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# EEL 4911C / 4914C / 4915C

# Electrical and Computer Engineering Senior Design

# Team 311: The Robotic Trash Cart

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**Abstract**

The elderly and disabled community struggle to push or pull heavy waste bins. This problem is magnified even further if their driveways are sloped, uneven, or become slick due to rain. The Robotic Trash Cart (RTC) removes the hassle of taking heavy waste bins to the curb for waste pick up. The RTC consists of a 2x6 foot aluminum frame with a fiberglass base holding the trash and recycling bins. The RTC is driven by two motorized wheels in the middle of the frame, with two caster wheels for additional support. This allows us to do zero point turning. Homeowners use a Bluetooth controller to direct the RTC to the curb for waste removal. The Americans with Disabilities Act of 1990 requires wheelchair access ramps for businesses and schools to have a maximum incline of 5-degrees. We designed the RTC to carry a 250 pound load up a 5-degree incline, because our users may have wheelchair ramps installed in their homes. The maximum speed of the RTC is limited to increase stability and battery life. A gate is built into the frame of the RTC to provide waste engineers easy access to the bins for quick trash removal.

A future goal of this technology is to develop self-navigating RTCs. They will automate the waste removal process by taking themselves to the curb for waste pick up. This model of the RTC is dependent on the proper implementation of autonomous functionalities. A potential commercial application of a self-navigating RTC is for single unit trash bins used in locales with dense foot traffic, such as amusement parks, shopping centers, and transportation hubs. These machines will sense when they are full, take themselves to a central waste site to be emptied, and return to their original location.

*Keywords*: trash disposal robot; wireless controller

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## Notation

| | |
|---|---|
| A | Amperes |
| AC | Alternating Current |
| ADA | American with Disabilities Act of 1990 |
| AWR | Artists in Waste Removal |
| BLE | Bluetooth Low Energy |
| BMC | Business Model Canvas |
| CoE | College of Engineering |
| CpE | Computer Engineering |
| DC | Direct Current |
| EE | Electrical Engineering |
| ESC | Electronic Speed Controller |
| FAMU | Florida Agricultural and Mechanical University |
| FSU | Florida State University |
| HDPE | High – Density Polyethylene |
| IDA | Information Decision Action |
| IDE | Integrated Development Environment |
| MCU | Microcontroller |
| RTC | Robotic Trash Cart |
| SBC | Single – Board Computer |
| V | Volts |

## Chapter One: EEL 4911C

### 1.1 Project Scope

Project Description:

The Robotic Trash Cart (RTC) will hold and carry both waste containers from the home base to the curb for waste disposal. The RTC design is focused on senior citizens, the disabled community, and people with limited mobility and strength in their extremities. The RTC will relieve the hassle, stress, and alleviate the physical labor involved in taking out the trash bins to the curb. The device needs to be inexpensive, easy to use, and durable. Its purpose is to limit human interaction in the chore of taking out the trash.

Key Goals:

- Limit human interaction and minimize the effort made when taking out the trash
- Prevents the waste bins from tipping over or falling out User Friendly
- Get waste bins to and from the curbside

Assumptions:

- Largest gradient that will be traversed is 5 degrees of incline
    - The Americans with Disabilities Act of 1990 (ADA) stipulates that all wheel chair access ramps of commercial business, school, and churches should be no more than a 5-degree gradient.
- The RTC will need to operate in South Florida Weather: rain, humidity, and wind
- RTC will be stored outside on the side of the house
- Pathway is paved

- Waste Engineers will return the bins into the RTC

Markets:

1. Primary Market – Residential
   a) Senior living communities
   b) Disabled communities
   c) Homeowners
2. Secondary Markets – Industrial and commercial
   a) Waste management companies
   b) Amusement parks
   c) Local, state, and national parks
   d) Locales with dense foot traffic, such as outlet malls and transportation hubs
   e) Anywhere with large amounts of waste being produced

The RTC can be used to hold waste bins in commercial settings, such as amusement parks, shopping centers, and any location with dense foot traffic.

Stakeholders:

Table 1 lists specific stakeholders and their contact information.

- Team 311
- Dean's Office of the FAMU-FSU College of Engineering
- Senior Citizens
- Waste Management Companies (Waste Pro USA, Waste Management, Inc.)
- FSU Jim Moran School of Entrepreneurship

Table 1 *RTC Stakeholders*

| Priority | Full Name | Email | Notes |
|---|---|---|---|
| 1 | Mike Devine | mdevine@fsu.edu | Sponsor |
| 1 | Chris Edrington | edrinch@eng.famu.fsu.edu | Adviser |
| 1 | Jerris Hooker | hooker@eng.famu.fsu | Reviewer |
| 2 | Jim Zheng | zheng@eng.famu.edu | Reviewer |
| 2 | Pedro Moss | pmoss@eng.famu.edu | Reviewer |
| 3 | Becky Hall | demerson1280@comcast.net | Customer |

**1.2 Customer Needs**

This section covers the customer interviews that were conducted to develop the customer needs and requirements. The interviews were conducted over the phone. The customer interviews helped to narrow down the focus of this project and the tasks that the RTC needs to accomplish. The interviewees were Shirley P., Salwa Soliman, and Becky Hall. The home base in this section refers to the location where the RTC is stored when it is not in use. Table 2 lists the specific questions we asked our interviewees.

Table 2 *Interview Questions*

| Number | Question |
|---|---|
| 1 | What Problems make it difficult to take your refuse to the designated pick up area? |
| 2 | Do you or any of your friends have trouble moving around and taking out the trash? |
| 3 | What is your biggest problem when taking out the trash? |
| 4 | Would you say most of your friends leave their trash can inside or outside their garage? |
| 5 | In general, would you say that most of your friends have concrete driveways or some have driveways of other materials, such as gravel or stone? |
| 6 | What is the easiest method for you to deal with the battery life of a trash cart? |
| 7 | Do you have problems placing your trash can, so it doesn't tip over? |

Table 3 lists the interviewee responses to our questions and the need we became aware of from their response.

Table 3 *Customer Responses*

| Question Number | Customer Statement | Interpreted Need |
|---|---|---|
| 1 | Shirley P: The containers are heavy to begin with. When they are full there is the possibility of the container tipping | The city of Tallahassee has a program in which they will get the waste containers for an elderly or |

| | | |
|---|---|---|
| | over on you when you either pull or push it. The edge of the carport to the pick-up area isn't far but for me it is hard when garbage is full. | handicapped person, but they need to fill out a questionnaire. A solution for this problem is any device that will help take the containers to the designated pick up area without tipping over. |
| 1 | Salwa Soliman: It's so heavy sometimes I can't bend it towards me to pull it to the pick-up location. Also, it's too far to walk to the pick-up area. | Salwa has a similar problem to Shirley and a device that takes the containers to the designated pick up area without tipping over would help resolve this problem. |
| 2 | Becky Hall: A couple of friends come to mind. One of my friends isn't very mobile at all and in a wheelchair; so, one thing that could help is to have the trash cans as low as possible to make it more accessible to people in wheelchairs. | People with disabilities have difficulty grabbing and moving things that are high off the ground or very low to the ground. We need a product that is well within reach of people with limited mobility. |
| 3 | Becky Hall: The distance of having a long driveway is my biggest problem I'd say. Some of my friends will put it in a certain spot to make it a shorter trip next | Carrying or pushing the heavy trash containers is difficult for the elderly, disabled, and anyone with limited mobility or strength. Reducing the |

| | | |
|---|---|---|
| | time, even if it's not the best location for a trash can. One of my friends had such a long driveway that they paid their neighbor to just come take out the trash for them. So, distance I'd say is the biggest problem for myself and most of my friends. | distance they have to travel to take out the trash is vital. |
| 4 | Becky Hall: Most of my friends actually have their trash cans inside their garage due to their communities demanding that the trash cans cannot be seen from the street. Some of my friends also hide their trash cans behind their fences or gates just in case the trash smells and they don't want to leave it in their own garage. | The RTC needs to prevent the trash containers from being an eyesore. |
| 5 | Becky Hall: Most of my friends including myself have concrete driveways, because we're in a more residential area. However, I do have a | The terrain the RTC traverses is important to know in order to use an appropriate transportation system, which can involve wheels, tracks, etc. |

| | | |
|---|---|---|
| | couple friends further away that have a gravel and/or dirt driveway. | |
| 6 | Becky Hall: A rechargeable battery I believe would be the easiest and best idea; like a rumba that does its job then goes and plugs itself back in. | A docking station can be built that recharges the batteries of the RTC when it is not transporting the trash to the pick-up location. Solar panels on the trash cart can help to supplement its power needs. |
| 7 | Becky Hall: I usually have trouble deciding where to place my trash can, whether it should be on the street or the driveway. I also usually think about if it's going to rain because there's almost a river running down my driveway to the shoulder of the street then to the storm drain. If I know it's about to rain, I'll place it on the flat part on the road so the river doesn't take my trash can. | A locking mechanism is needed to keep the RTC in place when it is at the designated pick up location or at the home base. Something needs to be done to prevent the RTC from hydroplaning in the rain. |

The customer needs were established based on the interviews with customers. Table 4 lists the customer needs for the RTC.

Table 4 *Customer Needs*

| Need Number | Customer Needs |
|---|---|
| 1 | Alleviate the stress for customers when transporting the trash containers from where they are stored to the curb for pick up. When the trash is full, the weight makes it difficult to move. |
| 2 | Minimizing the distance that the customers have to carry a heavy load of garbage to the curb for pick up or automate the process. |
| 3 | Allow for easy access for people to dispose of their trash into the trash containers. People in wheelchairs, people with limited mobility, or those with limited strength have difficulty reaching the trash bins to dispose of their trash. This also makes it difficult to transport the trash containers to the curb. |
| 4 | The RTC can cover the trash bins to prevent them from being seen from the street. This is required in certain communities. However, this is not a priority for this project. |
| 5 | The RTC needs to be held in place when at the curb or stored at home. |
| 6 | The RTC needs to allow for easy charging of the batteries and user-friendly interface. |

| | |
|---|---|
| 7 | The RTC needs to be able to withstand rain and other types of weather. |
| 8 | The RTC needs to withstand accidental impact from environment and when the Waste Engineers dispose of the trash from the bins. |
| 9 | The RTC needs to be stable when stationary and moving. It cannot tip over. |

Table 5 lists the project requirements that were developed from the interviewee responses and our interpreted needs.

