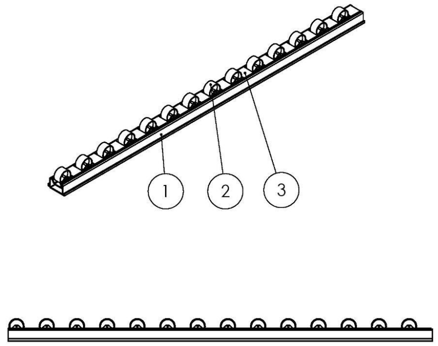
Part:

Drawn By: JH

Date: 2/23/22

Drawing #:





ITEM NO.	PART NUMBER	QTY.
1	5897K75_5 Feet Long Frame for Flow Rail	1
2	5897K21_9 16 Wide Wheels for Flow Rail	14
3	5897K51_7 8 Wide Spacers for Flow Rail	14

Notes:

Scale:

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

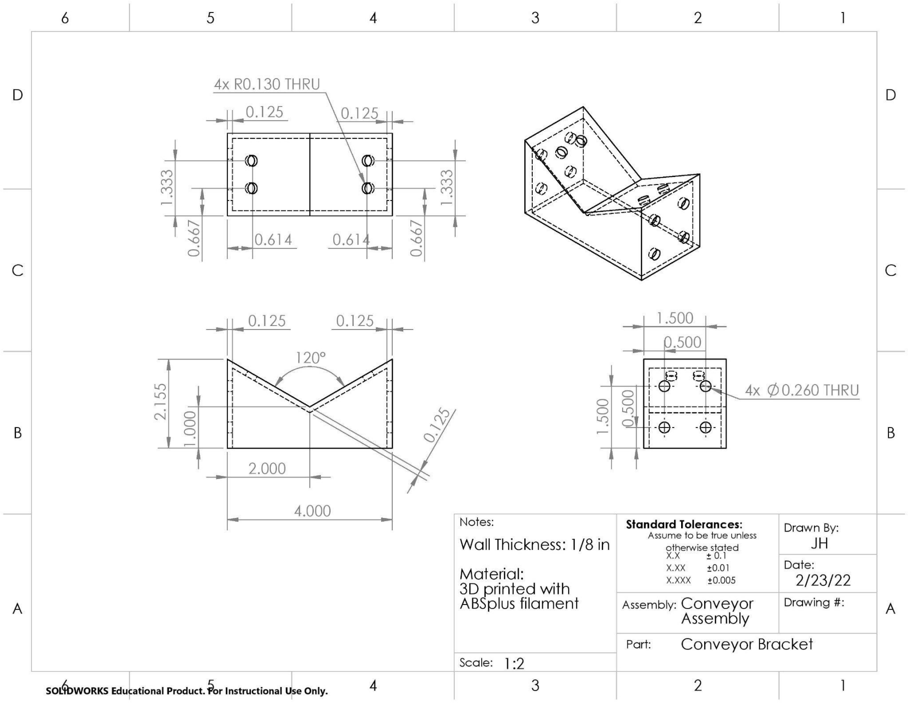
Assembly: Conveyor Assembly

Part: Conveyor Track

Drawn By: JH

Date: 2/23/22

Drawing #:



Notes:

Wall Thickness: 1/8 in

Material:
3D printed with
ABSplus filament

Scale: 1:2

Standard Tolerances:
Assume to be true unless otherwise stated

X.X	± 0.1
X.XX	±0.01
X.XXX	±0.005

Assembly: Conveyor Assembly

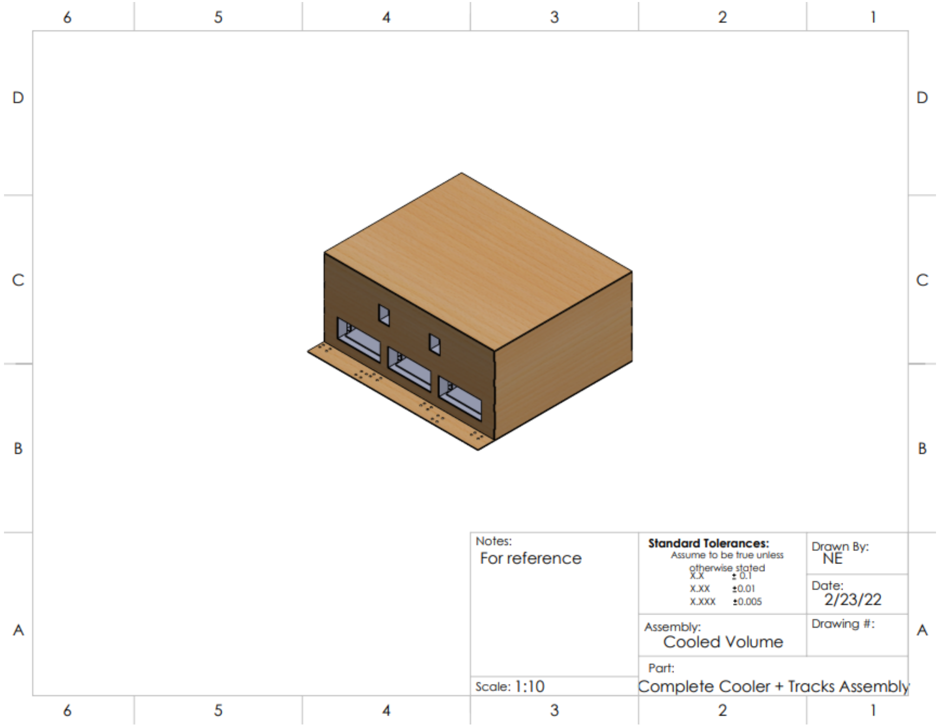
Part: Conveyor Bracket

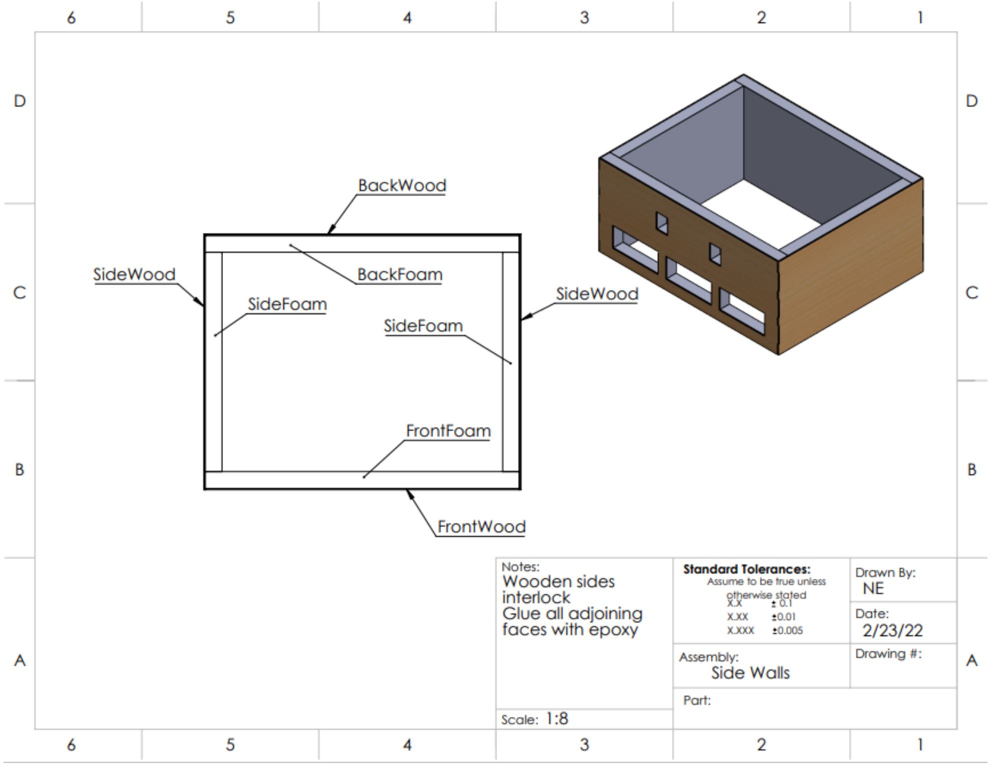
Drawn By: JH

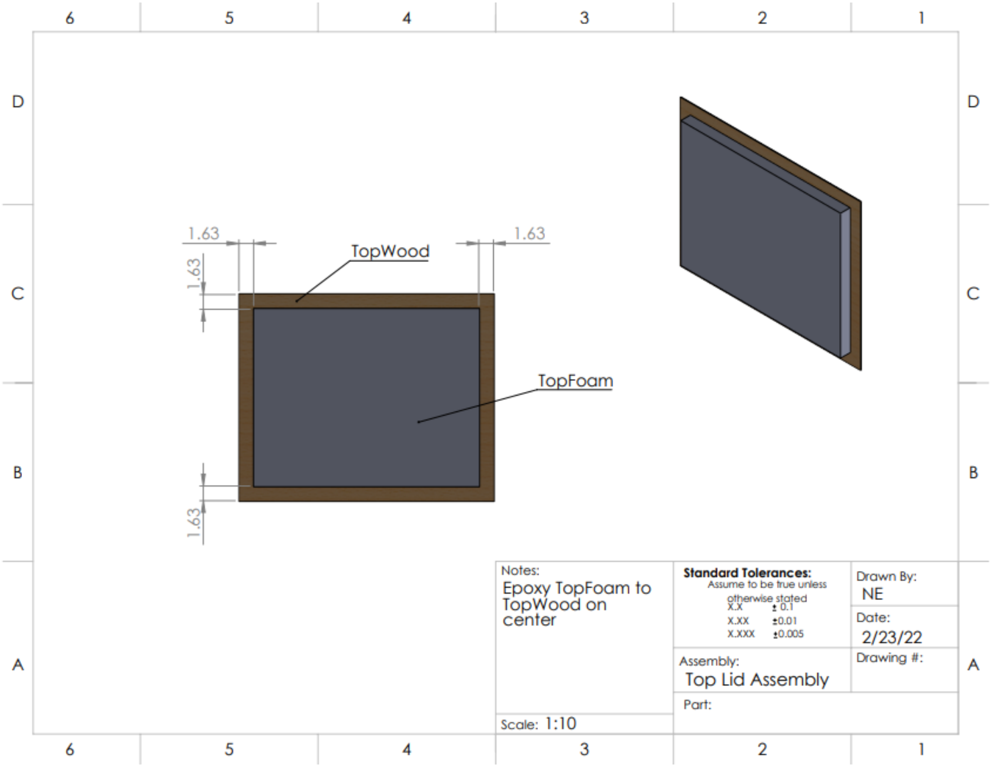
Date: 2/23/22

Drawing #:

G4: Refrigeration System Drawings







Notes:
Epoxy TopFoam to TopWood on center

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

Drawn By: NE

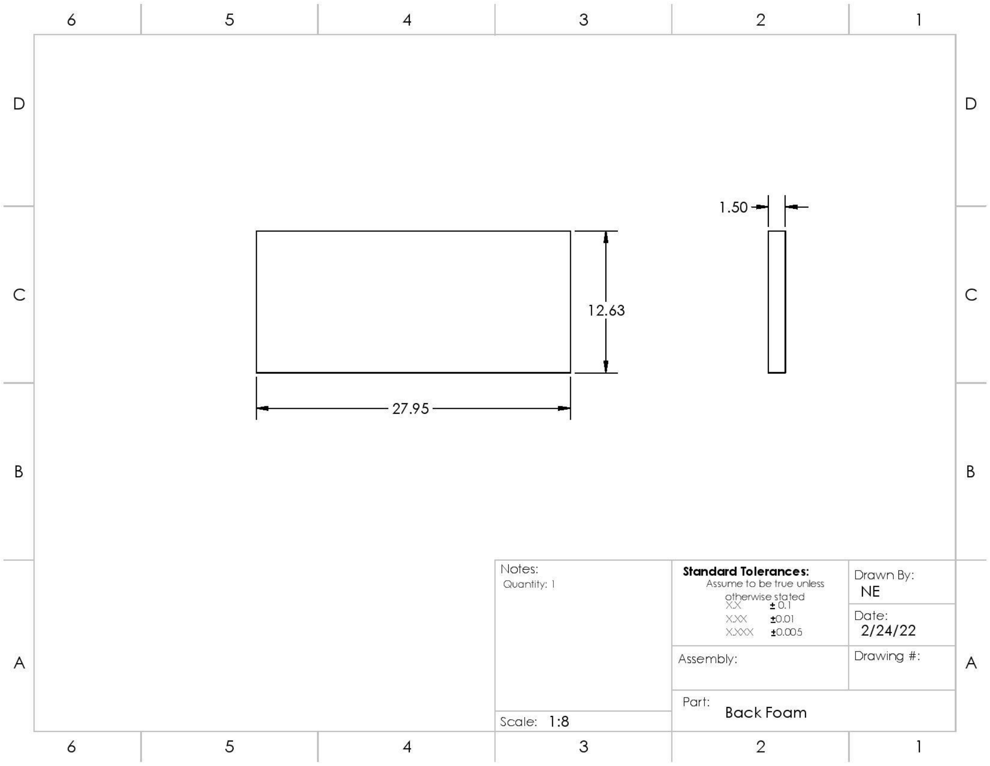
Date: 2/23/22

Drawing #:

Assembly: Top Lid Assembly

Part:

Scale: 1:10



Notes:
Quantity: 1

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

Drawn By: NE

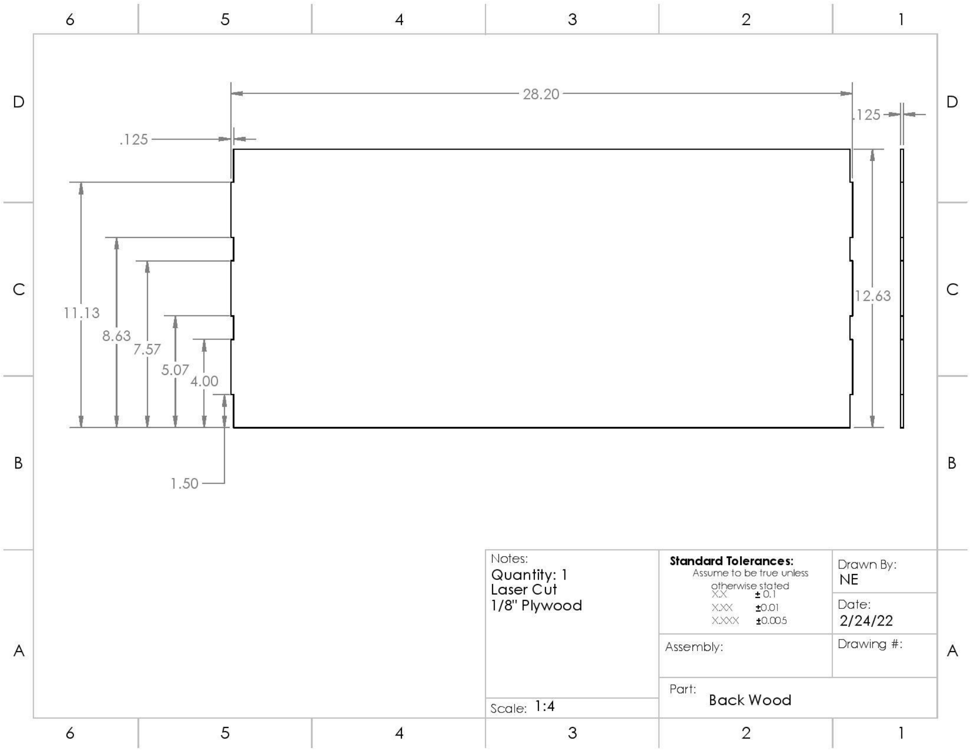
Date: 2/24/22

Assembly:

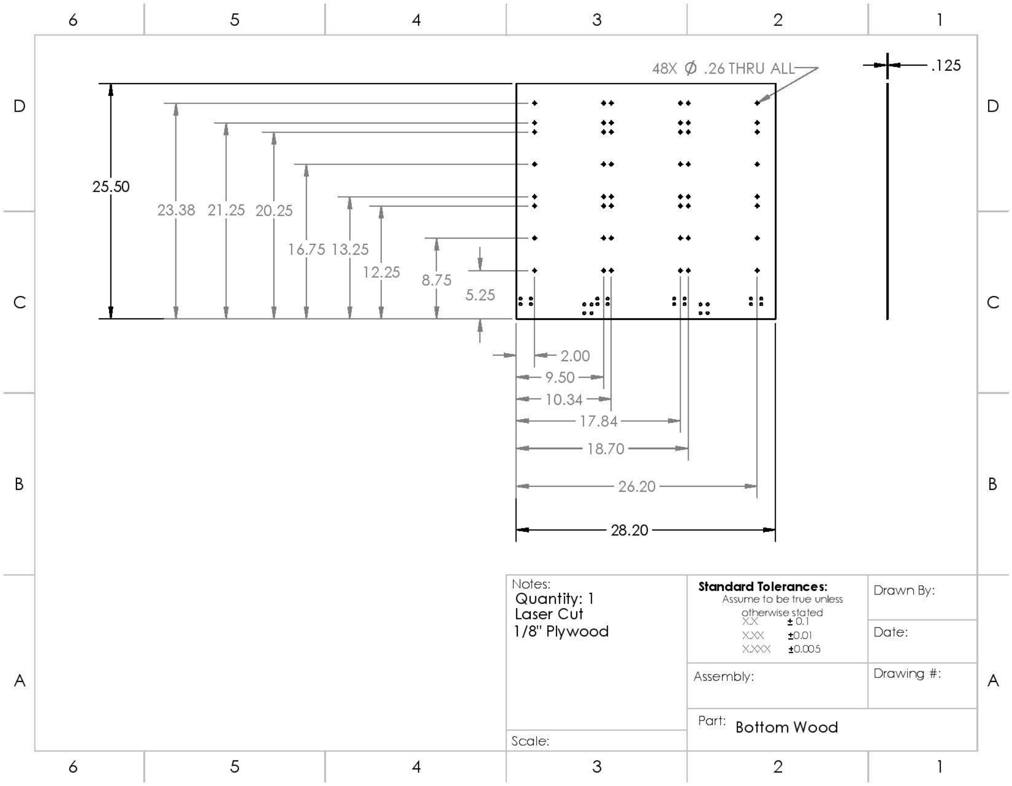
Drawing #:

Part: Back Foam

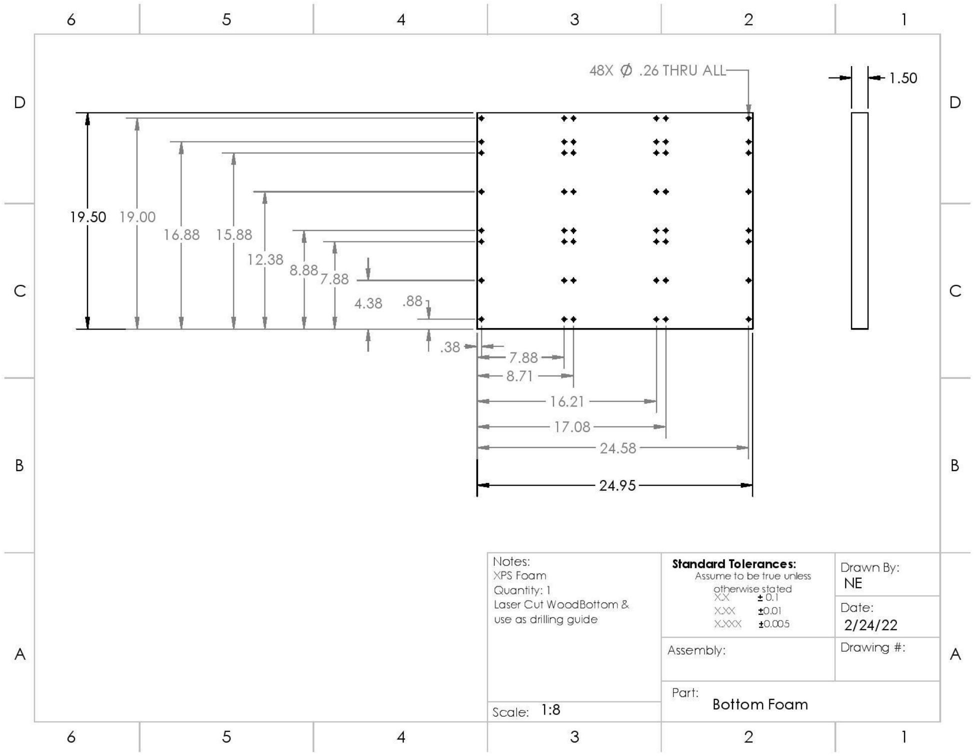
Scale: 1:8

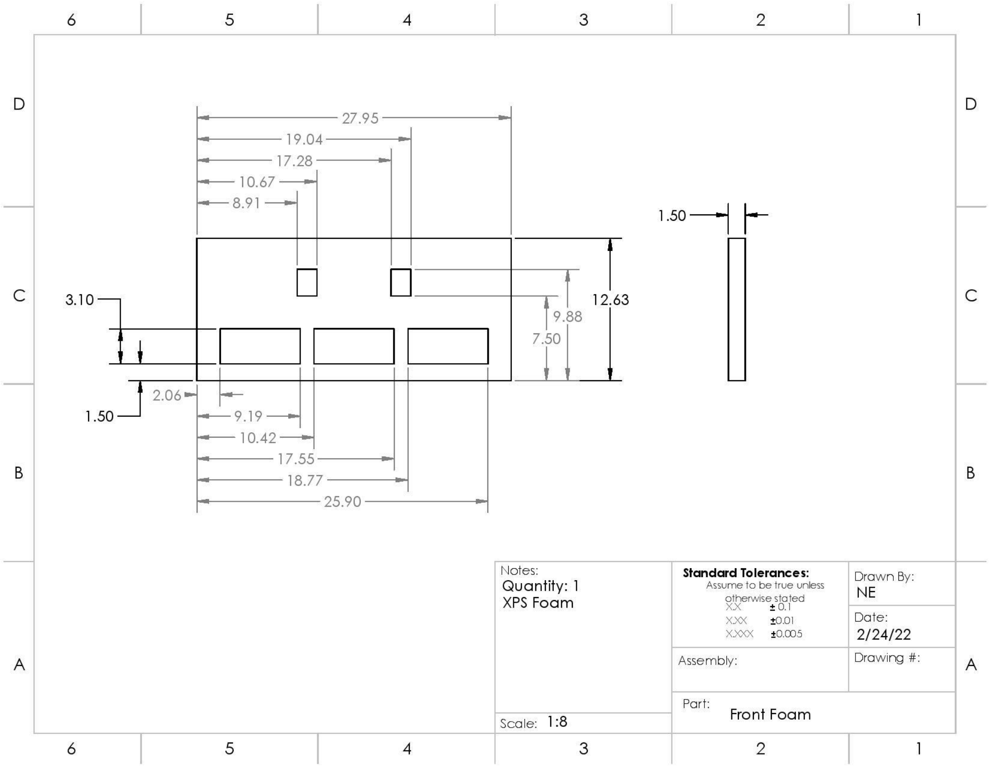


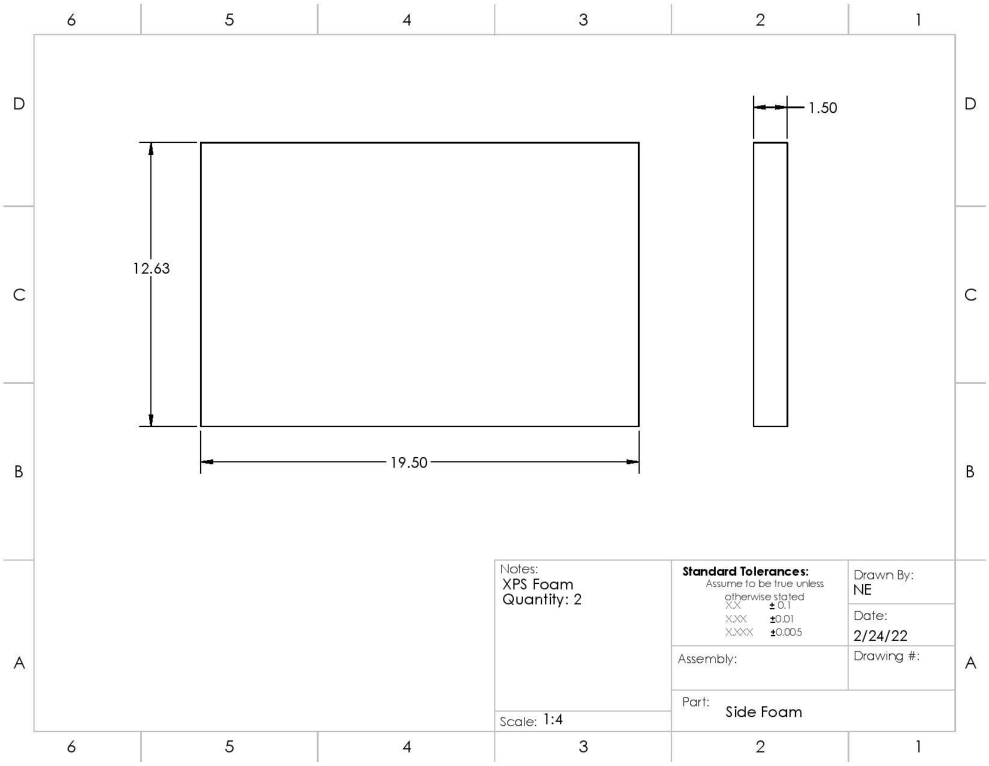
28.20
.125
.125
11.13
8.63
7.57
5.07
4.00
1.50
12.63
Notes:
Quantity: 1
Laser Cut
1/8" Plywood
Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005
Drawn By:
NE
Date:
2/24/22
Assembly:
Drawing #:
Part:
Back Wood
Scale: 1:4

