Automated Promotional Robot Ice Cream Machine

Senior Design Proposal submitted to the

Department of Mechanical and Materials Engineering

College of Engineering and Applied Science

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in partial fulfillment of the

requirements for the degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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Problem Statement

Create a portable soft ice cream machine that can be automated with a universal robot with an interactive display that provides made-to-order ice-cream to the customer at promotional university events. This project's purpose is to combine the University of Cincinnati Main Campus bachelor's degree program with the UC Clermont associate degree and CCP Curriculum to provide a project that can be used to highlight possibilities of automation, engineering principles, and show an interactive educational application of potential opportunities in manufacturing for high school students. This display will provide a tangible way for students and attendees to engage with robotics and understand its practical applications of manufacturing in everyday life.

Research

Background of the Problem

History of Soft Serve Ice-Cream Machines and How They Work

Tom Carvel, the founder of Carvel ice cream, is credited with inventing the first soft-serve ice cream machine in 1938. Unlike traditional ice cream, soft-serve ice cream is made with a lower milk fat content and is churned at a higher speed, which creates a smoother and creamier texture. The soft-serve ice cream machine made it possible to produce great quantities of soft-serve ice cream quickly and efficiently, which allowed ice cream shops to keep up with the demand. The basic format of a soft serve machine can be broken into three components; a hopper (device meant to store the ice cream mix), a freezing cylinder (to churn and create the proper consistency of the ice cream), and the dispenser. The process, albeit seeming quite simple, requires the proper finesse to yield the ice cream with the proper consistency, temperature, and taste. The freezing cylinder is arguably the most crucial part of the entire soft serve process, as the balance between the speed of the churning and the temperature of the mixture will make or break a good result. (1)

Improvements in Food Industry Using Universal Robots Has Grown

According to a study by the McKinsey Global Institute, food preparation looks promising for using automation, as it involves many predictable physical activities. (2) As a result, there has been an increase in robotics and automation throughout the food service industry. For instance, xrobotics xPizzacube uses robots to spread sauce, place cheese and toppings on pizzas. (3) This kind of automation simplifies the process and minimizes human error, ensuring a consistent product every time. The food industry began to see a substantial shift towards automation in the early 21st century, around the 2000s. (4) However, during the late 2010s, automation took off, due to advancements in artificial intelligence and robotics. Including innovative solutions such as automated coffee kiosks, robotic bartenders, and AI-powered ordering systems. (5) Several key players have emerged as leaders in the implementation of automation in the food industry.

Among them is Momentum Machines, which revolutionized the fast-food industry with their hamburger-creating robot capable of producing hundreds of burgers per hour. Cafe X has become well-known for their robotic baristas. Lastly, Chowbotics has a salad-making robot called Sally. (6)

Who is Affected by the Problem at Hand

The average everyday consumer is impacted through using automation to improve performance and time efficiency to perform repetitive tasks with ease. However, while automation can make lives easier for a large majority of people, the concern of automated robotics taking over the jobs that people once had remains a concern for some. As for the secondary target of this project, the teenaged students who would be exposed to this project would likely be affected by creating an increased interest in engineering or even attending UC. But an even larger group that is being impacted is the current state of the manufacturing industry and the lack of skilled workers that are available. If students still in high school could be exposed to the possibilities of what University of Cincinnati graduates are capable of, it could trickle into more students enrolling in STEM careers and employing themselves in the manufacturing industry of the future, which is going to be heavily automated.

The Magnitude of the Problem and the Current State of How the Problem is Being Addressed

The exact magnitude of this problem is not yet well defined. This solution incorporates a lot of time being saved, money being saved, and general safety savings. Meanwhile, there is currently the fear of a crisis forming in the manufacturing industry. According to the National Association of Manufacturers, there could be up to 2.1 million manufacturing jobs left unfilled by 2030, which could result in a loss of $1 trillion in 2030. (7) This emphasizes the need for current action in directing the youth toward the direction of this declining industry. The current solution for the lack of employees is that manufacturing companies are expanding their search for workers to include more women and people from diverse backgrounds. But as for the ice cream automation industry, there are many companies that have implemented robotics with Ice cream machines. There are two popular varieties of demonstrating the potential of automated Soft Serve Machines these are Kiosk Style and Industrial grade robots operating soft serve machines. The Kiosk style machine includes all components of a standard soft-serve machine (a refrigeration and dispensing system) and a digital touch screen and payment system for customer ease of use. Examples of these Kiosks include Connected Robotics Soft Serve Robot, PASMO – ICream, and Sweet ROBO. The use of industrial robots to serve the soft serve is used at tradeshows to show the capabilities of robots mimicking repeated actions with programmed instructions. Companies that have utilized these in soft-serve demonstrations are Kawasaki and Doosan. (8)

Why the Current Solutions Are Not Working

The current tactics used by manufacturing companies are mainly looking for the immediate solution for their lack of employees by hiring more diverse candidates or automated processes. This temporary solution will eventually run dry for these companies so our solution of increasing interest in both automation and manufacturing is going to prove more efficient in the future. This solution will act as a bit of a longer-term solution, but we believe that once the seed is planted for young teens interested in STEM, there will be more people merging into the industry. Our project will also show how at university, there are so many possibilities for young people to achieve their goals in STEM industries with innovation and automation.

Applicable Standards

- UL 621 (9)
- USDA Food Standards for Ice Cream (1)
- FDA Title 21 Section 135.110 Ice Cream and Frozen Custard (10)
- ANSI/ASHRAE Standard 15-2022 (11)
- ANSI/ASHRAE Standard 34-2022 (12)
- ASHRAE Refrigerant Fact Sheet Link (13)
- NSF/ANSI 6 (14)

State of the Art

Technology #1: SaniServ DF200 DuraFreeze

Figure 1 - SaniServ DF200 DuraFreeze Rear View

Figure 2 - SaniServ DF200 DuraFreeze Front View

Description: 7 Qt. Countertop Soft Serve Ice Cream Machine with 1 Hopper, can serve up to 6 oz. servings per minute, made of heavy-duty stainless steel, and uses R404A refrigerant. The overall dimensions of this unit are 14” width x 23 ¾” depth x 25 7/16” height, with a weight of the unit is 145 LBS. Important components include a ½ HP dasher and ½ HP compressor. (15)

Cost: $4,319.00 USD

Pros of technology:

- Space saving small footprint
- Fewer parts for easy cleaning and operation
- Designed for easy disassembled
- Affordable
- Versatile: Can serve ice cream, custard, yogurt. Gelato, or sorbet
- Lightweight

Cons of technology:

- Low-capacity hopper
- Reports of low-quality components breaking
- No monitoring devices (speed control, temperature, flow sensors)
- No programmed cleaning cycles

- Fixed dispensing speed

Technology #2: VEVOR Commercial Ice Cream Maker, Single Flavor. KM-A116 Model

Figure 3 - VEVOR Commercial Ice Cream Maker

Description: Up to 20L/hr. yield, 1200-watt Compressor, LCD panel control, 304 stainless steel frame, single flavor dispenser. Dimensions: 9.4 x 23.6 x 26.8 inches with a weight of 88.2 lbs. The machine is equipped with an LCD panel that can allow the user to adjust temperature, time, and the product's hardness. The interior mechanism contains a puffing tube that yields a product with an airier texture and fullness. (16)

Cost: $1059.99 USD

Pros of technology:

- Cheaper price compared to other models
- Does not emit much sound
- Does not use much energy or space
- Smart-touch interactive display on the device to alter machine settings/clean

Cons of technology:

- Low hopper capacity
- May not be able to keep up with large production demands
- Can only produce one flavor at a time, with one dispenser
- Not as versatile as other brands

Technology #3: Taylor C152 Soft Serve Freezer

Figure 4 - Taylor Soft Serve Machine

The Taylor model C152 works like most other soft serve ice cream machines. The C152 is a gravity fed soft serve machine (SSM). The 8-quart hopper, which is used to hold the soft serve mix, is located over top of the 1.5-quart freezing cylinder. Using a gravity fed drip into the freezing cylinder, where the liquid mix will be slowly turned and frozen until it is the correct viscosity. The C152 is run off single phase power, with only a 16-amp power draw. Allowing this machine to be run off a normal house outlet. These machines typically cost around $5,990.00 (17)

Pros of technology:

- Designed for easy daily cleaning and maintenance
- Safe: Has safety interlocks to stop the machine from running while doors are open
- Versatile: Can serve ice cream, custard, yogurt. Gelato, or sorbet
- Lightweight
- Top of the line controls system, using the Softtech™ controls system designed by Taylor
- Space saving small footprint
- Programmed cleaning cycle

Cons of technology:

- Low-capacity hopper
- High-level maintenance requires a service contract
- Cost
- Air-Cooled
- Requires unique OEM parts

Technology #4: Cuisinart ICE-45 Mix It In Soft Serve 1-1/2-Quart Ice Cream Maker, White

Figure 5 - Cuisinart ICE-45 Mix It In Soft Serve 1-1/2-Quart Ice Cream Maker

Description: A consumer grade 1.5 quart soft serve machine that has 3 separate containers for toppings to be mixed in. It produces the 1.5 quarts in 20-30 minutes, and it has space to hold cones. (18)

Cost: $129.95 USD

Pros of technology:

- The machine has a cheap design to make it consumer friendly.
- This has 3 separate storage containers for toppings to be mixed in after the ice cream has left the mixing chamber.

- It has storage for serving mediums.
- Drip dish for the inevitable drippage from the mixing chamber.

Cons of technology:

- The duty cycle and volume of ice cream it can produce does not meet our standards. 1.5 Quarts would run out after 24-32 customers. Then we'd have to wait 20-30 minutes for another 1.5 quarts.
- The volume of toppings does not meet our requirements. After 5 customers, they would probably run out.

Side Note: UR Collaborative Robot

The End user has determined that we will be using a UR Cobot in this project. The UR Cobot will be used to transport the ice cream container from its storage stack to the ice cream machine, and then to the carousel being used for the toppings. We are not including this in the State of the Art since we have no choice in using a different unit.

End User

Our target end user is an instructor or representative from UC Clermont. Our goal is to create a display that allows the instructor to engage and get people interested in manufacturing by bringing our machine to county fairs and high schools. The end user will be responsible for introducing these students to the processes involved in making the ice cream. Students will need to interact with a simple user interface to pick what toppings they would like on their ice cream. These high school-level students have not been exposed to manufacturing and automation as much as they could, and many students are about to decide on what profession they will enter and train in. Without any exposure to the manufacturing and automation industries, there is no inclination for them to enter the industry blindly. We are hoping to help the next generation to develop more passion and an understanding of the concepts of manufacturing and automation industries. This is the only limitation our end user has since the ice cream will be free. Our main concern with the end user is making it aesthetically interesting enough to catch the attention of teenagers. If we can accomplish this, we can bring more attention to the programs offered at UC Clermont, the UC MET Program, and the manufacturing automation field in general.

Summary of Research

After conducting our research regarding the current state of the art on soft serve ice cream machines and through conversations with the customer, we have derived several items to focus on in order to make our machine suitable for the customer’s demands. The biggest factors that we can pull from the state of the art research that best aligns with our customers' needed features would be the weight, cleaning, safety, pricing, and capacity of the machine. The pricing of the state of the art machines we researched varied greatly. We wanted to look at machines across every price range available, since we are limited to a budget of $6000 available to use for this project. The machines we found on the cheaper side of the market were not able to keep up with the capacity required out of, or into the ice cream machine. The only two machines that were able to keep up with the amount of desired ice cream dispensing both cost over $4000. We will have to find a way to keep up with the production rate needed, but also without spending over half of the budget on just the ice cream machine. Out of the machines we researched, only the Taylor machine had a preprogrammed cleaning cycle to aid with cleaning the machine. With our main desire for our senior design project being us showcasing our project at fairs and events across Ohio, the machine we design will have a lot of mileage on it. Due to the machine needing to move around and be in constant usage, we need the machine to be easy to clean. Having a programmed cleaning cycle will remove stress and downtime from the customer at the end of every demonstration that takes place. The most difficult factor that we will have to manage is the weight of the ice cream machine and its accompanying apparatus. From the state of the art research, the two main units (Taylor, SaniServe) that fit best with the needs of the machine that we are designing both weigh 204 and 153 pounds respectively. The weight of these machines would make the display cart that the machine will sit on exceedingly difficult to maneuver and set-up. With that being stated, we intend to lower the weight of the machine, whether it be from altering the design of the enclosure, or adjusting the materials involved.

Quality Function Deployment

Customer Features

- Portability (weight/size): The unit should be able to fit through a standard doorway (32 inches), it should also be able to be transported with ease by as few as two adults / fit in a transit van.

- Eye Catching (aesthetics, visibility of production): The unit should draw interest from people passing by at conventions or fairs.

- Explainable demonstration: The system should be designed to simply explain the components and their purpose in the system.

- Easily Operable HMI: Display for participants to interact with the system.

- Mode Flexibility (Fully Automated or Manual): Can operate both with a manual and fully automated dispensing ice cream.

- Easy Maintenance: Straightforward design, to have easy access to components that need to be inspected and taken care of.

- Safety: No fear of being injured by the machine while being operated or transportated.

- Low Power Requirements: Components should be designed / sourced to operate on standard outlets where the unit will be on display.

- Consistent Ice Cream Texture: Ability to make the ice cream have a desirable consistency.

- Ease of Assembly: Should be intuitive to put together in a short amount of time.

- Food Safe: Should meet standards and best practices to remain food safe.
- Single flavor: Simply dispense a single flavor.

Engineering Characteristics

- Collaborative Robot Arm
  - Universal Robotics UR3 or Universal Robotics UR5
- UC Designed Serving Dish
  - Injection Molded Plastic Dish
- Human Machine Interface
- Conveyor Transportation
- Carousel Transportation
- Mobile Display Unit
- Weight of the system (lb.)
  - Physical footprint
- Time per serving (min)
  - 1-2 minutes
- Freezing Cylinder
- Clean up time (min)
  - Squeegee attached to conveyor

- Food Grade Stainless Steel
    - 304 or 316 Stainless
    - A36 Steel Plate
- Power Usage (V)
    - 110V
- Volume per serving (oz.)
    - 1-2 oz
- Programable Logic Controller
    - Quick Disconnect Wirings
    - Beacon Lights/LEDS
    - 1-Way/2-Position, Normally Closed Solenoid Valves
- Physical Guarding
    - Fencing
    - Plexiglass surroundings
    - Access gates for Human Interaction

- ***2b) How Characteristics Address Features:***

- **Portability** will be addressed through a few different items. For a start, the physical footprint of the ice cream machine will be as small as we can feasibly make it and will sit on top of the display case.

- Making the display eye-catching will be interesting to address, for starters, we will have a robotic arm, with a fully functioning HMI (Human Machine Interface) that the public can interact with. The display will also have flashy visual components, like a beacon light and surrounding LEDs. Having a conveyor belt that transports the ice cream dish from the machine to the toppings carousel will help with having moving parts. Moving parts tend to catch the eye of most people. Finally, the UC designed serving dish will help show a recognizable brand.

- Having an **explainable demonstration** is a key aspect of this project, and having a functioning interactive HMI is essential. The HMI stands to provide the end user with a detailed explanation of the process happening before them. The PLC will also light beacon lights around the system to help the user with following the operation.

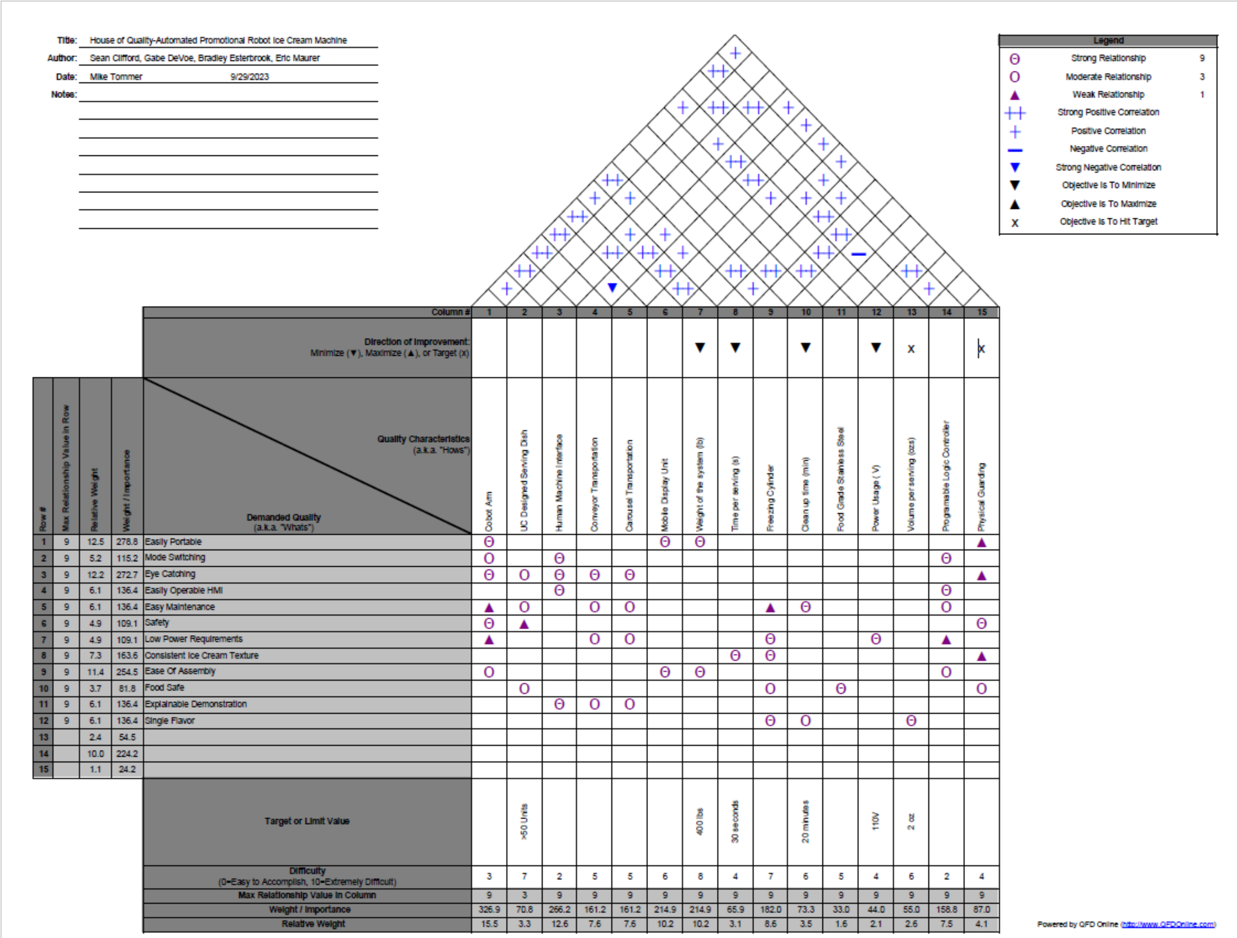
- We plan to ensure that there are **two modes of operation** (Manual and Automatic Dispensing) through the incorporation of 1-Way/2-Position, Normally Closed Solenoid Valves, with the PLC and HMI. The HMI will be used for the operator to switch the operation mode from manual to automatic. In turn the PLC will disable all signals to the Cobot, and remove its automatic control of the dispenser. The Solenoid valve will be controlled through a parallel logic in the PLC. If the system is in auto mode, the SOL will not be activated by the local pushbutton. If the system is in manual mode, only the local pushbutton can activate the SOL.

- Having the machine be **easy to maintain** is key, to do this we need to limit the mess that the machine makes. By simplifying the freezing cylinder and using less components, we can cut down on the amount of time required to flush and clean the main ice cream machine. Having predetermined and built serving dishes also allows us to have a disposable container that will remove any crumbs from cones, or spillages from pours.
- An **easily operable HMI** comes down to the pure programming on the HMI software. With the correct scope definition and set-up, this program will be easy to understand and operate. This will also be dependent on the correct programming set up on the PLC.
- **Safety** is one of the most complicated portions of this project. This entire demonstration cart has to stay portable, but safe for the public that it would be around. With the PLC being integrated into the system, several points of safety could be installed, such as light curtains, Estops, and LRPE. This can help with the SIL of the system. We can also take steps to install mechanical guarding into the system. With safety gates, plexiglass coverings, and fencing, we can remove access to high danger areas from the public.
- Since this assembly is meant to be used at state fairs or high schools, we have **limited access to power**. We will have to run our ice cream machine, conveyer, cobot arm, and any other devices off a 110V outlet, with a maximum of an16 amperage pull. We will have to consider the power usage of every component to ensure we do not overdraw the outlet and trip the breaker.
- We want to dispense a **consistent ice cream texture** to maintain the quality of our product. To ensure this, we need to consider the temperature of the freezing cylinder, the rate at which the auger spins and scrapes the ice crystals off the walls of the cylinder, and the feed rate of our powered ice cream product. We will lose our consistency if we add

too much or too little of product or if we are not dispensing enough soft serve at a given time.

- Designing an **easily assembled** machine will be important not only for the speed of setup but also for the people running the machine. The five of us ought to be able to assemble it, but we need to consider who will be setting it up after we are no longer working on the project. If it is only a couple of people running this at an event, then they need to be able to get it up and running efficiently.
- Keeping our design **food safe** is critical. We must ensure that our work environment is free of contaminants and that our material selection reflects the standards required for the food industry. We will attempt to make the ice cream machine out of food grade stainless steel, like 304 or 316.
- We wish to keep our soft serve machine a **single flavor unit** and to ensure this, we need to make sure that we only have one channel for the product to flow through, along with a single dispensing unit that can be controlled based on how much product is dispensed at once.