Table 5 *Project Requirements*

| **Requirement Number** | **Need number** | **Requirement** |
|---|---|---|
| 1 | 3 | Easy access to waste containers:<br>Waste containers can be taken out of the RTC in under 10 seconds. This is needed to make the waste disposal process time efficient and allows the user easy access to the bins if needed. |
| 2 | 7 | Weatherproof: water resistant, corrosion resistant and wind tolerant<br>The RTC needs to be water resistant. This prevents any damage due to rain, humidity, sprinklers, or accidental spills. The RTC needs to be corrosion resistant, especially in coastal areas with high concentration of salt. |

| | | |
|---|---|---|
| 3 | 8 | Impact proof.<br>The RTC needs to be able to withstand impacts from debris caught up by the wind or possible collisions with obstacles in its path. It needs to withstand the impact and abuse when the Waste Engineers dispose of the garbage. |
| 4 | 6 | The process of charging the batteries of the RTC needs to be simple and efficient. The user interface of the overall product needs to be user friendly. |
| 5 | 1, 2, 9 | Perform consistent transportation of waste bins from the home base to the curb and back home during scheduled trash removal without tipping over |
| 6 | 4, 5, 8 | Holds the waste bins securely |
| 7 | 1, 2 | The RTC needs to be able to go up a gradient of at least 5 degrees of incline. The Americans with Disabilities Act requires that most businesses, schools, and churches have a wheelchair ramp of at most 5 degrees of incline. The RTC should be able to handle the same gradient as an automated wheelchair. |

Table 6 lists our project constraints. Initially, every entrepreneurship project was granted $1,000.00 budget; however, more funds could be requested. We were granted an additional $900.00 giving us a total budget of $1,900.00.

Table 6 *Project Constraints*

| **Number** | **Constraints** |
|---|---|
| 1 | Our original budget was $1,000.00.<br>Our final budget is $1900.00 |
| 2 | Project must be completed within the 8-month school year window. Deadline by April 26, 2019. |

Extra notes from the interviews:

1. What if weather causes some of the trash to fall on the side of the trash cart or out of the bins because it is overflowing with trash?
2. Would the trash cart be durable enough for someone to wash off and not damage the electronic devices? This goes in line with it being weatherproof.
3. We may also want to look into the average dip/gradients of driveways to get an idea of how steep some driveways are.
4. The RTC will have to be resistant to corrosion from salt when in coastal areas.

## 1.3 Functional Decomposition

Figure 1 depicts the functional decomposition for the RTC. The self-aware module is a stretch goal and is highlighted in yellow.

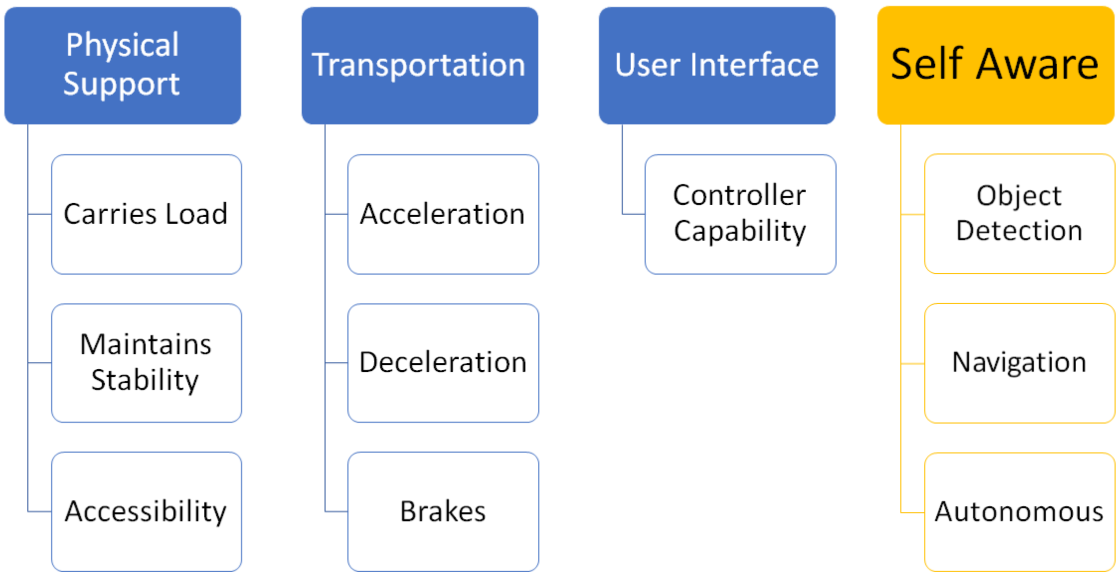


Figure 1. *Functional Decomposition.*

The entire purpose of the RTC is to be able to transport the RTC from the home base to the waste pick-up location and back to the home base. In order to accomplish this, the RTC must be mobile and able to accelerate, decelerate, and come to a complete stop. The RTC will need brakes as well to prevent it from rolling downhill or have someone steal it. The RTC must also be able to carry a heavy load (full waste bins) and maintain stability while transporting the waste bins. The local waste management company in the city of Tallahassee is Waste Pro USA, which from now on will be referred to as Waste Pro. The waste engineers for Waste Pro dispose of the trash in the waste bins by aligning the bins with a mechanical arm on the garbage trucks. This arm hooks into the front of the bins, lifts the bins towards the garbage truck, repeatedly dumps the trash in the waste bins, and sets the bins down onto the street. The waste engineers then take the bins back to curb. This process is lengthy, and we do not want to make it any longer. The waste engineers in Tallahassee are paid salary and will most likely not buy into a system that increases their work for no increased pay. For this reason, the bins need to be easily accessible for the waste engineers. It should also be simple for users to dispose of trash into the waste bins. Based on our customer interviews, the user interface and the controls of the RTC must be simple to use.

Our stretch goals are to make the RTC self-aware and autonomous. In order to implement autonomous functionalities, the RTC needs to have object detection. This is vital for self-navigation of the RTC. The terrain the RTC traverses can complicate autonomous navigation. The wheels or tracks of the RTC can slip in the mud or gravel. This will affect any tracking mechanism and the work performed by the RTC. Adding autonomous functionalities to the RTC can be the second iteration of this project. Below is a list of the tasks that the RTC must accomplish:

- Get from the home base to the drop-off location
- Return from the back from drop-off location
- Prevent the trash from tipping over during transport.
- Prevent the trash bins from tipping over

### 1.4 Target Summary

Target 1 quantifies the accuracy of the robotic trash cart to reach the dispensing location for curbside pick-up. From this point on, the robotic trash cart will be referred to as the unit. This target is necessary to ensure reliability of the unit's operation to maintain an arrival area for consistent waste removal operation. It was chosen based on the needs of the user and the service provider to eliminate delay in trash removal operations. To assess whether the target has been successfully achieved, multiple tests will be done. The objective of this project is to facilitate the dispensation of trash for curbside pick-up; therefore, the importance of this target is rated at 5. The waste needs to be removed and placed in a designated area to ensure proper removal. Failure to meet this target would result in calibration and reconfiguration of setpoint.

Target 2 quantifies the necessary battery capacity to ensure that the robotic trash cart operates long enough to complete its intended tasks. It is assumed that the unit will be stored at a location on the side of the house when not in use. This will be referred to as the home base. The marginal value for the battery capacity was chosen to be twice the capacity needed to complete four round trips from the home base to the dispensing location and back. One trip from the home base to the dispensing location will take a maximum of 10 minutes. It is also assumed that the maximum distance from the home base to the dispensing location is 90 meters. If the motors on the unit draw a combined 2.25A (with the help of gearboxes), then the unit should operate for 40 minutes resulting in 1500 mAh of charge being required for 40 minutes of operation. Under these conditions, the round-trip dispensation of trash could be completed without the battery being depleted below 50%. The ideal value would be 4500 mAh. With this capacity, eight rounds could be completed if necessary, without overly depleting the battery. This target will be verified by running the motors for a 10-minute duration and testing the battery afterwards to assess its remaining charge. This target is rated at 5 for importance, because it is essential for the operation of the RTC. Failure to meet this target can easily be corrected by adding batteries but is nonetheless an absolute requirement.

Target 3 quantifies the speed at which the robotic trash cart can maintain stability and prevent the unit from tipping over. The marginal value was chosen to be the same as the ideal. There is no real urgency to get to the designated pick up point since the operation can be started at an earlier time to achieve the same results. This target will be verified by using weights hanging from different points and applying manual resistance using scales and load cells to determine the tipping points. This target is rated at 5 for importance because it is essential to the robotic trash cart operation. Failure to meet this target can easily be detected by providing overloading alarms triggered from load cell differential detections at tipping limits. To get waste to the designated point, is an essential requirement.

Target 4 quantifies the necessary limits the robotic trash cart can travel over obstacles, such as a garden hose, extension cord, etc. The marginal value was chosen to be the approximate diameter of an extension cord and the ideal is that of a water hose. This target will be verified by using an actual extension cord and water house to determine the dexterity of the unit on real life obstacles. This target is rated at 3 for importance because although it may impede the movement of the unit, it can go in a sleep mode until the obstacle is removed and the unit is restarted. Failure to meet this target can easily be detected by providing sleep mode and alarm/notification of immobility.

Table 7 *Targets Summary*

| Target # | Need | Metric | Imp. | Units | Marginal Value | Ideal Value |
|---|---|---|---|---|---|---|
| 1 | Transport | Within Destination Target Area | 5 | meters | 1 | 0.5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 2 | Battery life | Capacity vs Runtime | 5 | mAh | 3000 | 4500 |
| 3 | Transit stability | Speed vs Wind | 5 | m/s | 0.10 | 0.10 |
| 4 | Drive over obstacles | Obstruction Height | 3 | cm | 1 | 2 |

## 1.5 Concept Generation

This section outlines the designs that were considered for the RTC. The designs are separated by the individual modules, namely General Concepts for the RTC, Drive System, Frame, Controls, and Brakes/Wheels. The designs were developed using group and individual brainstorming sessions, along with market research of similar products and engineering innovations in the automotive industry.

### 1.5.1 General Concepts

Below are possible concepts for the RTC.

**Concept 1.**

- Rectangular framed cart with 4 motorized wheels on each corner of the frame controlling the movement.

**Concept 2.**

- Oval shaped cart with 4 motorized wheels.