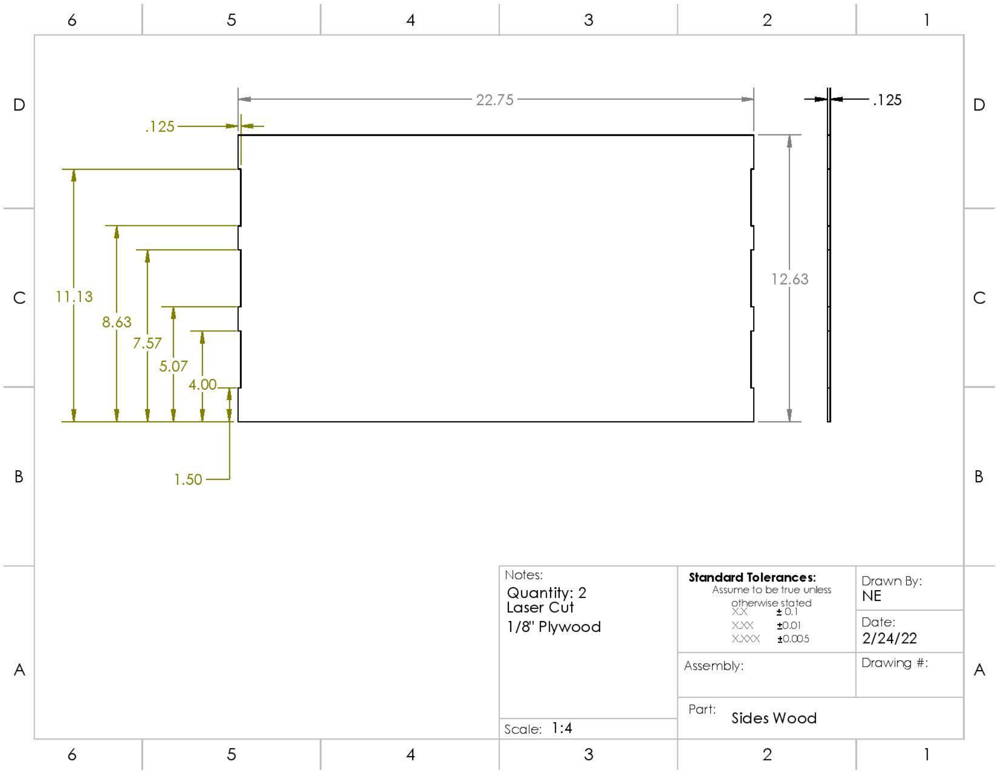


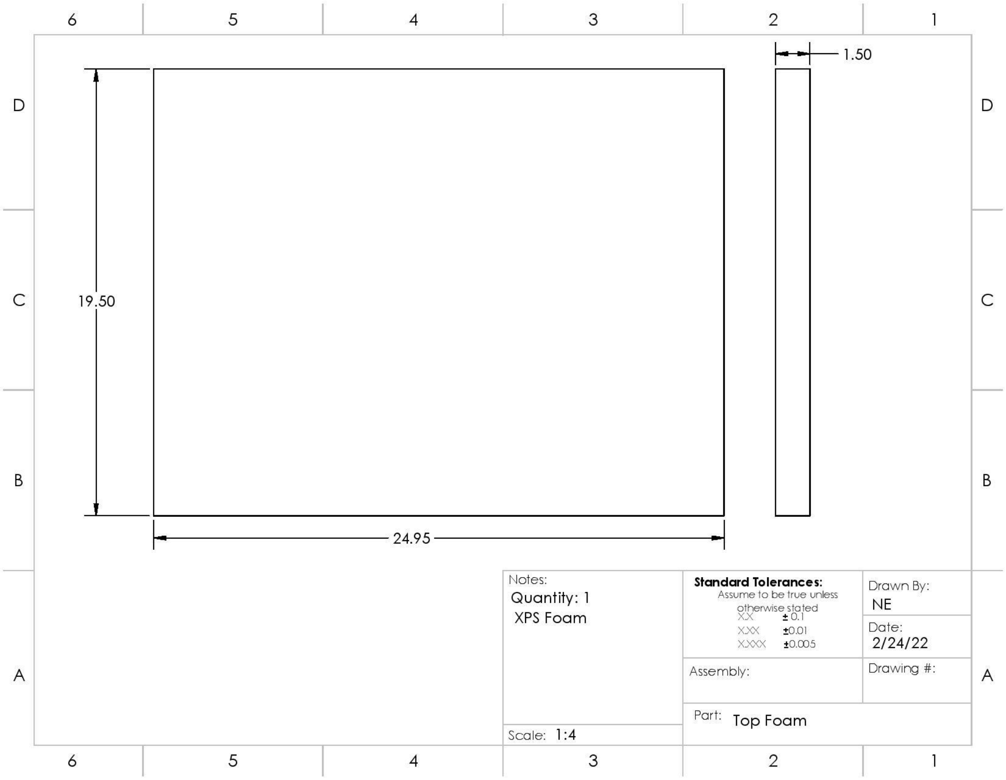
48X ∅ .26 THRU ALL
.125
25.50
23.38
21.25
20.25
16.75
13.25
12.25
8.75
5.25
2.00
9.50
10.34
17.84
18.70
26.20
28.20
Notes:
Quantity: 1
Laser Cut
1/8" Plywood
Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005
Drawn By:
Date:
Assembly:
Drawing #:
Part:
Bottom Wood
Scale:


48X ⌀ .26 THRU ALL
1.50
19.50
19.00
16.88
15.88
12.38
8.88
7.88
4.38
.88
.38
7.88
8.71
16.21
17.08
24.58
24.95
Notes:
XPS Foam
Quantity: 1
Laser Cut WoodBottom &
use as drilling guide
Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005
Drawn By: NE
Date: 2/24/22
Assembly:
Drawing #:
Part: Bottom Foam
Scale: 1:8


27.95
19.04
17.28
10.67
8.91
1.50
3.10
12.63
9.88
7.50
2.06
1.50
9.19
10.42
17.55
18.77
25.90
Notes:
Quantity: 1
XPS Foam
Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005
Drawn By: NE
Date: 2/24/22
Assembly:
Drawing #:
Part: Front Foam
Scale: 1:8


1.50
12.63
19.50
Notes:
XPS Foam
Quantity: 2
Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005
Drawn By:
NE
Date:
2/24/22
Assembly:
Drawing #:
Part:
Side Foam
Scale: 1:4

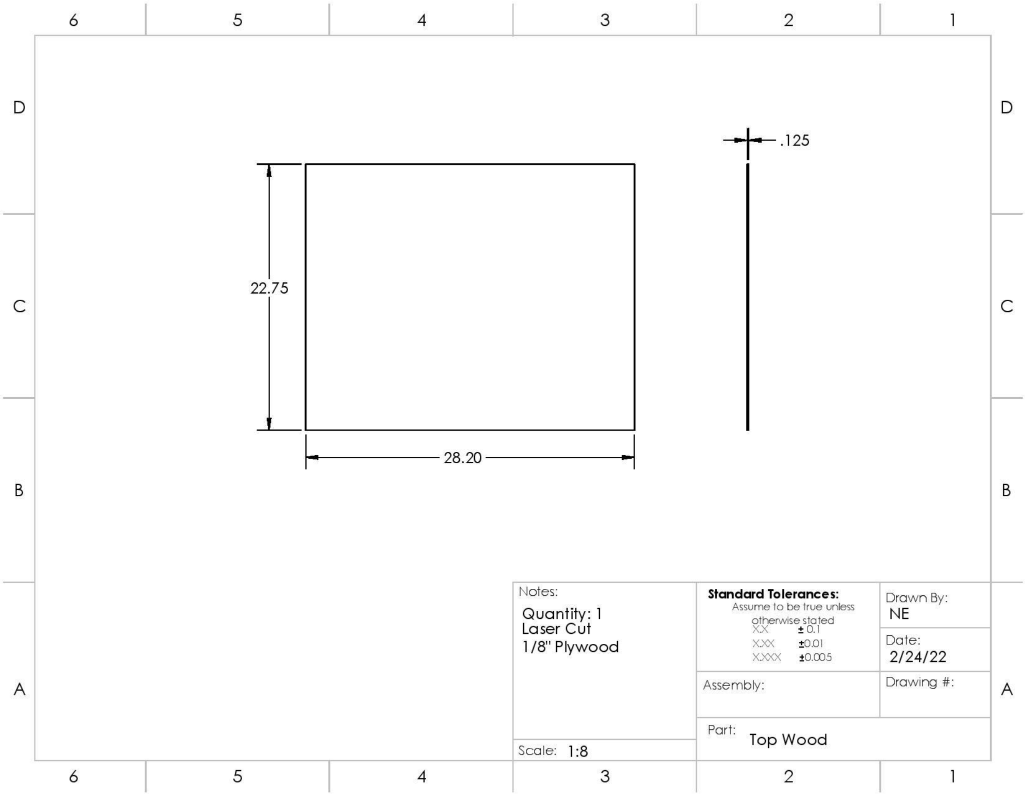

22.75
.125
.125
11.13
8.63
7.57
5.07
4.00
1.50
12.63
Notes:
Quantity: 2
Laser Cut
1/8" Plywood
Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005
Drawn By:
NE
Date:
2/24/22
Assembly:
Drawing #:
Part:
Sides Wood
Scale: 1:4



Notes:
Quantity: 1
XPS Foam

Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

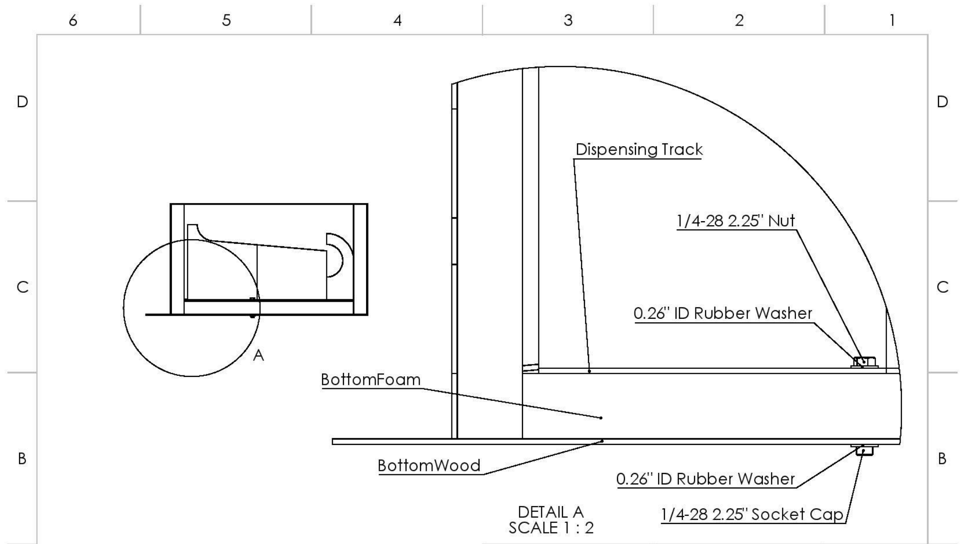
Drawn By: NE
Date: 2/24/22
Assembly:
Drawing #:
Part: Top Foam
Scale: 1:4



Notes:
Quantity: 1
Laser Cut
1/8" Plywood

Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

Drawn By: NE
Date: 2/24/22
Assembly:
Drawing #:
Part: Top Wood
Scale: 1:8



Notes:
Assembly applies
to all 48 holes

Standard Tolerances:
Assume to be true unless
otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

Drawn By:
NE

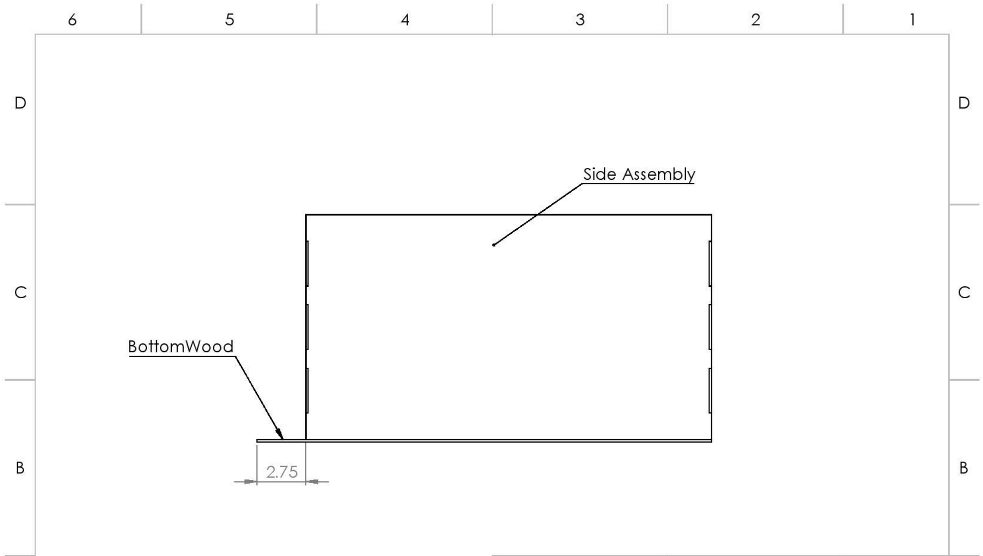
Date:
2/23/22

Assembly:
Dispensing Track/Bottom

Drawing #:

Part:

Scale:



Notes:
Epoxy side assembly
to the bottom if bolts
are not sufficient.

Standard Tolerances:
Assume to be true unless
otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

Drawn By:
NE

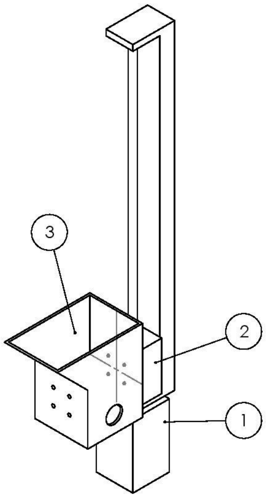
Date:
2/23/22

Assembly:
Sides + Bottom

Drawing #:

Part:

Scale: 1:5



ITEM NO.	PART NUMBER	QTY.
1	FSL40_Linear_Guide_and_Stepper	1
2	FSL40_Slider	1
3	FSL40_Can_Bucket	1

Notes:

Assembly contains:
- Lead Screw
- Lead Screw Housing
- Vexta PK268-03B Motor
- Lift Platform

Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

Drawn By: JH

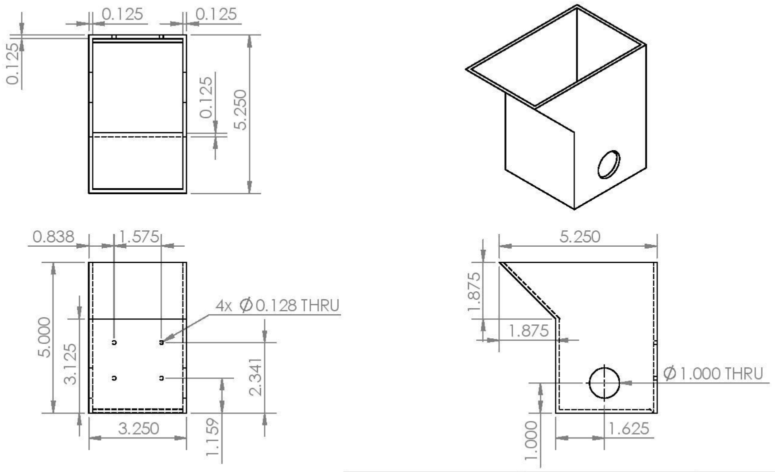
Date: 2/23/22

Assembly: Lead Screw Assembly

Drawing #:

Part:

Scale: 1:8



Notes:

Material:
3D printed with
ABSplus filament

Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

Drawn By: JH

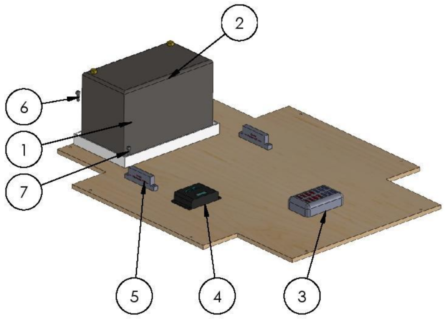
Date: 2/23/22

Assembly: Lead Screw Assembly

Drawing #:

Part: Lead Screw Lift Platform

Scale: 1:3



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Base Plate	Wooden Base Mounting Plate	1
2	Battery with holder		1
3	Fuse Block		1
4	Solar Charger	Solar Charger 10A Renogy	1
5	Bus Bar		2
6	1/4" Screw	1/4" Steel Socket Head Screw	16
7	M5 Screw	M5 Steel Socket Head Screw	12

Notes:
The assembly only shows 2 screws. However, there will be one for each hole in the baseplate.

Scale:

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

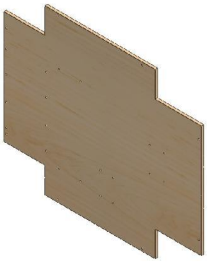
Drawn By: JJ

Date: 2/23/22

Assembly: Base plate and Electronic Components

Drawing #:

Part: Assembly Overview



Notes:

Scale: 1:10

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

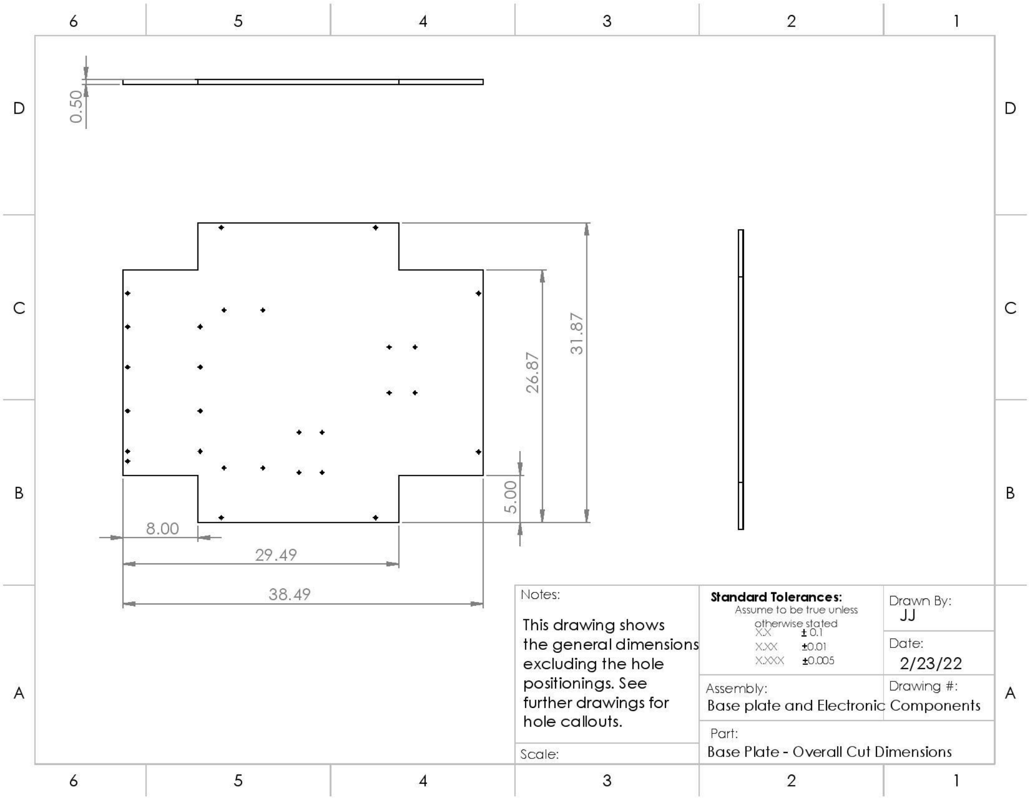
Drawn By: JJ

Date: 2/22/22

Assembly: Base Plate & Electronic Components

Drawing #:

Part: Base Plate - Overview



Notes:

This drawing shows the general dimensions excluding the hole positionings. See further drawings for hole callouts.