House of Quality / Interview with Sponsor



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality
1	9	12.5	278.8	Easily Portable
2	9	5.2	115.2	Mode Switching
3	9	12.2	272.7	Eye Catching
4	9	6.1	136.4	Easily Operable HMI
5	9	6.1	136.4	Easy Maintenance
6	9	4.9	109.1	Safety
7	9	4.9	109.1	Low Power Requirements
8	9	7.3	163.6	Consistent Ice Cream Texture
9	9	11.4	254.5	Ease Of Assembly
10	9	3.7	81.8	Food Safe
11	9	6.1	136.4	Explainable Demonstration
12	9	6.1	136.4	Single Flavor
13		2.4	54.5	
14		10.0	224.2	
15		1.1	24.2	

Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	3	7	2	5	5	6	8	4	7	6	5	4	6	2	4
Max Relationship Value in Column	9	3	9	9	9	9	9	9	9	9	9	9	9	9	9
Weight / Importance	326.9	70.8	266.2	161.2	161.2	214.9	214.9	65.9	182.0	73.3	33.0	44.0	55.0	158.8	87.0
Relative Weight	15.5	3.3	12.6	7.6	7.6	10.2	10.2	3.1	8.6	3.5	1.6	2.1	2.6	7.5	4.1

Figure 6 - QFD Diagram

Product Objectives:

Our House of Quality will impact our potential design decisions by providing a product with features based on our customer survey results. Our main conclusion from the analysis of our conversations with Clermont Campus was that the top 3 customer requirements were: Easily Portable (RW: 12.5), Eye Catching (RW: 12.2), Ease of Assembly (W: 11.4). Other important considerations were that the top 4 engineering characteristics were Cobot Arm (RW: 15.5), Human Machine Interface (RW: 12.6), and Mobile Display Unit and Weight of the system (lb.)

(RW: 10.2). These objectives will guide us in adding the most value when implementing these components into the design of our system.

Going through each of the areas in the direction of improvement section allowed us to see what changes need to be made to create a competitive and useful product. The correlation between our demanded quality and our quality characteristics will allow us to prioritize the highest preferences and will also have an impact on the final product we produce. Target or Limit values helped us quantify how much work is needed to see how our product can be tested to provide our customers with a safe, portable, and user-friendly product.

Team Members and Initial Responsibilities:

Name: Sean Clifford

Responsibility: Refrigeration Design (Compressor, Evaporator Coil, Expansion Valve)

Name: Gabe DeVoe

Responsibility: Dispenser Design (Pump / Nozzles)

Name: Bradley Esterbrook

Responsibility: Exterior and Hopper Design / Communication with Industrial Partners and Clermont Campus

Name: Eric Maurer

Responsibility: Freezing Cylinder / Interior Mechanical Design and Documentation

Name: Mike Tommer

Responsibility: Automation, Electrical Integration, Visualization

Concepts Drawings

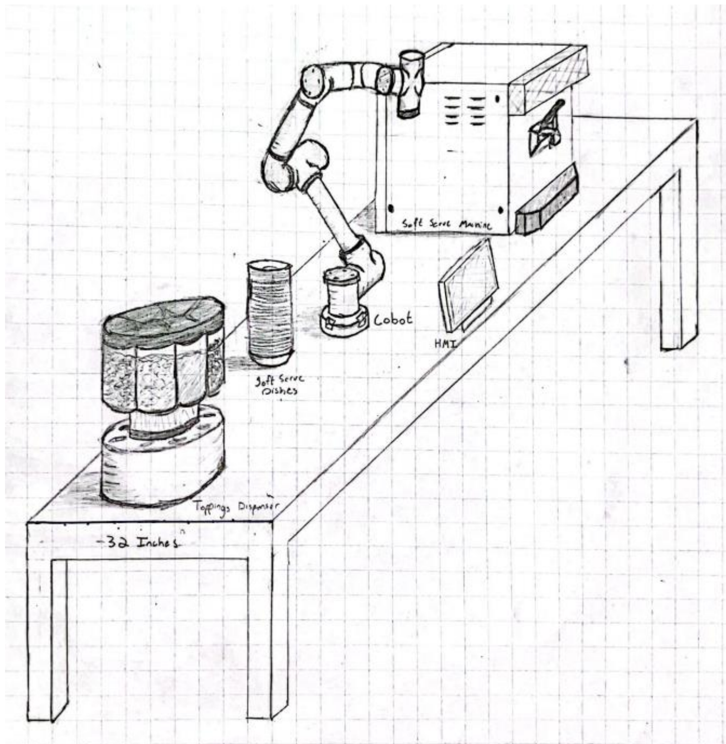


Figure 7 - Concept #1

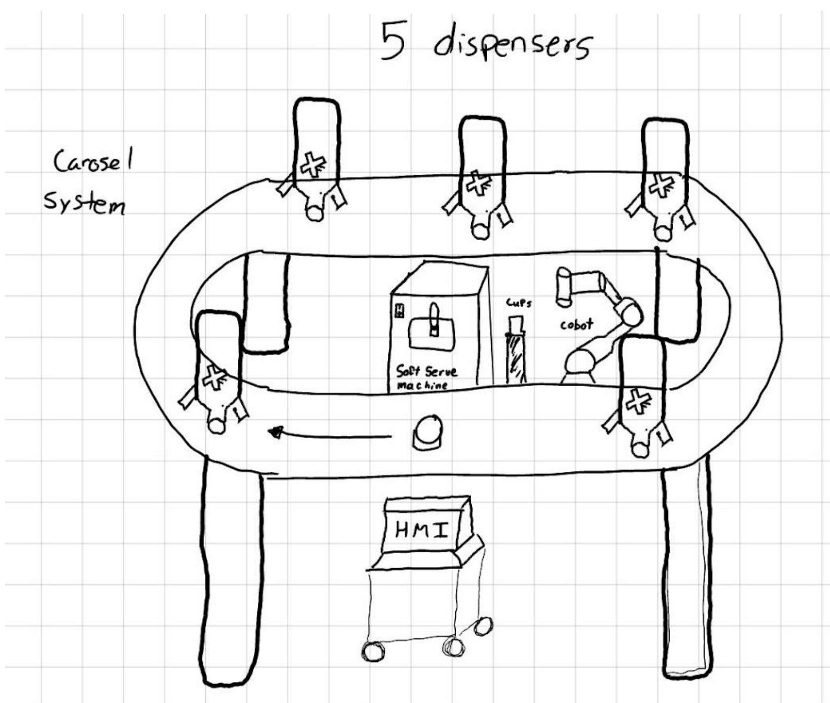


Figure 8 - Concept Drawing #2

Design Analysis

Design Alternatives and Selection

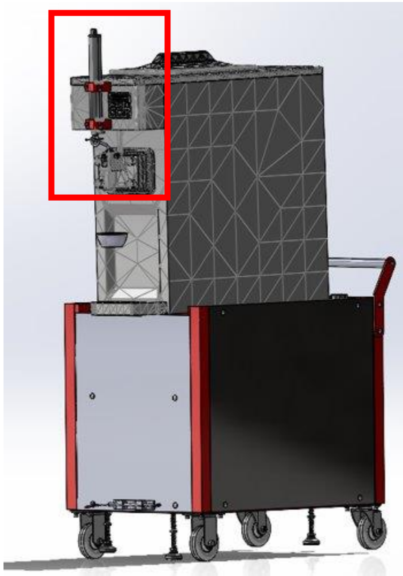
Automation:

We are responsible for overseeing elements of the design, programming, integration, and implementation of all controls/automation equipment across this system in coordination with our partners at U.C. (University of Cincinnati) Clermont. The major points of automation in this project have to do with the Toppings Carousel, Collaborative Robot (Cobot), Ice Cream Automation, and finally visualization. While electrical engineering or design is not within the purview of our degree, we will be providing some support backed from industry experience.

The start of the system is the Collaborative Robot. We are using a Universal Robots UR3e Cobot as the centerpiece of the system. The cobot is the most eye-catching piece, as it will be transporting the ice cream across the system from start to finish. We will be programming the robot to pick an ice cream bowl from the dispenser that is mounted to the side of the ice cream machine and place it under the dispenser. From there the linear actuator will start to dispense ice cream, as the robot performs a spiral motion to properly lay the ice cream in the bowl. After the ice cream has been dispensed the cobot will then move the bowl over to the topping's carousel. After the carousel the cobot will pick up the bowl and place it at the dispenser window.

The toppings carousel is being designed mechanically by our partners at U.C. Clermont. For this we have set aside a programming standard for them to use to keep the programming in-line with industry standards. We will be using a simplified version of a machine programming structure that Mike Tommer developed for a similar machine. This structure encompasses the sequencing structure of the machine, as well as all communications and interlocks between the carousel and the HMI. The carousel will be using either a DC stepper motor, or an AC Servo Drive to drive the main roller, that will have all 6 positional pucks attached. The first and last positions are in/out positions. Using a retro reflective photoelectric sensor to sense product presence at either position for interlocks with the Cobot. At the other 4 puck locations, after rotation the PLC will check the recipe data for the order that was placed. Using a FIFO (First in, First Out) we are able to store up to 100 recipes at a time, without mixing any of the orders out of place. Each position will have a storage tank above filled with different toppings. If called for by the recipe a 24V DC pneumatic valve will open for toppings to fall onto the ice cream. This will be repeated for every position until the puck is at the out location.

The ice cream machine automation is mostly coming from the linear actuator that we are mounting to the front plate of the machine. When called for by the PLC, the actuator will travel its full 4” stroke to dispense the ice cream onto the bowl in the end effector of the cobot below. This linear actuator will be disabled if the mode on the HMI is set to manual, that way the ice cream machine could be used without the controls system set-up.



Finally, the last major topic is the second most visual item, the human machine interface. We will be fully developing the HMI using the Panelview Plus 5310 donated by Tommer Enterprises

LLC. The Panelview 5310 can only be programmed using the Rockwell View Designer software. The HMI will consist of three main elements. The first is the interactive functional element. The HMI will be used to take orders from the public and store them in the PLC for the different toppings on the ice cream. This will mostly be done through a pop-up window selection of the main screen of the HMI. The second element is the educational element. As the Cobot steps through its major steps, the HMI will be displaying animated screens explaining the engineering ideas behind them. For example, when the Cobot is at the ice cream machine, the display will pop up a screen showing off the refrigeration cycle. The third element is maintenance. The instructions and mode switch for how to maintain the system will be displayed on the HMI when the system is set to Maint mode. This is especially helpful in lowering the knowledge required of operators to maintain the system.

Iteration 1:

During the first iteration of the project, our scope was to design an ice cream machine from scratch, with a single table that would contain all components of the system. We began by creating some concept drawings to visualize what we wanted our final design to look like and have a base design to make changes off of as we progressed through the design process. Two of the final initial concept drawings can be seen on page 28 of this document.

We also began to run some calculations so we could begin to specify components for our ice cream machine. We wanted to have a freezing cylinder that could hold 1.5 quarts, or 80 cubic inches. We wanted the inner surface of the freezing cylinder to reach a temperature of 20°F. The inner surface of the freezing cylinder is 102.44 in^2. We wanted the cylinder to be constructed of 304 stainless steel, which has a thermal conductivity of 8.09 BTU/Hr. With this information we could begin our calculations. Our calculations are based on the governing equations shown below.

$$R_w = \frac{In(D_o / D_i)}{2\pi KL} \qquad \dot{Q}_{cond,\,cyl} = \frac{T_1 - T_2}{R_{cyl}}$$

Our calculations showed that, using R-404A refrigerant, we would require at least 2,300 BTUH compressors.

We also wanted the scraper inside of the freezing cylinder to rotate at 180 RPM. This would allow us to scrape off ice crystals more quickly. This would allow for smaller ice crystals in the mix which would give a very smooth texture to the ice cream. Our machine would have to produce at least (1) 6 oz. Serving per minute, as we would want to have a smooth flow of customers seeing the display when it is at events.

We also wanted a 60% overrun in the ice cream, meaning that for every gallon of ice cream mix, 1.6 gallons of ice cream would be produced with the extra 0.6 gallons coming from the expansion as air is incorporated into the mix.

Unfortunately, we encountered some problems during this phase of our design. Our customer could not risk the ice cream machine not being to the quality of a typical commercial machine. If the ice cream machine was inconsistent in any way, the project would be deemed a failure. We were also not able to get the machine food safe certified in the time frame our customer is demanding, so no ice cream would be allowed be served that was produced from a machine manufactured by us. This forced us to turn and look for a possible partnership with a commercial/industrial ice cream machine manufacturer.

Iteration 2:

It was determined that we could no longer feasibly manufacture our own ice cream machine with the given budget and time constraints. We looked to use a donated 220V Spaceman USA machine instead of a homemade machine. The scope was then increased to include a cart for the machine with the intension of making the cart to be able to interface with the UC Clermont main cart that held the robot and control cabinet. Our ice cream machine cart was designed to hold the weight of the cart, have storage underneath for consumables, and to be made from readily available materials.

We designed the cart to be made of 3” x 3” x ¼” A36 steel angle iron, ½" A36 plate, and A36 10-gauge sheet metal. These materials are readily available via the company donating the materials, GE Vernova. Two angle iron frames would be welded together with angle iron posts to make an overall box shape. The plate and sheet metal would be welded on opposite sides of the box; casters would be attached to the plate.

The power issues we have encountered with the ice cream machine have turned out to have several possible solutions, all with different drawbacks.

The first solution we looked at is to get a step-up transformer to bring the wall outlet 110V to 220V required to power the machine. This brings several possible drawbacks. For a simple start, that kind of transformer costs several hundred dollars, and is typically about 30 lbs. This would eat into a large portion of our budget for the entire project, as well as detract from the whole notion of lowering the weight on the machine for the display cart. The second main drawback to this is the actual issues with power. Mike Tommer brought all our ideas and documentation on this machine to a certified power engineer with over 50 years of experience in the electrical engineering field. The power engineer and Mike were able to come up with several additional drawbacks to this idea. The first big one is the amperage draw that transforming the power would create. Any amperage we attempt to draw on the 220V side is doubled on the 110V side. With the minimum requirement for the machine's amperage drawn at 220V being 17 Amperes, this is doubled (with more added due to magnetization and heating losses) to approximately 37 Amperes. The largest typical 110V circuit commercially used is 20 Amperes. Therefore, introducing a 110V to 220V step-up transformer wouldn't be feasible with most of any of the 110V circuits across The United States. If we ignored the issue with the amperage draw, a secondary issue would present itself. This is the problem with the gauge of the wire being used from the load center to the outlet that the machine was being plugged into. The standard gauges for most 110V circuits for wall outlets are 12- or 14-gauge wire. With standard 12-gauge wire being typically able to handle approximately a 20 amp pull, and 14-gauge wire being able to handle up to a 15 amp pull, neither would be feasible. To be able to meet the amperage pull required of 37 Amperes, we would need to have the wiring from the load cell to the outlet replaced with 10-8-gauge wire. The only solutions with minimal downsides that we could produce were to purchase a generator to power the 220V or use a standard 220V outlet.

The other main solution that was discussed was to step the machine and its internal components down to 110V. The interesting piece is that if we attempt to do this with minimal incurred costs on the project, i.e., wiring up the existing equipment in a 110V configuration, we will encounter similar problems to the first solution. In accordance with Ohm's law, any amperage drawn at 220V will double if put in a 110V configuration. This brings the same complication with amperage draw, and load cell wire gauges from the first solution. To combat this, we could use multiple plugs to power the machine, which will also bring complications to the situation. Due to the wattage the machine pulls, we would need at minimum 2 to 3 separate circuits from the main load cell to power this machine. This is assuming the minimum load possible of 17 Amperes @ 220V, the machine would be pulling at minimum 3740 watts. The typical load of a 20 Amp circuit breaker is around 1920 watts. This number is prorated for proper load balancing on the circuit. Both the power engineer and Mike found it difficult to believe that it would be easy for an event center, or school to easily provide access to the information necessary to assure that separate circuits would be available and within range of the display cart or machine in use here. If the assumption of minimal incurred costs is removed, another issue is presented. To be within the Ampere and Watt limit presented by using 110V, most of the machine's major components would have to be retrofitted. The costs associated with pure part retrofitting would cost more than the $6000.00 budget currently available. This would include replacing the main compressors, motors, transformers, and potentially any resistors, contactors, or relays installed in the machine.

Between the two main solutions presented here, the power engineer and Mike both believe the easiest path forward for usage of the machine is to avoid changing the power coming into the machine. This will allow for a consistent product to be provided to the display cart audience and a solidified platform for modification/automation.

Iteration 3:

The cart design we began to develop for iteration three was one that would accommodate a 110V ice cream machine, and the main area of focus for us was to ensure that the cart would have a very reduced chance of tipping. To do this, we knew we needed a hefty enough cart with enough weight shifted toward the bottom of the cart to keep the design bottom-heavy and sturdy. The four main sections of the cart's design were the frame, side paneling, the base/top plates, and the cabinet. The frame was designed to be constructed using angle iron for the top, middle, and side of the frame. The dimensions and respective weights of the frame we decided to incorporate are listed below.

Frame			Angle Iron Bottom		
Angle Iron Top			Size	Length	Qty
Size	Length	Qty	3 x 3 x 0.25	30.5	4
3 x 3 x 0.25	30.5	4			
			Unit	11.893	
Unit	11.893		Weight(lbs)	47.572	
Weight(lbs)	47.572				
Angle Iron Middle			Corner Bracing		
Size	Length	Qty	Size	Length	Qty
3 x 3 x 0.25	30.5	3	3 x 3 x 0.25	23	4
Unit	11.893		Unit	8.969	
Weight(lbs)	35.679		Weight(lbs)	35.876	

The front and both side panels of the cart were designed to be made from stainless steel, with 10-gage thickness (roughly 0.135in). Below the respective weights and dimensions of the panels are listed.

Stainless Steel Paneling		
Front Panel		
Height	Width	Thickness
18.75	25.5	10 Gage
Weight(lbs	19.6402	
2 - Side Panels		
Height	Width	Thickness
23	25.5	10 Gage
Weight(lbs	24.092	

The cart design's top plate was designed to be made of 10-gage stainless steel, while the bottom plate was made significantly thicker with a 0.5-inch thickness. The motivation behind the decision to design a thicker base plate was an attempt to make the cart sturdier by having a hefty mass towards the bottom half of the cart. Below the dimensions and respective weights of the two plates are listed.

Base Plates		
Top Plate		
Height	Width	Thickness
30.5	30.5	10 Gage
Weight(lbs)	37.0995	
Bottom Plate		
Height	Width	Thickness
31	31	1/2"
Weight(lbs)	136.2698	

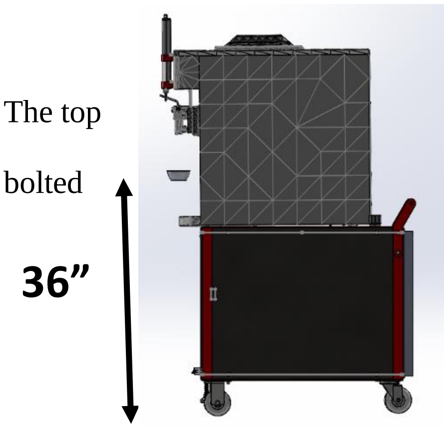
Lastly, the design of the cabinet was made so that the width of the cabinet was 25.6 inches and the height of the cabinet was 16.6 inches, with a double door opening. The total weight of the cabinet we planned to incorporate was 10.6 lbs.

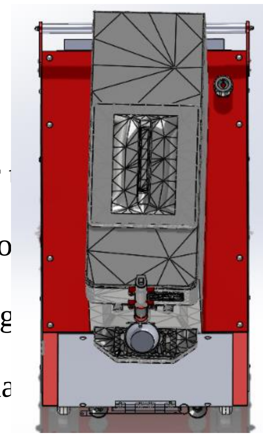
When adding up all the weights from each respective component, the overall weight of the designed cart came out to be 394.4 lbs. When incorporating the weight of the ice cream machine that was going to be sitting atop the cart (198 lbs.), the overall weight of the complete apparatus came out to be 592.4 lbs. Ultimately, it was obvious to us that a cart design of this much weight was not going to be acceptable for our project as we had a strict customer requirement of portability to fulfill the customer's demands. The customer intends on taking this cart to several promotional events for the university, and a cart and ice cream machine assembly of almost 600 lbs. was certainly not safe or possible to move around and set up easily whether it be one or a few people trying to do so.

Iteration 4:

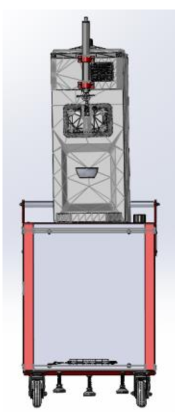
To meet our customers' most desired consideration, designing a display that could be transported by one or two instructors, we decided to reduce the thickness and width of the sides of the angle iron. The thickness of the A36 steel angle iron was reduced to 1/8th inch. The width of the angle iron was reduced from 3" to 1.5". This change in size also lead to reconfiguring the design of the top plate, front, and side 304 stainless steel sheet metal panels and rear cabinet. This also included the addition of a rear panel for the cabinet to mount onto. The stainless-steel panels were chosen to close off the bottom of the ice cream cart to provide an enclosed storage area. Iteration 4 For ease of access to necessary supplies this storage space is designed to have a 20-

inch cutout that allows for the cabinet door to fit inside. Four mounting brackets are placed to mount the cabinet to the frame of the cart. The side attached to the cart is spot welded to the inside of the angle iron. The other side of the bracket is secured using 5/16 ich socket head cap screws.





The top plate has four w for the machine to be bolted to as the feet o eaded studs that will be mounted using holes around the outer edge of the pla to the frame using carriage bolts. The hole location used allows for the bolts to be placed in the center of the angle iron.

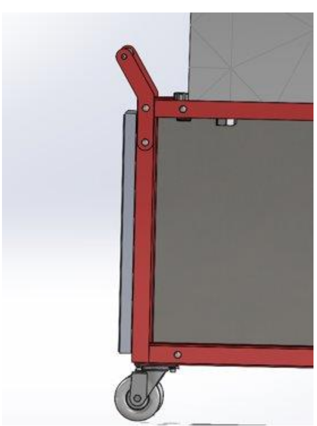


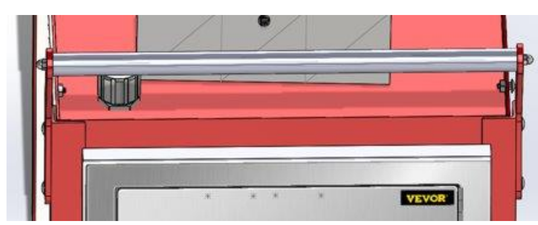
The front plate’s height increased as the angle iron that frames the top plate is now flush instead of standing on its side, eliminating the need to mill a slot in the angle iron. The holes are placed at the bottom for the alignment pins and the screws that go into the frame to connect the cart with the main display.