**Concept 3.**

- Two separate singular units
- One unit holds the recycling bin and the other holds the trash bin
- Can be used to take out the bins individually
- Each unit has three wheels on the bottom

**Concept 4.**

- One unit that is made up of two smaller, detachable units
- The two smaller units will hold either the recycling or trash bins
- The two smaller units can come together to form one larger unit. This could help with storage.
- Smaller units can have a triangular shape to save space

**Concept 5.**

- Square framed cart
- 2 caster wheels in the front of the frame
- 2 motorized wheels in the back the frame
- Rear - wheel drive
- Microprocessor, ESC, or SBC controlling the drive system

**Concept 6.**

- Square framed cart
- One caster wheel on the front of the frame
- One caster wheel on the back
- 2 motorized wheels in the middle of the cart
- Mid - wheel drive

The different concepts above show and highlight possible designs of the cart. The rectangular cart with a wheel on each corner is the most basic and common design possible. The oval shaped cart is designed to save space and use as little materials as possible. Two separate units have the advantage of moving independent of one another, which is beneficial if you have different garbage and recycling days. The advantage of having a detachable unit is that in the case of a big blow the cart can absorb a large force by splitting apart and dispersing the energy more efficiently. An advantage to having two motorized wheels and two caster wheels is that you can save money and space by only having to motorize and power two wheels instead of all four. The two motorized wheel design will require motors that are able to output more torque than the four motorized wheel design.

**1.5.2 Drive System**

The following are possible concepts for the drive system of the RTC. In all of these concepts, the drive system should be able to carry the load of two full waste containers. This is the worst-case scenario.

**Concept 1.**

- Engine drive

**Concept 2.**

- Electric motor drive

**Concept 3.**

- Four motorized wheels

**Concept 4.**

- One motorized wheel

**Concept 5.**

- Two motorized wheels

**Concept 6.**

- Front wheel drive

**Concept 7.**

- Rear wheel drive

**Concept 8.**

- Middle wheel drive

**Concept 9.**

- Non-motorized caster front wheel(s)
- Two motorized wheels in the back

- Rear wheel drive

**Concept 10**

- Two motorized motors in the center of the cart. They are placed on either side cart.
- When one motor reverses and the other motor moves forward, this allows for zero point turning.
- Middle wheel drive

To eliminate noise and protect the environment from fossil fuel hydrocarbons, the optimal drive system is electric, not engine powered. Keeping with environmental consciousness, the drive system requires less maintenance and produces less waste if the power system is rechargeable. If batteries are used, then the RTC will consume less batteries and produce less waste if they are rechargeable.

The platform of the drive system should enable max maneuverability to avoid objects. As a great example of operation, the steering for the drive system should have the same inherent operation as a mobile wheelchair in which it can hold a heavy weight and still steer within a small footprint. Therefore, middle drive forward/reverse steering enables the smallest footprint for turns and 360 degree actions using front and rear swiveling wheels to stabilize load.

### 1.5.3 Power System

**Concept 1.**

- AC electric cord power (tethered)

**Concept 2.**

- Rechargeable batteries

**Concept 3.**

- Disposable batteries

**Concept 4.**

- 12 Volts

**Concept 5.**

- 24 Volts

As previously mentioned, the power system will consume less resources and produce less waste, such as batteries, if it is rechargeable. The batteries for the power system should be sufficient enough to power the drive system for at least a month. This would equate to travelling from the home base to the curb and back to the home base once a week.

AC tethering inhibits the best mobility options and should not be used. Furthermore, both 12 V and 24 V operation is an acceptable power source. Using two 12 V batteries, allows you to use one as backup power or both can be separated to power any added accessories without depleting drive power. If a rechargeable power system is used, a minimum run time operation before charging is needed must be calculated (week, month, year?).

**1.5.4 Frame**

**Concept 1.**

- Plastic rectangular frame

**Concept 2.**

- Plastic square frame

**Concept 3.**

- Plastic circular frame

**Concept 4.**

- Plastic triangular frame

**Concept 5.**

- Plastic oval shaped frame

**Concept 6.**

- Steel rectangular frame

**Concept 7.**

- Steel square frame

**Concept 8.**

- Steel circular frame

**Concept 9.**

- Steel triangular frame

**Concept 10.**

- Steel oval shaped frame

**Concept 11.**

- Aluminum rectangular frame

**Concept 12.**

- Aluminum square frame

**Concept 13.**

- Aluminum circular frame

**Concept 14.**

- Aluminum triangular frame

**Concept 15.**

- Aluminum oval shaped frame

**Concept 16.**

- Frame with one ramp for the whole trash can

**Concept 17.**

- Frame with two separate ramps for each wheel of the bins

**Concept 18.**

- Emergency lights on the frame

**Concept 19.**

* Frame that holds 1 trash can; each bin will have its own trash cart

**Concept 20.**

* Frame can hold the trash bin and the recycling bin

Plastic is the ideal material for the RTC, because it can withstand the rain without corroding. Emergency lights on the RTC can ensure greater visibility for pedestrians and drivers to avoid collisions. A rectangular shape for the RTC will allow for an easier design to assemble and holds both the recycling and regular garbage bins; it will offer the best stability when the RTC is moving. Having a rectangular shape, also makes it easier to design a gate and a ramp to unload the bins quickly with minimal difficulty from the RTC. Ideally, building a frame as low as possible reduces any extraneous effort that users would normally not exert when taking out the trash. Providing a ramp that allows the containers to be rolled out of the cart rather than lifted out further reduces the stress put on users. It is assumed that the waste engineers will return the waste bins to the RTC once they have disposed of the garbage; therefore, the users only need to place the waste bins the first time they begin using the RTC. There is no need for users to take the waste bins off the cart, since they will be able to dispose of garbage bags into the waste bins while they are on the RTC. Lastly, it is cheaper to design one cart rather than two separate units.

**1.5.5 Control System**

**Concept 1.**

* Single - board computer (SBC)

They are faster than MCUs and small enough to fit on the unit itself. It can act as the control center for the drive system and the various sensors needed for the RTC. They have larger amounts of memory for various application capabilities, such as image or video processing, pattern recognition, sonar or radar, and GPS. The larger amounts of memory will be needed for autonomous applications. One possible way to add autonomous functionalities to the RTC is by creating a neural network, which will require a database. This needs large amounts of memory, which SBCs can provide; however, they are more costly than MCUs and more complicated to use.

**Concept 2.**

- Microprocessors and Microcontrollers

They can be used for a variety of control applications and are cheap, easily replaceable, and depending on the brand, have numerous open source development tools. They can be combined with a single-board computer to delegate tasks. Certain tasks that do not require as much memory or speed can be controlled with a microprocessor, while more computationally heavy tasks can be performed by the SBC.

**Concept 3.**

- Electronic Speed Controller (ESC)

This is a plug and play electronic motor control device with a lot of open source resources and software tools. It also allows for dual motor speed control; however, if we are using omni-directional wheels, then we will likely need one for each motor. The ESC is made specifically for motor control and many come with basic wiring done. This will simplify the installment to the power supply and motors.

**Concept 4.**

- Custom game/RC controller

A custom game controller can be used in conjunction with an SBC, MCUs, and/or ESC for user control of the RTC. A game controller uses a platform that many users would already be familiar with, which will simplify the user interface and enhance the user experience. It could cut down on the learning curve for user control of the RTC.

A combination of the options laid out above would be ideal. Using an SBC, provides enough memory and the speed needed to add autonomous controls to the RTC. The application specific qualities of ESCs make it ideal for motor control of the drive system and frees up memory and resources on the SBC to enable other features, such as sonar, image or video processing, and pattern recognition. The use of microprocessors and microcontrollers as cheap control solutions for simple tasks, which will also free up even more resources for the SBC. An SBC is compatible with various communication protocols, such as Wi-Fi and Bluetooth, and can allow for remote access. This will allow for the use of a wireless controller. Retrofitting a gaming controller for the RTC gives users some familiarity. This will shorten the learning curve needed to use the RTC. If more control capabilities are needed for user control, then there are a variety of remote controls available to meet our specific needs for the RTC.

**1.5.6 Brakes**

The following are concepts for the brakes of the RTC.

**Concept 1.**

- Drum Brakes

**Concept 2.**

- Disc Brakes

**Concept 3.**

- Single Circuit Hydraulic Brakes
- Do these brakes need to be moved more often than conventional brakes?

**Concept 4.**

- Dual-Circuit Hydraulic Brakes

**Concept 5.**

- Air Brakes

**Concept 6.**

- Power Brake Booster

**Concept 7.**

- Parking Brakes

**Concept 8.**

- Emergency Brakes

**Concept 9.**

- Electronic braking built in to motor

The RTC will need to travel to the drop-off location and securely stay in place until the waste bins have been emptied and returned to the RTC by the waste engineers. In order to ensure this process happens smoothly several times a year, multiple concepts must be considered for the brakes. A simple braking system, such as the drum and disc brakes, is a good option due to simplicity of frictionally braking. Another slightly more complex and expensive braking system is the hydraulic braking systems using pressure. The simplest and least expensive braking concept that we generated was a parking or emergency brake that prevents the cart from rolling and moving at all.

**1.5.7 Wheels**

**Concept 1.**

- Wheels should have small rubber spokes to grip the terrain better

**Concept 2.**

- Wheel made of a cast iron/semi-steel

**Concept 3.**

- Wheel made of forged or ductile steel

**Concept 4.**

- Wheels are made of nylon and glass
- They are good for high temperature applications

**Concept 5.**

- Wheels are made of hard rubber

**Concept 6.**

- Wheels are made of phenolic resin

**Concept 7.**

- Wheels are made of rubber wheels filled with air

**Concept 8.**

- Wheels are made of polyolefin

We need to consider a wheel's durability, lifespan, and the RTCs weight in order to ensure a durable, cost-effective option. The overall grip and maneuverability of the cart can be improved by including small rubber spokes around the wheels. The cast iron/semi-steel wheels have exceptional durability; however, their weight and cost are issues. The hard rubber wheels are good for high load capacity and easy rolling. The phenolic resin wheels have a high load capacity, are inexpensive, and are very durable. Lastly, the polyolefin wheels are a hard tread wheel. They are lightweight, economical, and are resistant to water.

## 1.6 Concept Selection

This section outlines the concepts chosen for each module of the RTC and why they were chosen. Some designs were modified as the school year proceeded. These design changes are also outlined in this section. The designs are separated by the individual modules, namely a Summary of the RTC Design, Drive System, Frame, Controls, Brakes, and Wheels. The designs were chosen by the team member that was assigned as the lead for the specific module. John Williams was assigned as the lead for the drive system and power system. Oscar Flores was the lead for the control system. Jacob Emerson was assigned as the lead for the brakes and wheels. Bishoy Morkos and Jacob Emerson were co-leads of the frame. The module leads have final say over the module designs chosen, unless a majority of the team agrees with a different design choice.