Scale:

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

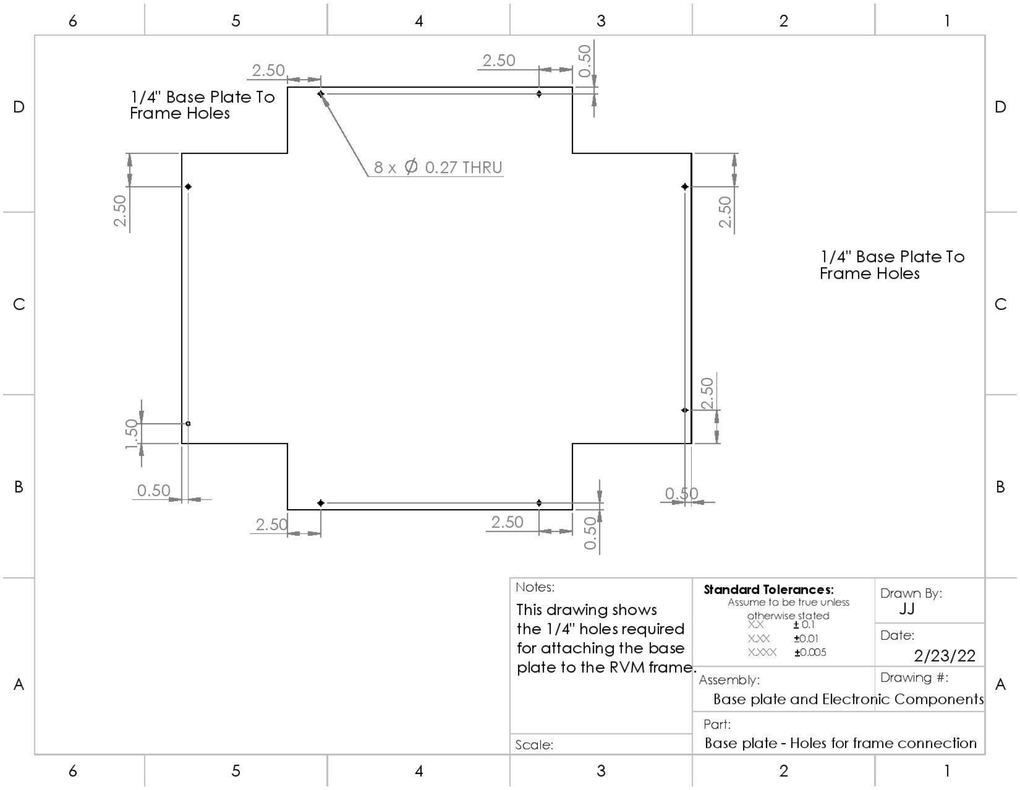
Drawn By:
JJ

Date:
2/23/22

Assembly:
Base plate and Electronic Components

Drawing #:

Part:
Base Plate - Overall Cut Dimensions



Notes:

This drawing shows the 1/4" holes required for attaching the base plate to the RVM frame.

Scale:

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

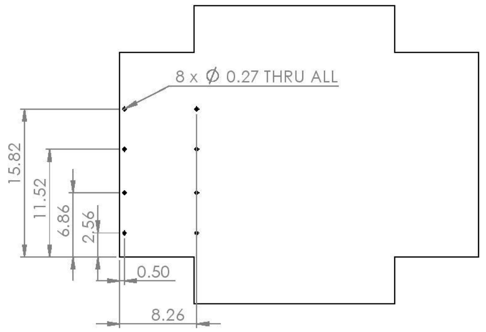
Drawn By:
JJ

Date:
2/23/22

Assembly:
Base plate and Electronic Components

Drawing #:

Part:
Base plate - Holes for frame connection



Notes:

This drawing shows only the holes for the battery tray mounting. See further drawings for the remaining holes.

Scale:

Standard Tolerances:
Assume to be true unless otherwise stated

X.X	± 0.1
X.XX	±0.01
X.XXX	±0.005

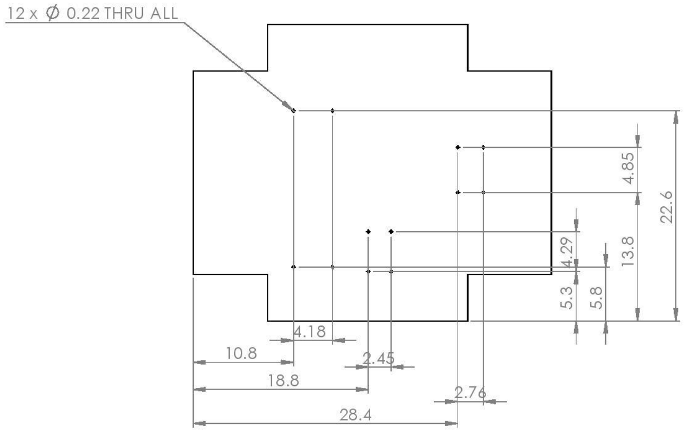
Drawn By:
JJ

Date:
2/23/22

Assembly:
Base plate and Electronic Components

Drawing #:

Part:
Base plate - Holes for Battery Tray



Notes:

This drawing shows the remaining mount holes, excluding the battery tray holes.

Scale:

Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

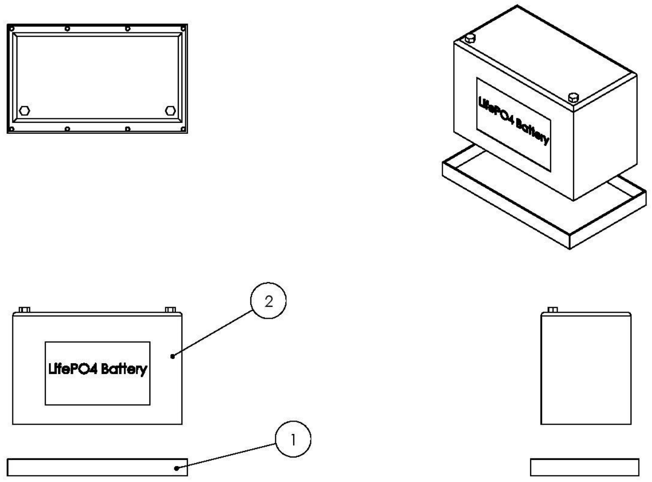
Drawn By:
JJ

Date:
2/23/22

Assembly:
Base plate and Electronic Components

Drawing #:

Part:
Base plate - Holes for Electrical Components



Item Number	Part
1	Battery Holding Tray
2	LifePO4 Battery

Notes:

-The battery is secured to the holding tray with straps that wrap around.
-The battery fits securely within the holding tray and does not require specific placement.

Scale:

Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

Drawn By:
JJ

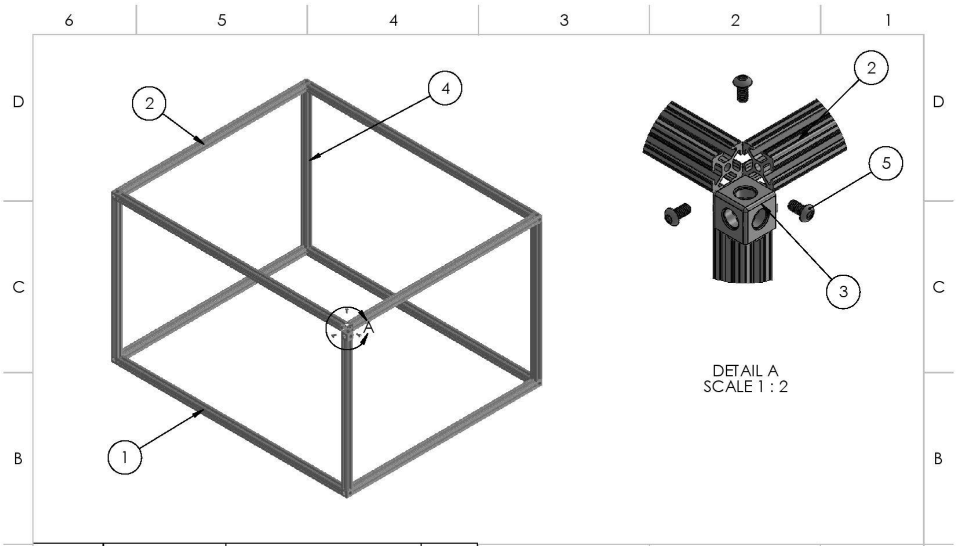
Date:
2/22/22

Assembly:
Base plate and Electronic Components

Drawing #:

Part:
Battery & Tray Holder Assembly

G5: Structural Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	47065T121	T-Slotted Framing - 37"	4
2	47065T121	T-Slotted Framing - 29.875"	4
3	47065T244	3-Way Corner Bracket	8
4	47065T121	T-Slotted Framing - 22"	4
5	97763A263	18-8 Stainless Steel Button Head Hex Drive Screws	3

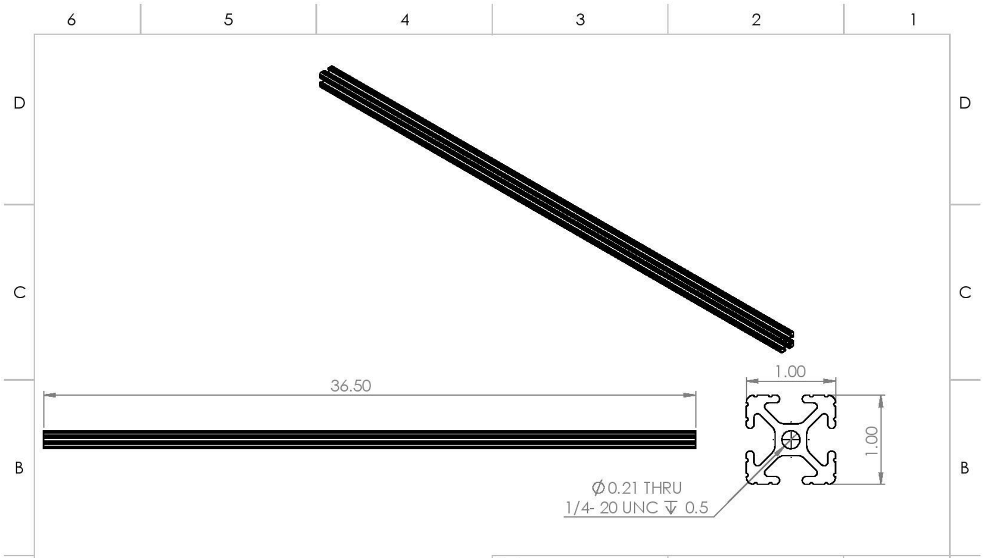
Notes:
Frame Subassembly
For Reference Only

Scale: 1:10

Standard Tolerances:
Assume to be true unless otherwise stated

X.X	± 0.1
X.XX	±0.01
X.XXX	±0.005

Drawn By: AL
Date: 2/23/22
Assembly: Frame Subassembly
Drawing #: 1
Part:



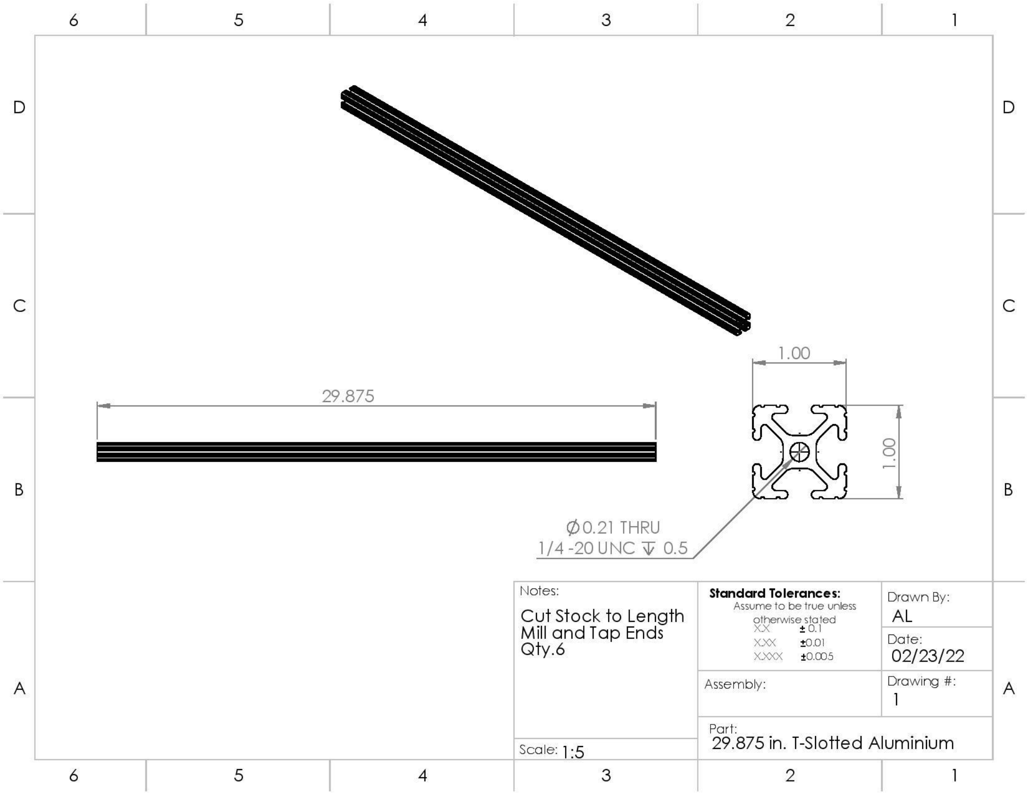
Notes:
Cut Stock to Length
Mill and Tap Ends
Qty.5

Scale: 1:5

Standard Tolerances:
Assume to be true unless otherwise stated

X.X	± 0.1
X.XX	±0.01
X.XXX	±0.005

Drawn By: AL
Date: 02/23/22
Assembly:
Drawing #: 1
Part: 36.5 in. T-Slotted Aluminium



Notes:

Cut Stock to Length
Mill and Tap Ends
Qty.6

Scale: 1:5

Standard Tolerances:
Assume to be true unless
otherwise stated

X.X	± 0.1
X.XX	±0.01
X.XXX	±0.005

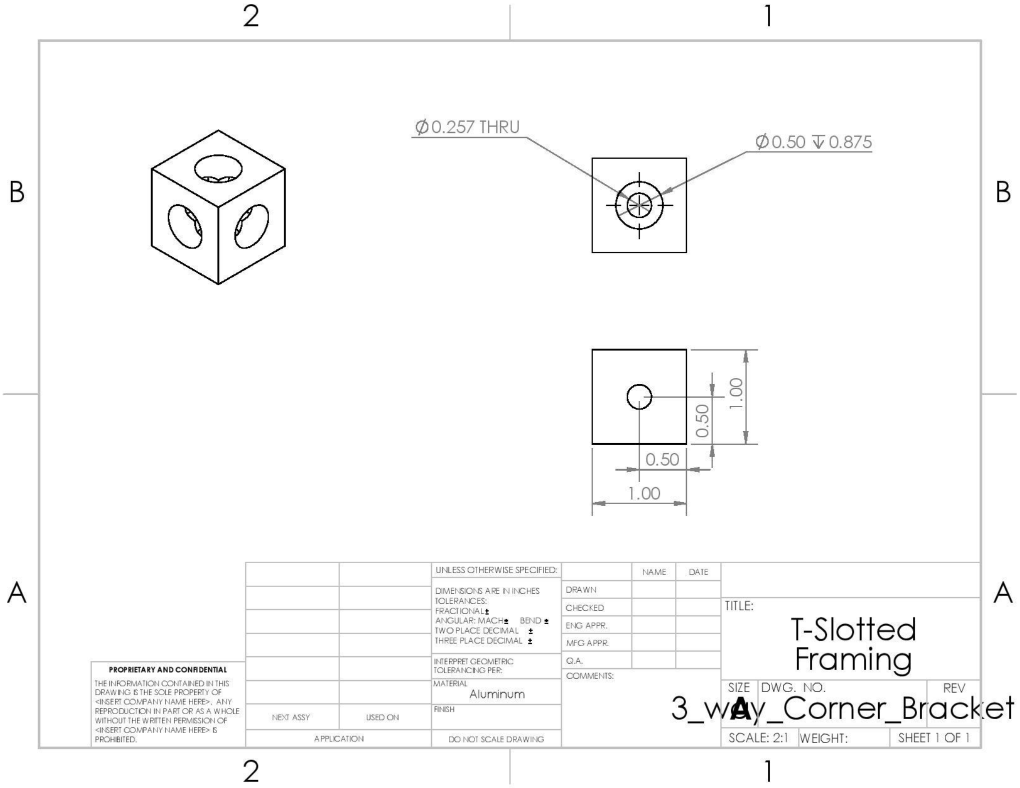
Assembly:

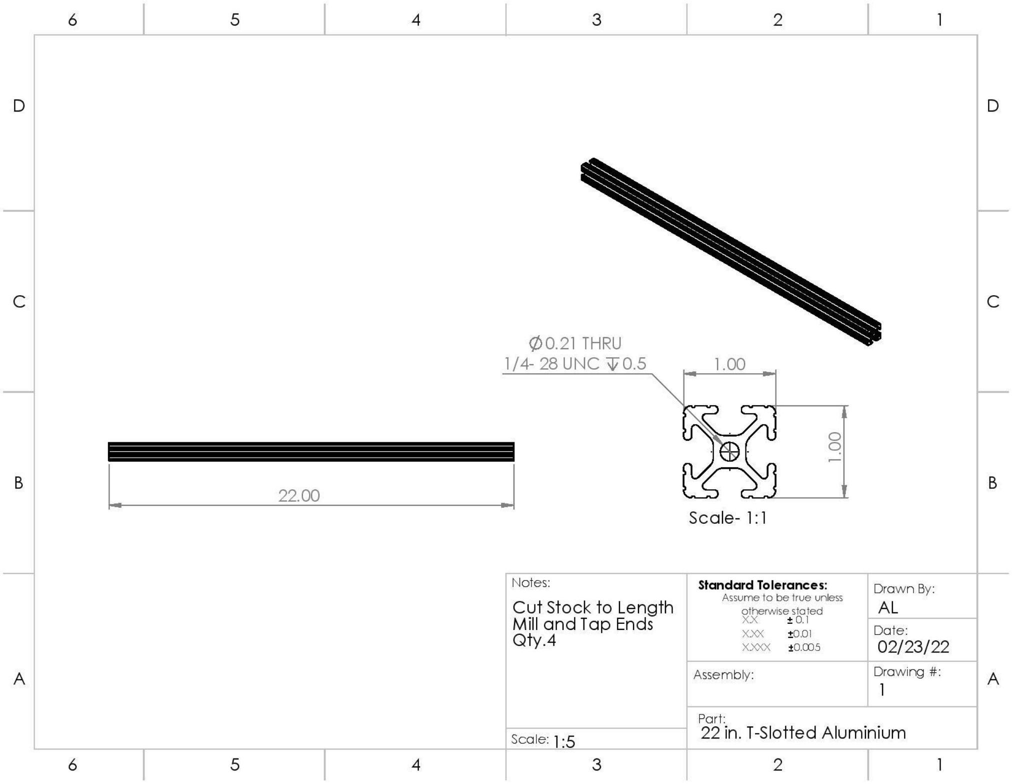
Part:
29.875 in. T-Slotted Aluminium

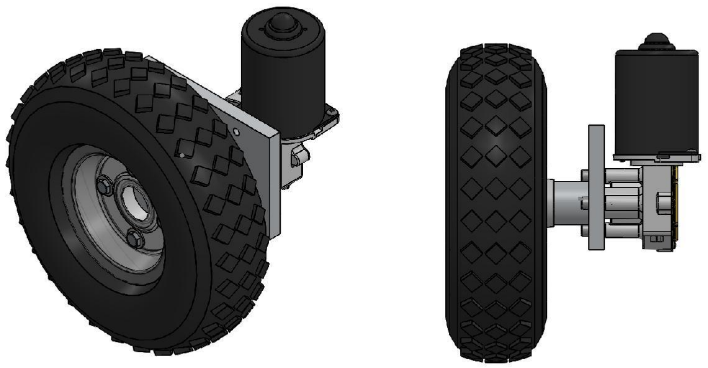
Drawn By:
AL

Date:
02/23/22

Drawing #:
1


2
1
B
A
Ø0.257 THRU
Ø0.50 ↧ 0.875
1.00
0.50
0.50
1.00
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
T-Slotted Framing
SIZE
A
DWG. NO.
3_way_Corner_Bracket
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1


6
5
4
3
2
1
D
C
B
A
Ø0.21 THRU
1/4- 28 UNC ↧ 0.5
1.00
1.00
22.00
Scale- 1:1
Notes:
Cut Stock to Length
Mill and Tap Ends
Qty.4
Scale: 1:5
Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005
Drawn By:
AL
Date:
02/23/22
Assembly:
Drawing #:
1
Part:
22 in. T-Slotted Aluminium



Notes:
Full Assembly
Visual Aid Only

Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

Drawn By: AL

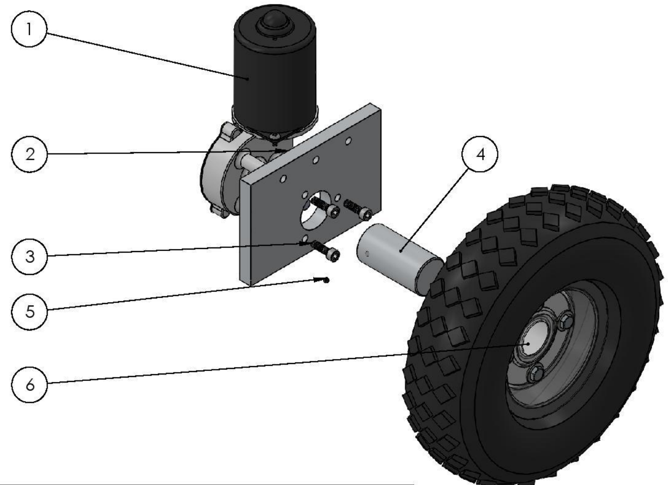
Date: 2/23/22

Assembly: Motor Wheel Assem.