The bottom plate has four sets of hole patterns to allow for the front rigid caster and back swivel casters to be mounted to the plate. It also has three holes for the leveling jacks. The thickness of the plate went from half inch to 10 gage steel plate. This reduced the weight of the cart by

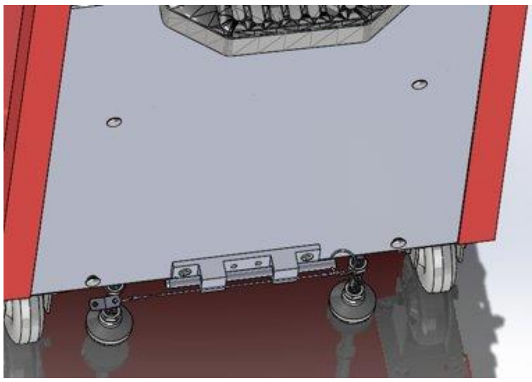
The angle iron frame consists of 13 pieces of angle iron. The 4 pieces in each corner are butt welded to the 4 pieces in the middle of the top and bottom pieces that support the front and rear panels. The pieces of angle iron that run the length of the cart are milled to allow for them to be welded flush with the corner pieces of angle iron. A main concern in our design presentation was that the deflection of the ten-gage sheet metal could lead to a structural failure. To decrease the probability of this happening by positioning a piece of angle iron in the center of the cart's height across the width of the cart.

The handle is 32 inches from the ground to allow for a person of average height to comfortably push the cart at elbow height. The assembly includes a threaded rod positioned between two custom cut pieces of sheet metal. It is held together by two acorn nuts on either side with a stainless-steel pipe that fits into a counterbore on the inside of the handle on the right side of the cart.

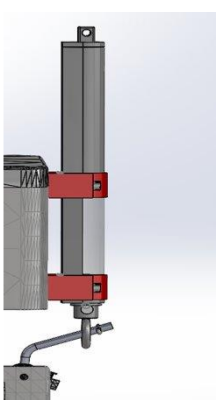


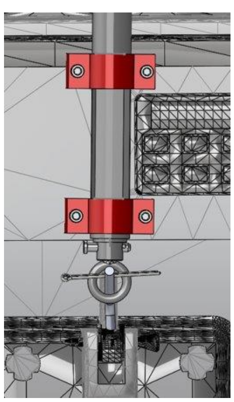


The mounting bracket is attached to the front panel of the cart. It is designed to create a consistent plane that connects the ice cream and the robot carts. The bracket will be positioned using the leveling jacks to maintain the necessary alignment. The robot cart will have a mating piece that is held together by the quick release pin.



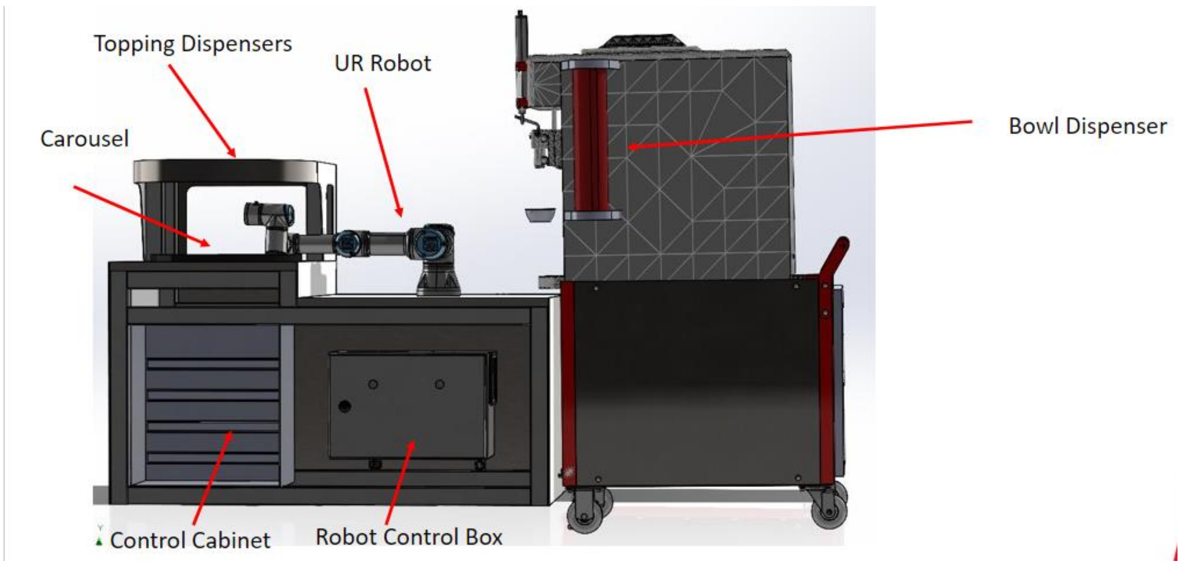
The linear actuator is attached to the top of the ice cream machine using socket head cap screws. The design is dependent on testing of the motion of the 3D printed handle and mechanism including a cotter pin, eye bolt, and quick release pin. Both brackets are designed and will be 3D printed to hold the linear actuator in place matching its contour.





Product Model

The ice cream machine cart is part of an assembly where the robot cart will house all the automated components for the project. The machine's height is set so that the robot will hold the cup and dispense with the top 36 inches from the ground.



Component Selection and Justification.

The carriage bolts were selected to minimize the additional processing before or after the frame is painted. They were also selected to get a professional look with flush fasteners and allow for the top plate to be bolted down instead of welding to provide more flexibility in design if modifications need to be made in the future.

The leveling feet were selected with a 6in total thread length to work with the 4 inch casters and at least 1.5 inches of additional length to account for unlevel surfaces where the machine will be demonstrated. Based on a total weight of 344 lbs each caster needs to be able to hold 115 lbs.

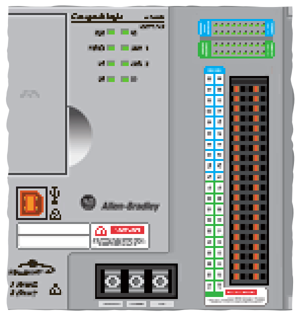
The weight capacity listed on the manufacturers web site of each mount is 3750 lbs. This falls well within our safety factor goal of 5 coming in at 32.

The casters selected are 4-inch wheels from a Hamilton Caster. The goal of the project was to create partnerships with local manufacturing companies to promote both their business and education in manufacturing. A main feature that the customer was looking for on these casters was that the front would be rigid and the back would swivel with locks on both sets. The rigid casters have a thumbscrew lock and the swivel have a combination brake.

Controls Components PLC:

The first item to cover is the Programmable Logic Controller, or PLC. The PLC is one of the most vital components of a controls system. PLCs run all the logic the controls every portion of the system. This includes any data tracking, I/O, as well as visualization data. The processor that is selected for this system needs to be able to handle multiple programs executing at the same time, as well as be able to work with the donated Human Machine Interface (HMI). For the PLC controller we selected the Allen Bradley 1769-L24ER-QB1B/A PLC Controller. This CompactLogix controller is able to support up to 8 ethernet nodes. Which gives us the ability to add remote IO or additional servo, or motor drives if the need arises. On the topic of ethernet, the PLC has 2 built in 100/10 mb/S ethernet ports. These are more than necessary to meet the requirements for the system our customer has planned. One of the main reasons this controller was selected is due to its embedded I/O. The L24ER CompactLogix has 32 embedded 24V DC inputs and outputs with optional expanded local and remote I/O capabilities. The embedded I/O is more than enough for us to handle hardwired interlocks with the cobot, as well as additional I/O for the linear actuator and the carousel. The PLC controller will be programmed using

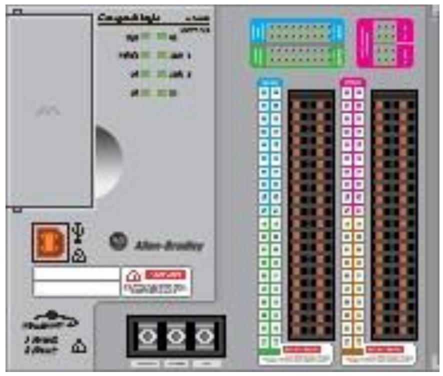
Rockwell Automation's Studio 5000 Logix Designer V32. This is the standard software used in industry with this controller. This software is capable of running multiple programs within the same PLC at the same time. This is great for our situation, allowing us to run a program for the robot, interlocks, and the toppings carousel at the same time.



Alternative PLCs:

We have selected two alternative controllers to use in case we use a servo drive for the topping's carousel. Both are Allen Bradley 1769 model CompactLogix. The L18ERM is capable of motion, with the only drawback being it has a smaller amount of memory available at 512 KB. The L24ER we selected as the main processor has a 750 KB memory.

The other alternative controller is the L27ERM. This controller was also selected as an alternative in case a servo drive was selected for use in the topping's carousel. This processor has a greater memory capacity of 1 MB. The embedded I/O on the L27ERM is different from the other two processors mentioned. It has the same I/O as the L24ER, in addition to 8 high-speed counter modules and outputs, as well as 6 analog outputs/inputs.



Controls Components Power Supply:

The power supplies are significantly important to the system, as we could not power the PLC or the HMI without them. We have selected the DIN rail mounted Allen-Bradley 1606-XLB120E. The AB 120E is a single-phase power supply capable of providing a 24 – 28V DC output voltage. As designated by its catalog name, the 120E takes a 120V AC input voltage, which is what we will have available to us from our customer. We have elected to use two separate power supplies so that we can power both the PLC and the HMI separately, with no strain on the power supplies. Both of these devices consume between 2 – 3 amps in current, which helped us to choose two of these 5-amp power supplies.

Alternative Power Supply:

We selected the Mean Well NDR-120-24 as an alternative power supply to use. This power supply has the same specifications as the Allen Bradley 1606-XLB120E. The only reason we choose an alternative is price. These are about 50-60 USD cheaper than the AB 120E power supplies.

Controls Components Circuit Breaker:

For the circuit breakers we selected the Allen-Bradley 1489-M1C080. This device is a miniature circuit breaker with a voltage range of 0-240V AC with an 8-amp current limit. Our main decision around using this is the fact that it is the same brand as the rest of our electrical equipment. Since we are using 5-amp power supplies for our DC devices, we need to properly size the circuit breakers for them. To properly size a circuit breaker, you need to multiply the used amperage by 125%. In our case that would be 5 amps per breaker, which would result in 6.25 Amps. With a little extra thrown in there just in case, we went with 8-amp trips on our circuit breakers.

Alternative Circuit Breakers:

We selected the Chtaixi 10 Amp Miniature Circuit Breaker as an alternative circuit breaker to use. This power supply has the same specifications as the Allen Bradley 1489-M1C080. The only reason we choose an alternative is price. These are about 30-40 USD cheaper than the AB M1C080 Circuit Breakers.

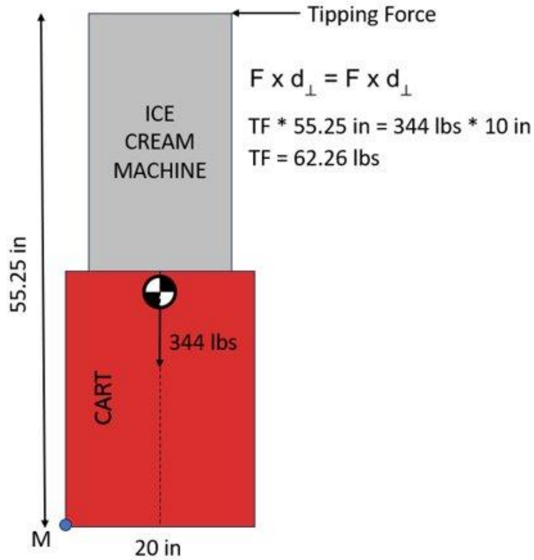
Controls Components Collaborative Robot:

For the collaborative robot on the main display cart we are using the Universal Robots UR3e Collaborative Robot (Cobot). The UR3e is a cobot with a 6.6 lbs payload capacity and 19.685 in reach. We did not select this robot for use as it was provided for use by our customer. However, this robot is a great solution for what we are attempting to create. The robot has a small enough of a footprint to easily fit on the main display cart, with the main base only being 4.3 inches in diameter. It also has a dedicated control cabinet that will be mounted underneath the main cart, next to the main controls cabinet.

Controls Components HMI:

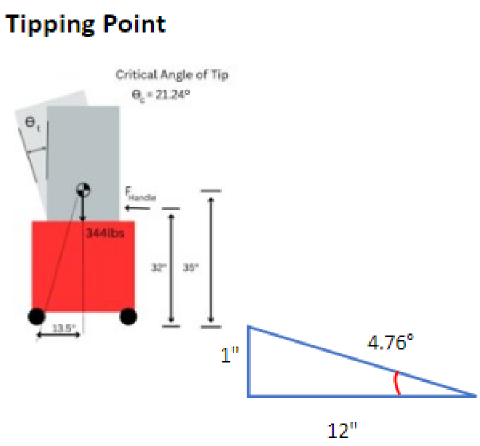
For the Human Machine Interface (HMI), we were kindly donated an Allen Bradley PanelView Plus 5310 from Tommer Enterprises LLC. The 5310 is a 10.4 in. color touch screen HMI with EthernetIP communications. This is a standard use HMI in the automation industry, most commonly used as local machine, or small system interfaces. The 5310 is only capable of using Rockwell's View Designer software. This software is completely compatible with all of the PLCs we selected earlier in the design process.

Appropriate Engineering Design and Analysis



With Iteration 4, our cart can be tipped over in the worst-case scenario with 62.26 lbs. The tipping force would be applied to the top of the ice cream machine and parallel to the shortest side of the cart. It is something we need to consider moving forward. We could add weight to the bottom of the cart to increase the amount of tipping force.

The maximum slope before tipping was calculated at 21.24 degrees. Comparing this value to the standard handicap accessible ramp at 4.76 degrees gives us a safety factor just under four and a half.



Application of Industry Codes, Specifications, and Standards

When it comes to industry specs or standards, there is a low amount for us to apply. Due to us no longer manufacturing the ice cream machine, a large majority of the specifications that we found in our research will no longer apply. However, we have a few that we will have to adhere to for other sections of the project. For the controls system, we have a large number of electrical standards set forth by the National Electrical Manufacturers Association (NEMA). Since we are providing oversight to our partners at U.C. Clermont with the control cabinet design, we have to make sure they create in accordance with these specifications. Listed below is our full set of standards we plan to use. All five of the NEMA standards are guidelines for the electrical build of the system. The guidelines are all common sense in building an electrical controls system. The other major specification we have found is the GE Vernova welding spec. Since GE Vernova has graciously decided to manufacture our ice cream cart, they will be applying their standard spec in doing so.

NEMA ICS 6-1993 (R2001, R2006, R2011, R2016): ICS: Enclosures

NEMA ICS 4-2015: Application Guideline for Terminal Blocks

NEMA ICE 16-2001 ISC: Motion/Position Control Motors, Controls, and Feedback Devices

NEMA ICS 5-2017 – ISC: Control-Circuit and Pilot Devices

NEMA ICS 1-2022 – Industrial Control and System General Requirements

WPS CS-FC-1 – Welding Specification for GE Vernova

Planned Fabrication and Assembly

Specialized Manufacturing Process/Fixtures & Tooling

Our cart will be manufactured at GE Steam Power/GE Vernova in Erlanger, Kentucky. The A36 steel and 304 stainless steel sheet metal will be burnt out with a CNC plasma cutting table. The angle iron will be cut to length on a saw. Any through holes or threaded holes will be drilled prior to welding at a drill press. All the processed materials will be moved to a welding booth where all the materials will be welded together. The final assembly will then be moved to a large paint booth where it will be painted with red oxide primer paint.

Specialized Assembly Methods/Tooling

The majority of the specific assembly process for the cart itself is listed above. Casters will be mounted to be bottom of the cart via threaded holes on the bottom plate. Three leveling feet will also be mounted to the bottom plate. Carriage bolts will be used to mount the stainless-steel sheet metal to the sides of the cart. To actuate the ice cream dispensing system, a linear actuator will be mounted to the front face of the ice cream machine. The wiring for the linear actuator will include quick disconnect M12 wiring to ensure that our cart can easily detach from the main cart assembly. Locking brackets will also be mounted to the mating side of the cart to ensure a level mounting plane between both carts.

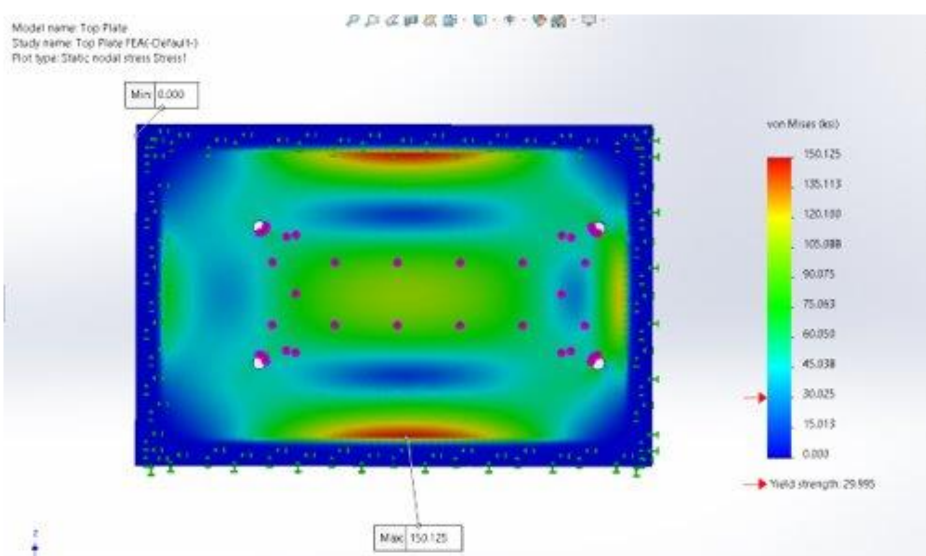
Planned Testing and Proof of Design

Testing Methods:

The testing methods we plan to conduct to validate our project's viability include ensuring that our cart is both sturdy and mobile, that our robotic arm has the appropriate range of motion, and that our cart can be easily mated with its adjoining counterpart cart. To be more specific, once we have our ice cream machine fully mounted on the cart, we will conduct a series of tests over uneven ground and grass to ensure the machine's mounting to the cart holds. As for the mobility of the cart, we will run tests like the ones mentioned above, as well as tests on inclined surfaces. The robotic arm's range of motion will have to be tested before we begin fabrication, and we will have to simulate the apparatus' layout to give us our best approximation of the robot's capabilities. Lastly, a locking mechanism was designed to mate the cart containing the ice cream machine and the cart containing the robotic arm, and once this is fabricated, several tests will have to be done so that we can ensure the entire setup is secure together, there is no chance for separation of the two carts, and checking for any unseen interferences.

Proof of Design

Finite Element Analysis Stress



This is the Finite Element Analysis before the central support was added and the top plate was bolted down. With these adjustments we assume that the support now located across the width will prevent stress and displacement.

Project Management

Project Budget Limit: $6000.00 USD

Donated materials include the Panel View 5310, A36 Steel Plate, and Casters (~$3000)

Materials that will be sourced include:

Component Type	Description	Manufacturer	Quantity	Cost		# in Assembly
Lockwashers	92146A622	McMaster-Carr	100	$ 7.94		16
5/16" Hex nuts	95036A016	McMaster-Carr	100	$ 13.09		32
5/16" Socket Head Cap Screws	90128A580	McMaster-Carr	25	$ 9.05		24
Carriage Bolts	92356A117	McMaster-Carr	25	$ 11.43		8
Quick release pin	90156A507	McMaster-Carr	10	$ 7.77		1
Cotter Pin	90157A116	McMaster-Carr	10	$ 3.45		1
Eyebolt	3109T51	McMaster-Carr	1	$ 15.81		1
Leveling Mounts	6111K255	McMaster-Carr	3	$ 53.49		3
Angle Iron 1.5" x 1.5" x 1/8	240" long	Get Metals	1	$ 37.79		1
Stainless Steel Sheets - 10 gage	48" x 48"	Get Metals	1	$ 1,460.59		1
stainless steel sheets - 20 gage	48" x 48"	Get Metals	1	$ 399.50		1
Nuts for securing to Top Plate		McMaster-Carr	25	$ 20.00		4
Cord Grip		McMaster-Carr	1	$ 13.40		1
TOTAL	$ 2,053.31					

Schedule: Shown below is our Gantt Chart describing the specific timeline we followed to stay on pace to meet our objectives before the end of the semester. We also describe the remaining tasks that need to be met during the upcoming term, and we are currently in good form regarding our progress. To be more specific, a large majority of our components have already been sourced and attained including the Spaceman ice cream machine, the UR robotic arm, and a multitude of electronic components to help with the integration of the apparatus and HMI. The key to the success attained so far would be the group's dedication in terms of holding routine meetings, making weekly progress reports, and prioritizing group harmony and productivity.