**1.6.1 Summary of the Selection Process**

This section outlines the selection process for the concepts that were selected for each module of the Robotic Trash Cart and why they were chosen. Table 8 shows the customer criteria that were considered when deciding upon a design. Senior citizens, the disabled community, and those with limited mobility and strength are the focus for the design of the RTC. Their needs and requirements were outlined through customer interviews. The customers' needs were kept in mind while completing the quality of house chart in Table 8 below. The improvement direction specifies the importance of each characteristic of the RTC. Material durability, battery life, speed of the RTC, and the RTC's price are the top 4 most influential characteristics when designing the RTC to meet the customers' needs and requirements. The RTC needs to be operable for a considerable amount of time considering trash collection generally occurs at least once a week year round. Therefore, the materials used to build the RTC must be able to withstand the weight of the bins and environmental factors. The batteries need to be able to supply enough power to the motors, control system, and emergency lights in order to dispense the waste containers to the curb for pickup on time. The speed that the RTC travels at will affect its stability when transporting the waste containers, the time that it will need to leave the home base in order to get to the pickup location on time, and the drain on the power supply. The cost of the materials and components used to create the RTC will dictate the quality of the product and the price point at which it will be sold at. A quality product will need to be made in order to incentivize the waste management companies to invest in the RTC, but will need to be reasonably priced in order to encourage customers to purchase the RTC and make a profit as well.

Table 8 *Selection Criteria*

| Improvement Direction | | ↑ | ↓ | ↓ | ↓ | ↑ | ↑ | N/A | ↑ | N/A | ↓ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Units | | N/A | kg | Dollars | Seconds | Meters | mAh | kg/m^2 | cm | m/s | N/A |
| **Customer Requirements** | **Importance Weight Factor** | **Material Durability** | **Weight** | **Price** | **Time** | **Transportation distance** | **Battery life** | **Weight Distribution** | **Drive over obstacles** | **Speed** | **Size** |
| **Waterproof/ Weatherproof** | 4 | 9 | | 3 | | | 3 | | | | 1 |
| **Impact Proof** | 3 | 9 | 1 | 3 | | | 3 | | | | 1 |
| **Easy Access to Waste Containers** | 4 | 3 | | | 3 | | | | | | |
| **Recharging RTC** | 3 | 3 | | 9 | 9 | | 9 | | | | |
| **Perform Consistent Transportation** | 5 | 9 | 1 | 3 | 3 | 9 | 9 | 3 | 3 | 9 | 3 |
| **Ensure RTC doesn't topple** | 5 | | 3 | | | 3 | | 9 | 9 | 9 | 3 |
| **RTC must be able to Traverse Incline** | 4 | | 3 | 3 | | 3 | 3 | 3 | 9 | 3 | 9 |
| **User Friendly** | 3 | | | 9 | | 1 | 1 | | | 1 | 1 |
| | | | | | | | | | | | |
| | Raw Score | 129 | 35 | 102 | 54 | 75 | 108 | 72 | 96 | 105 | 76 |
| | Relative Weight % | 15.14 | 4.11 | 11.97 | 6.34 | 8.80 | 12.68 | 8.45 | 11.27 | 12.32 | 8.92 |
| | Rank Order | 1 | 10 | 4 | 9 | 7 | 2 | 8 | 5 | 3 | 6 |
| | Raw Score Sum | 852 | | | | | | | | | |

### 1.6.2 Drive System

The drive system was selected due to the criteria referred to in the concept generation. A robust 12 V or 24 V drive system is needed to handle the weight, maneuverability, and power requirements for the RTC. In order to simplify the integration of the drive system to the frame of the RTC, the drive system of a used motorized wheelchair was purchased. The Hoveround CIM part #808-075 drive system has the capabilities to consistently carry a 300 pound load and is easily incorporated into our design. This drive system has the motors, gearboxes, and wheels as a single unit when purchased in an aftermarket environment. It is a proven drive system and is used in many of the mobility carts and scooters for the handicapped community and meshes perfectly with the desired conceptual design of the RTC. The drive system is capable of reaching speeds up to 2.24 m/s. This exceeds the target speed of 0.10 m/s, so operating within our target speed will have minimal drain on the power system. This will allow added features to the RTC to have access to the available power system. The drive system specifications are outlined in Tables 9.

Table 9 *Drive System Motor Specifications*

| **Motor with Gearbox** | **Cim Number # CM 808-075 with gearbox** |
|---|---|
| **DC Voltage (V)** | 24 |
| **Braking ($V_{DC}$)** | 24 |
| **Cost** | $149.00 – $299.00 |
| **Gearbox** | Pre attached |
| **Speed Capacity (m/s)** | 2.24 |

### 1.6.3 Power System

To keep manufacturing costs down, the preferred power supply is a Sealed Lead Acid - Absorbed Glass Mat (SLA/AGM) battery. They are the most common types of batteries used with the chosen drive system, because they are both sealed and the casing require little to no maintenance. Lithium ion batteries were also considered, but the cost would make up at least 75% of our $1,000 budget. Our budget has increased to $1,900.00, but even with this increase in funds, purchasing lithium ion batteries would force us to do away with other design aspect. Both

SLA/AGM and lithium ion batteries will power the RTC, but using SLA/AGM batteries is more cost-effective. This will make the RTC more marketable to homeowners, as well as waste collection companies. As an added bonus, the SLA/AGM batteries provide more weight allowing us to keep the RTC's center of gravity lower and counteract any top heavy loading problems that may occur. We will use two 12 V SLA/AGM batteries to power the 24 V motors. Table 10 compares the cost of SLA/AGM and lithium ion batteries. Other battery types were considered, but SLA/AGM and lithium ion batteries were considered the best option because of their cost and how readily available they were. If a battery needs to be replace, we can walk into Walmart and purchase an SLA/AGM battery.

Table 10 *Power System Battery Specifications*

| Battery | Sealed Lead Acid (SLA) rechargeable maintenance free battery | Lithium Ion rechargeable maintenance free battery |
|---|---|---|
| DC Voltage (V) | 12 | 12 |
| mAh | 3500 | 3500 |
| Cost for 2 | $99.00 – $149.00 | $698.00 – $898.00 |

### 1.6.4 Frame

Aluminum was chosen as the material for the frame of the RTC. A rectangular shape was chosen for the RTC because it will maximize the space to hold both the recycling and garbage bins. The rectangular shape will also minimize the effective size of the RTC. Additionally, the rectangular shape will offer the better stability when comparing to a circular design. The longer sides of the rectangular frame will allow for a large gate and ramp to unload the bins quickly from the RTC with minimal effort. The frame will have four vertical square tubes welded on each corner with two horizontal flat bars welded in between to increase overall stability. Adding siding to the RTC will offer little in terms of structural support. It is added more for aesthetic appeal; therefore, the RTC will not have any siding for the most part. This will lower the overall cost for the RTC. Initially, we were going to use HDPE sheets for the flooring, but we decided to use fiberglass grating instead. It is stronger and more corrosion resistant than the HDPE sheets. The floor of the RTC was chosen to be fiberglass grating for multiple reasons. The first is to allow the rain to seep through the base to avoid any issues with water pooling. The second reason is that the grated fiberglass can also withstand the heat from the sun without warping. Lastly it was chosen due to its high strength to weight ratio that can carry a large weight, such as two full trash cans, for an extended period of time without any structural problems. Using grated fiberglass is more cost-effective compared to aluminum or other metals. This allows for more funds to be allocated to other aspects of the budget, such as the drive system. Table 11 compares the cost between the aluminum and HDPE sheets. These materials are sold in specific proportions. For example, the HDPE sheets are sold in 8’ x 4’ sheets from Grainger. We do have to order through FSU suppliers, which can raise the costs of our materials.

Table 11 *Frame Material Costs*

| Frame Material | Aluminum | Plastic |
|---|---|---|
| Type | 6061-T6 | HDPE |
| Length (ft.) | 35.5 | 8 |
| Width (ft.) | 2.5 | 4 |
| Thickness (in.) | 0.375 | 0.187 |
| Cost | $110.40 | $114.00 |

### 1.6.5 Control System

Initially, we were considering using a combination of a single board computer (SBC) with microprocessors handling the incoming environmental data and tasks to be completed. The SBC acts as the control center delegating tasks to microprocessors. The stretch goal for the RTC is to make it self-aware. In order to make the RTC autonomous and add object detection capabilities, there will need to be sufficient memory. The increased memory and speeds at which SBCs can operate at makes it the ideal choice; however, for our purposes it is over spec'd. Initially, we chose to use and SBC, specifically the Raspberry Pi 3 Model B+, because it had the greatest amount of open resources and the largest community of users. This would help simplify the programming of the wireless controller. However, SBCs require you to load an operating system on to them and are difficult to debug with. Because of this we chose to go just use a microcontroller, specifically the ESP-32. The ESP-32 has Wi-Fi and BLE capabilities and is Arduino compatible, which helped with programming. It was also supposed to be compatible with the motor controller that came with the used drive system we had purchased; however, the drive system did not come with a motor controller. We tried contacting CIM to purchase a motor controller, but they did not respond to our emails or phone calls. Eventually, they responded when we contacted them through their education/research department, but they would not give us specific information on the motor controller nor allow us to purchase one due to its proprietary nature. We instead purchased a Cytron SmartDriveDuo for our motor controller. It was compatible with the Arduino UNO and MEGA. When we attempted to link it with the ESP-32, we had issues using the PWM. We would have purchased an Arduino MEGA along with an HC-10 BLE module instead of the ESP-32 to simplify the programming, but we had already purchased the ESP-32. The rest of this section outlines why the Raspberry Pi 3 Model B+ and the MSP430 were originally chosen. Table 12 outlines the SBCs we were considering to use.