Drawing #: 1

Part:

Scale: 1:2



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Drive_Motor_MakerMotor_PN01007-38		1
2	Motor_Mount		1
3	96144A120	Fine-Thread Alloy Steel Socket Head Screw	3
4	Drive Shaft		1
5	91375A188	Alloy Steel Cup-Point Set Screw	1
6	10in_pneumatic_wheel		1

Notes:
Exploded View

Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

Drawn By: AL

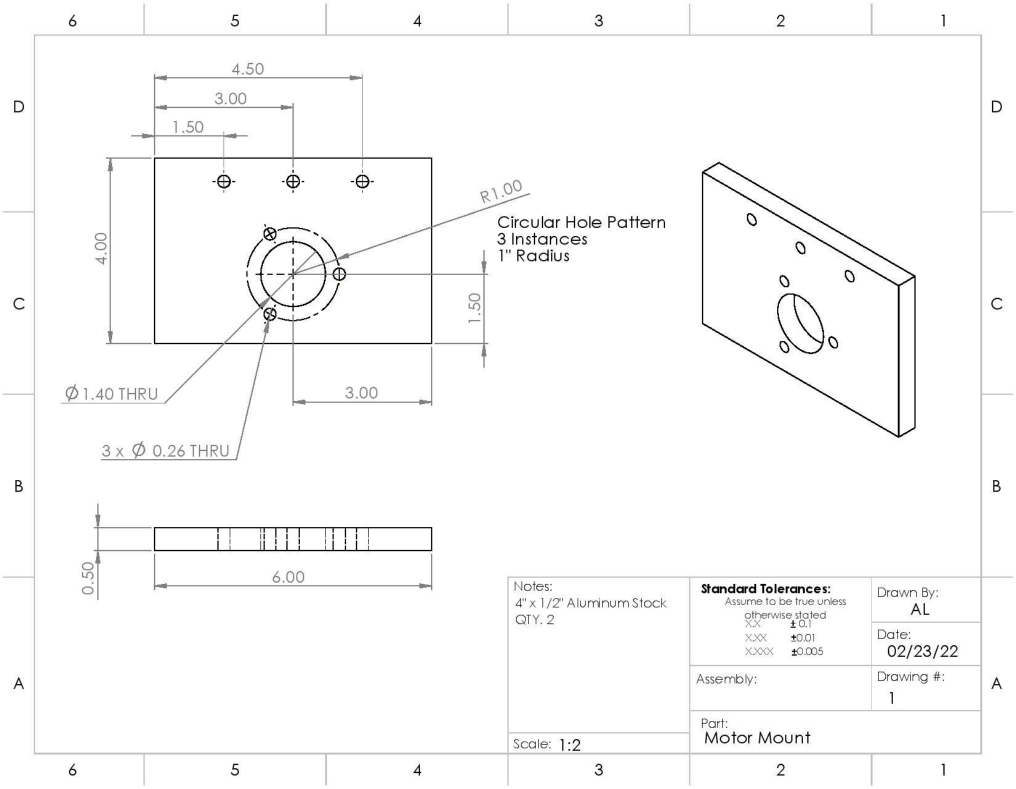
Date: 2/23/22

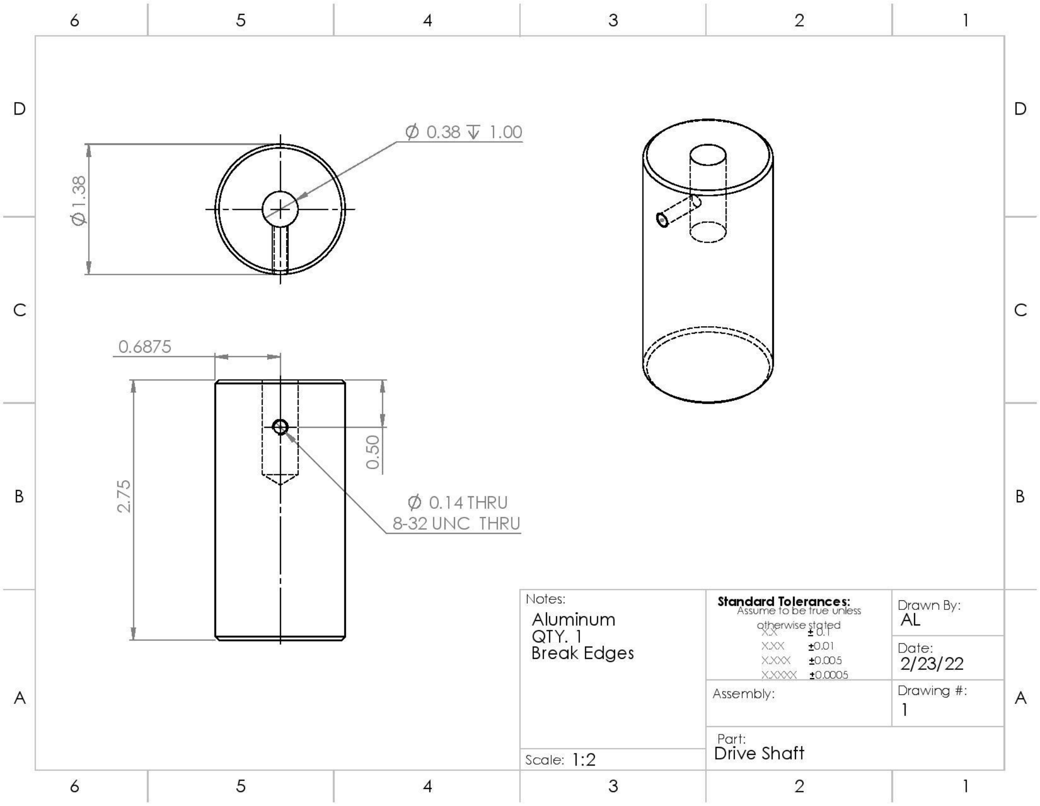
Assembly: Motor Wheel Assem.

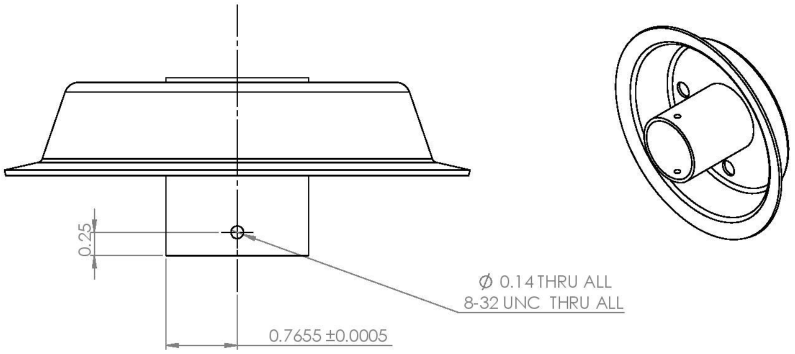
Drawing #: 2

Part:

Scale: 1: 3


4.50
3.00
1.50
4.00
R1.00
Circular Hole Pattern
3 Instances
1" Radius
1.50
3.00
Ø 1.40 THRU
3 x Ø 0.26 THRU
0.50
6.00
Notes:
4" x 1/2" Aluminum Stock
QTY. 2
Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005
Drawn By:
AL
Date:
02/23/22
Assembly:
Drawing #:
1
Part:
Motor Mount
Scale: 1:2


Ø 0.38 ↧ 1.00
Ø 1.38
0.6875
2.75
0.50
Ø 0.14 THRU
8-32 UNC THRU
Notes:
Aluminum
QTY. 1
Break Edges
Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005
X.XXXX ±0.0005
Drawn By:
AL
Date:
2/23/22
Assembly:
Drawing #:
1
Part:
Drive Shaft
Scale: 1:2



Notes:
8-32 Tapped Hole
For Set Screw
Center Hole On Hub
Diameter
QTY. 2

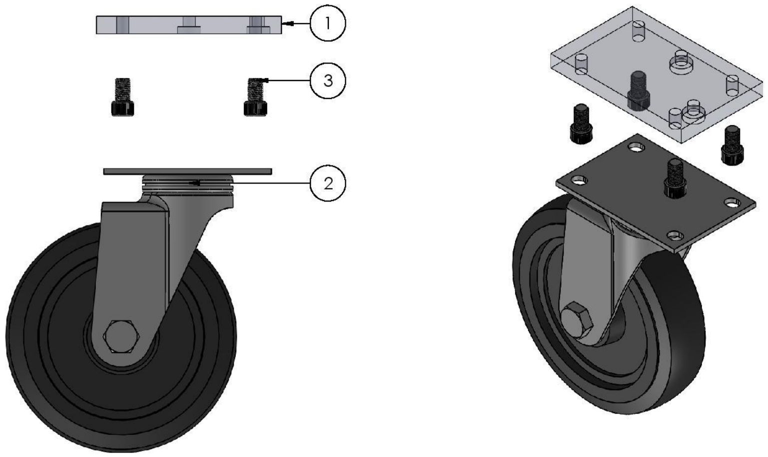
Scale: 1:1

Standard Tolerances:
Assume to be true unless
otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

Assembly:

Drawn By: AL
Date: 02/23/22
Drawing #: 1

Part: 10 inch HF Wheel - Inner Hub



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	5in_HF_Swivel_Caster_Adapter_Plate	Adapter Plate	1
2	20135T32	5 in. Swivel Caster	1
3	91251A378	Black-Oxide Alloy Steel Socket Head Screw	4

Notes:
Exploded view shows
part orientation

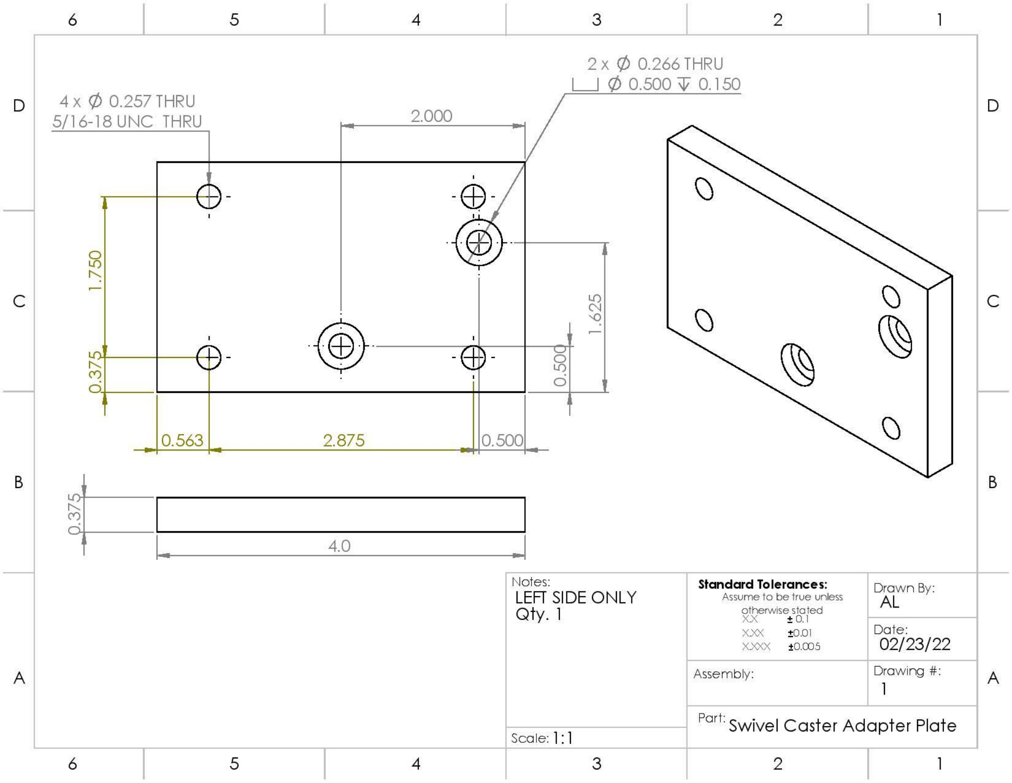
Scale: 1:2

Standard Tolerances:
Assume to be true unless
otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

Assembly: Caster Assembly

Drawn By: AL
Date: 2/23/22
Drawing #: 1

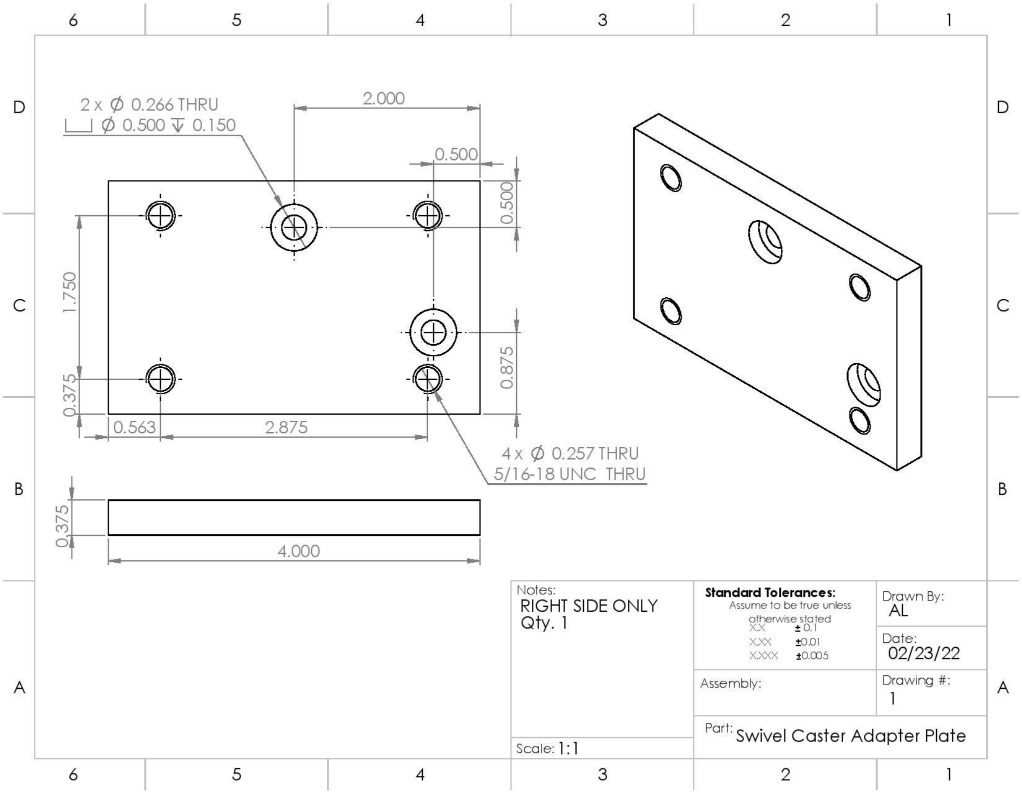
Part:



Notes:
LEFT SIDE ONLY
Qty. 1

Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

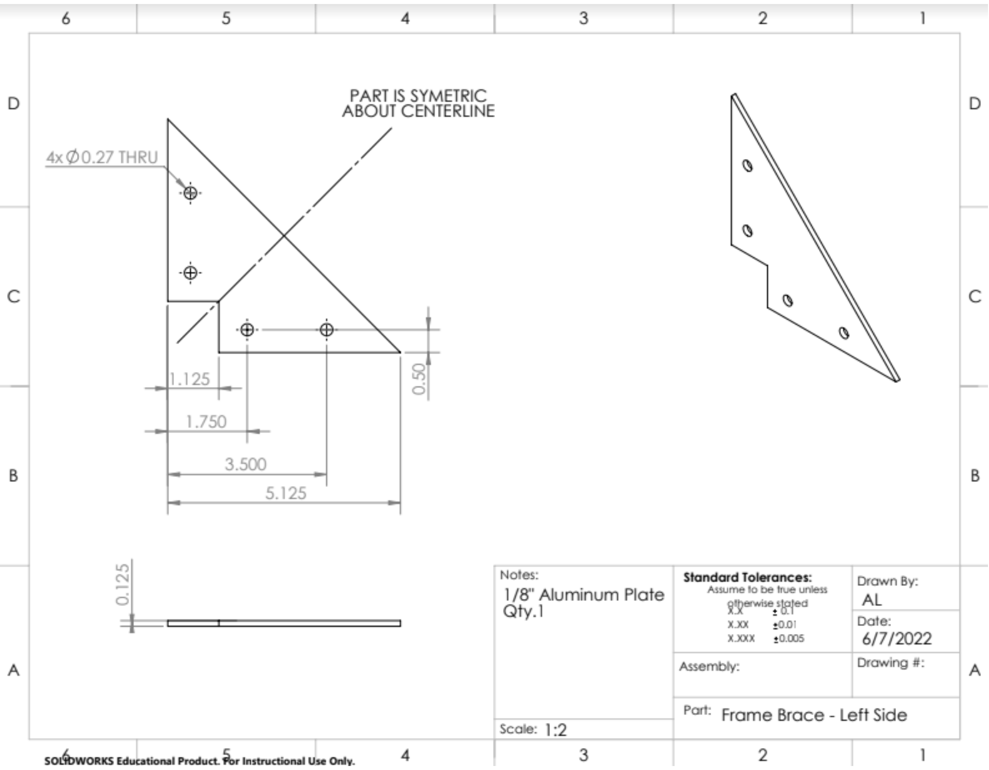
Drawn By: AL
Date: 02/23/22
Assembly:
Drawing #: 1
Part: Swivel Caster Adapter Plate
Scale: 1:1



Notes:
RIGHT SIDE ONLY
Qty. 1

Standard Tolerances:
Assume to be true unless otherwise stated
XX ± 0.1
XXX ±0.01
XXXX ±0.005

Drawn By: AL
Date: 02/23/22
Assembly:
Drawing #: 1
Part: Swivel Caster Adapter Plate
Scale: 1:1



Notes:
1/8" Aluminum Plate
Qty.1

Standard Tolerances:
Assume to be true unless otherwise stated
X.X ± 0.1
X.XX ±0.01
X.XXX ±0.005

Drawn By: AL

Date: 6/7/2022

Assembly:

Drawing #:

Part: Frame Brace - Left Side

Scale: 1:2

Appendix H: Safety Review

Student Project Hazard Assessment Form

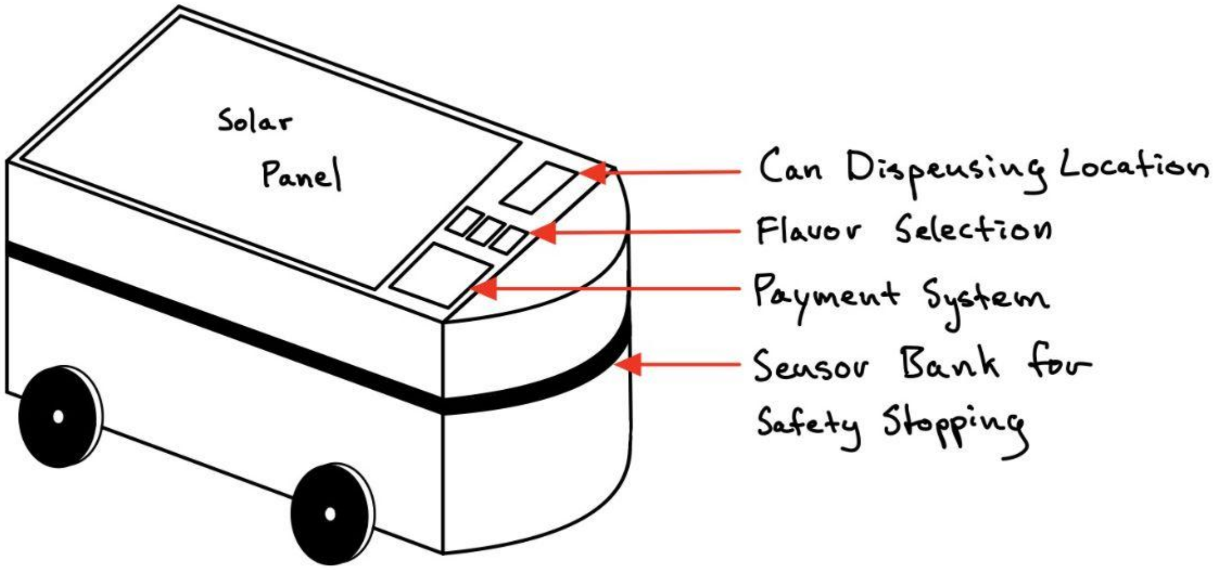
This form is to be used for student projects where the primary hazards are associated with engineering work (physical, mechanical, electrical, etc.). Chemical and biological focused projects require a separate form.

Complete this form and obtain all the required approvals (Faculty Advisor, Department Chair, Laboratory Manager, EH&S, etc.) before proceeding with the project. Please refer to the hazard assessment guide for assistance in filling this form.