Project Schedule										
Class	Due Date	Item	September	October	November	December	January	Februrary	March	April
Senior Design I	9/15/2023	Background Research								
	9/29/2023	QFD								
	10/10/2023	Final Proposal								
Senior Design II	10/3/2023	Advisor Assigned								
	11/10/2023	Calculations								
	11/10/2023	Reverse Engineering								
	12/1/2023	Final Design								
	12/8/2023	Drawings Ready for Manufacturing								
	12/8/2023	Senior Design 2 Report								
	12/8/2023	Senior Design 2 Presentation								
	12/10/2023	Parts List								
	12/10/2023	Bill of Materials								
Senior Design III	1/8/2023	Fabrication Start								
	3/3/2023	Fabrication Finish								
	3/6/2023	Testing Start								
	3/18/2023	Testing Complete								
	4/16/2023	Tech Expo								
	4/25/2023	Final Presentation								

Implementation of Design:

Fabrication:

The fabrication of the cart's components required a facility that could perform some machining techniques such as plasma cutting, flat grinding, drilling, etc. These actions were able to be done through the access provided to us by GE Vernova in Erlanger, Kentucky and University of Cincinnati Clermont's Grant Career Center machine shop. The bulk of the cart's components were able to be fabricated with A36 Steel and angled iron provided to us by GE Vernova. The smaller components, such as the cart handle and linear actuator accessories, were provided by UC Clermont. The plate and angle iron were processed through the material processing department at Erlanger. The welding and painting were also done at Erlanger. While the cart was being transported to UC Clermont, the initial paint job was damaged. The assembly was repainted at UC Clermont.

Assembly:

After painting the angle iron frame of the cart with industrial matte black paint and giving the stainless-steel side panels a clear coat finish, assembly began. The 4-inch casters were the first thing assembled onto the cart, to allow for mobility for the rest of the assembly process. With swivel casters being installed on the handle side, and rigid casters being installed on the front. Next, the stainless-steel handle was mounted to the frame. The stainless-steel side panels were then mounted to the frame using carriage bolts, along with the cabinet door for access to the inside of the cart. The stainless-steel pushing handle was also mounted to the frame of the cart using carriage bolts. After this, the 3 leveling feet were mounted to the bottom plate of the frame to allow for the entire cart to be leveled.

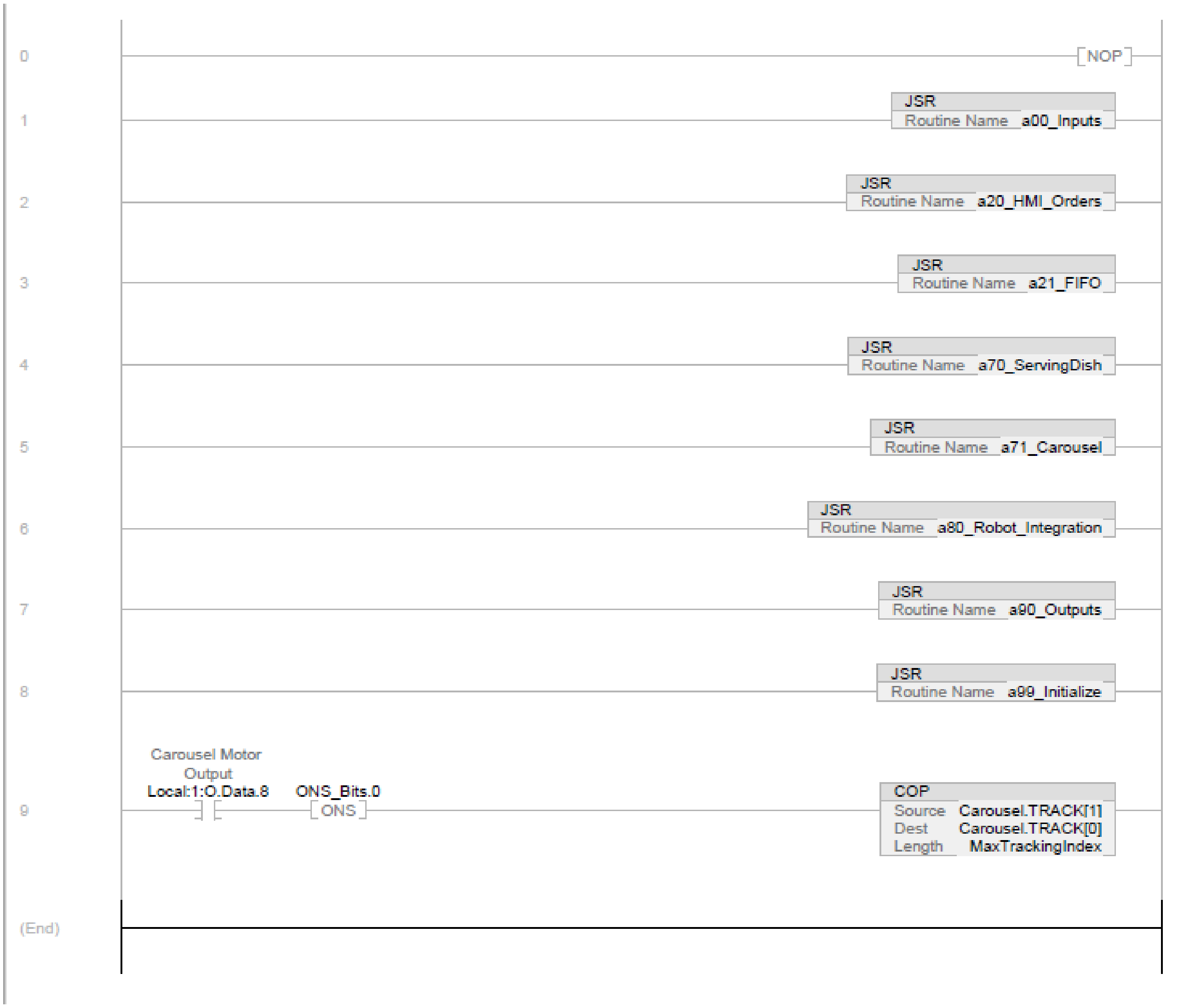
The linear actuator that would push the nozzle down to allow for the dispensing of ice cream as then installed on top of the ice cream machine. The following step was to install the ice cream machine onto the cart. The ice cream machine was lowered on top of the cart over pre-drilled holes in the top panel of the cart. Hex nuts were then used to fasten the ice cream machine to the cart. Another hole was then drilled into the top of the cart to allow for the machine's chord to be run through. University of Cincinnati themed vinyl stickers were also added to the panels of the cart to make the display more eye-catching.

The last part of the physical assembly was to conjoin the cart up with the one manufactured by UC Clermont.

- Mating Piece
- Mounting with UC Clermont Cart

PLC Code Integration:

- **Main Routine**


0
NOP
1
JSR
Routine Name a00_Inputs
2
JSR
Routine Name a20_HMI_Orders
3
JSR
Routine Name a21_FIFO
4
JSR
Routine Name a70_ServingDish
5
JSR
Routine Name a71_Carousel
6
JSR
Routine Name a80_Robot_Integration
7
JSR
Routine Name a90_Outputs
8
JSR
Routine Name a99_Initialize
9
Carousel Motor Output
Local:1:O.Data.8
ONS_Bits.0
ONS
COP
Source Carousel.TRACK[1]
Dest Carousel.TRACK[0]
Length MaxTrackingIndex
(End)

- **Inputs**

****

Input Mapping

This routine is used to map inputs from their direct IO memory tag to an intermediate tag for usage throughout the program. Please check drawings before modified

****

0 ——— [NOP]

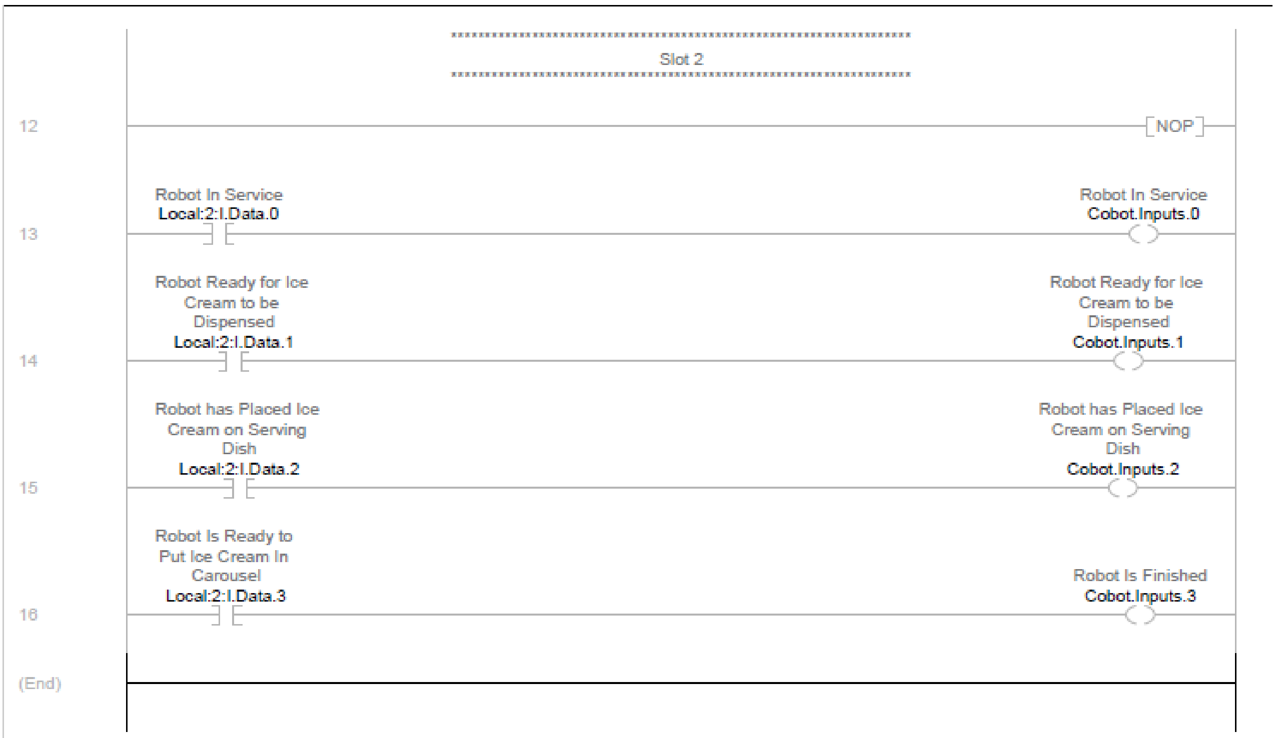
****

Slot 1

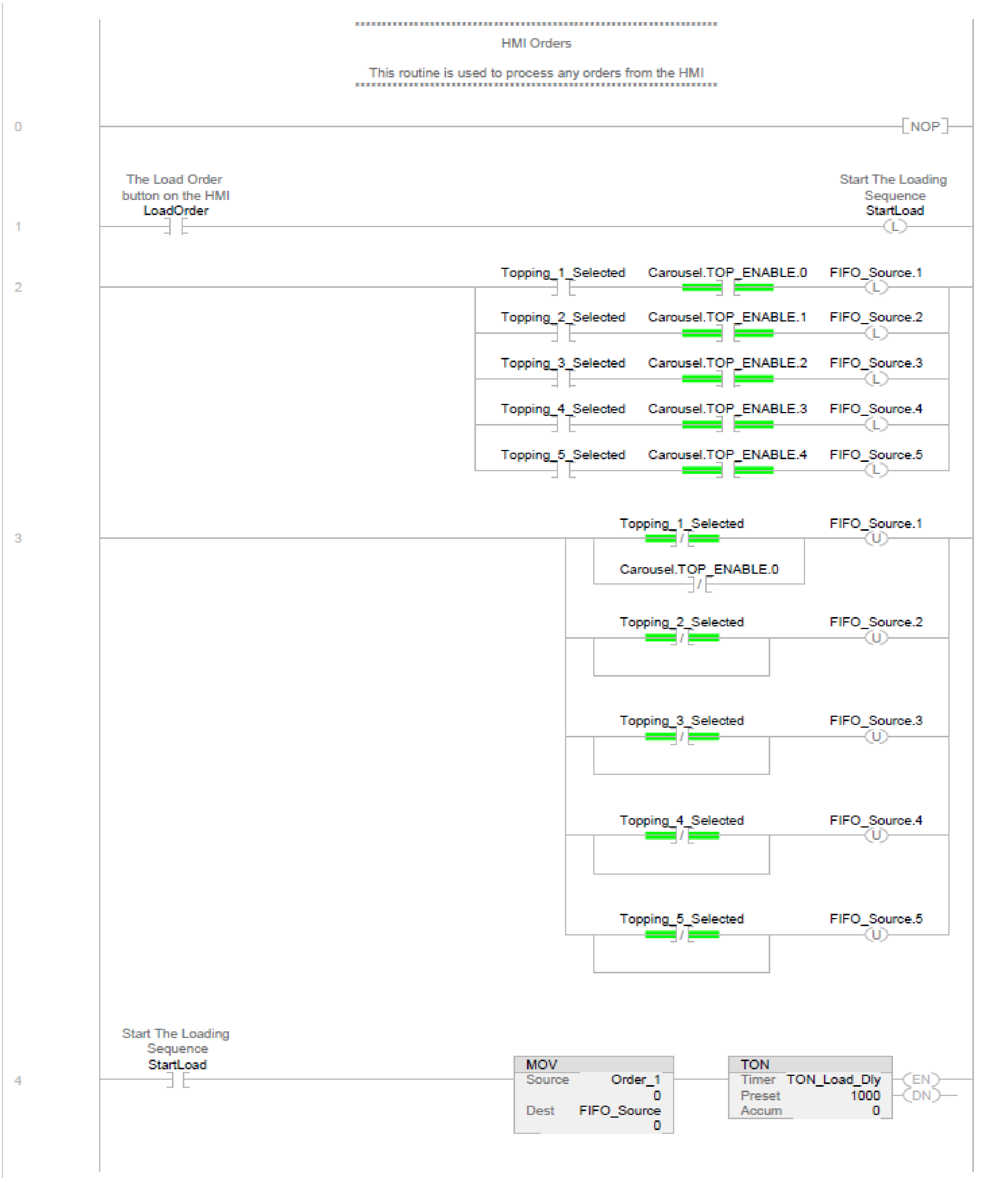
****

1 ——— [NOP]

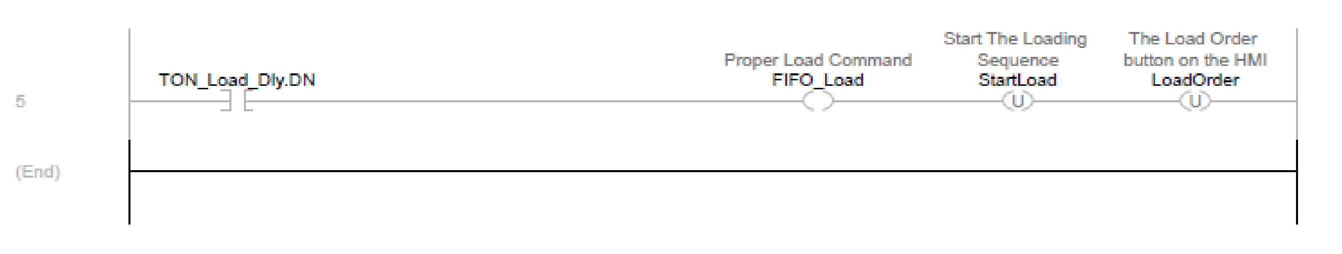
2	Dish Server Clamp In	Local:1:I.Data.0	Server Dish In Home Position	IN_Server_Dish_NC
3	Dish Server Clamp Out	Local:1:I.Data.1	Server Dish In Out Position	IN_Server_Dish_NO
4	Dish Detected on Server Tray	Local:1:I.Data.2	Product Present on Server Dish	IN_SD_Prod_Pres
5	WC On Det	Local:1:I.Data.3	Whipped Cream Output On	IN_WC_On
6	WC Off Det	Local:1:I.Data.4	Whipped Cream Output Off	IN_WC_Off
7	Low Choc Level	Local:1:I.Data.5	Level Sensor for Chocolate Syrup 1 = Good	IN_Choc_Lvl
8	Low Straw Level	Local:1:I.Data.6	Level Sensor for Strawberry Syrup 1 = Good	IN_Straw_Lvl
9	Sprinkle Level	Local:1:I.Data.7	Level Sensor For Sprinkles 1 = Good	IN_Spink_Lvl
10	M&M Level	Local:1:I.Data.8	Level Sensor for M&M's 1 = Good	IN_MM_Lvl
11	Carousel Position	Local:1:I.Data.9		SPARE


Slot 2
12
NOP
Robot In Service
Local:2:I.Data.0
13
Robot In Service
Cobot.Inputs.0
Robot Ready for Ice Cream to be Dispensed
Local:2:I.Data.1
14
Robot Ready for Ice Cream to be Dispensed
Cobot.Inputs.1
Robot has Placed Ice Cream on Serving Dish
Local:2:I.Data.2
15
Robot has Placed Ice Cream on Serving Dish
Cobot.Inputs.2
Robot Is Ready to Put Ice Cream In Carousel
Local:2:I.Data.3
16
Robot Is Finished
Cobot.Inputs.3
(End)

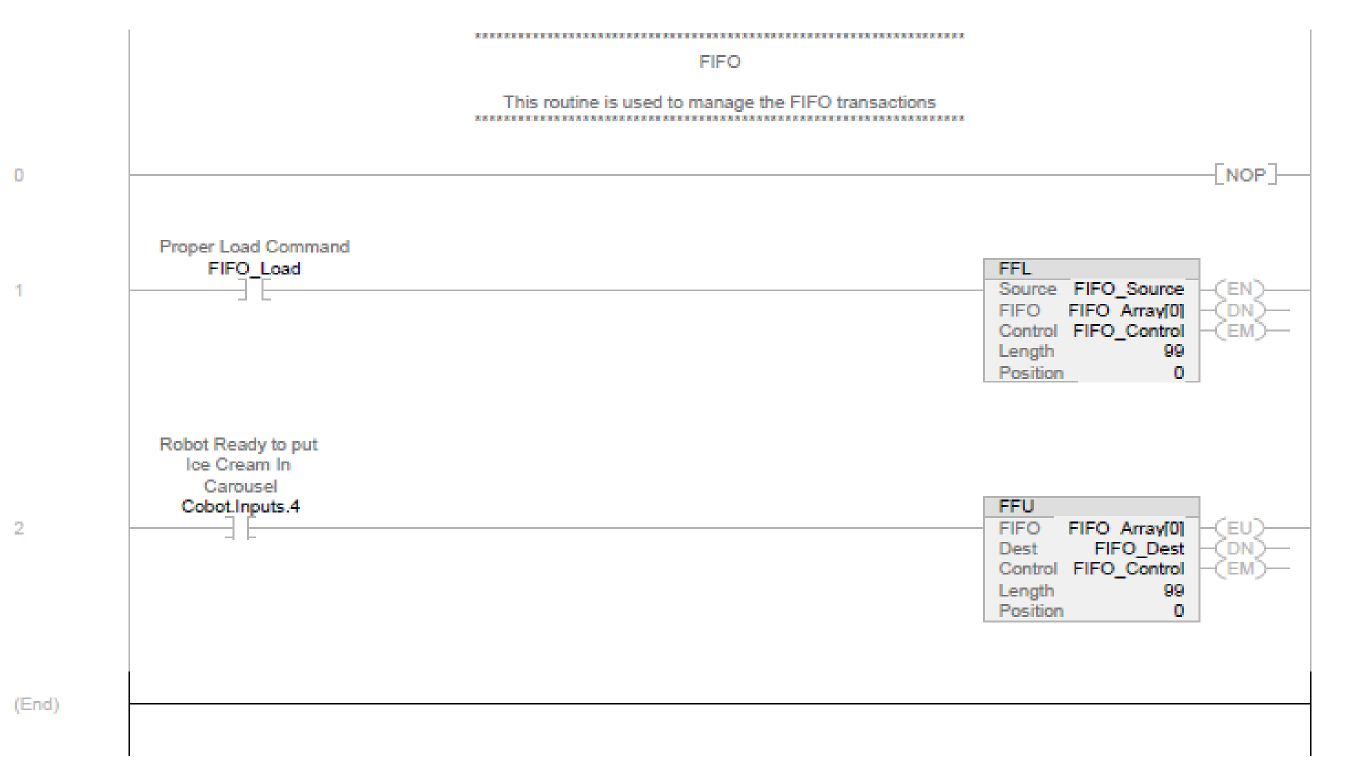
- **HMI Orders**



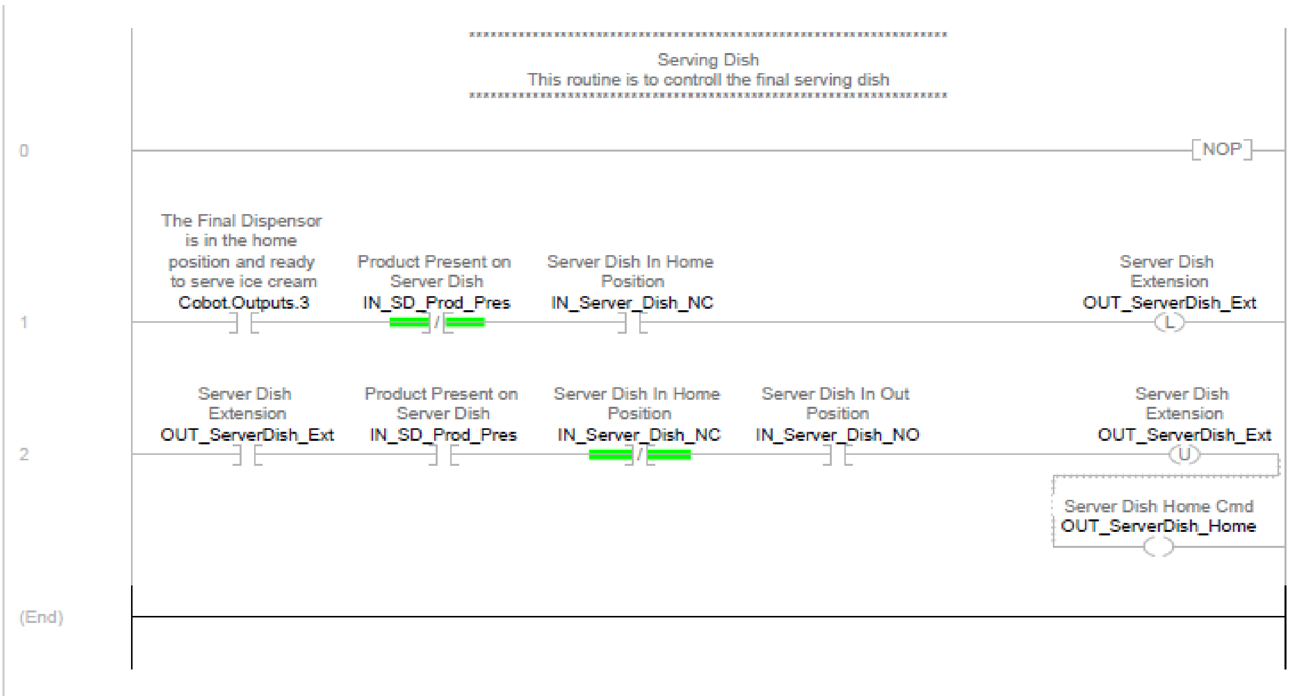
HMI Orders
This routine is used to process any orders from the HMI
0
NOP
1
The Load Order button on the HMI
LoadOrder
Start The Loading Sequence
StartLoad
L
2
Topping_1_Selected
Carousel.TOP_ENABLE.0
FIFO_Source.1
Topping_2_Selected
Carousel.TOP_ENABLE.1
FIFO_Source.2
Topping_3_Selected
Carousel.TOP_ENABLE.2
FIFO_Source.3
Topping_4_Selected
Carousel.TOP_ENABLE.3
FIFO_Source.4
Topping_5_Selected
Carousel.TOP_ENABLE.4
FIFO_Source.5
3
Topping_1_Selected
Carousel.TOP_ENABLE.0
FIFO_Source.1
U
Topping_2_Selected
FIFO_Source.2
Topping_3_Selected
FIFO_Source.3
Topping_4_Selected
FIFO_Source.4
Topping_5_Selected
FIFO_Source.5
4
Start The Loading Sequence
StartLoad
MOV
Source Order_1
0
Dest FIFO_Source
0
TON
Timer TON_Load_Dly
Preset 1000
Accum 0
EN
DN