Table 12 *SBC Comparison*

| Board | BeagleBone Blue | SanCloud BeagleBone Enhanced | LattePanda | Raspberry Pi 3 Model B+ |
|---|---|---|---|---|
| Processor | ARM3358 ARM Cortex - A8 | ARM3358 ARM Cortex - A8 | Intel Cherry Trail Z8350 Quad Core | Broadcom BCM2837B0 Quad core |
| Max. Processor Speed | 1 GHz | 1 GHz | 1.8 GHz | 1.4 GHz |

| | | | | |
|---|---|---|---|---|
| Analog Pins | 4 Pins at 1.8V | 7 Pins - 1.8 V | 6 Pins | None: needs add on |
| Digital Pins | 24 Pins - 3.3 V | 65 Pins - 3.3 V | 6 Pins | 40 pins |
| RAM | 512 MB DDR3 | 1 GB DDR3 | 2 GB DDR3L | 1 GB LPDDR2 |
| Memory on-Board | 4GB (eMMC) | 4GB (eMMC) | 32 GB (eMMC) | None: Micro SD port |
| USB | 1x micro USB 2.0<br>1x USB 2.0 | 1x mini USB 2.0<br>4x USB 2.0 | 1x USB 3.0<br>2x USB 2.0 | 4x USB 2.0 |
| Video | 1x SPI Displays | 1x micro HDMI | 1x HDMI<br>1x MIPI-DSI | 1x HDMI<br>4x Pole Stereo Output and composite video |
| Audio | Bluetooth | micro HDMI | Audio jack | Included in Video |
| Interface | 4x UART<br>1x 2-cell LiPo<br>2x SPI<br>1x I2C<br>4x A/D converter | 4x UART<br>12x PWM/Timers<br>1x LCD<br>1x GPMC<br>1x MMC1 | 1x 100 Mbps Ethernet<br>WiFi<br>Bluetooth 4.0 | WiFi<br>Bluetooth 4.2<br>Bluetooth Low Energy (BLE) |

| | | | | |
|---|---|---|---|---|
| | 1x CAN bus<br>8 6V servo motor 4x DC motor<br>4x quadrature encoder | 2x SPI<br>2x I2C<br>1x A/D Converter<br>2x CAN Bus | 6x Touch Panel Overlay Connectors | 1x 300 Mbps Ethernet |
| Cost | $79.00 | $69.00 | $89 without Windows 10 | $35.00 |
| Notes | 1x Micro SD port<br>Small amount of open source resources and community forums, projects and support. | 1x Micro SD port<br>Small amount of open source resources and community forums, projects and support. | Option to install Windows 10 on the board.<br>Power: 5V/2A<br>There is an option for 4G RAM and 64G eMMC | Power: 5V/2.5A<br>Has a micro SD port for memory.<br>1x CSI camera port<br>1x DSI display port |

Trade Offs:

The LattePanda tends to get hot, so a cooling system may need to be added. It has connections already integrated for an Arduino Leonardo, which is a microcontroller that sells for $19.80. It is a cheaper version of the Arduino UNO, and has 20 GPIO pins. The LattePanda is slightly larger than the other SBCs; however, the SBCs and microprocessors are small and light enough that their size and weights are negligible. The LattePanda has only been around since

2015; therefore, it has the least amount of open source resources and the least amount of assistance from global users. It is also the most expensive of the four options. There is a version with Windows 10 already installed on the board for $119.00, but Windows 10 is not needed for this project. The LattePanda has the largest amount of memory at 32 GB and the fastest processing speed at 1.8 GHz. This ensures enough resources for other features to be enabled, such as object detection and autonomous capabilities. However, 32 GB is excessive for this project. The LattePanda has the most features that can be used for a broad range of applications, but is also the most costly. The Raspberry Pi 3 B+ and BeagleBone boards have much larger open source resources and community forums, projects, and support than the LattePanda. These are the primary reasons why it was not used.

The BeagleBone boards have the most communication protocols. The SanCloud BeagleBone Enhanced would be preferred to the BeagleBone Blue due to the larger number of analog and digital pins. This will allow for more features and applications to be enabled. It is $20.00 cheaper than the LattePanda, but the community assistance is not as extensive as the Raspberry Pi SBCs.

The Raspberry Pi 3 B+ is the cheapest of the SBCs at $35.00, but does not have any on board memory. A Micro SD can be added, but will add $15.00 to the cost. Even with this add on, it is still the cheapest option. It does not have any analog pins either, but this isn't a problem, because we plan to use microprocessors to interface with the sensors and motors. The Raspberry Pi will primarily be used to add autonomous functionality and object detection capabilities. Having to use a Micro SD, increases the chances of having a fault or error due to loose or damaged connections. It is compatible with various programming languages, such as Python, C, C++, and JAVA. The Raspberry Pi 3 B+ was chosen because of the easy user interface, price, and simple integration with microprocessors. Table 13 outlines the microprocessors and microcontrollers we considered using.

Table 13 *Microprocessor and Microcontroller Concept Selection*

| Boards | MSP430F5529LP (Reference) | Arduino UNO Rev3 | Arduino Leonardo with Headers | ESP-32 |
|---|---|---|---|---|
| Operating Voltage | 5V and 3.3V | S | S | 5V and 3.3V |
| Number of Pins | 40 | -2 | -1 | 0 |
| RAM | 8 KB | -1 | -1 | 0 |
| Flash Memory | 128 KB | -2 | -2 | +2 |
| Clock Speed | 25 MHz | -1 | -1 | +1 |
| Cost | $12.99 | -1 | -1 | -1 |
| Programming Ease | 0 | +2 | +2 | +2 |
| Score | 0 | -5 | -4 | +4 |

The MSP430F5529LP outscored both Arduino microcontrollers in every category except for the Operating Voltage and Programming Ease. The ESP-32, however, outscored the MSP430. Its compatibility with the Arduino IDE simplified the coding. The coding syntax used for Arduino is much easier than the TI boards, which use Assembly and C programming language. However, this limits the capabilities of Arduinos and ESP-32. For a cheaper price, the MSP430F5529LP has more memory, faster clock speed, more pins, and has greater capabilities than Arduino boards. The MSP430F5529LP is also the best option, because of our familiarity with the coding platform. We ended up using the ESP-32 because it was compatible with the CIM motor controller. We had to purchase a separate motor controller, which was compatible with Arduino microcontrollers. We ended up not using a PlayStation controller like we originally had planned. We spoke to gaming shops in the Tallahassee area and found that many times refurbished controllers many times have several alterations to their components and may not use BLE as its communication protocol. To avoid any surprises, we decided to use a free smartphone app call BLE JoyStick. This app is free and compatible on iOS and Android. This way anyone can download the app and you do not have to keep track of a controller.

### 1.6.6 Brakes

The best types of brakes for the Robotic Trash Cart are either electronic brakes. The electronic brakes can be integrated into the drive system. This wouldn't require any additional components other than manipulating the motor to become the brake for the cart. The size and cost of these brakes would also be nothing due to it already being built in the motor. However, one downside of the electronic brakes is that it would draw a small amount of energy over time. Table 14 shows a Pugh chart we made when consider different types of brakes. Fortunately, the drive system we purchased came with brakes already integrated into the motors; therefore, we no longer used brakes as a module for the RTC from this point forward.

Table 14 *Brake Concept Selection*

| | | Electric Braking | Hydraulic Braking | Air Brakes | Drum Brakes | Disc Brakes | Parking Brakes |
|---|---|---|---|---|---|---|---|
| Price | 0.2 | 6 | 1 | 2 | 3 | 4 | 5 |
| Size/Compactability | 0.25 | 6 | 1 | 2 | 4 | 3 | 5 |
| Ease of Integrating | 0.15 | 6 | 1 | 2 | 4 | 3 | 5 |
| Doesn't Require Additional Componets | 0.15 | 6 | 1 | 2 | 3 | 4 | 5 |
| Effectiveness | 0.25 | 1 | 6 | 5 | 2 | 3 | 4 |
| Raw Score | | 4.75 | 2.25 | 2.75 | 3.15 | 3.35 | 4.75 |
| Relative Weight % | | 22.6 | 10.7 | 13.1 | 15 | 16 | 22.6 |

### 1.6.7 Wheels

The wheels that were selected for motor wheel of the RTC are the rubber air filled wheels because of multiple factors shown in Table 15 below. The rubber air filled wheels scored the highest on the Analytical Hierarchy Process with plastic wheels coming in a close second. One reason why the rubber air filled wheels beat the plastic wheels is due to their high availability with rubber wheels being the most common type of wheel. Another reason why plastic wheels aren't the best option is due to their durability and toughness of how quickly they wear out when rolling over rough surfaces that aren't completely flat. Lastly, rubber air filled wheels will be the best option for the motor wheels due to the ease with which they roll. Senior citizens and the disabled persons have difficulty pushing and pulling heavy objects. If the RTC malfunctions and needs to be brought back to the home base, then it needs to be easily retrieved. Rubber air filled wheels additionally provides the best rolling properties while providing some damping. The caster wheels were chosen to be a hard rubber due to its high reliability and toughness. These caster wheels will take most of the brute force of any bump so toughness is a key factor.

The drive system we purchased came with partially foam filled and air filled tires. They are used tires from a wheelchair drive system. The caster wheels we chose to use are an industrial hard rubber with heavy tread to ensure good traction.

Table 15 *Wheels Concept Selection*

| | | Rubber Foam Filled | Rubber Air Filled | Hard Rubber | Plastic | Steel |
|---|---|---|---|---|---|---|
| Price | 0.3 | 6 | 8 | 4 | 10 | 2 |
| Reliability | 0.1 | 2 | 4 | 10 | 8 | 6 |
| Availability | 0.2 | 8 | 10 | 4 | 6 | 2 |
| Toughness | 0.25 | 2 | 4 | 8 | 6 | 10 |
| Ease of Rolling | 0.15 | 8 | 10 | 6 | 4 | 2 |
| Raw Score | | 5.3 | 7.3 | 5.9 | 7.1 | 4.4 |
| Relative Weight % | | 17.66 | 24.33 | 18.66 | 23.66 | 14.66 |

### 1.7 Spring Project Plan

The tasks that need to be completed and their tentative due dates for the Spring 2019 semester are listed below. These tasks were made during the Fall 2018 semester and are subject to change.

| | |
|---|---|
| 1. Finalize Parts selections | Due Date: 1/10/18 |
| 2. Order Parts | Due Date: 1/15/18 |
| 3.Spring 2019 Graduation Application | Due Date: 1/25/18 |
| 4. Assembly | Due Date: 2/5/18 |
| 5. Testing | Due Date: 2/15/18 |
| 6. Finalize Project | Due Date: 04/26/2019 |
| 7. Shark Tank Semifinals | Due Date: |
| 8. Final VDR | Due Date: TBA |
| 9.Engineering Design Day | Due Date: 04/18/19 |
| 10. Finals | Due Date: 04/29/19 |
| 11. Graduation | Due Date: 05/3/19 |

## Chapter Two: EEL 4914C/4915C

### 2.1 Spring Plan

The following milestones represent a timeline of the tasks that need to be completed in the Spring 2019 semester. The primary tasks are the frame assembly, power system integration into the frame, programming of the control system, testing of the various modules, modifications to modules, presentations, Engineering Design Day, and the final project demonstration. The final project must be completed by April 26. There is a Gantt chart separated into two parts to help with legibility and provide a visualization of the timeline.

This was an entrepreneurial project, which required us to enter the Jim Moran School of Entrepreneurship InNOLEvation Challenge and the FAMU-FSU Engineering Shark Tank. The applications for both of these business competitions can be found in Appendix G and Appendix H.