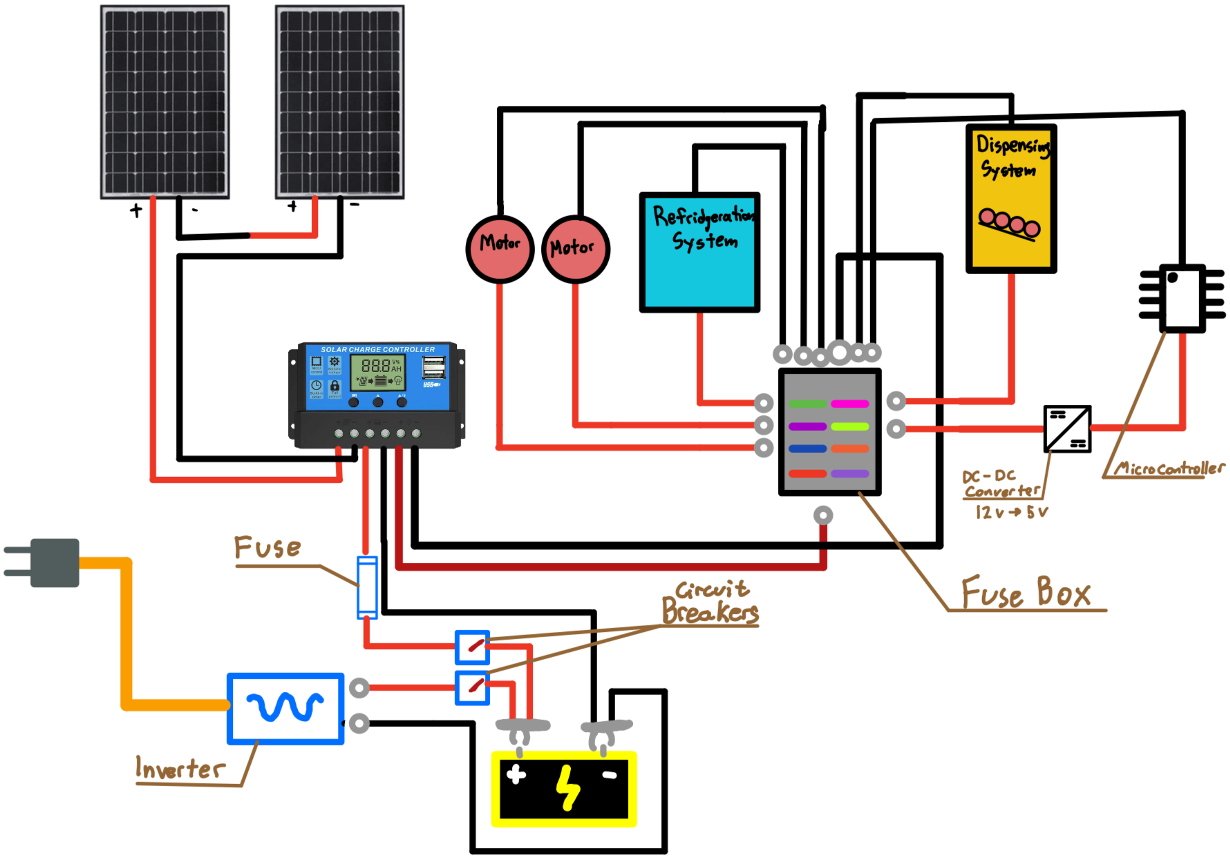
Project Title: Roving Vending Machine			
Project Team Members: Antonio Matusich - amatusich@scu.edu Alec Lindeman - alindeman@scu.edu Nick Elwell - nelwell@scu.edu Jordan Hibbs - jhibbs@scu.edu Jagos Jovanovic - jjovanovic@scu.edu			
Project Advisor			
Name: Dr. Godfrey Mungal	**Department:**	**Phone:**	**Email:**
	Mechanical Engineering	408-554-2375	mgmungal@scu.edu
Proposed Project Location(s) (Department, building, room#): Mechanical Engineering, Sobrato Campus for Discovery and Innovation, SCDI 1110 (Project Space)			
Anticipated Dates of Project Duration: January 3rd, 2022 (Start of Building/Testing Phase) – May 9th, 2022 (Week of Final Presentation)			
Summary of Project Objectives: ● Remote controlled roving vending machine that can turn up to 360 degrees, move forward and backward, and stop on command			

- Solar energy conversion subsystem that uses a solar panel to charge an on-board battery that provides power for all of the vehicle's functions
- Built-in refrigerator that keeps the canned drinks at a cold temperature of approximately 37 degrees Fahrenheit
- User-friendly payment system that is integrated with the dispensing system to deliver the customer their purchase
- Structure that houses all components, keeping them safe and minimally affected by external forces

External Sketch:



Internal Power and Components Diagram:


+
-
+
-
Motor
Motor
Refridgeration System
Dispensing System
SOLAR CHARGE CONTROLLER
888
DC-DC Converter
12v → 5v
Microcontroller
Fuse
Circuit Breakers
Fuse Box
Inverter
+
-

Hazard Checklist (check all that apply)

Identify all the tasks that must be completed for your project. Carefully evaluate each task to determine if there are any associated hazards. After identifying the hazards of your project, you will be asked to assess the risk connected to each hazard and to identify control measures that will either eliminate the hazard or reduce the risk to an acceptable level. Safe work procedures for each step involving a known hazard will need to be developed.

HAZARDOUS CONDITIONS/PROCESSES/ACTIVITIES		
Electrical Hazards ☐Electrical parts and assemblies > 50V or high current ☒Batteries ☐Control Panels	**Mechanical Hazards** ☒Power tools and equipment ☒ Machine guarding/power transmission – gears, rotors, wheels, shafts, belt/chain drives, rotating parts, pinch points ☒Robotics ☐Sharp Objects ☐ Stored Energy (springs, gravity, pneumatic, hydraulic, pressure)	**Physical Hazards** ☐ Extreme temps (high temp fluids: water > 160 °F, steam, hot surfaces > 140 °F, cryogenic fluids ☐ Material handling of heavy objects ☐ Elevated heights (scaffolding, ladders, roofs, lifts, etc.) ☐ Overhead falling objects (cranes, hoists, drones, projectiles, etc.) ☐ Confined Spaces ☐Airborne Dusts ☐Bonding / Grounding ☐Electrostatic Discharge
Reaction Hazards	**Hazardous Processes**	**Other Hazards**

☐Explosive
☐Exothermic, with potential for fire, excessive heat, or runaway reaction
☐Endothermic, with potential for freezing solvents decreased solubility or heterogeneous mixtures
☐Gases Produced
☐Hazardous reaction intermediates/products
☐Hazardous side reactions
☐Generation of air contaminants (gases, aerosols, or particulates)
☐Heating Chemicals
☐Large mass or volume
☐Pressure > Atmospheric
☐Pressure < Atmospheric
☐Scale-up of Reaction
☒Metal Fabrication (welding, cutting, drilling, etc.), Soldering,
☒Construction/Assembly, etc.
☒Noise > 80 dBA
☐Vehicle traffic
☐Hazardous waste generation
☐Other (list):

Hazard Checklist (continued)

HAZARDOUS AGENTS

Physical Hazards Of Chemicals	Health Hazards of Chemicals	Non-Ionizing Radiation	Biohazards
☒Compressed Gases ☐Cryogens ☐Explosives ☐Flammables ☐Oxidizers ☐Peroxides or Peroxides Formers ☐Pyrophorics ☐Water Reactives	☐Acute Toxicity ☐Carcinogens ☐Nanomaterials ☐Reproductive Toxins ☐Respiratory or Skin Sensitization ☐Simple Asphyxiant ☐Skin Corrosion/ Irritation ☒Hazards Not Otherwise Classified	☐Lasers ☐Magnetic Fields (e.g. NMR) ☐RF/Microwaves ☐UV Lamps	☐Bsl-2 Biological Agents ☐rDNA ☐Human Cells, Blood, BBP ☐Animal Work ☐Other (List):

Description of Potential Hazards

Provide a summary of the procedure and describe the risks associated with the each hazard that you have identified above or on the previous page. Use one box below per hazard. You may add supplemental pages if needed. Define the hazard control measures that will be employed to minimize the risks based on the hierarchy of controls (elimination, substitution, engineering controls, administrative controls, PPE), and then describe specific control measures you will use (e.g. Work on system de-energized, receive hazard specific training, shield hot surfaces, guard pinch points, relieve stored energy, wear protective equipment, use less hazardous chemical, etc.). Refer to "Hierarchy of Controls" in the instructions sheet for more information to decide which hazard controls measures are most appropriate

Hazardous Activity, Process, Condition, or Agent : Power tools and equipment

Summary of Procedure or Tasks:

Raw material processing (cutting to length / deburring)

Milled and Lathed parts

Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk):

Mills and Lathes and general power tools are very powerful machines that can be very hazardous if used incorrectly. Some hazards present when using these machines are:

- Sharp cutters
- Hair/clothing getting caught in moving machine parts.
- Eye injuries.
- Metal splinters and burrs.
- Flying debris.

Hazard Control Measures (what you will do to eliminate the hazard or minimize risks):

Ways to minimize the risk associated with using power tools and machine tools:

- Remove any baggy clothing, jewelry and tie back long hair before operating machines
- Take proper training and safety course prior to attempting any work involving power and machine tools
- Locate and ensure you are familiar with all machine operations and controls.
- Ensure all guards are fitted, secure and functional. Do not operate if guards are missing or faulty.
- Check workspaces and walkways to ensure no slip/trip hazards are present.
- Ensure the cutter is in good condition and securely mounted.
- Check coolant delivery system to allow for sufficient flow of coolant.
- Keep clear of moving machine parts.
- Follow correct clamping procedures. Keep overhangs as small as possible and check workpiece is secure.
- Set the correct speed to suit the cutter diameter, the depth of cut and the material.
- Switch off the machine when work is completed.
- Remove milling cutters and store them safely.
- Before making adjustments and measurements or cleaning swarf accumulations, switch off and bring the machine to a complete standstill.
- Leave the machine and work area in a safe, clean and tidy state.

Hazardous Activity, Process, Condition, or Agent : Battery

Summary of Procedure or Tasks:

The battery will be connected up to a solar panel and will power all electrical subsystems within the project. The battery will be 12V, roughly 60 Ah. Currently the battery type is between nickel metal hydride and Lithium-ion. The final decision will come down to the power needs of other subsystems, and the available budget space. Both perform similarly with safety measures.

Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk):

Shorting the circuit can cause a rapid spike in current and heat leading to a fire or even combustion of the battery.

This can occur due to:

- Poorly connected wiring that may come loose or become exposed.
- Insufficient water protective measures

Hazard Control Measures (what you will do to eliminate the hazard or minimize risks):

To minimize this risk, additional care must be taken when wiring the systems to ensure no wires will come loose. The wiring should be well protected from water as well as the structural system must provide sufficient water proofing measures. Lastly a fail safe system which disconnects wiring when a short is detected.

Hazardous Activity, Process, Condition, or Agent (identified from previous page): Machine guarding/power transmission – gears, rotors, wheels, shafts, belt/chain drives, rotating parts, pinch points

Summary of Procedure or Tasks:

The roving vending machine will contain four wheels for movement of the robot and 4 servo motors for the dispensing system.

Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk):

The first hazard presented with the wheels is a collision between the robot and exterior objects, specifically people as the robot will be maneuvering in high human traffic areas. In addition, the presence of rotating parts within the robot presents a hazard for injury while under operation.

Hazard Control Measures (what you will do to eliminate the hazard or minimize risks):

The main control measure for eliminating the collision hazard will be our safety system that will use proximity and infrared sensors to detect the presence of an object in front of the robot. As for the presence of rotating parts within the robot, we will implement guards surrounding the area to limit the possibility of something impacting the device while in rotation

Hazardous Activity, Process, Condition, or Agent : Robotics

Summary of Procedure or Tasks:

A user will be controlling the movement of the roving vending machine with a remote control. The vehicle will be able to turn up to 360 degrees, move forward and backward, and stop on command.

Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk):

This activity is one of the primary goals of the roving vending machine. However, this vehicle will be driving and maneuvering through groups of people on campus. This means there is a risk someone may be hit by the machine.

Hazard Control Measures (what you will do to eliminate the hazard or minimize risks):

There will be infrared sensors located on the exterior faces of each side of the roving vending machine.

The goal is to create a system that utilizes these sensors to force the vehicle to stop on its own when an obstacle is in the way.

Hazardous Activity, Process, Condition, or Agent: Compressed Gasses

Summary of Procedure or Tasks:

R-134a refrigerant will be a compressed gassed used in the refrigeration subsystem.

Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk):

Hazards of using R-134a refrigerant can occur when it is both compressed and handled in general. If not contained properly, the gas could leak and become both a breathing and eyesight hazard. If the gas is overpressurized, it can cause damage to the system and in extreme scenarios, explosions and fires. This can occur in the building process as well as general operation if proper precautions are not taken.

Hazard Control Measures (what you will do to eliminate the hazard or minimize risks):

To begin with, we will be purchasing an existing refrigeration system and modifying it for our application. This will minimize the risk of improper fittings between the pipes. Additionally, any modification to this system will be done wearing the proper safety clothing, gloves, facewear, and eyewear. We will perform all of these actions in well-ventilated areas. Thorough inspection must be performed before actual use of the system.

Hazardous Activity, Process, Condition, or Agent: Hazards Not Otherwise Classified (Health Hazards of Chemicals)

Summary of Procedure or Tasks:

The refrigerant in the refrigeration system includes potential chemical hazards.

Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk):

Leaking refrigerant can release toxic fumes if not in a well ventilated area, this can be negative for the health of individuals around. Additionally, leaking refrigerant in an outdoor setting would be detrimental to the local environment, and will be washed into larger water systems with rainfall.

Hazard Control Measures (what you will do to eliminate the hazard or minimize risks):

Along with purchasing a pre-existing refrigeration system, additional precautions can be taken. Working in a well ventilated space when operating or modifying the system can minimize health risks to those nearby. Additionally, for initial testing, anticipating that a leak may occur can better prepare for a safe response. Doing things such as a drip pan underneath, close inspection to detect leaking as soon as possible, and ensuring all are wearing proper safety equipment.

Hazardous Activity, Process, Condition, or Agent : Metal Fabrication (welding, cutting, drilling, etc.), Soldering,

Summary of Procedure or Tasks:

Constructing the robot will primarily consist of a metal frame and a plastic shell. Electrical components will be soldered for final connection.

Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk):

Cutting and drilling metal can expose the operator to a number of hazards:

- Sharp cutters
- Hair/clothing getting caught in moving machine parts.
- Eye injuries.
- Metal splinters and burrs.
- Flying debris.

Soldering components of the electrical system present its own set of hazards:

- Toxic fume inhalation
- High temperature iron can burn skin
- High temperature iron can lead to fires

Hazard Control Measures (what you will do to eliminate the hazard or minimize risks):

Proper PPE will be worn at all times when using power tools. Additionally, the team will go through proper safety and operational training for all fabrication machines that will be used, thus everyone will be confident in their ability to safely operate all necessary tools. Metal fabrication will be done in a safe, controlled environment under faculty supervision.

Ways to minimize the risk associated with using power tools and machine tools:

- Remove any baggy clothing, jewelry and tie back long hair before operating machines
- Take proper training and safety course prior to attempting any work involving power and machine tools
- Wear proper eye protection and other PPE to reduce the risk of injury
- Locate and ensure you are familiar with all machine operations and controls.
- Ensure all guards are fitted, secure and functional. Do not operate if guards are missing or faulty.
- Check workspaces and walkways to ensure no slip/trip hazards are present.

- Ensure the cutter is in good condition and securely mounted.
- Check coolant delivery system to allow for sufficient flow of coolant.
- Keep clear of moving machine parts.
- Follow correct clamping procedures. Keep overhangs as small as possible and check that workpiece is secure.
- Set the correct speed to suit the cutter diameter, the depth of cut and the material.
- Switch off the machine when work is completed.
- Remove milling cutters and store them safely.
- Before making adjustments and measurements or cleaning swarf accumulations, switch off and bring the machine to a complete standstill.
- Leave the machine and work area in a safe, clean and tidy state.

Ways to minimize the risk associated with soldering:

- Proper room ventilation to prevent fume inhalation
- Turn off soldering machine when finished to reduce the risk of fires.
- Set up all soldering operations in stable fixtures to reduce the risk of burns.
- Wear eye protection to reduce the risk of splatter injuring eyes.

Hazardous Activity, Process, Condition, or Agent: Construction/Assembly, etc. (welding, cutting, drilling, etc.), Soldering,

Summary of Procedure or Tasks:

Bolting/ welding frame components and mounting all subsystems to frame.

Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk):

Hazards associated with bolting frame and mounting subsystems to frame:

- Pinch points between components in tight places
- Drills, impact wrenches, and air ratchets can catch loose and baggy clothing.
- Air ratchets and drills can kickback when loosening or tightening bolts

Hazards associated with welding frame components:

- Electrical shock resulting from unmaintained equipment or faulty ground
- Burns from metal splatter or contacting welding spots
- Eye damage from electrical arc

- Eye damage from metal splatter
- Toxic fume inhalation
- Fires from sparks landing on flammable materials

Hazard Control Measures (what you will do to eliminate the hazard or minimize risks):

Ways to reduce risk associated with bolting frame and mounting subsystems to frame:

- Wear protective gloves to reduce risk of fingers getting caught in pinch points
- For torquing bolts to final spec, use manual ratchet to avoid kickback from drill or air ratchet
- Remove loose clothing, jewelry and tie back long hair prior to using drills, impact wrenches, and air ratchets

Ways to reduce risk associated with welding frame components:

- Wear proper welding attire (i.e. Welding gloves, apron, long pants, closed toed shoes, etc.)
- Wear auto darkening welding helmet to protect eyes and face from metal splatter and bright arc of welding puddle
- Weld in well ventilated areas to reduce risk of toxic fume inhalation
- Inspect welding equipment for damage prior to every use
- Ensure workpiece is properly grounded to avoid electrical shock
- Clear welding area of any flammable materials (i.e. cardboard, cloth, paper, flammable liquids, etc.)
- Inspect welding area for 10-15 minutes after welding to ensure no sparks have started embers in surrounding material
- Know where fire extinguisher is and be prepared to use it in the case of fires

Hazardous Activity, Process, Condition, or Agent (identified from previous page): Noise > 80 dBA

Summary of Procedure or Tasks:

Metal fabrication, construction, testing, and assembly processes will emit noise potentially greater than 80 dBA.

Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk):

Possible hearing damage could occur for individuals. Also, loud noises can disturb nearby people.

Hazard Control Measures (what you will do to eliminate the hazard or minimize risks):

We intend to perform our metal fabrication, construction, testing, and assembly in a closed area to mitigate how much sound is emitted to nearby individuals. Additionally, each member of our team will wear construction over-the-head earmuffs so no hearing damage occurs.

SAFETY EQUIPMENT and PPE

Select the appropriate PPE and safety supplies you will need for the project (Check all that apply)

☒ Appropriate street clothing (long pants, closed-toed shoes)

☒ Gloves; indicate type: Latex gloves for raw material handling and assembly. Not to be used for machining

☒ Safety glasses/ goggles

☒ Face shield and goggles

☐ Lab coat

☐ Hearing protection

☒ Fire extinguisher

☐ Eyewash/safety shower

☐ Spill kit

☐ Other (list):

TRAINING REQUIREMENTS

Identify the appropriate training (check all that apply)

☐ Biology & Bioengineering Lab Safety Camino Course – contact Lab Manager or EHS to enroll

☐ Chemistry & Biochemistry Lab Safety Camino Course – contact Lab Manager or EHS to enroll

☒ Electrical Safety for Engineering Camino Course – contact EHS to enroll

☒ LiPo Battery Safety Training – contact MAKER Lab to enroll

☒ Review of SDS for chemicals involved in project – access SDS library at: rms.unlv.edu/msds/

☒ Laboratory Specific Training – contact Lab/Shop Owner

☐ Project Specific Training – contact Project Advisor

☐ Other (describe below):

Appendix I: Senior Design Conference Slides

SANTA CLARA UNIVERSITY
School of Engineering

AVA

The Roving Vending Machine

Nick Elwell, Jordan Hibbs, Jagos Jovanovic, Alec Lindeman, Antonio Matusich

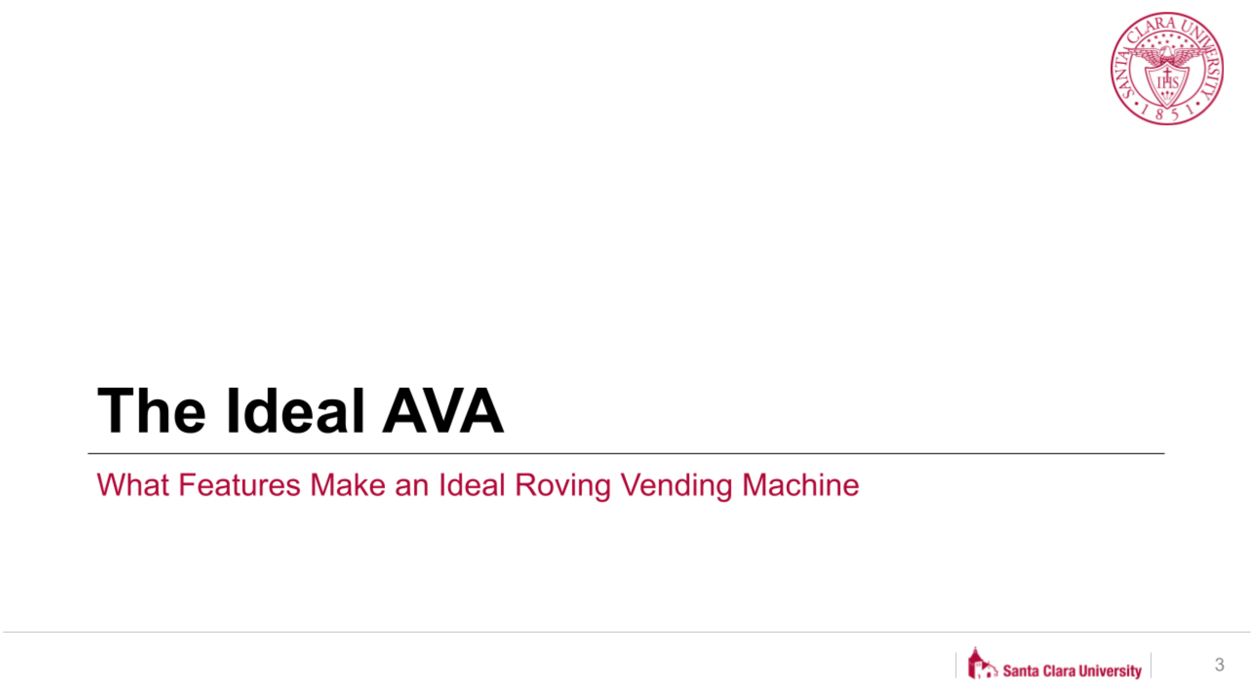
Advisor: Dr. Godfrey Mungal

Santa Clara University

Why a Roving Vending Machine?