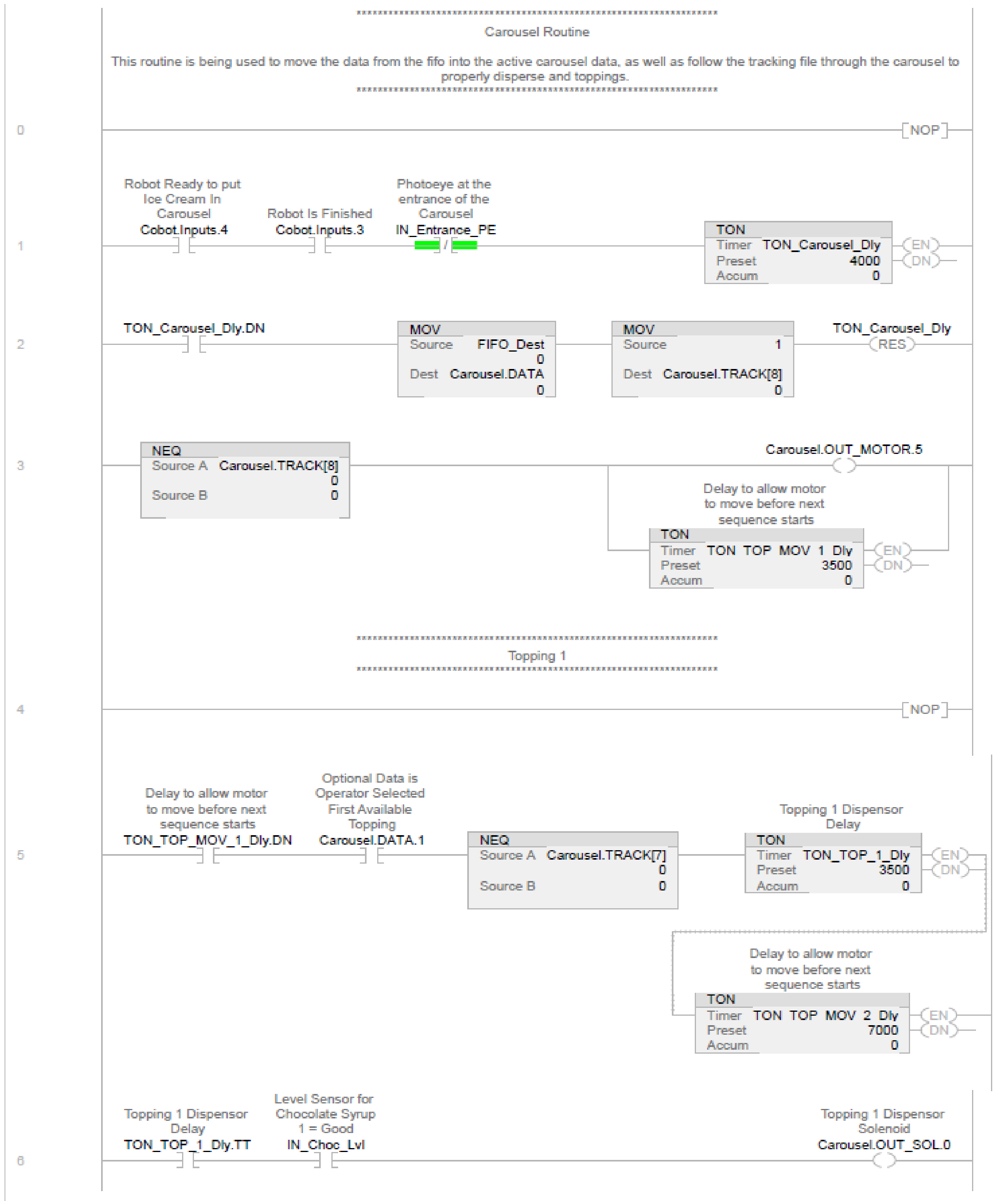
- **FIFO**

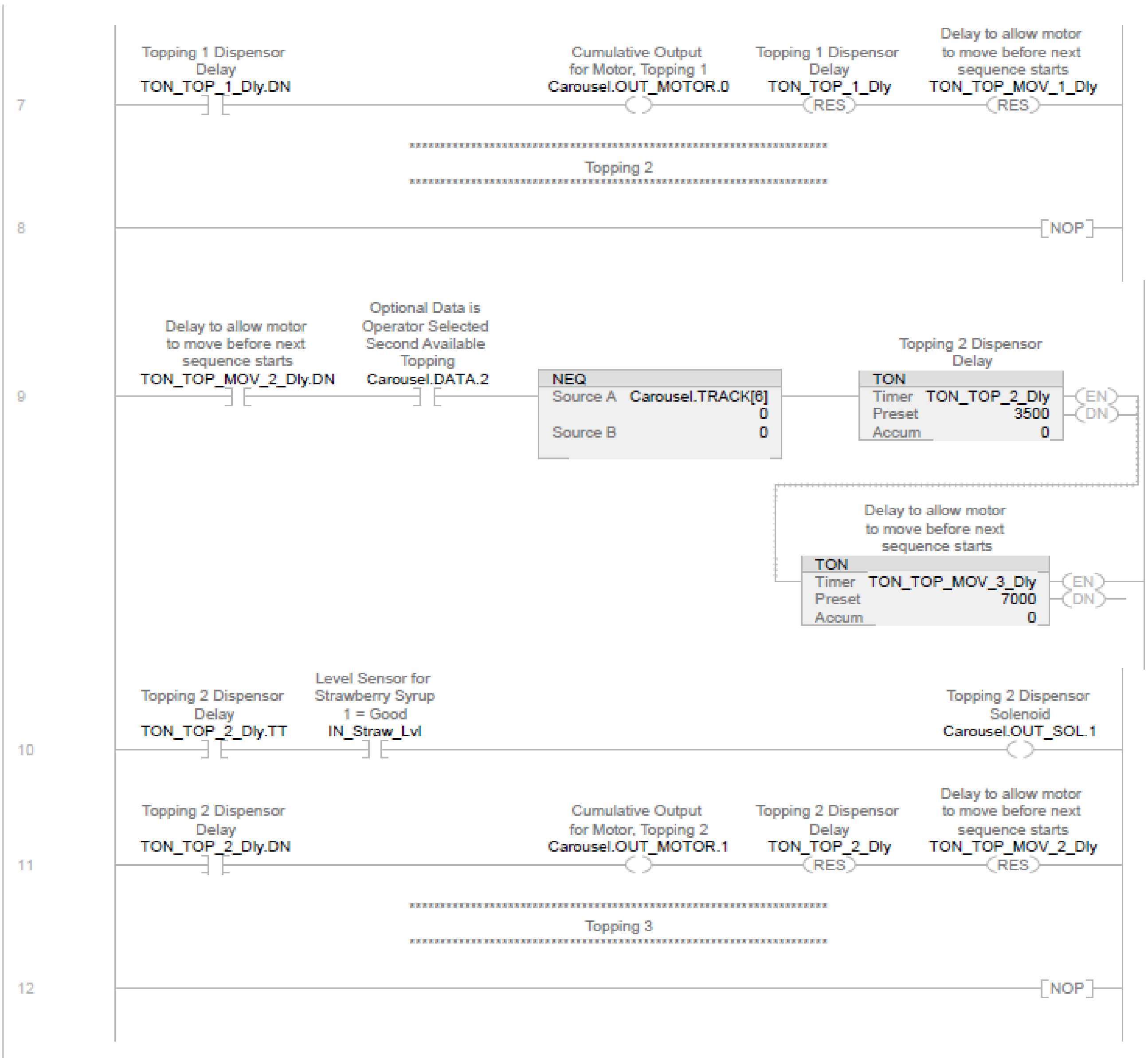


- **Serving Dish**

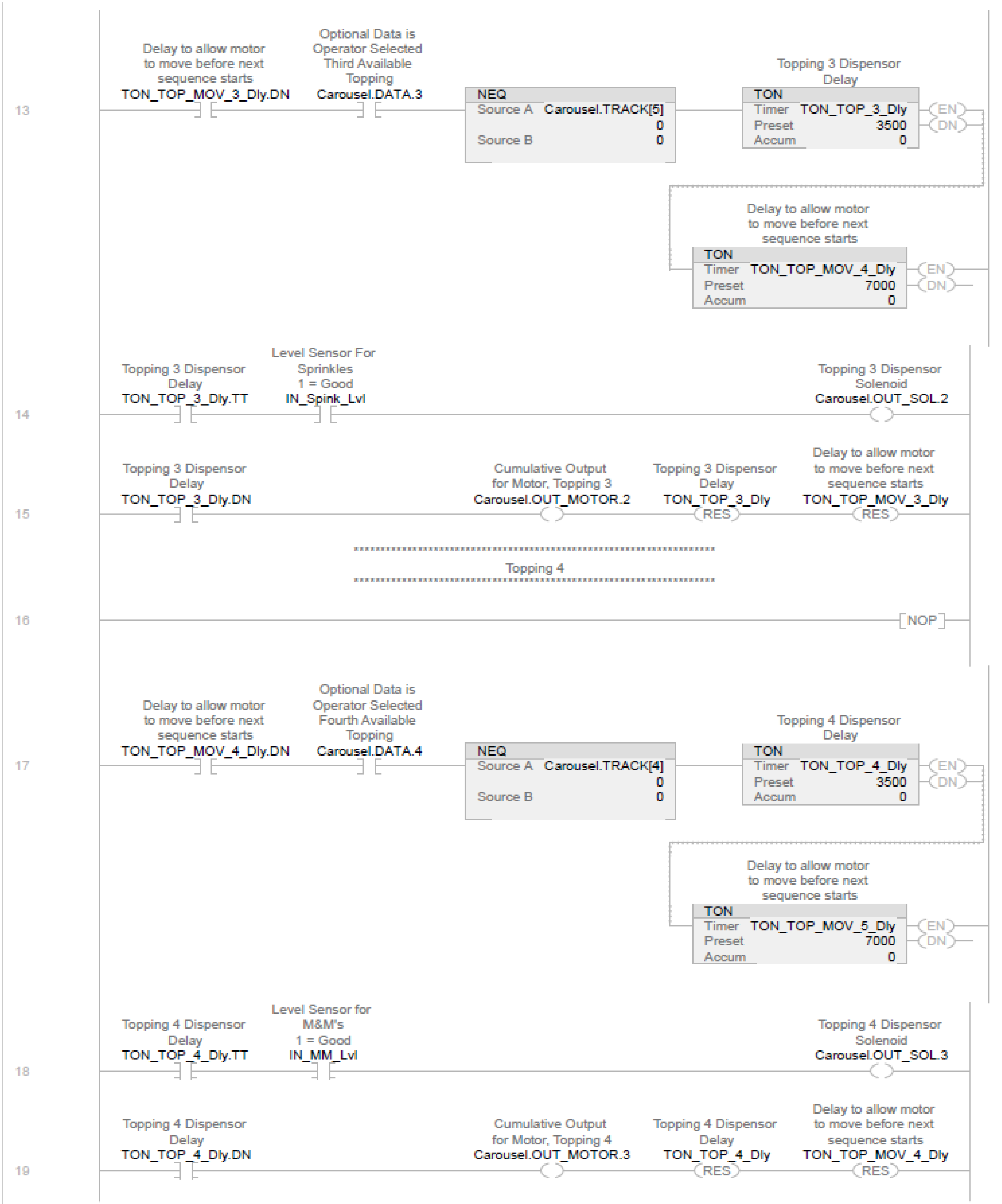

Serving Dish
This routine is to controll the final serving dish
0
NOP
The Final Dispensor is in the home position and ready to serve ice cream
Cobot.Outputs.3
Product Present on Server Dish
IN_SD_Prod_Pres
Server Dish In Home Position
IN_Server_Dish_NC
Server Dish Extension
OUT_ServerDish_Ext
L
1
Server Dish Extension
OUT_ServerDish_Ext
Product Present on Server Dish
IN_SD_Prod_Pres
Server Dish In Home Position
IN_Server_Dish_NC
Server Dish In Out Position
IN_Server_Dish_NO
Server Dish Extension
OUT_ServerDish_Ext
U
2
Server Dish Home Cmd
OUT_ServerDish_Home
(End)

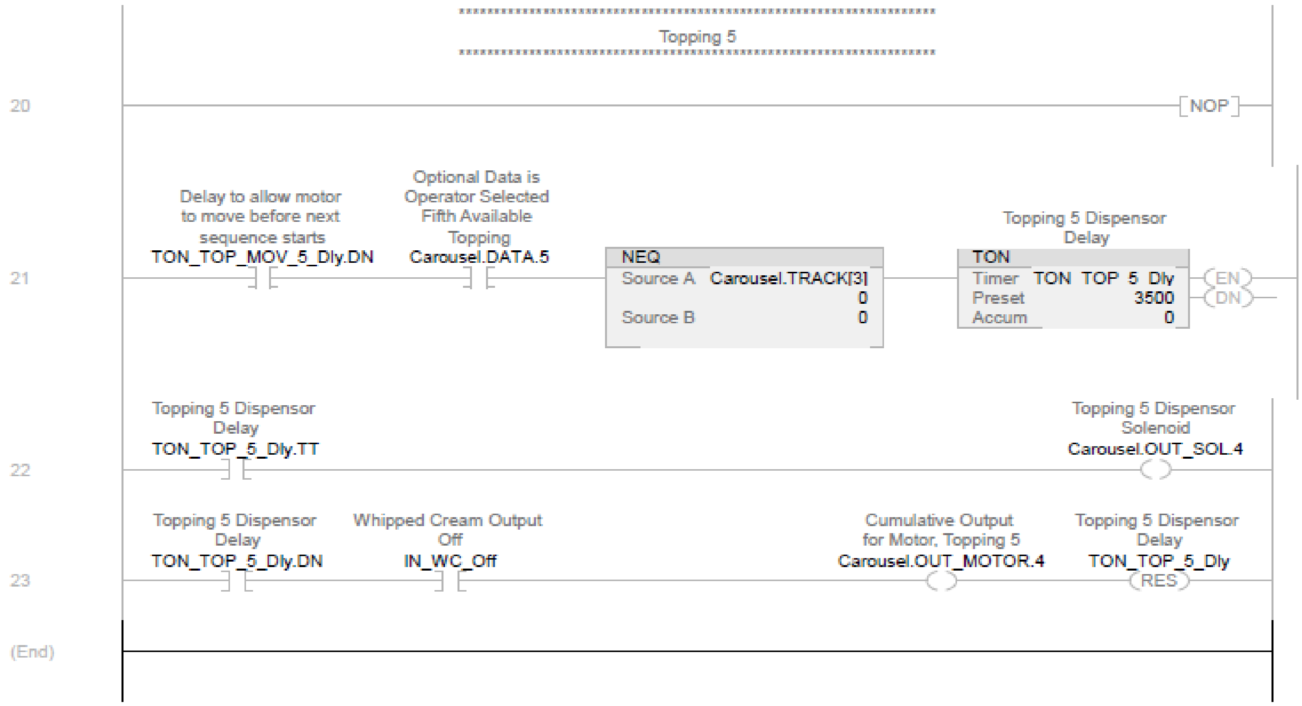
- **Carousel**


Carousel Routine
This routine is being used to move the data from the fifo into the active carousel data, as well as follow the tracking file through the carousel to properly disperse and toppings.
0
NOP
1
Robot Ready to put Ice Cream In Carousel
Cobot.Inputs.4
Robot Is Finished
Cobot.Inputs.3
Photoeye at the entrance of the Carousel
IN_Entrance_PE
TON
Timer TON_Carousel_Dly
Preset 4000
Accum 0
EN
DN
2
TON_Carousel_Dly.DN
MOV
Source FIFO_Dest
0
Dest Carousel.DATA
0
MOV
Source 1
Dest Carousel.TRACK[8]
0
TON_Carousel_Dly
RES
3
NEQ
Source A Carousel.TRACK[8]
0
Source B 0
Carousel.OUT_MOTOR.5
Delay to allow motor to move before next sequence starts
TON
Timer TON TOP MOV 1 Dly
Preset 3500
Accum 0
EN
DN
Topping 1
4
NOP
5
Delay to allow motor to move before next sequence starts
TON_TOP_MOV_1_Dly.DN
Optional Data is Operator Selected First Available Topping
Carousel.DATA.1
NEQ
Source A Carousel.TRACK[7]
0
Source B 0
Topping 1 Dispensor Delay
TON
Timer TON_TOP_1_Dly
Preset 3500
Accum 0
EN
DN
Delay to allow motor to move before next sequence starts
TON
Timer TON TOP MOV 2 Dly
Preset 7000
Accum 0
EN
DN
6
Topping 1 Dispensor Delay
TON_TOP_1_Dly.TT
Level Sensor for Chocolate Syrup 1 = Good
IN_Choc_Lvl
Topping 1 Dispensor Solenoid
Carousel.OUT_SOL.0

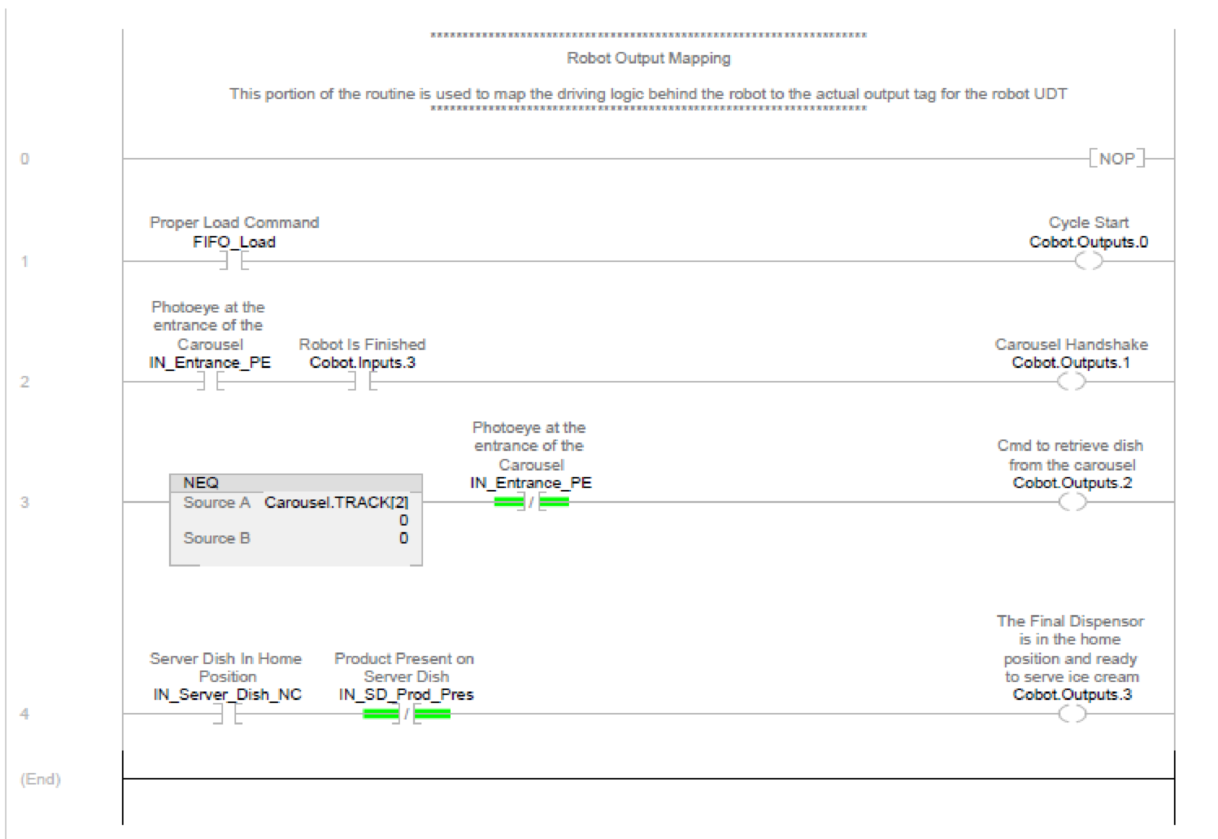


7
Topping 1 Dispensor Delay
TON_TOP_1_Dly.DN
Cumulative Output for Motor, Topping 1
Carousel.OUT_MOTOR.0
Topping 1 Dispensor Delay
TON_TOP_1_Dly
RES
Delay to allow motor to move before next sequence starts
TON_TOP_MOV_1_Dly
RES
Topping 2
8
NOP
9
Delay to allow motor to move before next sequence starts
TON_TOP_MOV_2_Dly.DN
Optional Data is Operator Selected Second Available Topping
Carousel.DATA.2
NEQ
Source A Carousel.TRACK[6]
0
Source B 0
Topping 2 Dispensor Delay
TON
Timer TON_TOP_2_Dly
Preset 3500
Accum 0
EN
DN
Delay to allow motor to move before next sequence starts
TON
Timer TON_TOP_MOV_3_Dly
Preset 7000
Accum 0
EN
DN
10
Topping 2 Dispensor Delay
TON_TOP_2_Dly.TT
Level Sensor for Strawberry Syrup 1 = Good
IN_Straw_Lvl
Topping 2 Dispensor Solenoid
Carousel.OUT_SOL.1
11
Topping 2 Dispensor Delay
TON_TOP_2_Dly.DN
Cumulative Output for Motor, Topping 2
Carousel.OUT_MOTOR.1
Topping 2 Dispensor Delay
TON_TOP_2_Dly
RES
Delay to allow motor to move before next sequence starts
TON_TOP_MOV_2_Dly
RES
Topping 3
12
NOP