Milestone 1: First week of the Spring 2019 semester

- Set up a team meeting to discuss the tasks that need to be completed this semester
- Update Spring Project Plan
- Update each team members schedules on Google Calendar
- Set up a meeting with the sponsor to discuss the InNOLEvation Challenge Stage 2
- Set up a meeting with the advisor to discuss frame drawings and components
- Contact the machine shop regarding welding for the frame of the RTC

Milestone 2: January 15

- Prepare for VDR4 – 1st senior design presentation
- Finalize parts for the frame, power system, drive system, and control system
- Order parts

Milestone 3: January 31

- Complete advisor and sponsor meetings
- Begin assembly of frame
- Complete final draft of business model canvas for the InNOLEvation Challenge
- Prepare InNOLEvation Challenge semifinal business pitch

- Begin developing the website
- Prepare for VDR5 – 2nd senior design presentation

Milestone 4: February 28

- Complete the frame, excluding the gates
- Meet with advisor and sponsor
- Apply for the Engineering Shark Tank
- Begin wiring of the RTC
- Begin coding of the control system
- Push an update to the web page

Milestone 5: March 15

- Begin prototype testing of power system and control system
- Complete Engineering Shark Tank Round 2 submission
- Complete Risk Assessment
- Begin operations manual
- Prepare for VDR6 – 3rd senior design presentation

Milestone 6: March 31

- Meet with sponsor and advisor
- Push update to the web page
- Prepare poster and presentation for Engineering Design Day
- Continue testing on the control system

Milestone 7: April 14

- Complete poster and presentation for Engineering Design Day
- Finalize wireless controller
- Prepare for project demonstration

Milestone 8: April 26

- Complete prototype
- Prepare for final project demonstration
- Complete evidence book
- Push last update to the web page

**Project Plan.**

The following is a Gantt chart for the Spring 2019 semester. Figure 2 shows the project tasks and assignments outlined in a list view with assignments assigned to specific team members.

| TASK NAME | START DATE | DAY OF MONTH* | END DATE | DURATION* (WORK DAYS) | DAYS COMPLETE* | DAYS REMAINING* | TEAM MEMBER | PERCENT COMPLETE |
|---|---|---|---|---|---|---|---|---|
| **Second Semester of Senior Design** | | | | | | | | |
| Innolevation: Stage 2 Business Model Canvas | 1/6 | 6 | 1/14 | 9 | 9 | 0 | Oscar | 100% |
| Advisor Meet & Greet | 1/7 | 7 | 1/11 | 5 | 5 | 0 | All | 100% |
| Abstract | 1/8 | 8 | 1/11 | 4 | 4 | 0 | Oscar & Jacob | 100% |
| Budget Update | 1/9 | 9 | 1/18 | 10 | 10 | 0 | Oscar & Jacob | 100% |
| Web Master | 1/10 | 10 | 1/18 | 9 | 9 | 0 | Oscar | 100% |
| Advisor Meeting 1 | 1/11 | 11 | 1/31 | 21 | 21 | 0 | All | 100% |
| Web Page Development | 1/12 | 12 | 2/1 | 21 | 21 | 0 | Oscar | 100% |
| Innolevation: Stage 3 Final Business Model Canvas | 1/13 | 13 | 2/6 | 25 | 25 | 0 | Oscar | 100% |
| Innolevation: Semi-Final Presentation Judging | 1/14 | 14 | 2/8 | 26 | 26 | 0 | All | 100% |
| Shark Tank Application | 1/15 | 15 | 2/8 | 25 | 25 | 0 | Oscar | 100% |
| DR5 (Senior Design Presentation) | 1/16 | 16 | 2/18 | 34 | 34 | 0 | All | 100% |
| Advisor Meeting 2 | 1/17 | 17 | 2/28 | 43 | 43 | 0 | All | 100% |
| Risk Assessment | 1/18 | 18 | 2/28 | 42 | 42 | 0 | All | 100% |
| Web Page Update 1 | 1/19 | 19 | 3/1 | 42 | 42 | 0 | Oscar | 100% |
| Shark Tank Round 2 Submission | 1/20 | 20 | 3/8 | 48 | 48 | 0 | Oscar | 100% |
| Shark Tank Preliminary Round Business Pitch | 1/21 | 21 | 3/8 | 47 | 47 | 0 | All | 100% |
| DR6 (Senior Design Presentation) | 1/22 | 22 | 3/25 | 63 | 63 | 0 | All | 100% |
| Operation Manual | 1/23 | 23 | 3/29 | 66 | 66 | 0 | Lead: John | 100% |
| Web Page Update 2 | 1/24 | 24 | 4/5 | 72 | 72 | 0 | Oscar | 100% |
| Engineering Design Day | 1/25 | 25 | 4/18 | 84 | 84 | 0 | All | 100% |
| Final Report | 1/26 | 26 | 4/26 | 91 | 91 | 0 | Lead: Oscar | 100% |
| Protyope Demo | 1/27 | 27 | 4/26 | 90 | 90 | 0 | All | 100% |

Figure 2. *List View of the Gantt Chart*

Figure 3 shows a calendar view of the project tasks and assignments. An IDA chart was also used to track progress on specific assignments. The IDA can be found on the project website.

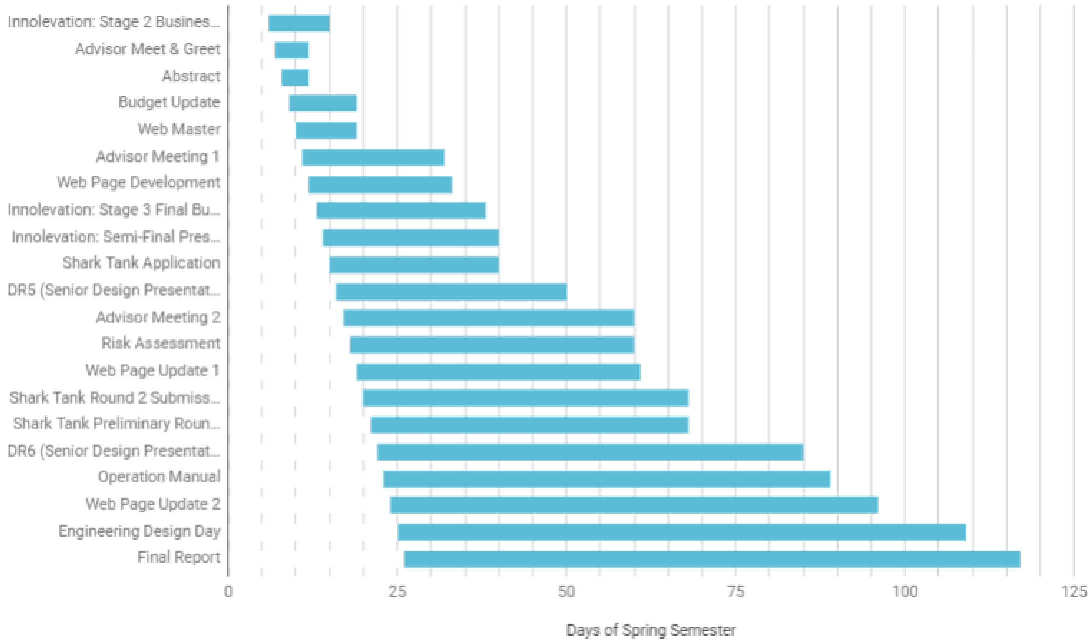


Figure 3. *Calendar View of Gantt Chart*

**Build Plan.**

The milestones for the project have been outlined above. The separation of tasks between the MEs and CpE/EEs is shown below in the Table.

Table 16 *Project Tasks Broken Down by Engineering Discipline*

| CpE/EE Tasks | ME Tasks |
|---|---|
| • Order parts for the power, drive, and control system<br>• Help MEs with mounting motors on the frame (MEs take the lead)<br>• Assemble the power and control systems<br>• Test power systems and motors<br>• Program the motor controller and wireless controller<br>• Conduct testing on the wireless controller | • Complete CAD drawings for the RTC frame<br>• Order parts for the frame<br>• Weld the frame or have the machine shop weld the frame<br>• Cut the fiberglass grating for the base<br>• Assemble the frame<br>• Mount the motors and tires onto the frame<br>• Weld/mount the gates onto the frame |

### 2.2 Testing and Validation

Voltage and Current

- Batteries voltage – fully charged: 25.6 V
- No load current: 2.79 A

Water Tightness

- Test:

  A steady stream of water was poured for 5 min onto the power and control compartments.

- Results:

  Upon inspection, no water infiltration occurred.

Weight Load

- Test:

  A 250-pound load was placed onto the RTC.

- Results:

  The RTC was able to maneuver successfully at a 2-minute interval with no overloading.

### 2.3 Scholarship in Practice

The development, prototyping, and debugging of the Robotic Trash Cart (RTC) requires a collaborative effort between computer, electrical, and mechanical engineering students. It is an entrepreneurship project, meaning it needs to be a feasible commercial product and requires business acumen. Our engineering curriculum does not provide us with any sort of business or entrepreneurship foundation, which put us at a disadvantage in the business competitions we entered. In terms of the actual development of the RTC, we have been able to apply the concepts we've learned about power systems, mechanics, and controls to create a working prototype. We decided against making the RTC autonomous because environmental factors would make this excessively difficult within the scope of the project. We used aluminum for the frame of the RTC. We purchased used wheelchair motors, gearbox, and wheel assembly to simplify the integration of the drive system with the frame. Using a board compatible with Arduino, helped streamline the development and debugging of the control system. Project management is crucial when developing a product like the RTC. Proper time management would have helped us to solve problems we ran into regarding our budget, purchasing components, and welding using the machine shop. Our engineering coursework allowed us to design and make informed decisions regarding the overall functionality of the RTC, the frame, the drive system, and the control system; however, we initially lacked the business knowledge and entrepreneurship skills to properly pitch a viable commercial product to potential investors. Also, proper time management would have helped streamline our product development process.

When we were initially presented the project, the idea was to create a fully autonomous cart that would transport the waste bins to and from the curb for waste pick-up. The original design focus was for senior citizens who struggled to carry heavy loads for long distances. Researching the waste management industry and interviewing members of our community led us to believe there is a market for this product and was applicable for the disabled community; however, there are extensive issues and environmental variables that need to be considered when creating an autonomous robot operating outdoors. Driveways are not uniform and vary greatly from their lengths to changes in elevation. We needed to consider the type of terrain the RTC would be traversing. Wheels are more likely to slip on dirt or gravel as opposed to asphalt or cement. Debris, such as sticks, leaves, or dirt, could be swept onto the driveway and the weather can play a factor. Rain causes driveways to become slick or creates mud. Snow, sleet, and hail in northern states create problems that generally aren't an issue in Florida. Wooded, remote areas can cause connection issues for GPS. All of these potential factors made it impossible for us to develop a fully autonomous cart on our timeline of one school year. Companies, such as iRobot (creators of the Roomba) and Tesla, push out new iterations of their products or provide software patches to improve their autonomous functionalities. Their products are constantly needing updates and improvements. The founders of iRobot had been creating autonomous robots for space exploration and mine sweeping for over a decade before they came out with the Roomba. They had years of experience developing autonomous robots with years of research and development. We had nine months to create a prototype. We decided on an agile development approach with five modules (power system, drive system, control system, frame, and wheels). The first iteration is an open frame cart with a wireless controller. Once this has been completed, we can focus on gradually adding autonomous functionalities to the RTC. But first, the project scope needed to be narrowed.