Provides drinks to students and staff
On college campuses
Quickly, on the go, in between classes

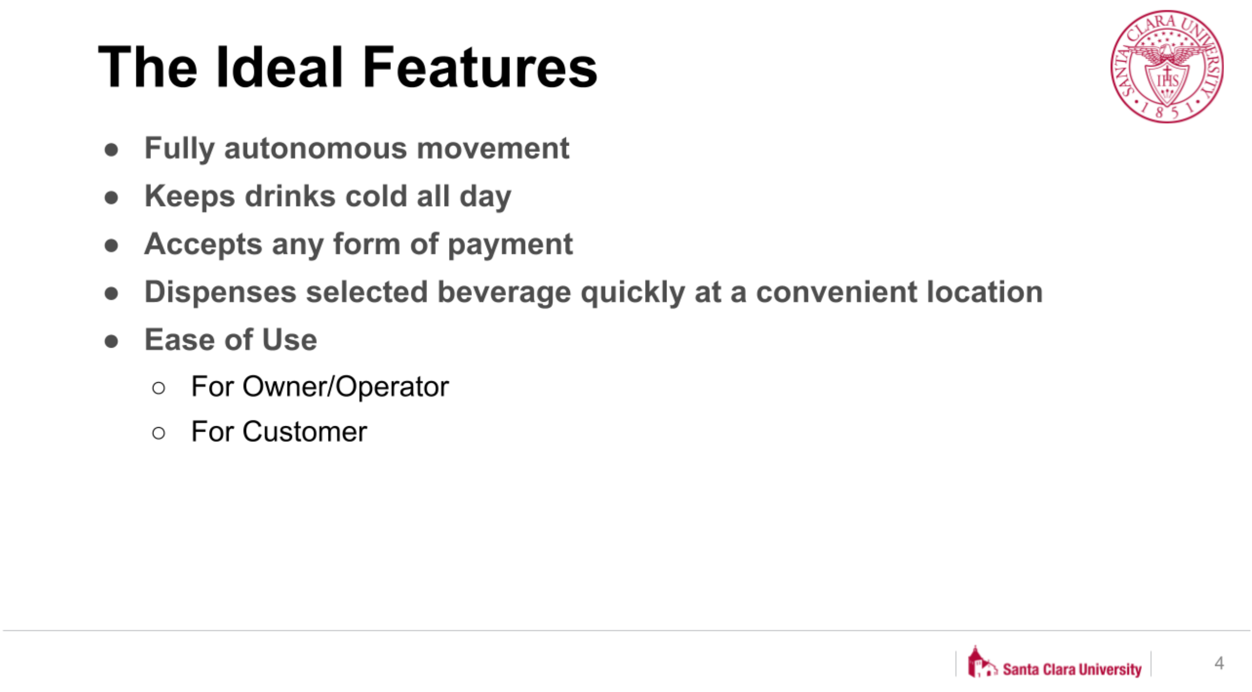
Santa Clara University



The Ideal AVA

What Features Make an Ideal Roving Vending Machine

Santa Clara University 3



The Ideal Features

- **Fully autonomous movement**
- **Keeps drinks cold all day**
- **Accepts any form of payment**
- **Dispenses selected beverage quickly at a convenient location**
- **Ease of Use**
  - For Owner/Operator
  - For Customer

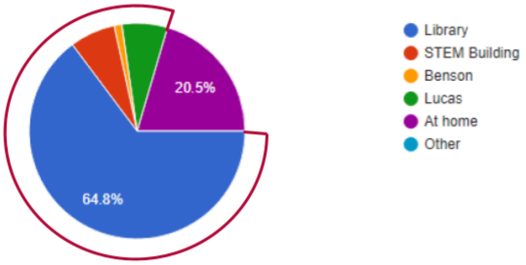
Santa Clara University 4

Market Research

Is there a reason to build AVA?

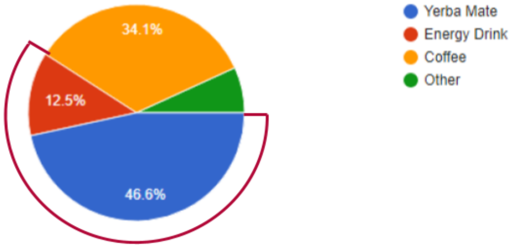
Customer Survey

Q: What is your preferred location to study or do homework in?



79.5% of Students prefer to study on campus

Q: What is your preferred beverage while doing schoolwork?



59.1% of Students prefer canned caffeinated beverages when doing school work

Scope of Senior Design Project

What can 5 Mechanical Engineers do in 30 Weeks?

Revised Prototype Goals

- ~~Fully autonomous movement~~

  ↳ Remote control with autonomous stopping
- ~~Accepts all forms of payment~~
- Keeps drinks cold all day
- Dispenses one drink at a time at a convenient location
- Ease of use
  - For owner/operator
  - For customer

The Big 4

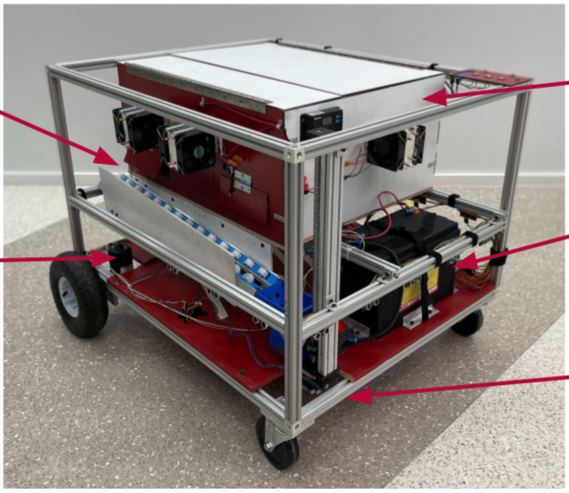
The Core Problems that Need to be Solved

4 Problems to Solve

1. How to dispense a can?
2. How does this thing move?
3. How do we keep cans cold?
4. How do we tie everything together?

Solution: Subsystems

Subsystem Breakdown



Dispensing Subsystem

Control Subsystem

Refrigeration Subsystem

Integration Subsystem: Power

Integration Subsystem: Structural

Dispensing

Getting the Can from the Cooler to the Customer

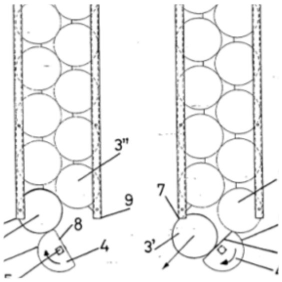
Existing Technology

1. Spiral Mechanism:

Design Inspiration:

- Multiple rows of dispensing to allow for multiple flavor options

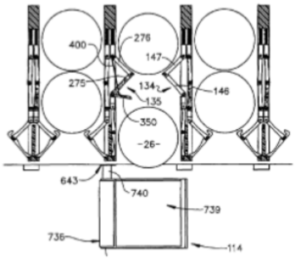
2. Vertical Stack Method:



Design Inspiration:

- Gravity feeding to release mechanism.
- Rotating Mechanism

3. Mechanical Gate:



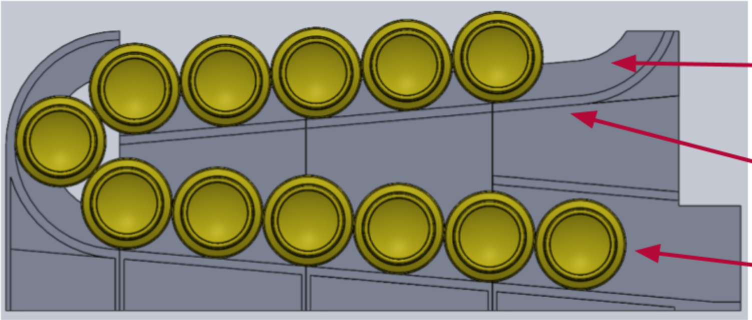
Design Inspiration:

- Linkage gate mechanism to release cans

Can Storage

Requirements:

1. Minimize height requirement of AVA
2. Reliable can movement
3. Hold 36 total cans



Guide walls to ensure reliable can movement

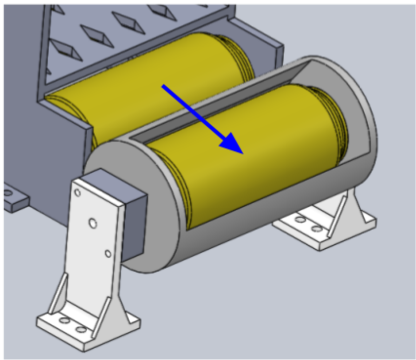
5° decline to utilize gravity feeding

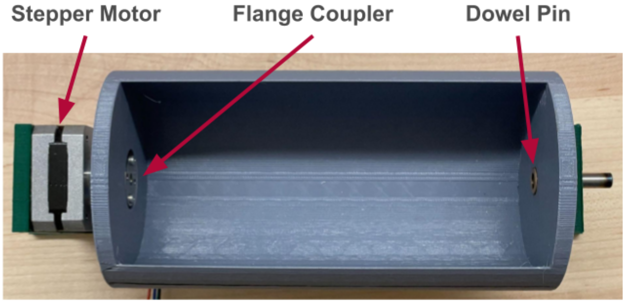
Track holds 12 cans

Rotating Mechanism

Requirement:

- Consistently dispense one can of selected flavor

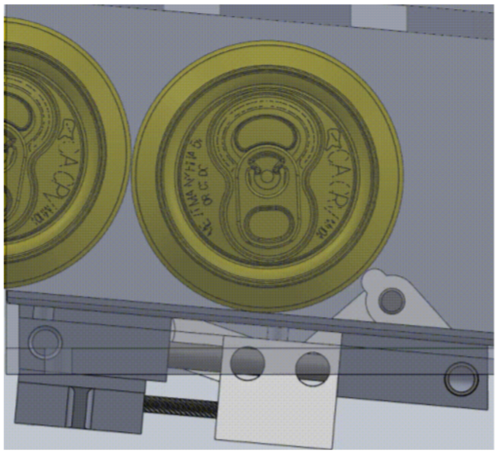


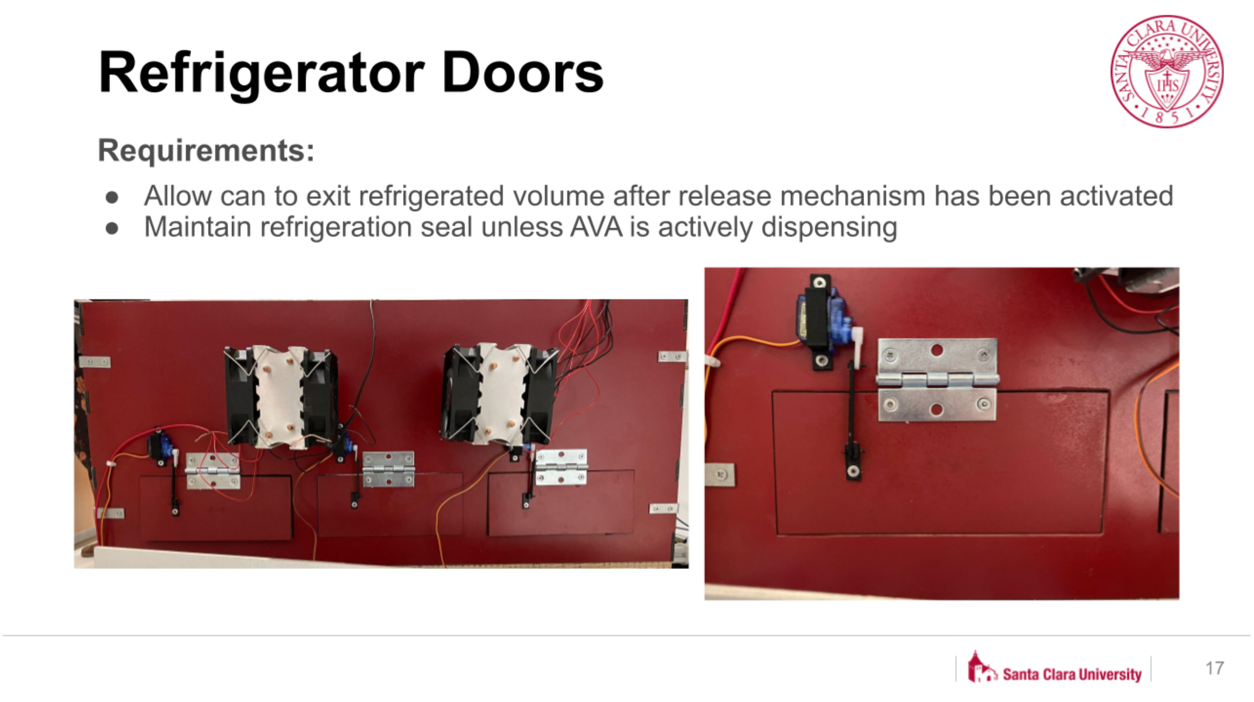


Release Mechanism

Requirements:

- Consistently dispense a can without needing to overcome the gravitational force of the other cans in the track.

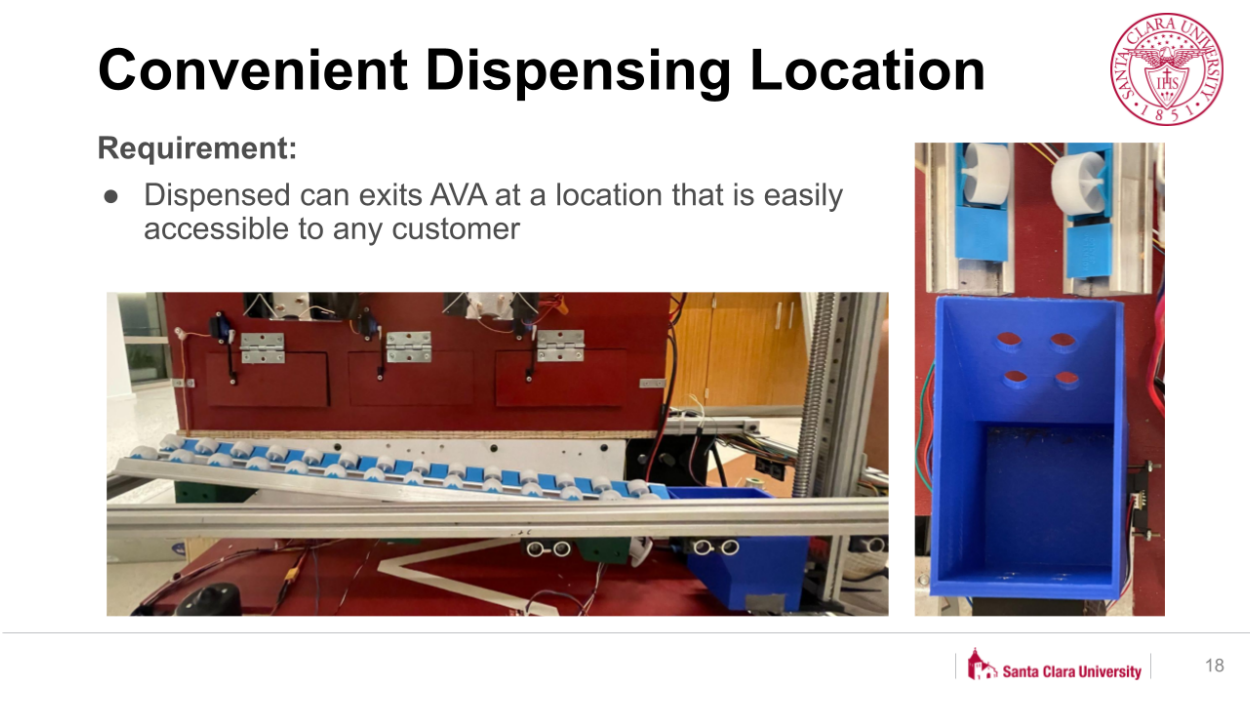




Refrigerator Doors

Requirements:

- Allow can to exit refrigerated volume after release mechanism has been activated
- Maintain refrigeration seal unless AVA is actively dispensing

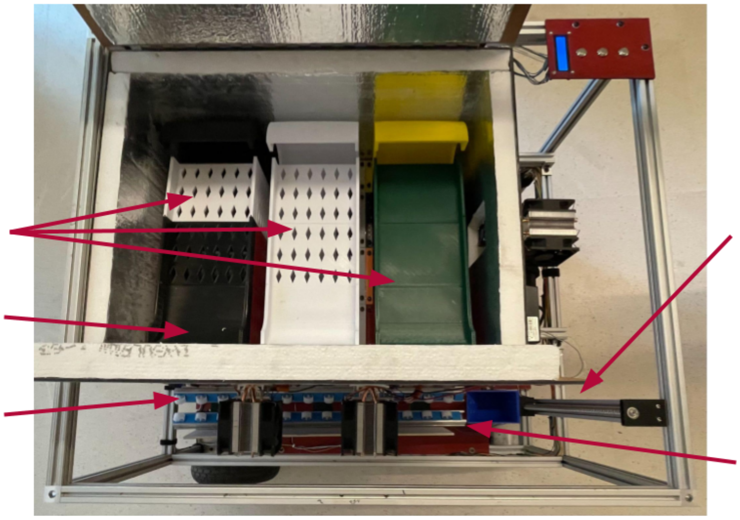


Convenient Dispensing Location

Requirement:

- Dispensed can exits AVA at a location that is easily accessible to any customer

Final Dispensing Design



Storage Tracks

Release Mechanism

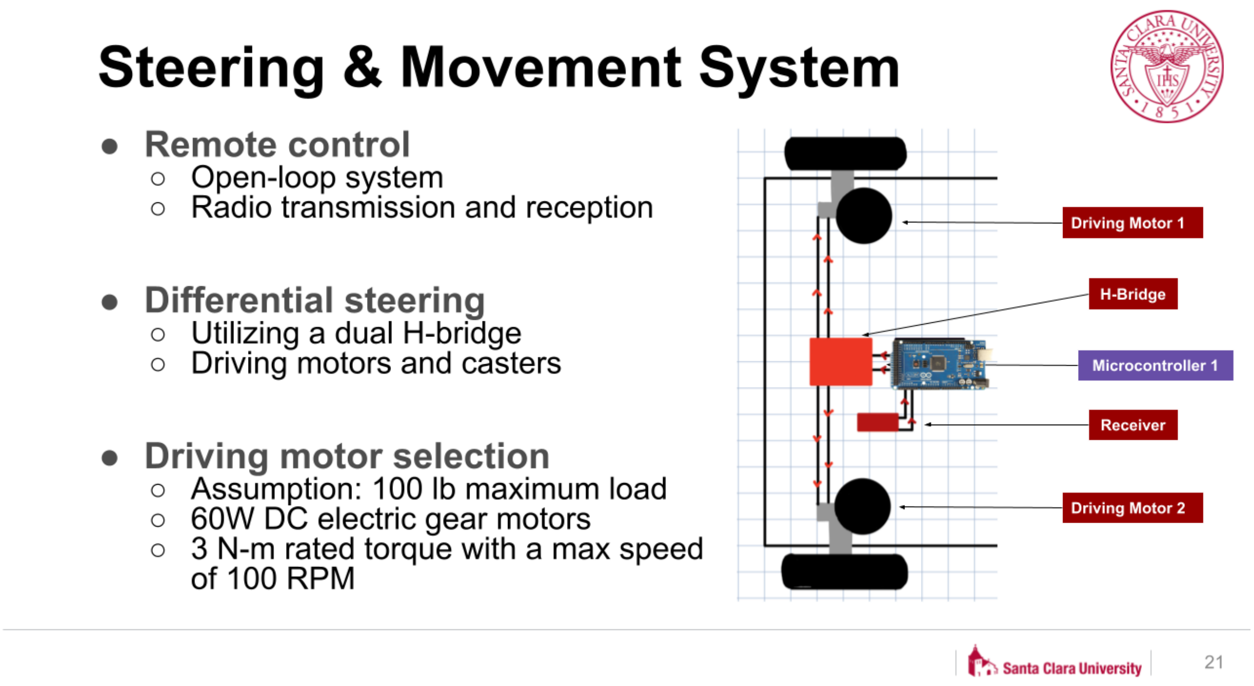
Refrigerator Doors

Lead Screw Assembly

Conveyor Track

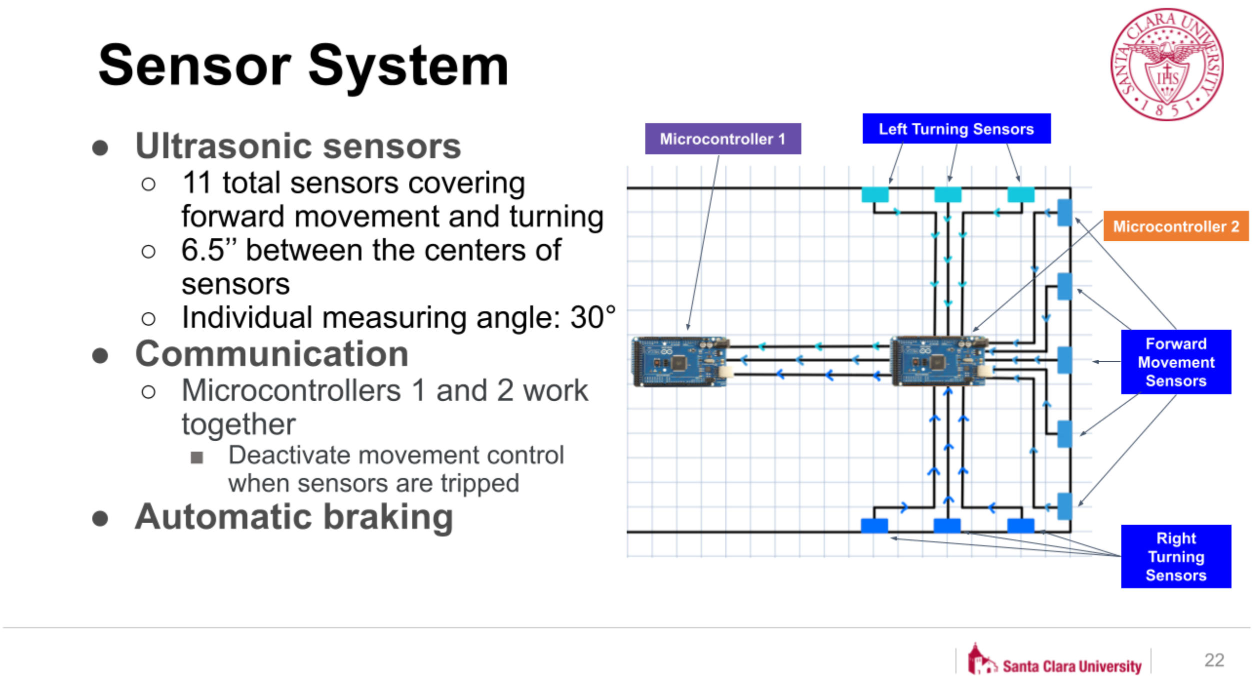
Control

The Brains of AVA



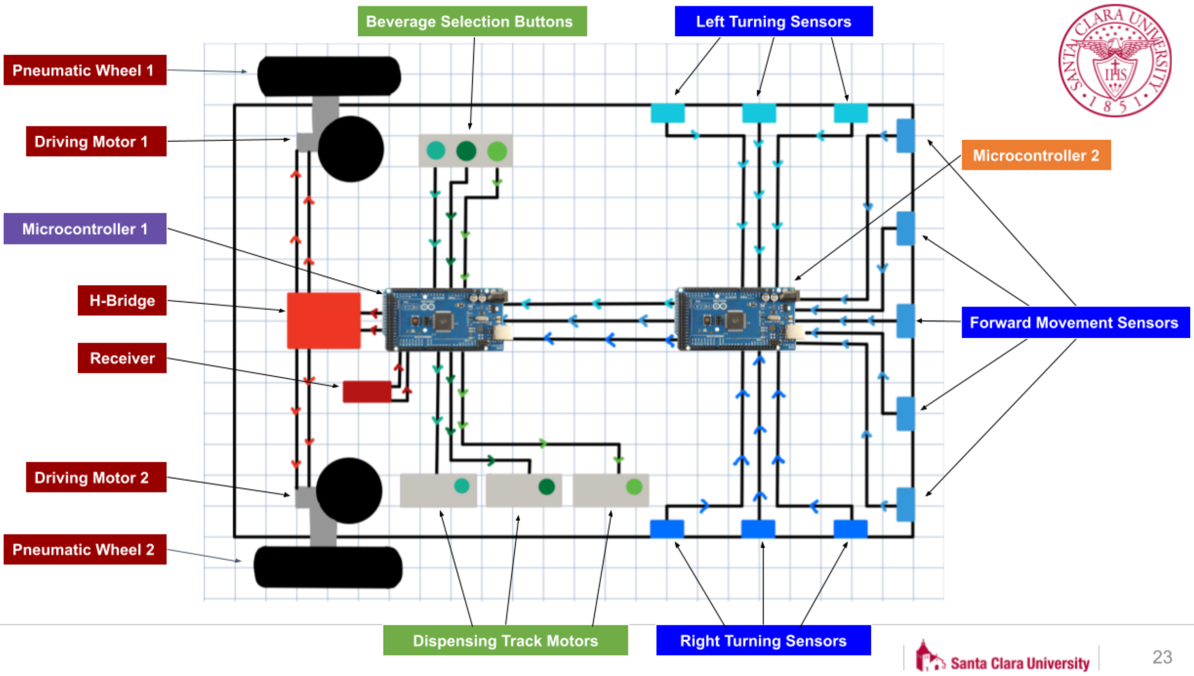
Steering & Movement System

- **Remote control**
  - Open-loop system
  - Radio transmission and reception
- **Differential steering**
  - Utilizing a dual H-bridge
  - Driving motors and casters
- **Driving motor selection**
  - Assumption: 100 lb maximum load
  - 60W DC electric gear motors
  - 3 N-m rated torque with a max speed of 100 RPM