13
Delay to allow motor to move before next sequence starts
TON_TOP_MOV_3_Dly.DN
Optional Data is Operator Selected Third Available Topping
Carousel.DATA.3
NEQ
Source A Carousel.TRACK[5]
0
Source B 0
Topping 3 Dispensor Delay
TON
Timer TON_TOP_3_Dly
Preset 3500
Accum 0
EN
DN
Delay to allow motor to move before next sequence starts
TON
Timer TON_TOP_MOV_4_Dly
Preset 7000
Accum 0
EN
DN
14
Topping 3 Dispensor Delay
TON_TOP_3_Dly.TT
Level Sensor For Sprinkles 1 = Good
IN_Spink_Lvl
Topping 3 Dispensor Solenoid
Carousel.OUT_SOL.2
15
Topping 3 Dispensor Delay
TON_TOP_3_Dly.DN
Cumulative Output for Motor, Topping 3
Carousel.OUT_MOTOR.2
Topping 3 Dispensor Delay
TON_TOP_3_Dly
RES
Delay to allow motor to move before next sequence starts
TON_TOP_MOV_3_Dly
RES
Topping 4
16
NOP
17
Delay to allow motor to move before next sequence starts
TON_TOP_MOV_4_Dly.DN
Optional Data is Operator Selected Fourth Available Topping
Carousel.DATA.4
NEQ
Source A Carousel.TRACK[4]
0
Source B 0
Topping 4 Dispensor Delay
TON
Timer TON_TOP_4_Dly
Preset 3500
Accum 0
EN
DN
Delay to allow motor to move before next sequence starts
TON
Timer TON_TOP_MOV_5_Dly
Preset 7000
Accum 0
EN
DN
18
Topping 4 Dispensor Delay
TON_TOP_4_Dly.TT
Level Sensor for M&M's 1 = Good
IN_MM_Lvl
Topping 4 Dispensor Solenoid
Carousel.OUT_SOL.3
19
Topping 4 Dispensor Delay
TON_TOP_4_Dly.DN
Cumulative Output for Motor, Topping 4
Carousel.OUT_MOTOR.3
Topping 4 Dispensor Delay
TON_TOP_4_Dly
RES
Delay to allow motor to move before next sequence starts
TON_TOP_MOV_4_Dly
RES

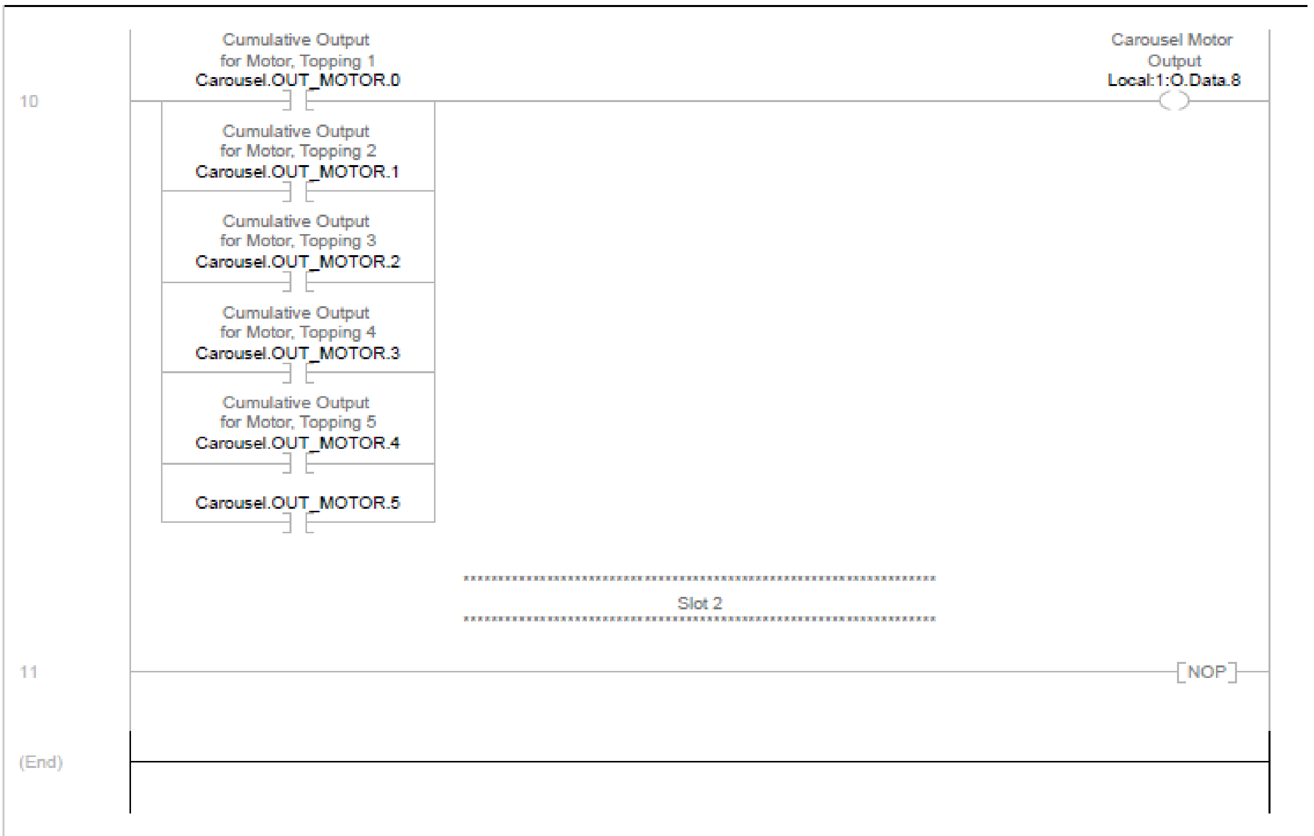


- **Robot Integration**

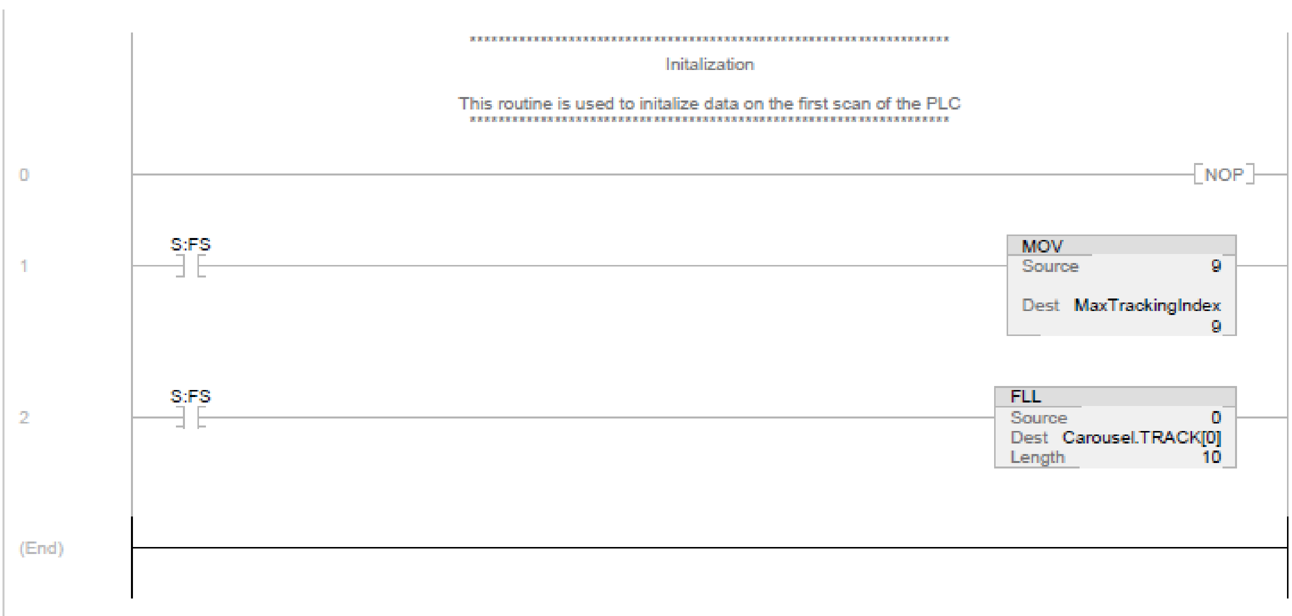


- **Outputs**

Outputt Mapping
This routine is used to map outputs from their intermediate tag for usage throughout the program to an direct IO memory tag. Please check drawings before modified
0
NOP
Slot 1
1
NOP
2
Server Dish Extension
OUT_ServerDish_Ext
Server Tray Out
Local:1:O.Data.0
3
Server Dish Home Cmd
OUT_ServerDish_Home
Server Tray In
Local:1:O.Data.1
4
Topping 5 Dispensor Solenoid
Carousel.OUT_SOL.4
WC On Solenoid
Local:1:O.Data.2
5
Topping 5 Dispensor Solenoid
Carousel.OUT_SOL.4
WC Off Solenoid
Local:1:O.Data.3
6
Topping 1 Dispensor Solenoid
Carousel.OUT_SOL.0
Chocolate Syrup Solenoid
Local:1:O.Data.4
7
Topping 2 Dispensor Solenoid
Carousel.OUT_SOL.1
Strawberry Syrup Solenoid
Local:1:O.Data.5
8
Topping 3 Dispensor Solenoid
Carousel.OUT_SOL.2
Sprinkles Solenoid
Local:1:O.Data.6
9
Topping 4 Dispensor Solenoid
Carousel.OUT_SOL.3
M&M Solenoid
Local:1:O.Data.7


Cumulative Output
for Motor, Topping 1
Carousel.OUT_MOTOR.0
Carousel Motor
Output
Local:1:O.Data.8
10
Cumulative Output
for Motor, Topping 2
Carousel.OUT_MOTOR.1
Cumulative Output
for Motor, Topping 3
Carousel.OUT_MOTOR.2
Cumulative Output
for Motor, Topping 4
Carousel.OUT_MOTOR.3
Cumulative Output
for Motor, Topping 5
Carousel.OUT_MOTOR.4
Carousel.OUT_MOTOR.5
Slot 2
11
NOP
(End)

- **Initialize**


Initalization
This routine is used to initalize data on the first scan of the PLC
0
NOP
1
S:FS
MOV
Source 9
Dest MaxTrackingIndex
9
2
S:FS
FLL
Source 0
Dest Carousel.TRACK[0]
Length 10
(End)

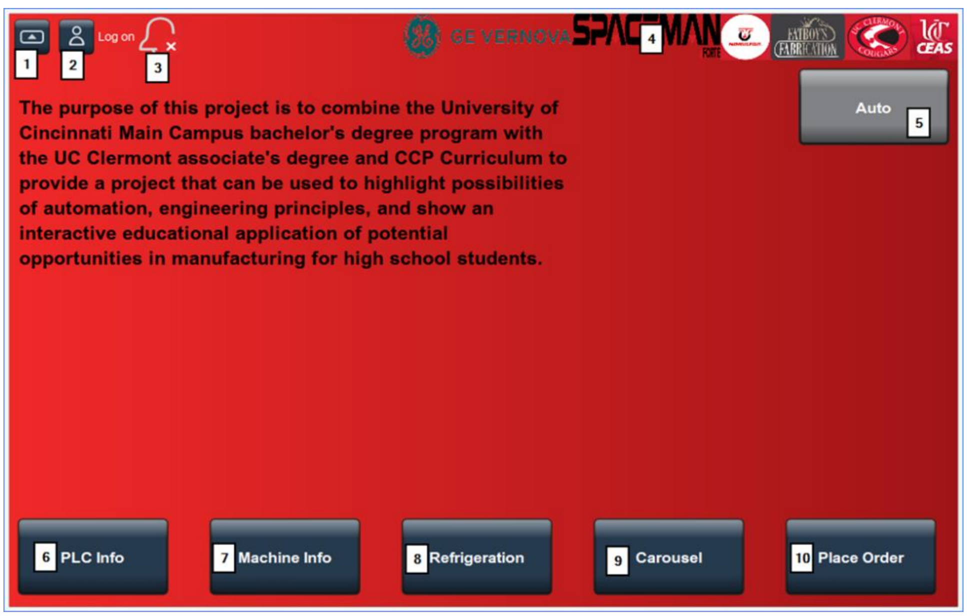
HMI Integration:

The following portion of the document describes the operation and monitoring of the automated ice cream cart senior design project in collaboration with University of Cincinnati Clermont.

When the system is ready to run, no alarm will be active, no e-stop will be active. If the system is off the HMI will show all the conveyors in white status. To start the system the operator needs to press the global start pushbutton on the panel. Depending on the selected mode “Auto” or “Manual” the system will start running the system in accordance.

The system has two main forms of operation, the first is the “automatic mode” Mode, the system will run without human interaction with the exception of placing orders for ice cream.

- **Main Overview Screen**

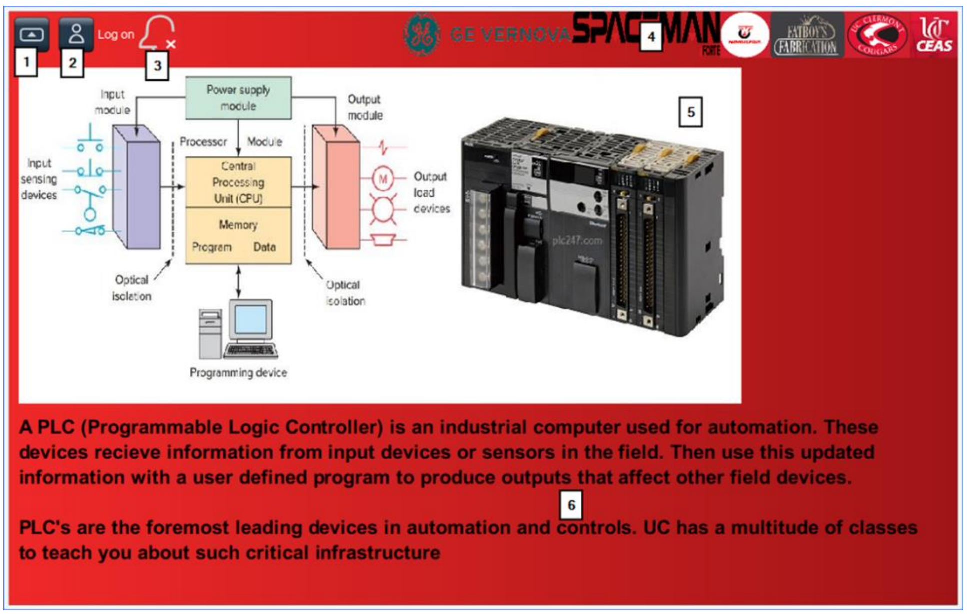


This overview is the main return point of the system, with navigation available to the different screens available in the system.

Element	Description
1	Navigation Drop Down, this is used to navigated back to the home screen, or to any alarm or diagnostics screens
2	User Login and Display
3	Active Alarm Display

4	Sponsors of the System displayed at the top of every non-pop-up screen.
5	When logged to the admin user it will show the auto/manual switch button  When there is a default user it will be hidden. This button is used to switch the mode of the system
6	Button to go to PLC Info screen.
7	Button to go to Machine Info screen.
8	Button to go to Refrigeration Info screen.
9	Button to go to Carousel Info screen.
10	Button to go to start the Order Placing process.

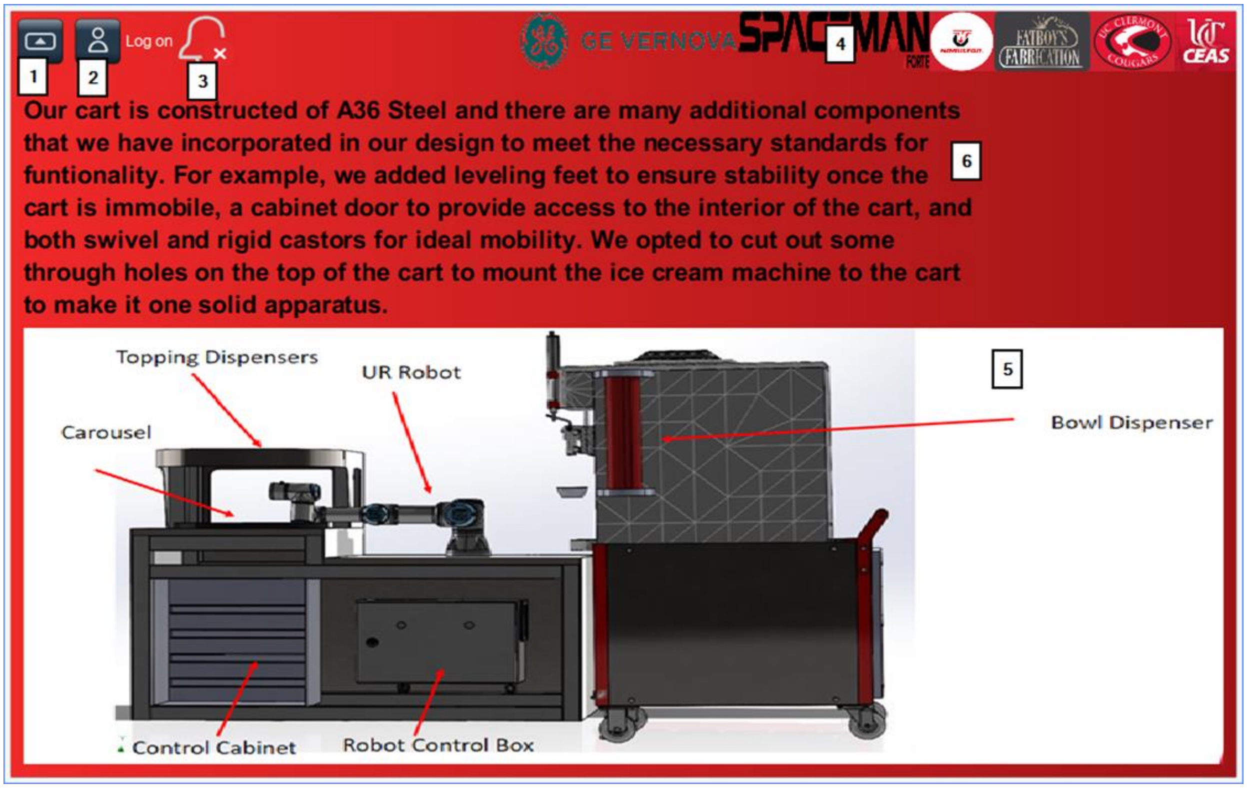
- **PLC Info Screen**



Since the main point of this display is to be informative, we have several screens either depicting or describing important parts of the project. This screen is used to inform the operator about PLC's, the main control device for the system.