The Computer and Electrical Engineering Department has added a design concepts course this past year, which taught us the product development cycle and how to apply design thinking when addressing a problem. We learned that once a problem has been identified the scope of the project must be outlined. The environmental factors previously mentioned will impact the operation of the RTC and need to be addressed. We made five assumptions to narrow our scope. First, the RTC will operate in Florida and need to be able to operate in South Florida weather conditions, namely rain, humidity, and wind. Second, the pathway the RTC traverses will be paved. Third, the RTC will be stored outside the house, not inside the garage. Fourth, the waste engineers will return the waste bins to the RTC once the trash has been disposed. If waste engineers picked up the whole cart to empty the waste bins, the impact of setting it back down would be detrimental to the lifetime of various components and the frame of the RTC. We designed a gate into the RTC to allow easy access to the bins. We assumed that the waste engineers would place the bins back into the cart once the bins had been emptied. Lastly, the largest gradient the RTC would traverse is a five-degree incline. The Americans with Disabilities Act of 1990 (ADA) mandates the gradient of all wheelchair accessibility ramps for schools, churches, and commercial establishments can be at most five degrees. Because our customers may have a wheelchair ramp for their homes, we decided that the RTC needs to be able to go up these ramps. Some driveways are sloped even more than five-degrees, so this limits the path gradient the RTC will travel. These assumptions narrow down the capabilities that the RTC must have and make it easier to add autonomous functionalities for the next iteration of the RTC. With these constraints, we could now design the RTC starting with the frame.

When the project originally began, we decided fairly quickly on using Aluminum 6061 for the frame of the RTC. There are a couple of reasons why we chose this kind of material versus other materials. The first reason is due to its high strength to weight ratio. It has a Young's Modulus of 68.9 GPa with a tensile strength of 124-290 MPa. The second reason we chose Aluminum 6061 is due to its corrosion resistant properties. We assumed that the cart would be left outside in Florida and needed to be resistant to rain and humidity. The last reason we chose Aluminum 6061 is due to its cost compared to other lightweight, high strength materials. The machinability and good joining characteristics are also added benefits. Having taken the Mechanics and Materials course at the College of Engineering, Aluminum 6061 was well known to our team's two mechanical engineers. In this course, students are taught about the properties of different materials, how they differ, and conduct tests on materials in the lab. After the cart had finally been assembled, everything came out as originally planned; however, the motor bolt holes were slightly off position, so spacers were added to the motors. The team wouldn't change our original decision due to the accessibility and affordability of using aluminum.

Waste Pro USA is responsible for the waste management of Tallahassee. Their garbage bins have a 95-gallon capacity. The recycling bins have a 65-gallon capacity. We assumed the RTC would weigh 250-pounds worst-case scenario. We found motors that we assumed could output the necessary torque to carry a 250-pound load up a five-degree incline. During our second senior design presentation in the fall, we were marked off for not having calculated the necessary torque for our worst-case scenario. We used the concepts taught in engineering mechanics to create the free body diagram for the RTC and found that the motors could not provide the necessary torque. We needed a motor that could provide at least 115.3 N-m of torque to go 0.1 m/sec. We learned that as engineers we cannot assume something will work out. You need to do the necessary calculations and triple check your work, because lives could depend on it. There have been over 18 recalls from car manufactures in the month of March 2019 alone. Some of these recalls deal with faulty airbags. As an engineer, your job can put lives at stake, and it is imperative that you do not take shortcuts. We came up with the idea of using the drive system of a motorized wheelchair, because they are made to carry loads in excess of 300 pounds. The motors we found came with gearboxes already assemble and wheels. The motors can output 115.3 N-m of torque, which is more than what we need. We looked at individual motors, gearboxes, and wheels and found using the wheelchair drive system to be the cheapest option for the RTC.

For our control system, we're using an ESP-32 to interface with a gaming controller and a Cytron SmartDriveDuo motor controller using Bluetooth and PWM, respectively. At Florida State University, we are taught object-oriented programming, specifically C++ and C. These are low level languages that give us greater control of functionalities on boards, especially C. These languages are more difficult to code in than higher level languages, such Python and Java. The ESP-32 is Arduino compatible. Arduino is an Integrated Development Environment (IDE) that uses a simplified version of C++. This makes it user friendly and easy to use. We were taught in our Microprocessors class to code in C using TI boards and Code Composer Studio, which is more complicated and requires bit manipulation. We created motor controllers using PWM. This gave us the technical knowledge and coding skills to program in both high- and low-level languages and made it easy to use Arduino. Initially, we were going to use a Raspberry Pi to interface with the motor controller that was provided with the wheelchair drive system, but it did not come with a motor controller. We could have continued to use a Raspberry Pi, but we would have needed to load an operating system onto it and it is more difficult to debug code using a Raspberry Pi. The switch to the ESP-32 and Cytron SmartDriveDuo was done out of necessity but made testing much easier.

The engineering curriculum does not have any business-oriented coursework. The Design Concepts class is the only one that teaches product development and entrepreneurship but is not in depth. We entered two business competitions: the InNOLEvation Challenge and the Engineering Shark Tank. We made it to the semifinals of both competitions but found that we were at a significant disadvantage during the InNOLEvation Challenge due to our lack of business acumen. We were pitted against entrepreneurship, business, and finance majors, who had experience creating a business model canvas and making business pitches. Dr. Mike Devine, the engineering entrepreneur-in-residence, guided us through the process. Our senior design presentations are all technical. Generally, our professors are not interested in our primary and secondary markets, the value proposition, revenue stream, or customer relationships. The judges for the InNOLEvation Challenge do not want to know how you created the product, but will instead, grill you on your cost structure, revenue streams, and customer segments. We created our company, Artists in Waste Removal (AWR), but our business pitch was too technical and not as developed as other teams. If we were to enter the InNOLEvation Challenge again, we would use the resources at the School of Entrepreneurship and the School of Business to better develop our company, product, and business model.

Project management is vital to senior design. We developed a work break down structure for each semester but did not follow it rigorously. Time management would have greatly helped to completing the RTC as stress free as possible. We began ordering parts in January and were not aware that the College of Engineering has contractual vendors. The parts were generally more expensive from these vendors and increased our budget. We had to request more funds from the Dean's Office. This set us back on our timeline for assembling the frame. We spoke to the machine shop and they generally had a two-week minimum wait time for welding projects. We chose to use fiberglass for the base of the RTC due to its lightweight and high strength properties; however, the machine shop would not cut the fiberglass grating we had purchased and refused to weld the whole cart until the base had been cut. This made no sense to us, since the fiberglass would sit on top of the aluminum frame and was not needed to weld the frame. No one on the team had ever cut fiberglass and there are significant health hazards when handling fiberglass. In the end, we wet cut the fiberglass outside using respiratory protective equipment and covered any exposed skin. We should have begun assembling the frame in the fall after the CAD drawings had been completed. This would have given us enough time to find alternatives for the fiberglass grating, more time to mount the motors and wheels, and more time for testing. We would redo our Gant chart and been more diligent delegating specific tasks with deadlines. If the deadlines were not met, then we would update our timeline. We had a little more than a month for testing and were unable to meet our stretch goals. With better time management, we could have had time to begin implementing autonomous functionalities.

Developing the RTC was a group effort and required the expertise of mechanical, electrical, and computer engineers. The most important change we would make to our project is improving our time management. Following the established timeline more diligently would have helped us to solve unforeseen purchasing issues and fiberglass restrictions in the machine shop in a timely manner and reduced our budget. We chose not to make the RTC autonomous because it would have been put us over budget, again, and was not feasible given our timeline. The constraints and assumptions we made helped to narrow our project scope and create a detailed design. We chose to make the frame from Aluminum 6061 because it's cost effective, easily available, and our previous experience handling it in lab. The drive system we initially chose did not meet our requirements. It was not spec'd to go up a five-degree incline with a 250-pound load. We had assumed it would. We learned to not take shortcuts and that doing the hard work is why we are payed to be engineers. If we make a mistake, then we are liable for the consequences. For the control system, we had to change our design because the drive system we purchased did not come with a motor controller. Fortunately, our changes improved our design and simplified programming and testing of the RTC. When working on an entrepreneurship project, you will face problems that you're not qualified to resolve. You will need to make yourself knowledgeable in numerous disciplines, including finance and business. We had no previous experience with business models and pitches. We had to take on different roles and become proficient in them. This is part of being an entrepreneur. If you make yourself the person that will learn and do whatever is necessary, then you will continue to grow and eventually succeed. This is the most important lesson that this project taught us.

### 2.4 Conclusion

The goal of this project was to create and implement a functional design for the Robotic Trash Cart that can transport both the trash and recycling bins. This design utilized an all-aluminum frame that is corrosion resistant with a fiberglass grating floor to allow proper drainage of any liquids. This design also incorporates a wireless controller to control the speed and the direction of the RTC; however, the wireless controller was not fully functional and the RTC is controlled using the motor controller push buttons. Throughout the project, there were hardships and mistakes made but the team generally worked well together and supported one another to find a solution and complete the RTC.

One such problem we ran into, initially, was the fact that the drive system we purchased did not come with the motor controller it had been advertised with. We contacted the manufacturer of the motors but they would not sell us the motor controller due to the fact it is a proprietary product. Instead, we purchased a Cytron SmartDriveDuo to use as our motor controller, but the Cytron is directly compatible with Arduino microcontrollers, not the ESP-32, which we had already purchased to communicate with the original motor controller and a free smartphone app. Initially, we were going to use a PlayStation controller to control the RTC, but many times refurbished controllers have significant alterations done. The Bluetooth on the controller may not be functional. Instead, we chose to use a free smartphone app called RemoteXY. The ESP-32 is not compatible with this app and the libraries needed to be altered in order to make it compatible. This was a lengthy, tedious process and eventually we switched to the BLE JoyStick app. It does not have as much functionalities as the RemoteXY app, but we are able to connect to the ESP-32 through BLE. We are able to read output from the app to the console, but when we connected the ESP-32 to our Cytron motor controller, we had issues. The motors did not function the way we expected them to. We suspect this is due to an issue with the PWM analog connections on the Cytron. We are able to control the RTC using the push buttons on the Cytron. The pushbuttons control the direction but not the speed of the RTC. Since we were unable to get the PWM working to control the speed of the RTC, we attempted to reduce the current passing to the motors using a voltage divider. We implemented a voltage divider using potentiometers rated for 50A and 500V, but the potentiometers were fried due to excessive current passing through them from the motors. The majority of the project was completed. The main portion missing was the wireless controller.