Sensor System

- **Ultrasonic sensors**
  - 11 total sensors covering forward movement and turning
  - 6.5” between the centers of sensors
  - Individual measuring angle: 30°
- **Communication**
  - Microcontrollers 1 and 2 work together
    - Deactivate movement control when sensors are tripped
- **Automatic braking**



Refrigeration

Keeping the Drinks Cold

Refrigeration Calculations

Goal: Maintain 37 °F inside the refrigerated volume

$$\mathrm{Height} := 10.90\,\mathrm{in} \qquad h := 5\,\frac{\mathrm{W}}{\mathrm{m}^2\cdot\mathrm{K}}$$

$$\mathrm{Width} := 24.5\,\mathrm{in} \qquad \mathrm{Ti} := 275.9\,\mathrm{K}$$

$$\mathrm{Length} := 20.89\,\mathrm{in} \qquad \mathrm{To} := 305.4\,\mathrm{K}$$

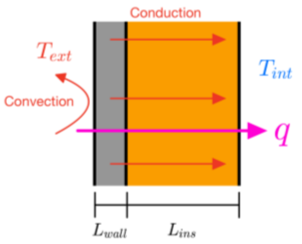
$$\mathrm{Kins} := 0.02\,\frac{\mathrm{W}}{\mathrm{m}\cdot\mathrm{K}} \qquad \mathrm{Lins} := 1.5\,\mathrm{in}$$

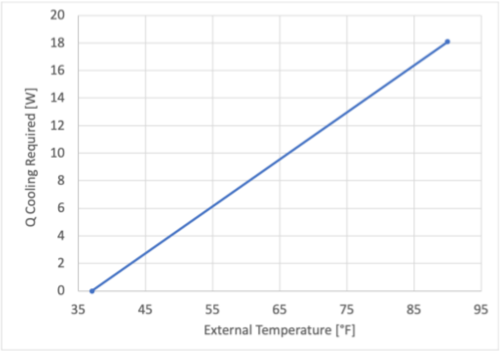
$$\mathrm{Kwall} := 0.25\,\frac{\mathrm{W}}{\mathrm{m}\cdot\mathrm{K}} \qquad \mathrm{Lwall} := \frac{1}{8}\cdot\mathrm{in}$$

$$\mathrm{Area} := 2\mathrm{Height}\cdot\mathrm{Width} + 2\mathrm{Height}\cdot\mathrm{Length} + 2\mathrm{Width}\cdot\mathrm{Length}$$

$$q := \frac{\mathrm{To} - \mathrm{Ti}}{\frac{\mathrm{Lins}}{\mathrm{Kins}} + \frac{\mathrm{Lwall}}{\mathrm{Kwall}} + \frac{1}{h}}\cdot\mathrm{Area}$$

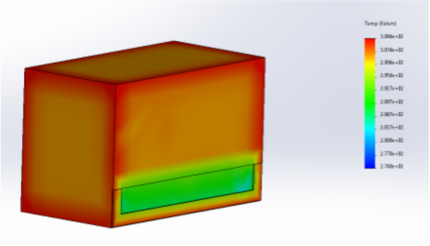
$$q = 18.092\,\mathrm{W}$$



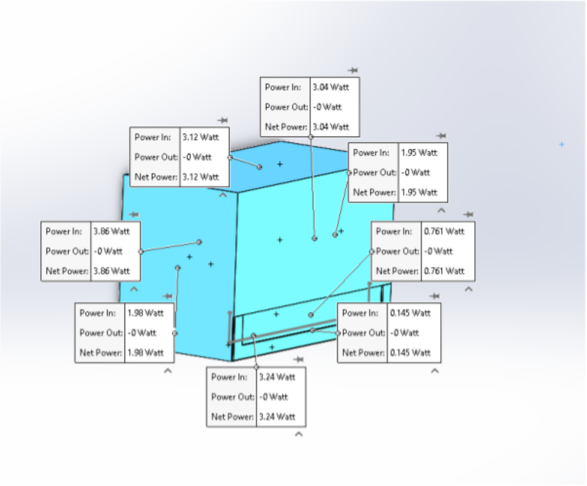


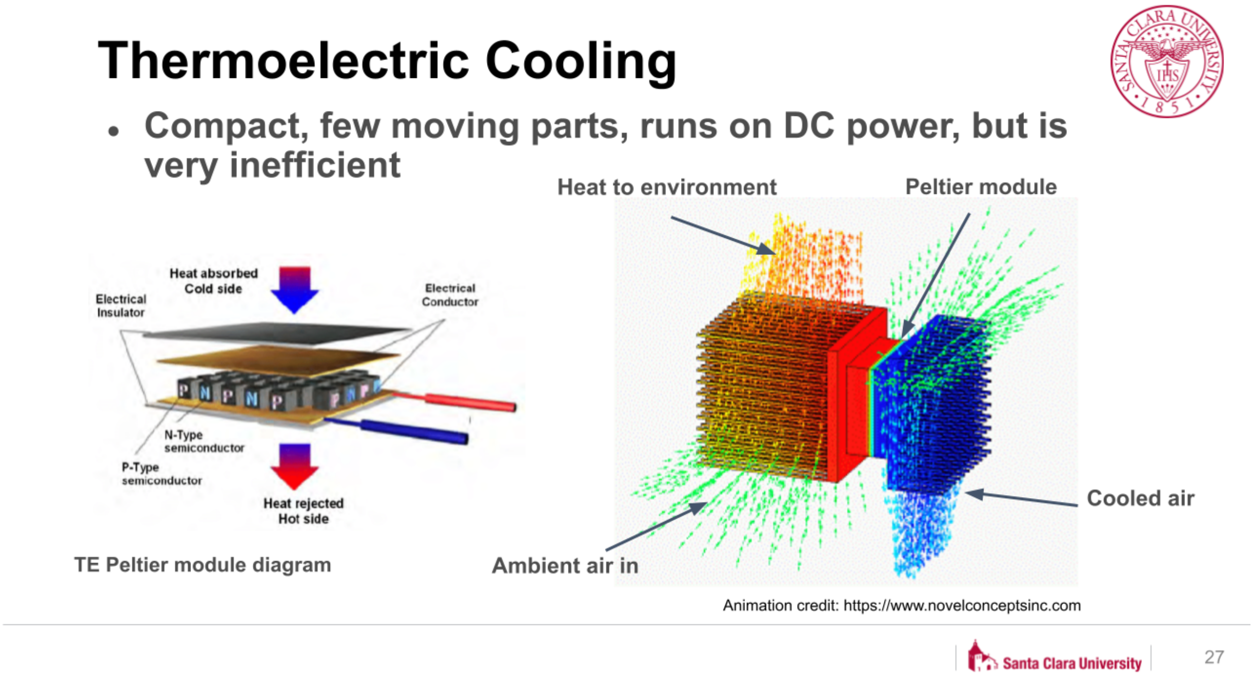
Cooling Power Required [W] vs. External Temperature [°F]

Refrigeration FEA



- Interior set to 37 °F, exterior to 90 °F
- Conduction through walls, convection outside
- Results show 17.5 W of heat loss, agreeing with hand calculations
- Set our estimated need to 20 W of cooling



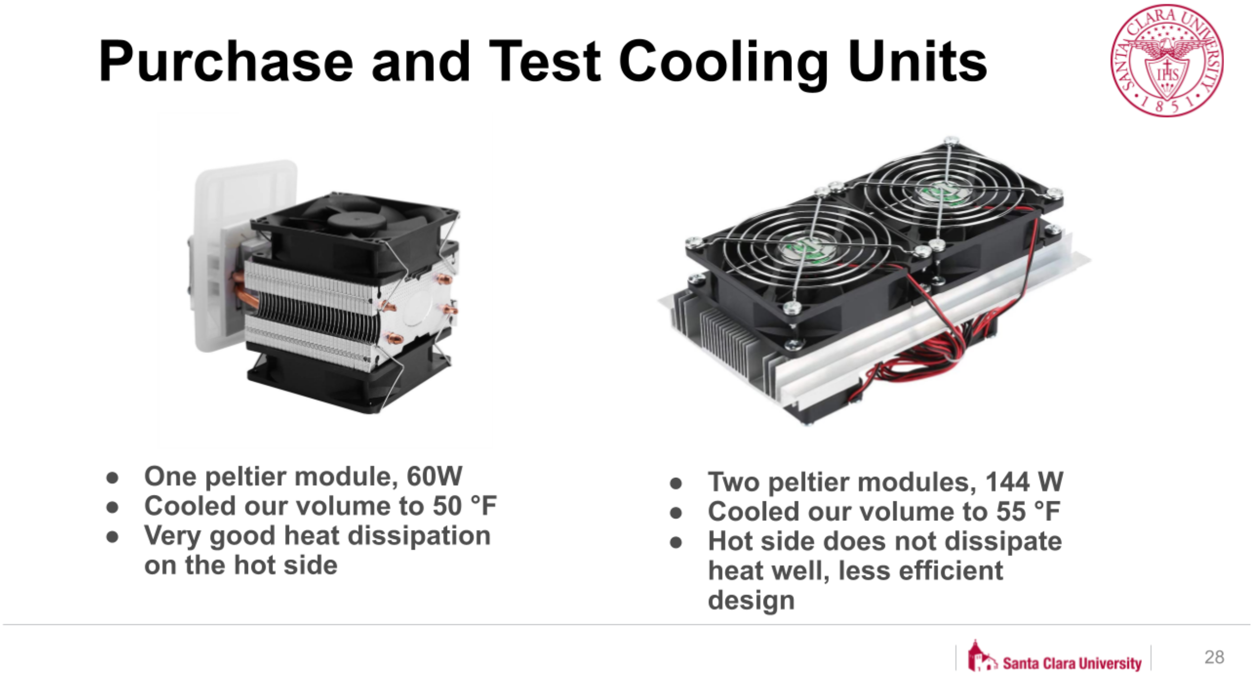


Thermoelectric Cooling

- Compact, few moving parts, runs on DC power, but is very inefficient

TE Peltier module diagram

Animation credit: https://www.novelconceptsinc.com



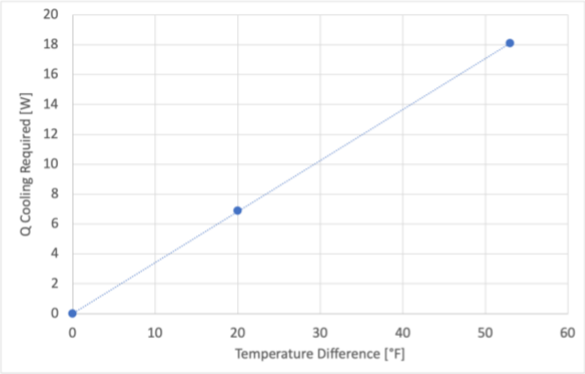
Purchase and Test Cooling Units

- One peltier module, 60W
- Cooled our volume to 50 °F
- Very good heat dissipation on the hot side

- Two peltier modules, 144 W
- Cooled our volume to 55 °F
- Hot side does not dissipate heat well, less efficient design

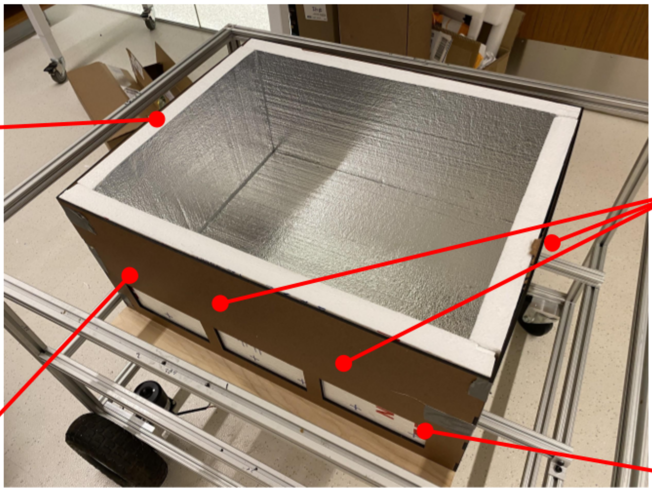
Optimization of Cooling Unit

- Analysis of 50 °F test results
  - As shown, one cooler produced 6.5 W of cooling (≈11 % Efficiency)
- Found that maximum temperature difference is achieved at 3 Amps (½ Power)
- Using 3 coolers will use 108W and should combine to ≈ 19.5 W of cooling power



Cooling Power Required [W] vs. Temperature Difference [°F]

Refrigerated Volume



1.5” Insulation Foam

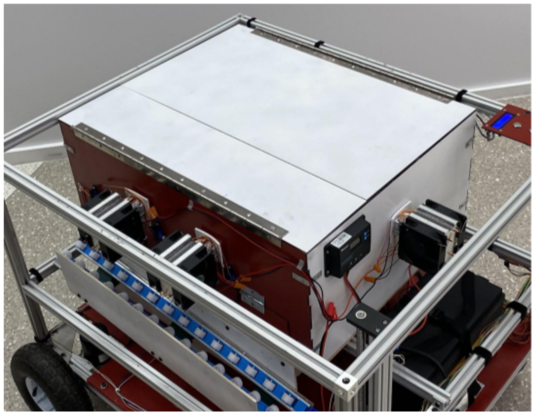
Cooling Unit Locations

3/16” Hardboard Walls

Dispensing locations

Final Refrigeration System

- **Two hinged lids**
- **Cooled air from two of four sides**
- **Temperature testing shows 46 °F at the bottom of the cooler**
  - Inefficiency of TEC made large discrepancies between calculations and testing
- **Lightweight, safe, and compact**



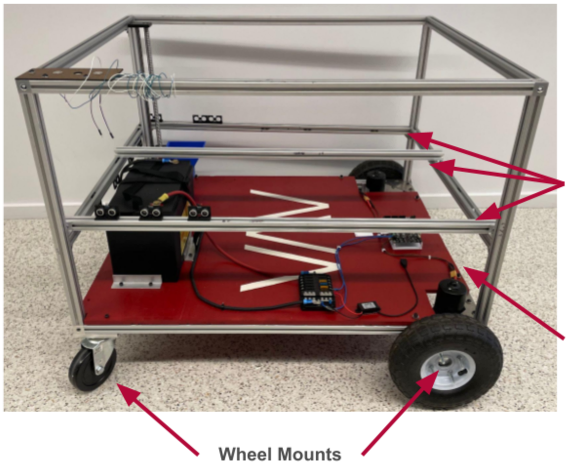
Integration

Tying everything together

Structural Integration

2 Primary Challenges:

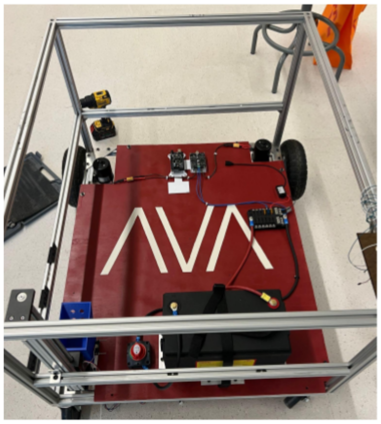
- Capable of withstanding expected loads
- Convenient and adjustable mounting locations

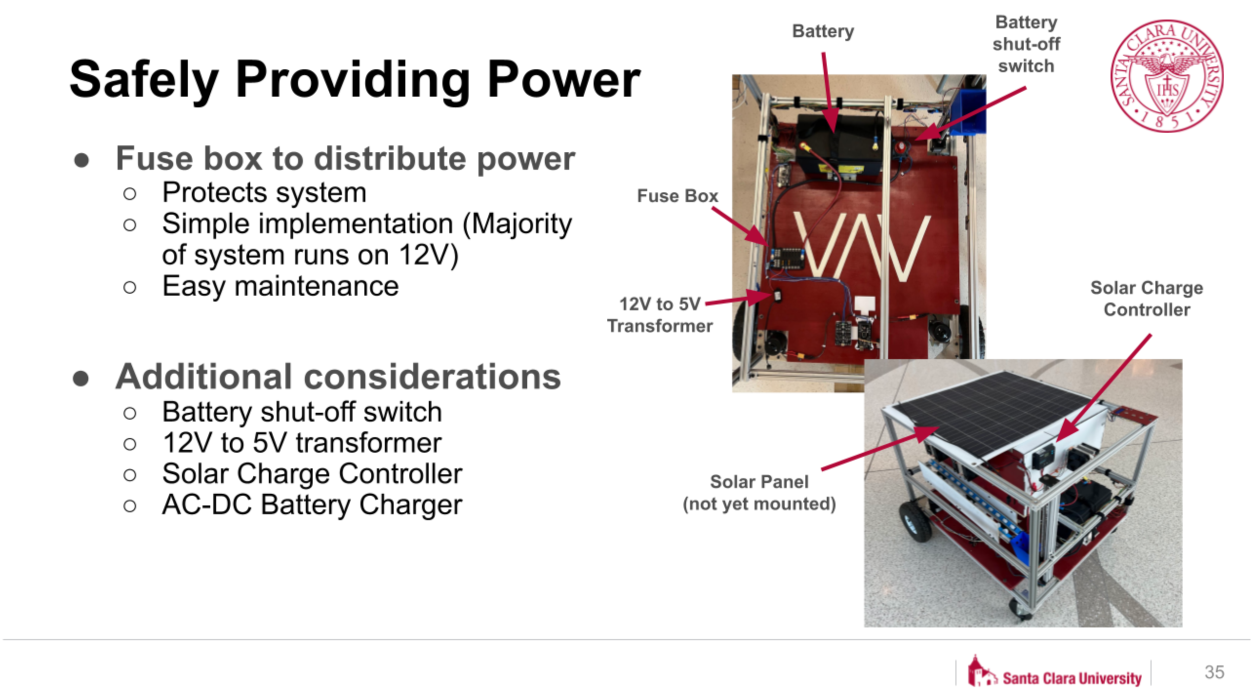


Power Integration

Primary Objectives:

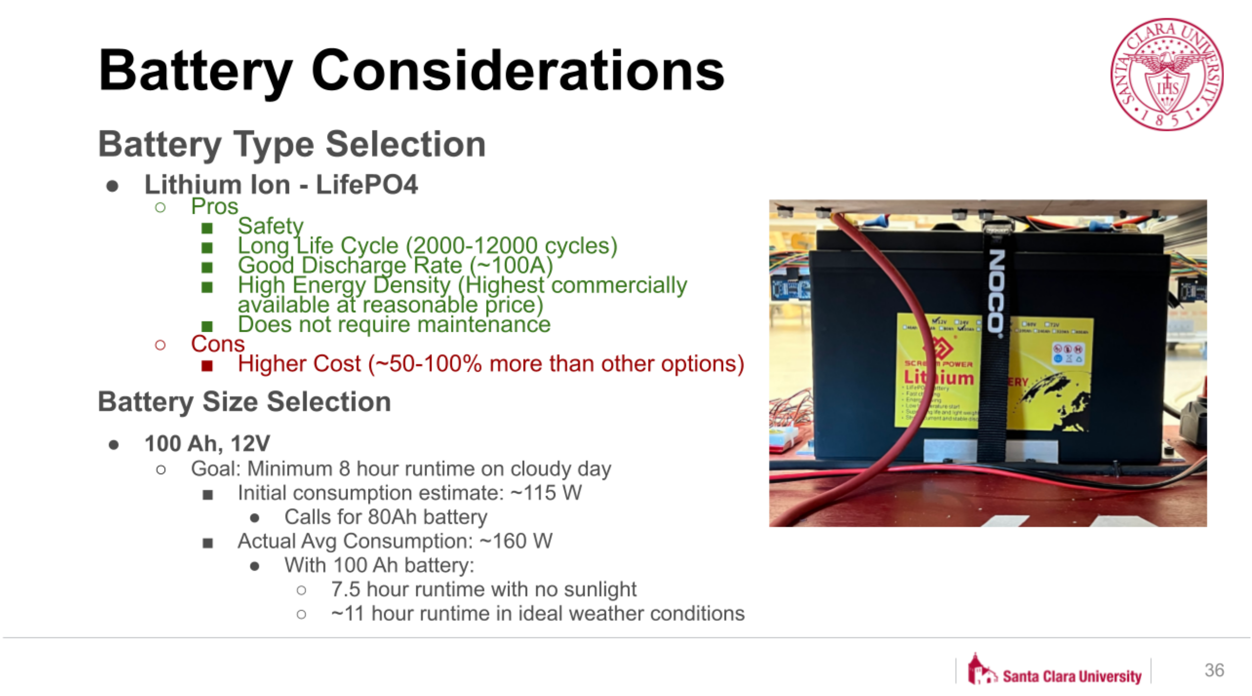
- Safely Provide Power to all Systems
- Anticipate Power Requirements