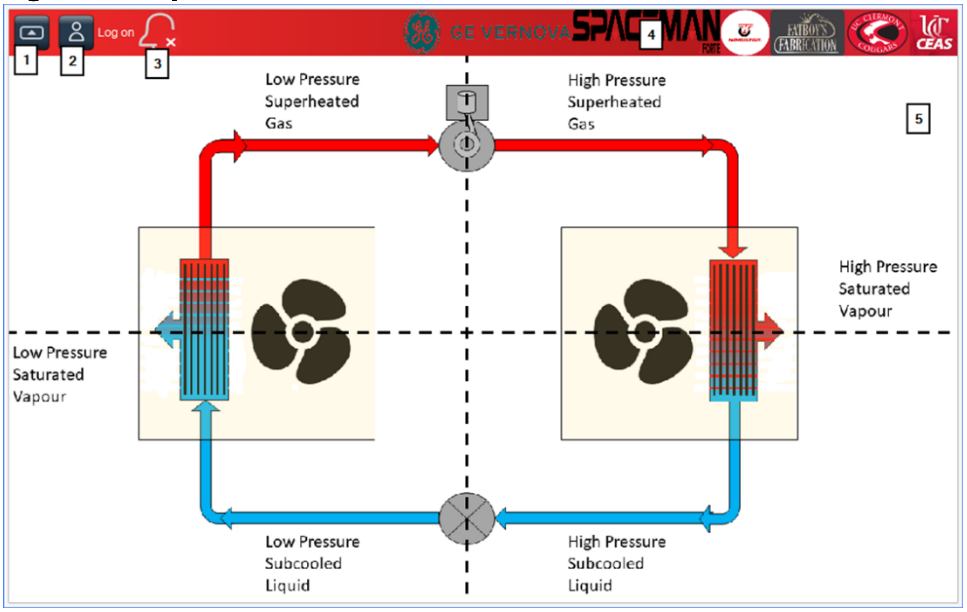
Element	Description
1	Navigation Drop Down, this is used to navigated back to the home screen, or to any alarm or diagnostics screens
2	User Login and Display
3	Active Alarm Display
4	Sponsors of the System displayed at the top of every non-pop-up screen.
5	A Graphic explaining the basics of a PLC in an standard environment
6	A text explanation of a PLC

- **Machine Info Screen**



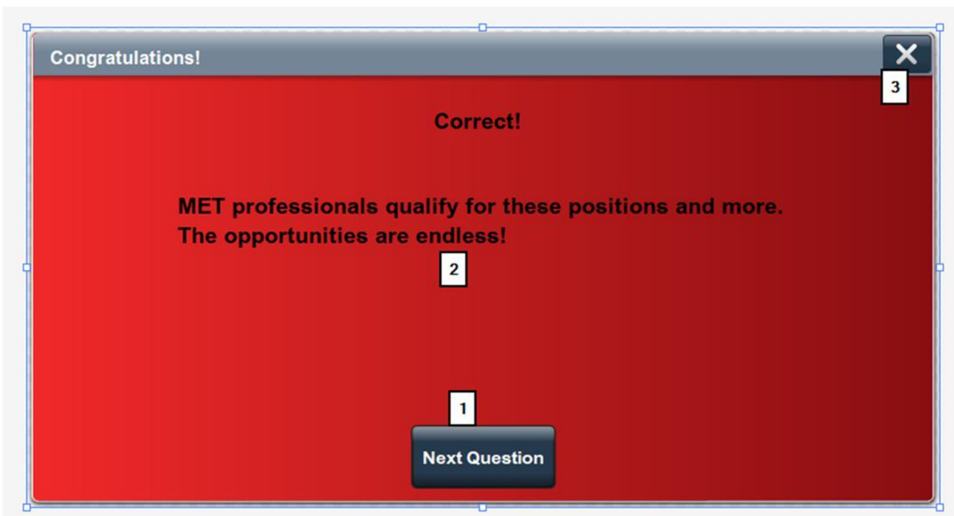
Element	Description
1	Navigation Drop Down, this is used to navigated back to the home screen, or to any alarm or diagnostics screens
2	User Login and Display
3	Active Alarm Display
4	Sponsors of the System displayed at the top of every non-pop-up screen.
5	A model with descriptors of the system design
6	A text explanation of the system

- **Refrigeration Cycle Screen**



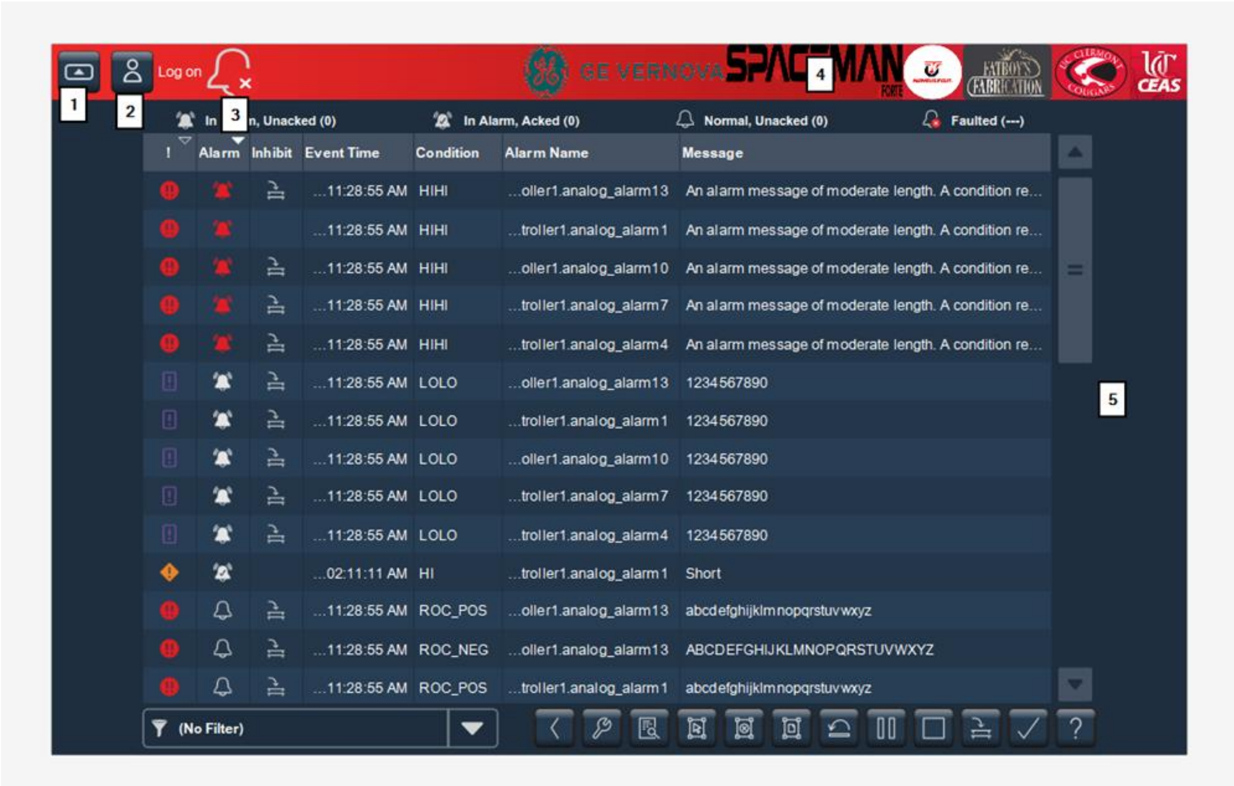
Element	Description
1	Navigation Drop Down, this is used to navigated back to the home screen, or to any alarm or diagnostics screens
2	User Login and Display
3	Active Alarm Display
4	Sponsors of the System displayed at the top of every non-pop-up screen.
5	Graphic displaying the Refrigeration Cycle

- **Question Result Screen**



Element	Description
1	Button to Proceed to Next Question
2	Answer Description
3	Close Pop Up

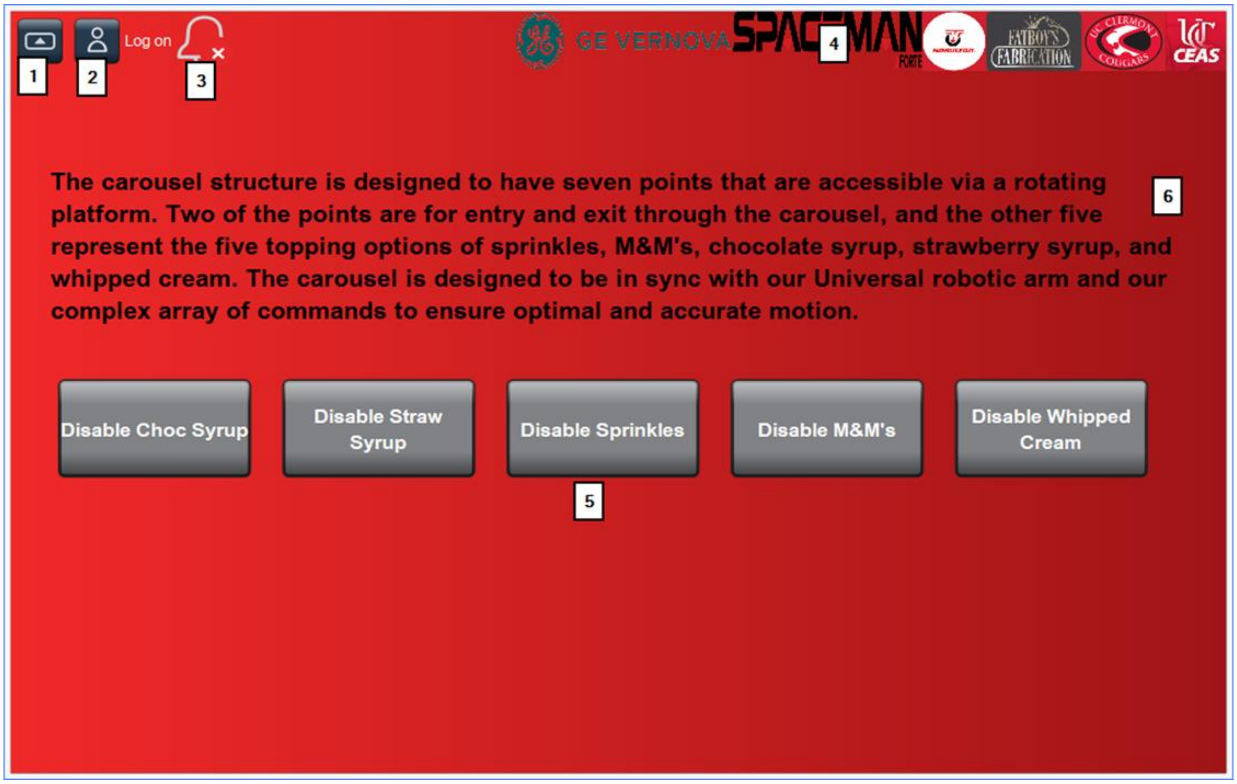
- **Alarm Summary**



Element	Description
1	Navigation Drop Down, this is used to navigated back to the home screen, or to any alarm or diagnostics screens
2	User Login and Display
3	Active Alarm Display
4	Sponsors of the System displayed at the top of every non-pop-up screen.
5	Summary of Alarms in System

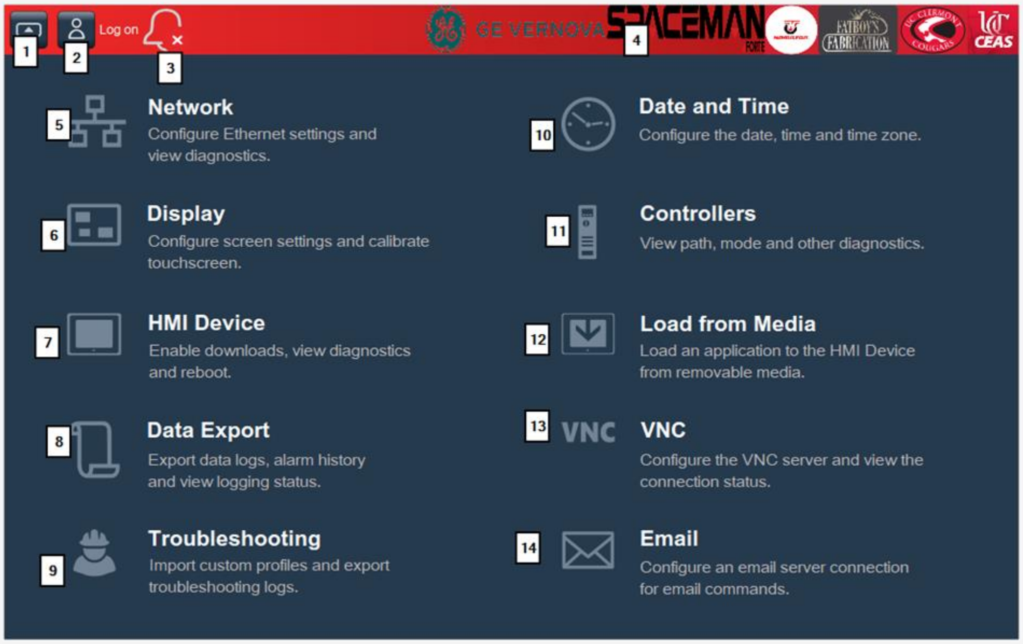
\

- **Carousel**



Element	Description
1	Navigation Drop Down, this is used to navigated back to the home screen, or to any alarm or diagnostics screens
2	User Login and Display
3	Active Alarm Display
4	Sponsors of the System displayed at the top of every non-pop-up screen
5	Button to Disable Selected Topping, Only Available With Admin Login
6	Description of the Toppings Carousel

- **Diagnostics**



Element	Description
1	Navigation Drop Down, this is used to navigated back to the home screen, or to any alarm or diagnostics screens
2	User Login and Display
3	Active Alarm Display
4	Sponsors of the System displayed at the top of every non-pop-up screen.
5	Configure Ethernet Settings and View Diagnostics of Network
6	Configure Screen Settings and Calibrate Touchscreen
7	Enable Downloads, View Diagnostics and Reboot HMI Device
8	Export Data Logs, Alarm History, and View Logging Status
9	Import Custom Profiles and Export Troubleshooting Logs
10	Configure Date, Time, and Time Zone
11	View Path, Mode, and Other Diagnostics of Controllers
12	Load an Application to the HMI Device from Removable Media
13	Configure the VNC Server and View the Connection Status
14	Configure an Email Server Connection for Email Commands

- **Place Order**

Element	Description
1	Select Chocolate Syrup as Topping Button
2	Select Strawberry Syrup as Topping Button
3	Select Sprinkles as Topping Button
4	Select M&Ms as Topping Button
5	Select Whipped Cream as Topping Button
6	Confirm Order Button Once All Desired Toppings Are Selected
7	Close Pop Up.

- **Question Screen**

Element	Description
1	Close Pop Up
2	Question Description
3	Answer Buttons

Lessons Learned:

This project has offered us many lessons and learning opportunities throughout its course. One of the main learning points was the difficulties surrounding manufacturing a food making apparatus. Initially, we did not understand the requirements, risks, and time involved in creating a food safe, commercial grade ice cream machine. It was infeasible to get the machine food safe in the time our customer was demanding.

A secondary learning point was the risks involved in outsourcing parts of the project. Issues with this occurred on two separate occasions. The ice cream machine donated by Spaceman was 220V. This did not align with one of our main project goals of being able to operate the system using a standard 110V outlet. The second occurrence of outsourcing issues involved the cart manufactured by GE Vernova. The paint job began chipping and had to be stripped and redone.

Lastly, a great deal was learned about the intricacies of collaborating and communicating with another organization for the competition of a project. There are many pros and cons that are intertwined with a collaborative project. One of the biggest pros of collaborating on a project is that each party involved offers their own unique skills and specialties. One of the major cons of collaborating is the amount of coordination and communication required to ensure that all parties involved are on the same page and are harmonious in the manufacturing process. If any of the parties involved were not coordinated, the project would become ineffective and messy. This means that every design change, no matter how big or small, must be communicated across all parties clearly to guarantee a fully operational system without flaws.

Conclusion:

Our project began with the end goal being to produce an eye catching, portable, interactive display that could be used to highlight the possibilities of automation, engineering principles, and be engaging with a younger audience. Overall, this end goal was attained. The display is an effective way of captivating the youth with the potential of automation and engineering. Our hope is that it will encourage those who interact with the display to consider a future in automation and engineering, specifically at UC’s Mechanical Engineering Technology program or UC Clermont’s Manufacturing Engineering Technologies program, as well as inspire these individuals in general.

Acknowledgements:

There are a lot of recognitions deserving to be made for people’s contributions toward the success of this project, as without them, it would have been immensely more difficult to be successful. A large majority of this team’s success can be attributed to the impact that Doug McPhillips and his team at University of Cincinnati, Clermont had on the scope of the project.

As far as bigger corporations go, Spaceman Ice Cream kindly donated us an ice cream machine, GE Vernova provided material and some manufacturing capabilities, Hamilton Casters provided the casters, UC Clermont allowed us access to a machine room amongst other amenities, and lastly, Tommer Enterprises provided a large deal of the electronic and automation equipment. In our final acknowledgement, a great deal of thanks is owed to Dr. Christopher Calhoun, our senior design advisor, who offered a great deal of advice to our team and helped settle a lot of nerves surrounding the stress of all the deadlines.

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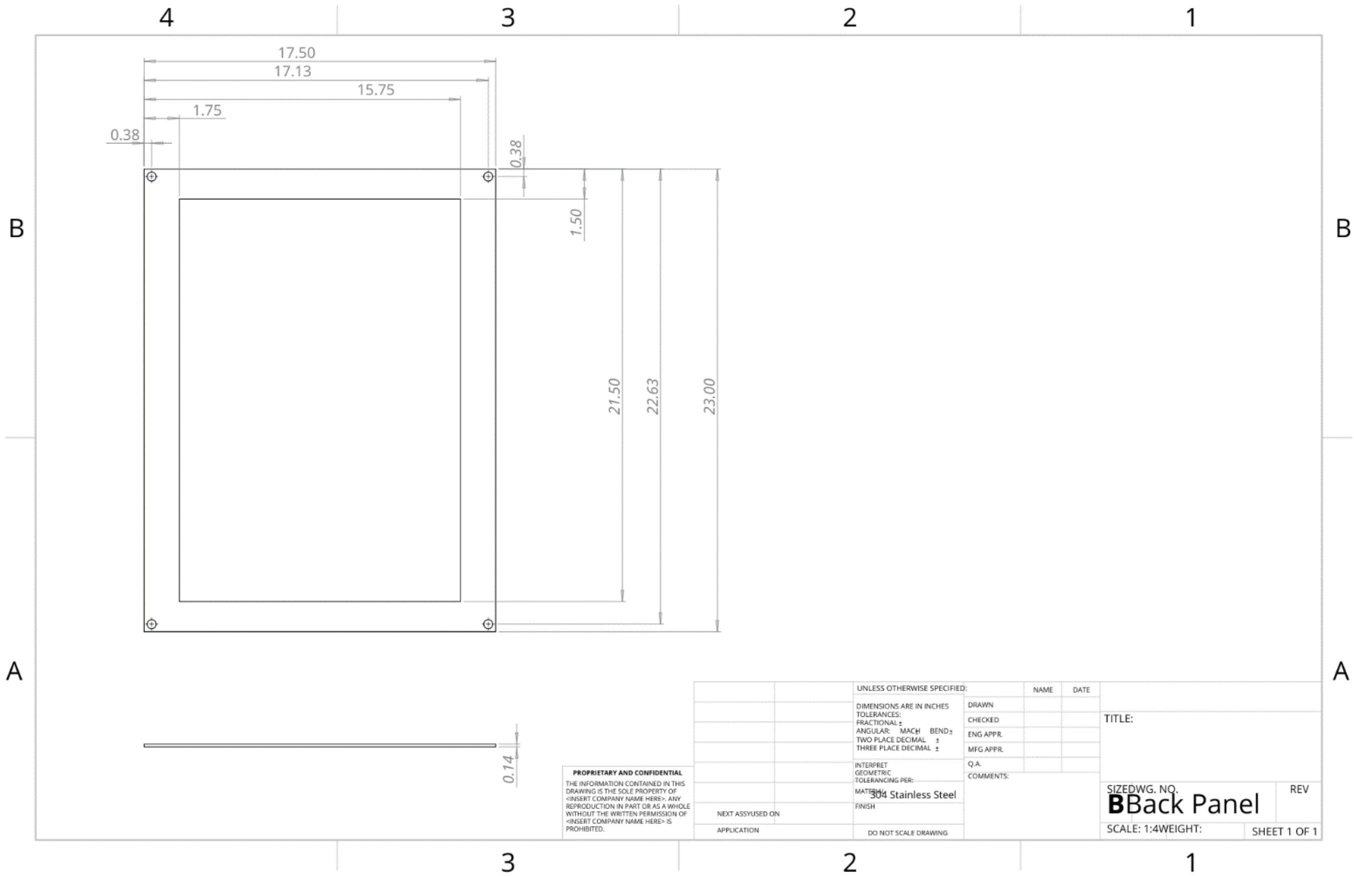
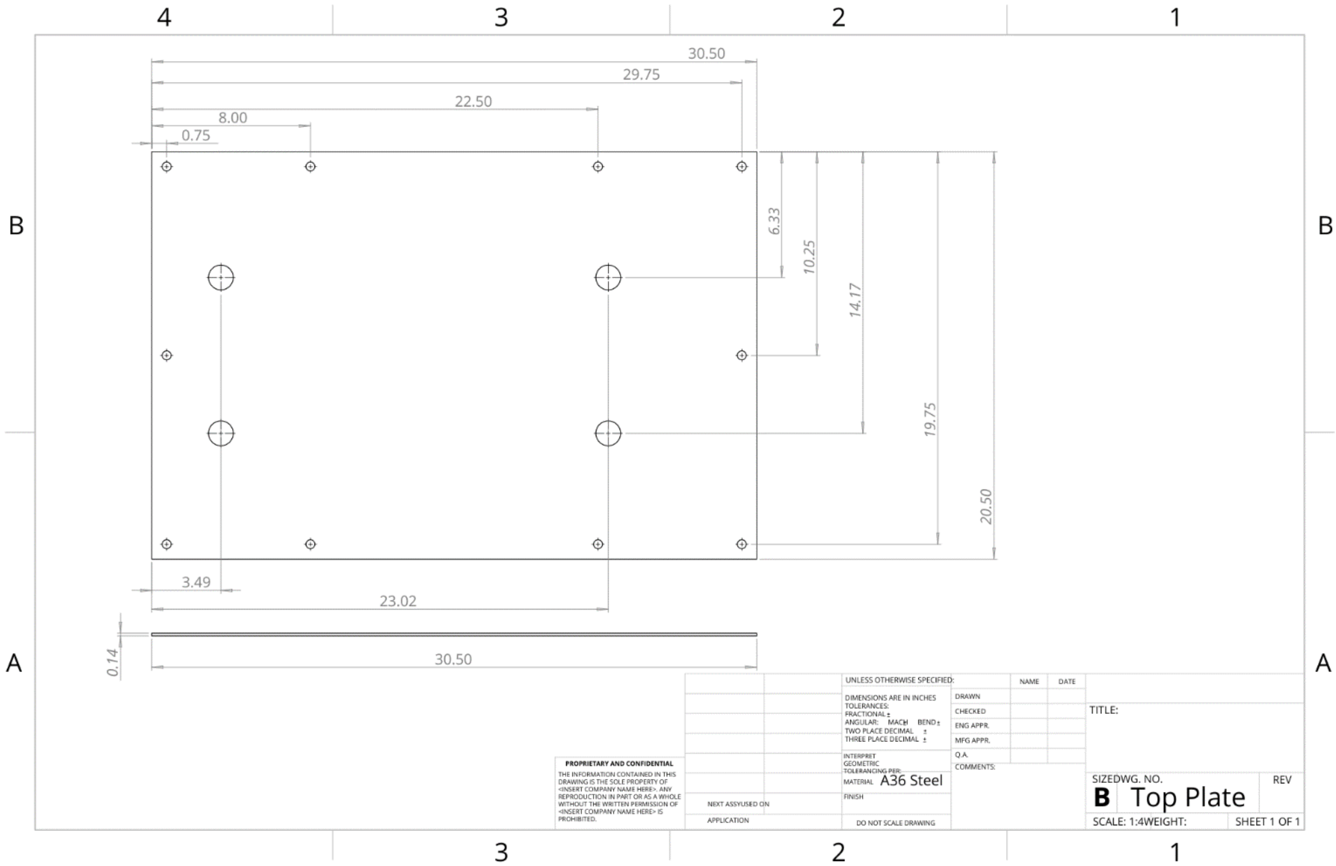
Appendices

Drawings





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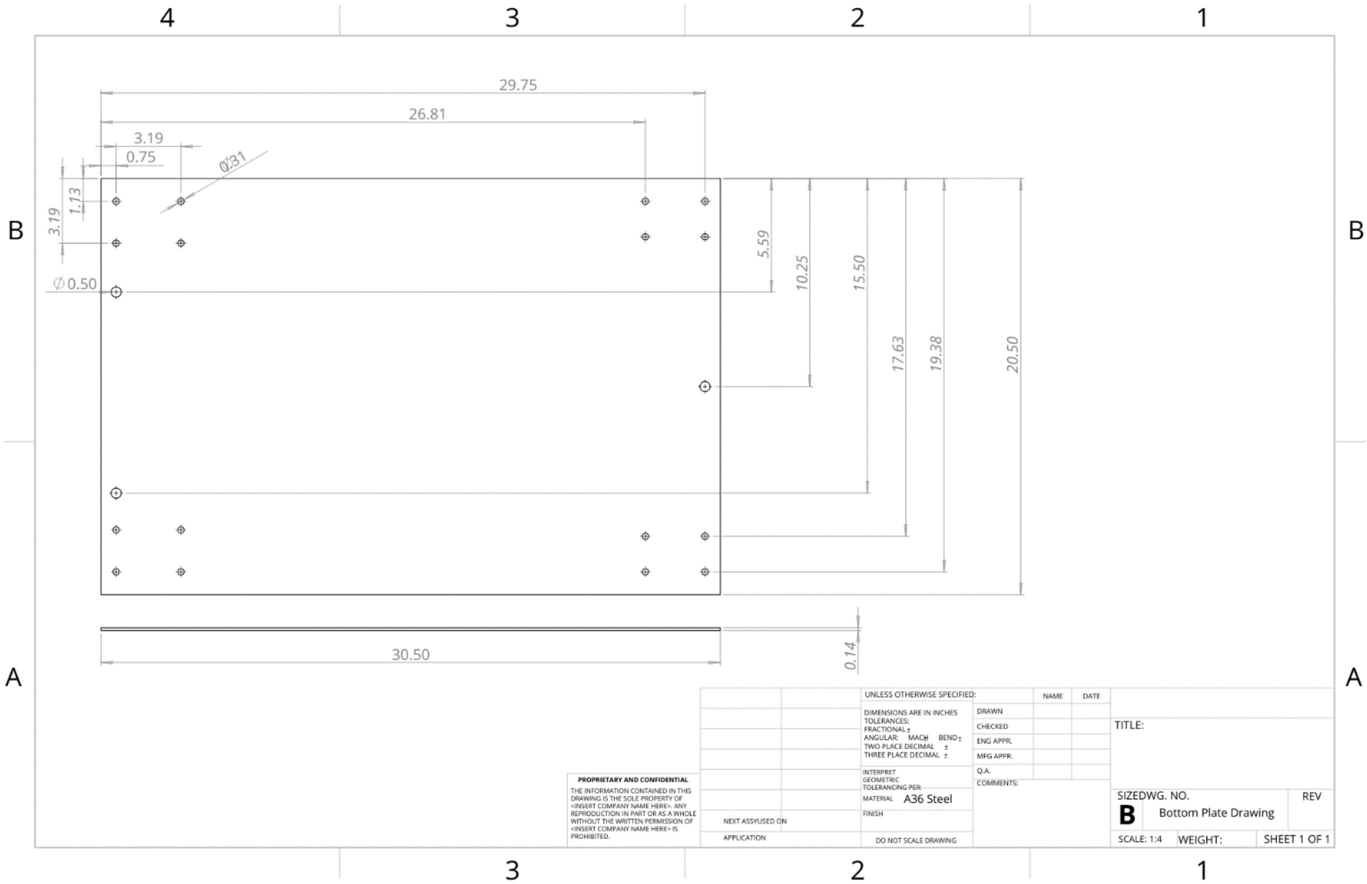

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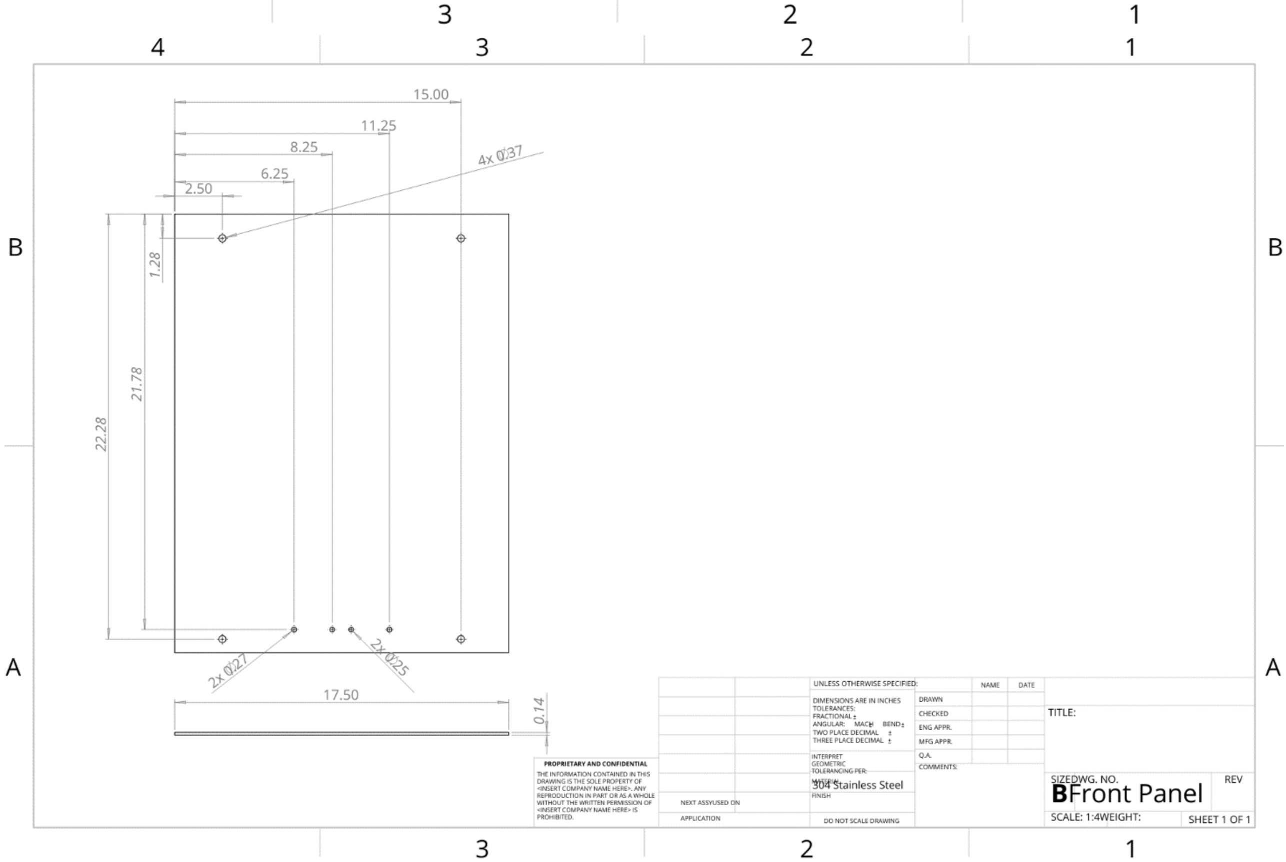

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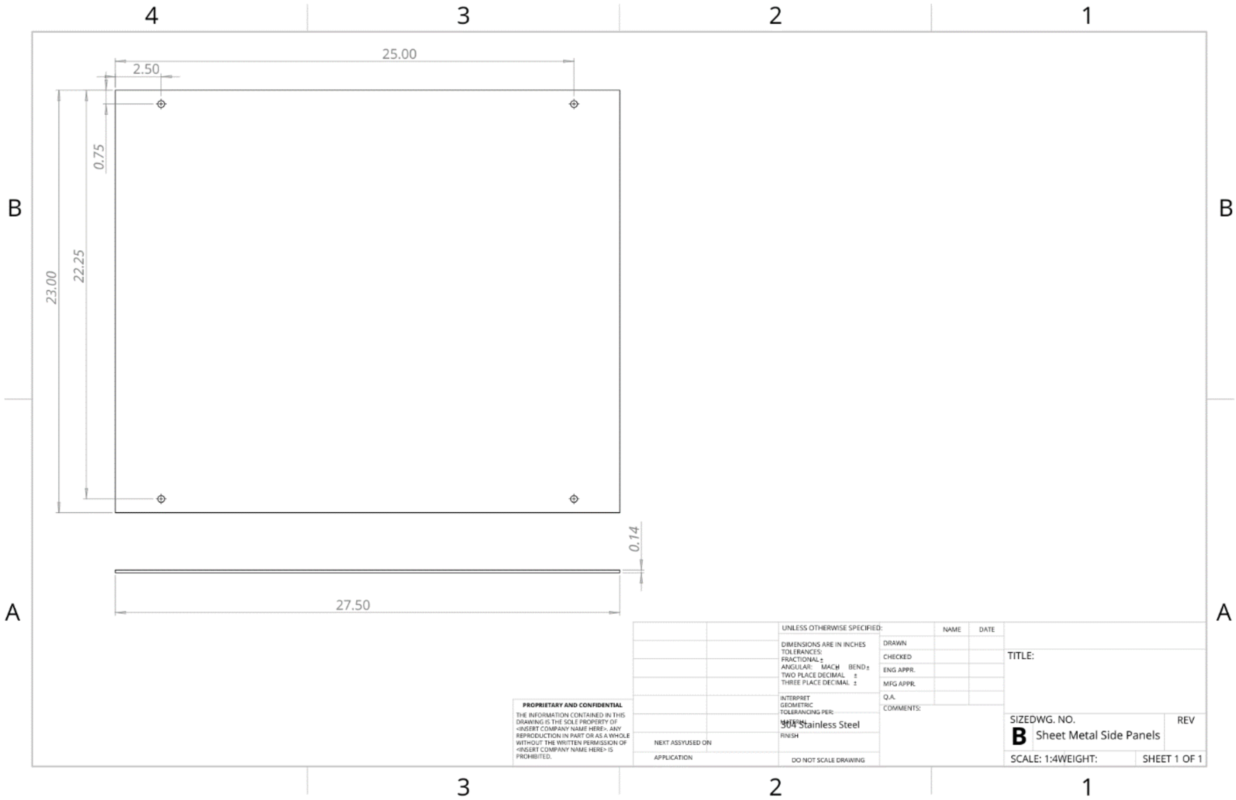
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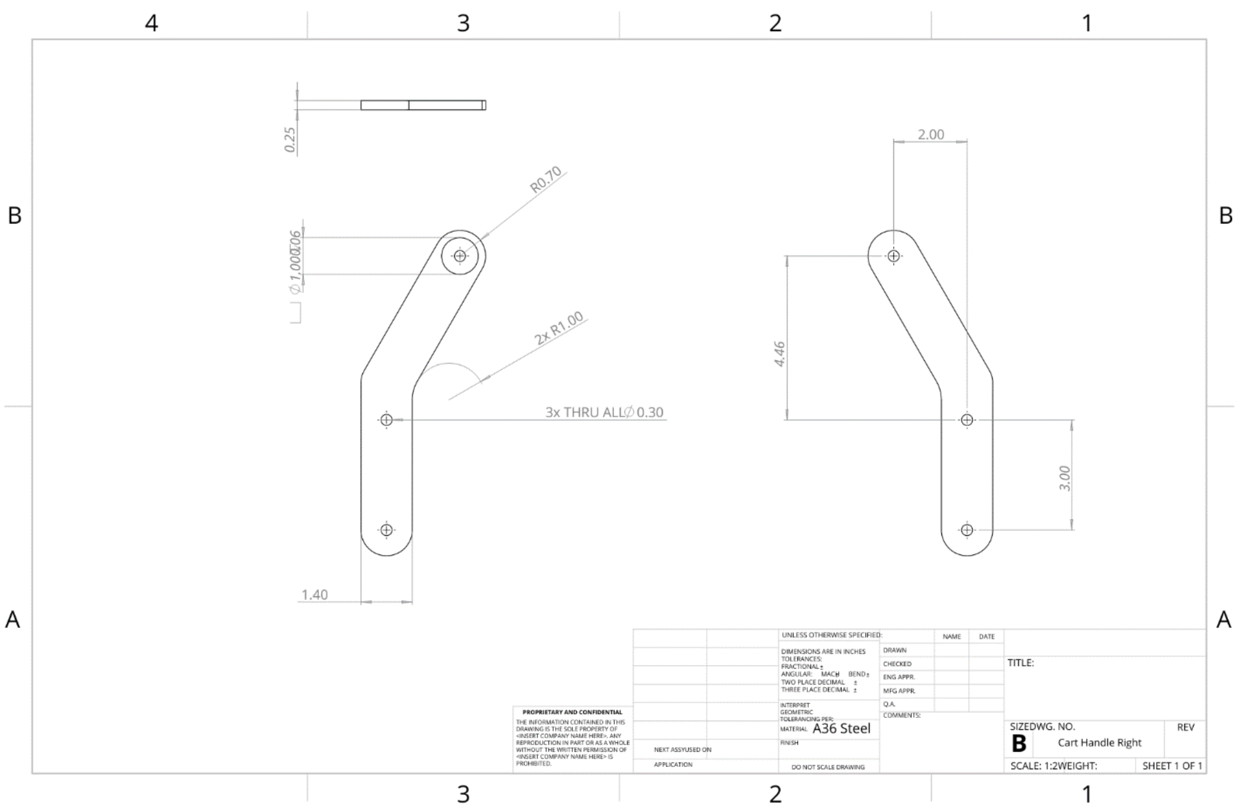
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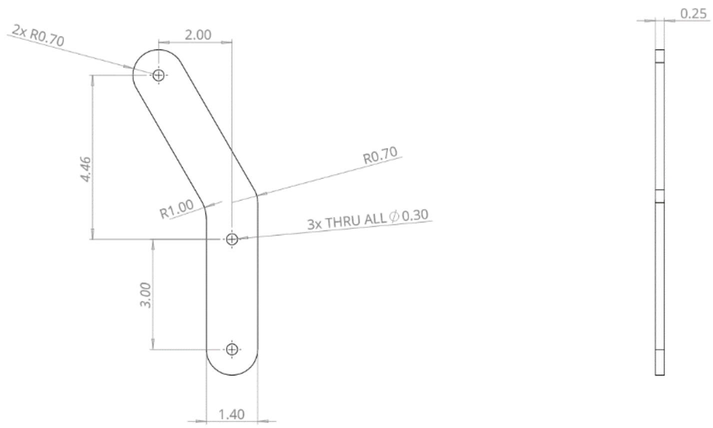

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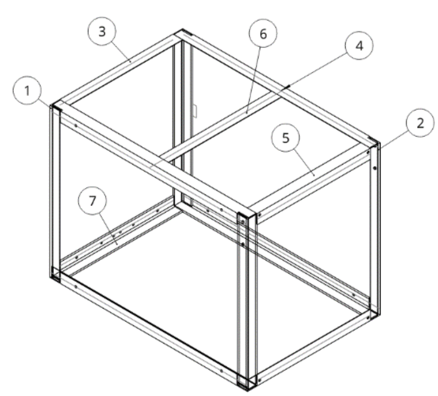

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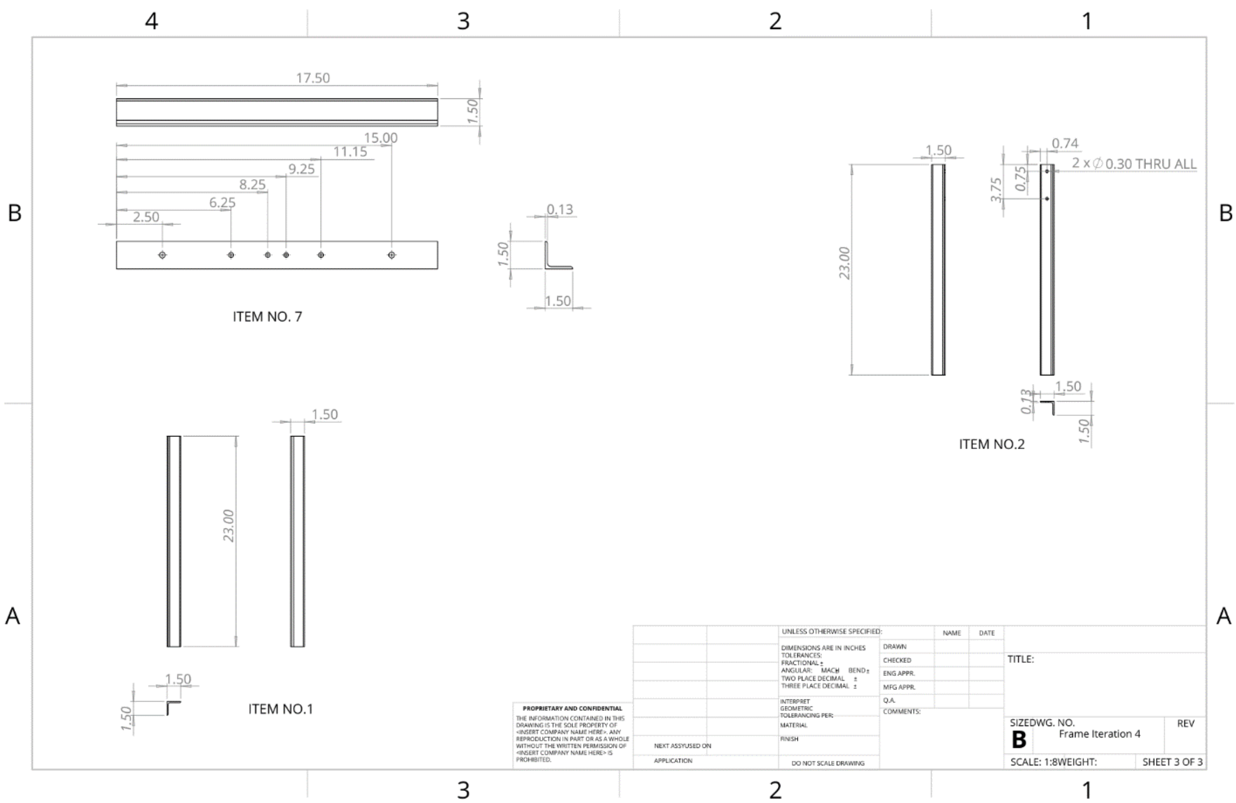
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FINISH
NEXT ASSY USED ON
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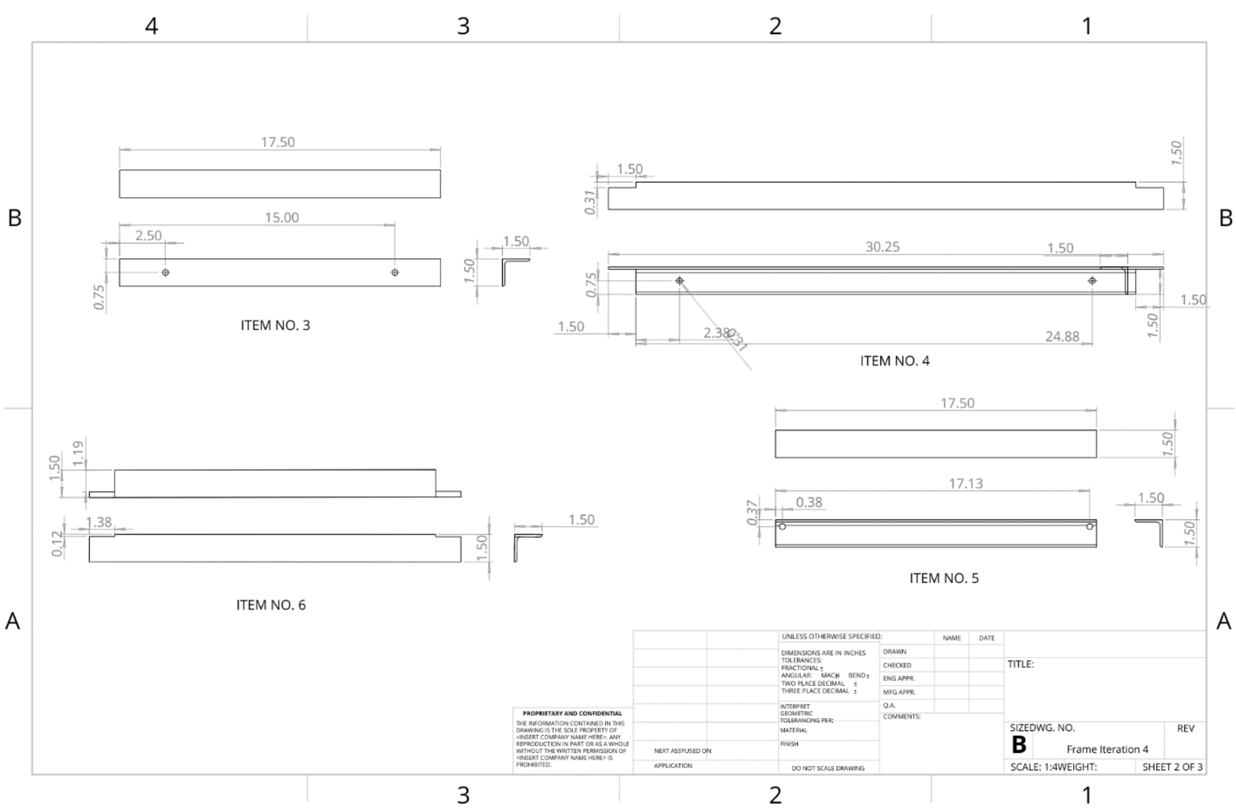
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