Safely Providing Power

- **Fuse box to distribute power**
  - Protects system
  - Simple implementation (Majority of system runs on 12V)
  - Easy maintenance
- **Additional considerations**
  - Battery shut-off switch
  - 12V to 5V transformer
  - Solar Charge Controller
  - AC-DC Battery Charger



Battery Considerations

Battery Type Selection

- **Lithium Ion - LifePO4**
  - Pros
    - Safety
    - Long Life Cycle (2000-12000 cycles)
    - Good Discharge Rate (~100A)
    - High Energy Density (Highest commercially available at reasonable price)
    - Does not require maintenance
  - Cons
    - Higher Cost (~50-100% more than other options)

Battery Size Selection

- **100 Ah, 12V**
  - Goal: Minimum 8 hour runtime on cloudy day
    - Initial consumption estimate: ~115 W
      - Calls for 80Ah battery
    - Actual Avg Consumption: ~160 W
      - With 100 Ah battery:
        - 7.5 hour runtime with no sunlight
        - ~11 hour runtime in ideal weather conditions

The Results

Demonstration Video

Manufacturability

Making AVA ready for the mass market

Manufacturing Techniques

Dispensing

- Injection molded tracks and release mechanism
- Bulk discounts for lead screws

Control

- Bulk discount motors

Refrigeration

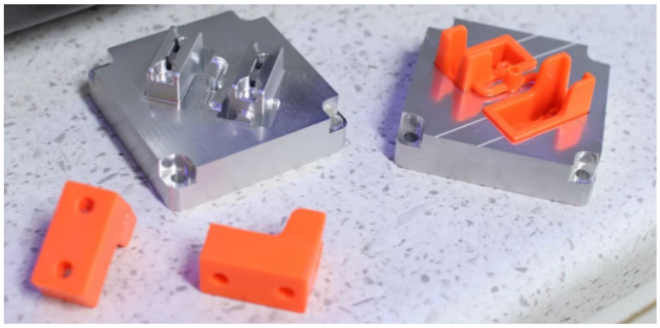
- Rotomolded Cooler
- Bulk Discount TE Coolers

Power

- Bulk discount components

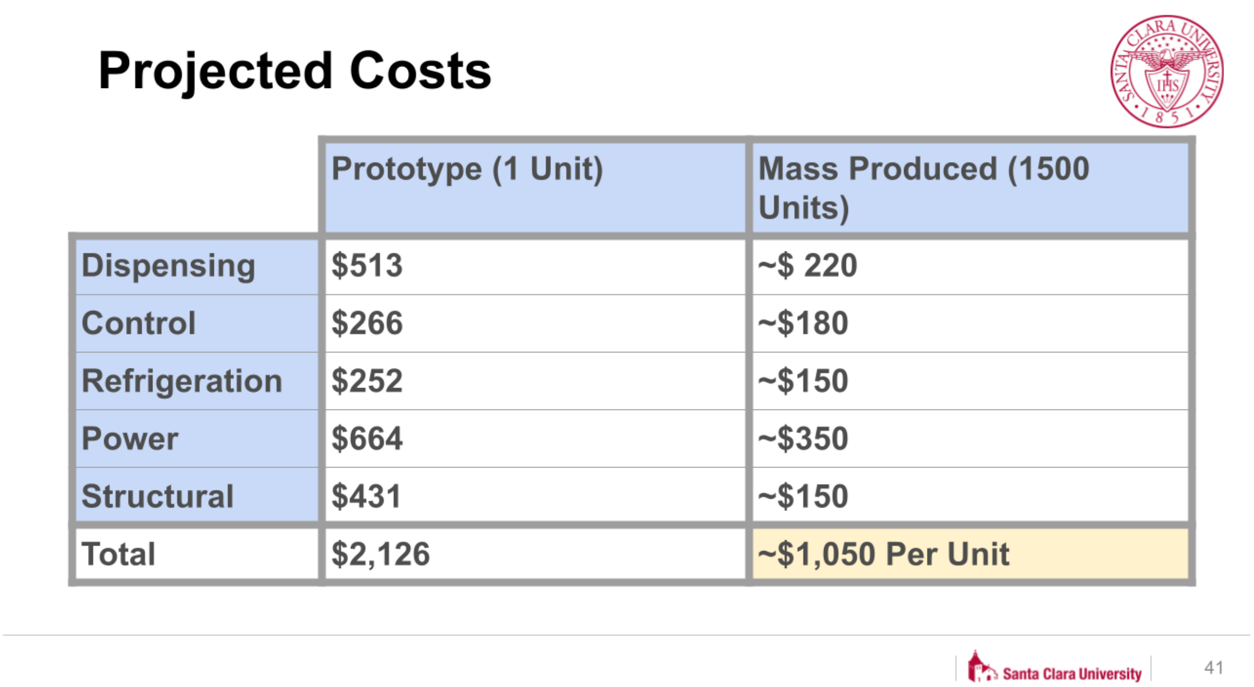
Structure

- Welded tube steel frame



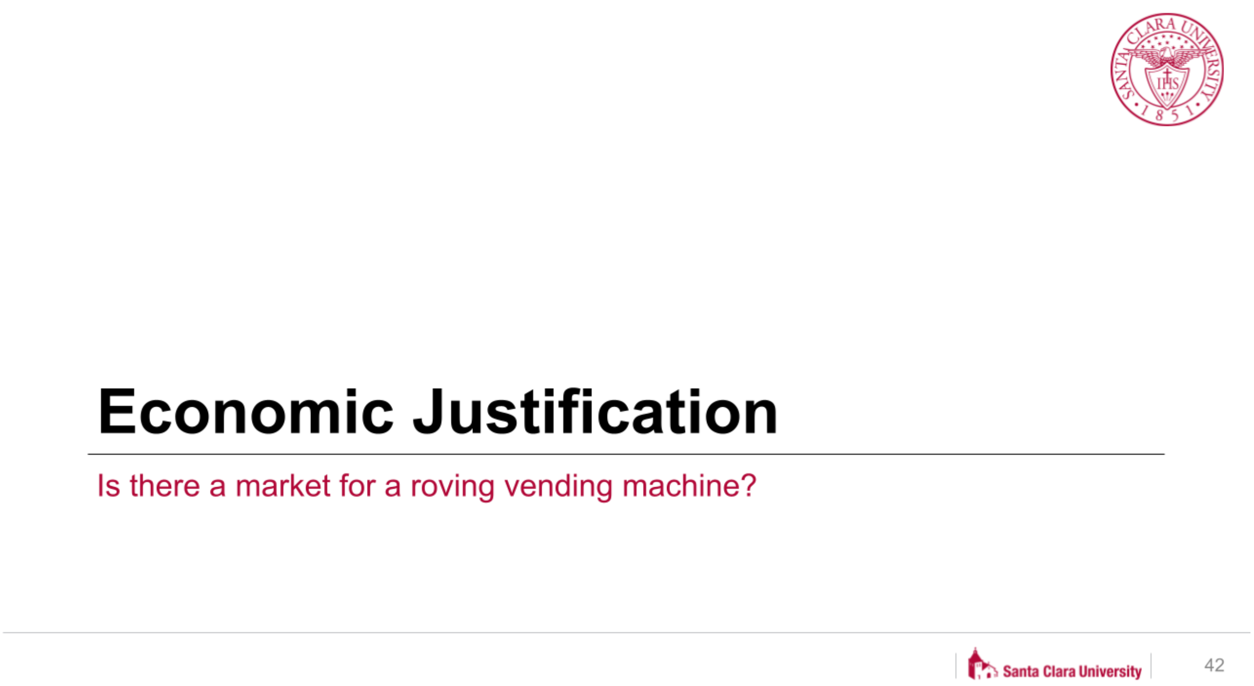
Injection Molding to Reduce Cost

https://all3dp.com/2/desktop-diy-injection-molding-machine/



Projected Costs

	Prototype (1 Unit)	Mass Produced (1500 Units)
Dispensing	$513	~$ 220
Control	$266	~$180
Refrigeration	$252	~$150
Power	$664	~$350
Structural	$431	~$150
Total	$2,126	~$1,050 Per Unit



Economic Justification

Is there a market for a roving vending machine?

Business Assumptions

Product: Guayaki Yerba Mate

- Wholesale cost: $2.25/Can
- SCU selling price: $4.29/Can

Anticipated usage protocol for operator:

- Refilling cans and charging once per day (~45 min)
- Only running AVA on weekdays during school year (165 days)

Profitability for Owner

Assuming half the cans are sold daily on average (18 cans):

Annually:

+ <u>Profit from cans:</u> $6,060
- <u>Cost of labor:</u> $2,028
- <u>Cost of electricity:</u> $12

Profits = $4,020/Year

Assuming a life cycle of 2000 cycles (conservative estimate based on battery):

- AVA will bring **$43,700** in profit during its lifetime of 12 years

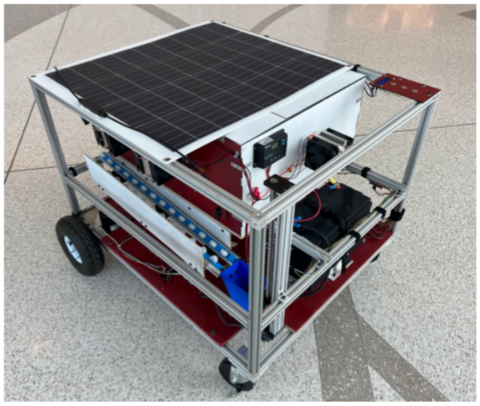
Profitability for AVA owners

Percent of capacity sold per day	Annual Profit	Lifetime Profit
30% (~11 cans)	$1,600	$14,350
50% (~18 cans)	$4,020	$43,700
100% (36 cans)	$10,075	$117,200

Conclusion

Accomplishments

- **Remote controlled movement**
  - Autonomous stopping
- **Convenient dispensing**
  - Runtime ~20s
- **Chilled beverages**
  - Temperature ~46 °F
- **Fully integrated system**



Acknowledgements

Dr. Godfrey Mungal - Project Advisor

Dr. Christopher Kitts - Control Advice

Dr. Andrew Wolfe - Electrical Advice

Dr. Tony Restivo - Course Instructor

Dr. Calvin Tseng - Course Instructor

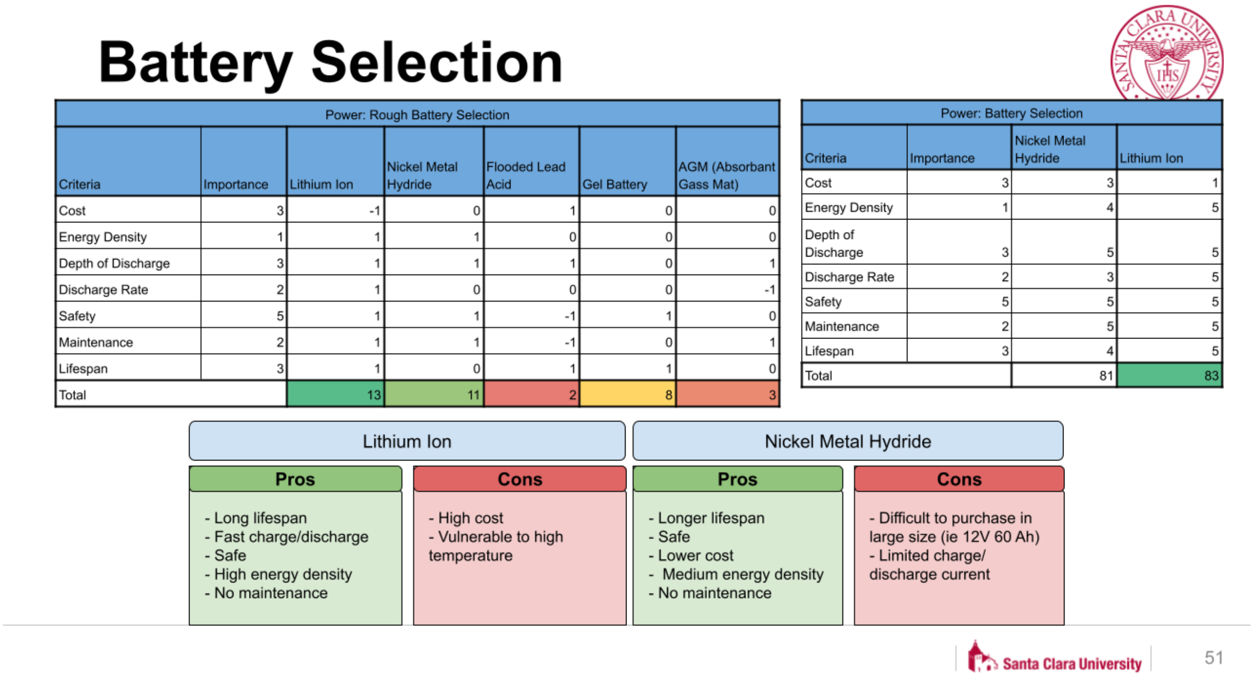
Rod Broome - Machine Shop Manager

Nicole Borgaard - Maker Lab Manager

Appendix

Driving Motor Selection

Table 1: GN&C Drive Motor Selection			
Criteria	Importance	12V 100 RPM DC Gear Motor	24V 1000 RPM Brushless DC Motor
Low Cost	3	1	1
Performance at Low Voltage	5	1	0
High Torque	4	1	1
Safety	4	1	1
Simple Integration & Control with Microcontroller	5	1	0
Total		21	11

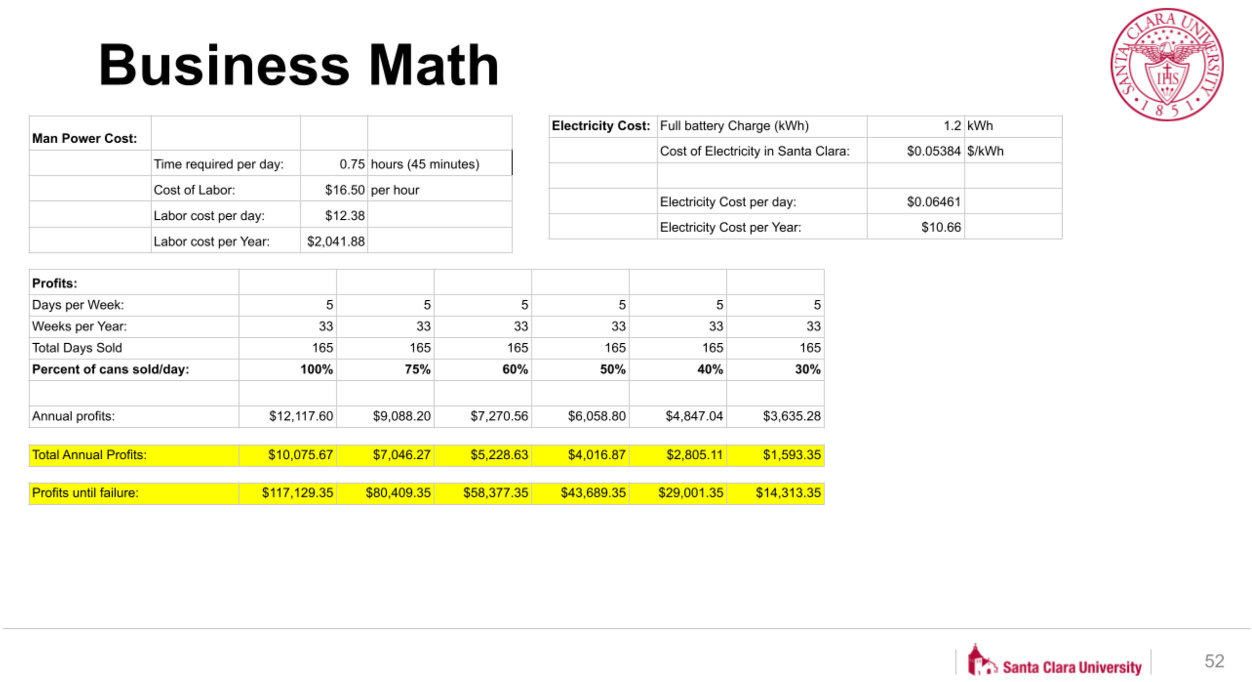


Battery Selection

Power: Rough Battery Selection						
Criteria	Importance	Lithium Ion	Nickel Metal Hydride	Flooded Lead Acid	Gel Battery	AGM (Absorbant Gass Mat)
Cost	3	-1	0	1	0	0
Energy Density	1	1	1	0	0	0
Depth of Discharge	3	1	1	1	0	1
Discharge Rate	2	1	0	0	0	-1
Safety	5	1	1	-1	1	0
Maintenance	2	1	1	-1	0	1
Lifespan	3	1	0	1	1	0
Total		13	11	2	8	3

Power: Battery Selection			
Criteria	Importance	Nickel Metal Hydride	Lithium Ion
Cost	3	3	1
Energy Density	1	4	5
Depth of Discharge	3	5	5
Discharge Rate	2	3	5
Safety	5	5	5
Maintenance	2	5	5
Lifespan	3	4	5
Total		81	83

Lithium Ion		Nickel Metal Hydride	
Pros	**Cons**	**Pros**	**Cons**
- Long lifespan - Fast charge/discharge - Safe - High energy density - No maintenance	- High cost - Vulnerable to high temperature	- Longer lifespan - Safe - Lower cost - Medium energy density - No maintenance	- Difficult to purchase in large size (ie 12V 60 Ah) - Limited charge/ discharge current



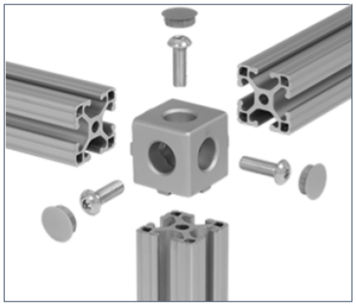
Business Math

Man Power Cost:			
	Time required per day:	0.75	hours (45 minutes)
	Cost of Labor:	$16.50	per hour
	Labor cost per day:	$12.38	
	Labor cost per Year:	$2,041.88	

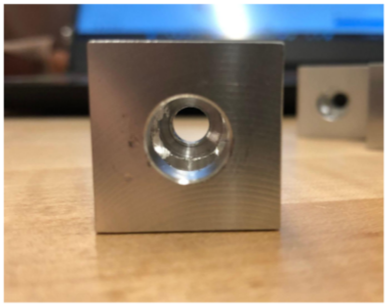
Electricity Cost:	Full battery Charge (kWh)	1.2	kWh
	Cost of Electricity in Santa Clara:	$0.05384	$/kWh
	Electricity Cost per day:	$0.06461	
	Electricity Cost per Year:	$10.66	

Profits:						
Days per Week:	5	5	5	5	5	5
Weeks per Year:	33	33	33	33	33	33
Total Days Sold	165	165	165	165	165	165
Percent of cans sold/day:	**100%**	**75%**	**60%**	**50%**	**40%**	**30%**
Annual profits:	$12,117.60	$9,088.20	$7,270.56	$6,058.80	$4,847.04	$3,635.28
Total Annual Profits:	$10,075.67	$7,046.27	$5,228.63	$4,016.87	$2,805.11	$1,593.35
Profits until failure:	$117,129.35	$80,409.35	$58,377.35	$43,689.35	$29,001.35	$14,313.35

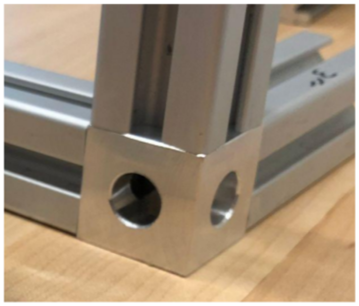
Structural Design Iterations



McMaster-Carr Product Image : 3-way outside corner bracket

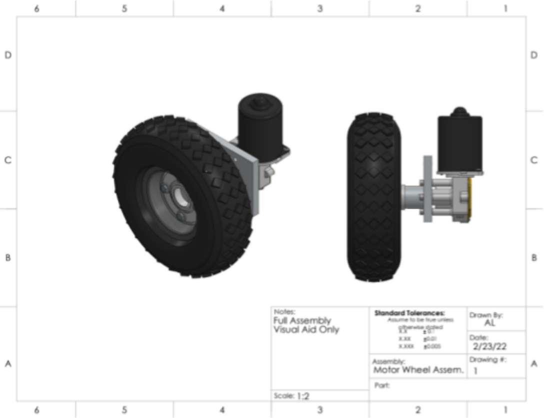


Machined Corner Bracket



Machined corner bracket assembled with t-slotted aluminum

Motor Wheel Assembly



Notes: Full Assembly Visual Aid Only

Standard Tolerances: Assume to be true unless otherwise stated X.X ±0.1 X.XX ±0.01 X.XXX ±0.005

Drawn By: AL

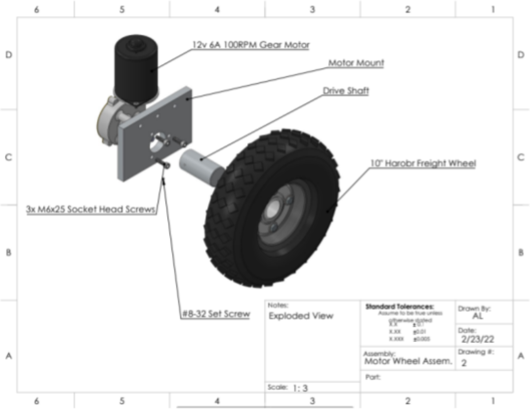
Date: 2/23/22

Assembly: Motor Wheel Assem.

Drawing #: 1

Part:

Scale: 1:2



Notes: Exploded View

Standard Tolerances: Assume to be true unless otherwise stated X.X ±0.1 X.XX ±0.01 X.XXX ±0.005

Drawn By: AL

Date: 2/23/22

Assembly: Motor Wheel Assem.

Drawing #: 2

Part:

Scale: 1: 3

Cooler Mounting