These issues with the controller taught us that we need to better manage our time and adhere to the project timeline. The frame has taken more than three months to build and we ran into unexpected issues with the machine shop and purchasing through FSU. The majority of the frame was completed, with the mounted motors, at the very end of March/beginning of April. This left us a month to work on the electrical and programming portion of the RTC. If we could do this again, we would begin assembling the frame in the fall semester, this way we have more time to deal with problems as they arise. Also purchasing boards that are already compatible with one another greatly simplifies the coding portion of the project. Ideally, we would have used an Arduino UNO or MEGA with an HC-10 BLE module to connect to the RemoteXY app. The Cytron motor controller is compatible with both the Arduino UNO and MEGA and the RemoteXY app is compatible with the HC-10 BLE module. The HC-10 BLE module works with both iOS and Android smartphones. This way you always have your RTC controller with you as long as you have your smartphone with you.

This project taught us a lot about project management and entrepreneurship skills. The process of building a business model is not taught in our engineering curriculum and is more practical than the majority of the concepts we’re taught. All in all this project allowed us to grow both as engineers and individuals working together in a multidisciplinary team to reach one common goal.

## Appendices

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## Appendix A: Code of Conduct

### Mission Statement

Team 311 is committed to ensuring a positive work environment that supports professionalism, integrity, respect, and trust. Every member of this team will contribute a full effort to the creation and maintenance of such an environment in order to bring out the best in all of us as well as this project.

### Roles

The team consists of two mechanical engineering (ME) students, an electrical engineering (EE) student, and a dual-computer and electrical engineering (CpE/EE) student. The roles of the CpE and EE students will focus on the electrical and coding portion of the project. They will assist the MEs as needed. The roles of the MEs will focus on the mechanical components of this project and will assist the CpE/EEs as needed. Each team member is delegated a specific role based on their experience and skill sets. They are responsible for all here-within:

### Team members:

#### Project Manager - Oscar Flores

Oscar Flores is a senior undergraduate computer and electrical engineering student at Florida State University. He is responsible for managing the team. He develops the plan and timeline for the project, delegates tasks among group members according to their skill sets, finalizes all documents and provides input on other positions where needed. He is responsible for promoting a positive work environment and teamwork. If a problem arises, he will act in the best interest of the project. He is responsible for keeping communications between the sponsor and the technical advisor. He is responsible for organizing, planning, and setting up of meetings and recording the meeting minutes. He works together with other leads to keep the project on track. He manages the budget and maintains a record of all purchases. Any product or expenditure requests must be presented to the advisor for approval. Once approved, he will then relay the information to the team and order the product. If a task arises that does not fall under a specific role, he is responsible for delegating the task to the team member with the best skill set needed to complete the task and assist when needed.

**Lead ME - Jacob Emerson**

Jacob is a senior undergraduate mechanical engineering student at Florida State University. He is responsible for the mechanical design drawings of the project and communicating with the lead ECE. He is also responsible for the details of the project design and presenting design ideas to the team for a final design to be chosen. He is responsible for logging all the mechanical reports and drawings. He coordinates all communication and projects done through the machine shop.

**Lead ECE - John Williams**

John is a senior undergraduate electrical engineering student at Florida State University. He is responsible of the EE or CE design portion of the project. He maintains communication with the lead ME. He keeps a log of all electrical designs and coding files. He is responsible for the power system and control system of the RTC.

**Assembly Engineer - Bishoy Morkos**

Bishoy is a senior undergraduate mechanical engineering student at Florida State University. He works in unison with the Lead ME on the mechanical portions and designs of the project. He is responsible for the assembly of the frame for the RTC.

**All Team Members:**

- Work on some parts of the project
- Buy into the project goals and success
- Deliver on commitments
- Adopt team spirit
- Listen and contribute constructively (feedback)
- Be effective in trying to get messages across
- Be open minded to other's ideas
- Respect other's ideas

**Communication**

The main form of communication will be over phone and text-messaging among the group, as well as through regular meetings of the team. Email will be a secondary form of communication for issues not being time-sensitive. For the passing of information, i.e. files and presentations, email and Google Drive will be used for file transfer and proliferation.

Each group member must have a working email for the purposes of communication and file transference. Members must check their emails at least twice a day to check for important information and updates from the group. Although members will be initially informed via a phone calls or text messaging, meeting dates and pertinent information from the sponsor will additionally be sent over email so it is very important that each group member checks their email frequently.

If a meeting must be canceled, the group must be notified through either phone, text messaging, or email ASAP. Any team member that cannot attend a meeting must give notice ASAP informing the group of his absence. The reason for the absence will be appreciated but not required if personal. Repeated absences in violation with this agreement will not be tolerated.

**Team Dynamics**

The students will work as a team while allowing one another to feel free to make any suggestions or constructive criticisms without fear of being ridiculed and/or embarrassed. If any member on this team finds a task to be too difficult, it is expected that the member should ask for help from the other teammates. If any member of the team feel they are not being respected or taken seriously, that member must bring it to the attention of the team in order for the issue to be resolved. We shall NOT let emotions dictate our actions. Everything done is for the benefit of the project and together everyone achieves more.

**Ethics**

Team members are required to be familiar with the NSPE Engineering Code of ethics as they are responsible for their obligations to the public, the client, the employer, and the profession. There will be stringent following of the NSPE Engineering Code of Ethics.

**Dress Code**

Team meetings and sponsor/adviser meetings will be held in casual attire. Group presentations will be formal as decided by the team per the event.

**Weekly and biweekly Tasks**

Team members will participate in all meetings with the sponsor, adviser and instructor. During said meeting, ideas, project progress, budget, conflicts, timelines and due dates will be discussed.  In addition, tasks will be delegated to team members during these meetings. Repeat absences will not be tolerated.

**Decision Making**

The decision making is conducted by consensus and the majority of the team members. Should ethical/moral reasons be cited for dissenting reason, then the ethics/morals shall be evaluated as a group and the majority will decide on the plan of action. Individuals with conflicts of interest should not participate in decision-making processes but do not need to announce said conflict. It is up to each individual to act ethically and for the interests of the group and the goals of the project. Achieving the goal of the project will be the top priority for each group member. When a conflict cannot be resolved amongst the team, the advisor/sponsor or instructor will act as the tiebreaker. Each member needs to support their solution to the instructor. Below are the steps to be followed for each decision-making process:

- Problem Definition – Define the problem and understand it. Discuss among the group.
- Tentative Solutions – Brainstorms possible solutions. Discuss among group most plausible.
- Data/History Gathering and Analyses – Gather necessary data required for implementing Tentative Solution. Re-evaluate Tentative Solution for plausibility and effectiveness.

- Design – Design the Tentative Solution product and construct it. Re-evaluate for plausibility and effectiveness.
- Test and Simulation/Observation – Test design for Tentative Solution and gather data. Re-evaluate for plausibility and effectiveness.
- Final Evaluation – Evaluate the testing phase and determine its level of success. Decide if design can be improved and if time/budget allows for it.

**Conflict Resolution**

In the event of discord amongst team members the following steps shall be respectfully employed:

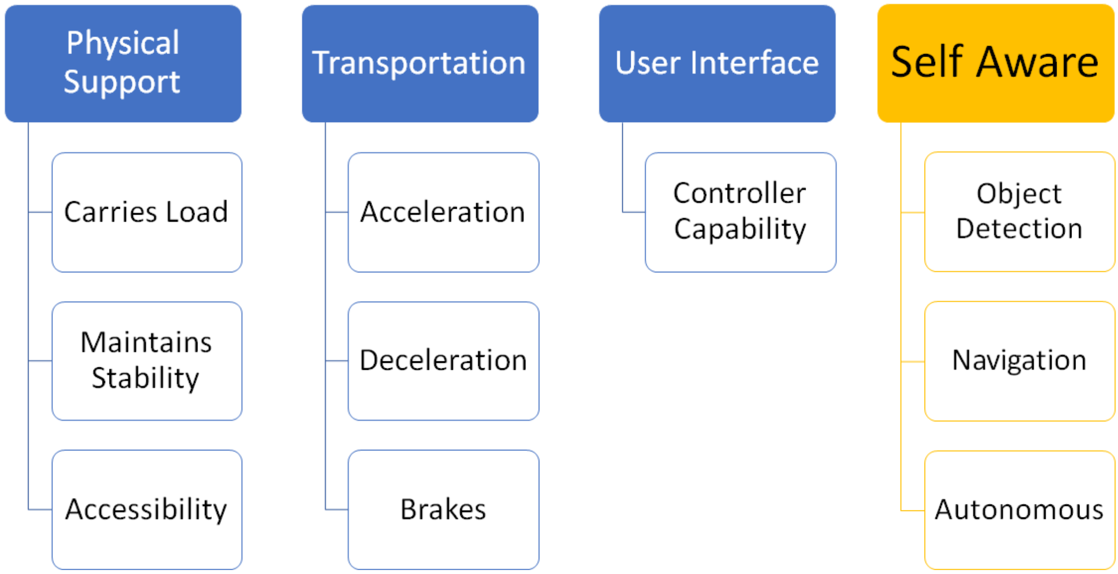
- Communication of points of interest from both parties which may include demonstration of active listening by both parties through paraphrasing or other tool acknowledging clear understanding.
- Administration of a vote, if needed, favoring majority rule.
- Team Leader intervention.
- Instructor will facilitate the resolution of conflicts.

## Statement of Understanding

By signing this document, the members of Team 311 agree to all of the above and will abide by the code of conduct set forth by the group.

| Name | Signature | Date |
|---|---|---|
| John Williams | [illegible] | 9-17-18 |
| Bishoy Morkos | Bishoy Morkos | 9-17-18 |
| Oscar Flores | Oscar Flores | 09/17/18 |
| Jacob Emerson | Jacob Emerson | 9/17/18 |

## Appendix B: Functional Decomposition



# Appendix C: Target Catalog

| Target # | Need | Metric | Imp. | Units | Marginal Value | Ideal Value |
|---|---|---|---|---|---|---|
| **1** | **Transport** | **Within Destination Target Area** | **5** | **meters** | **1** | **0.5** |
| **2** | **Battery Life** | **Capacity vs Runtime** | **5** | **mAh** | **3000** | **4500** |
| **3** | **Transit Stability** | **Speed vs Wind** | **5** | **m/s** | **0.10** | **0.10** |
| **4** | **Drive over Obstacles** | **Obstruction Height** | **3** | **cm** | **1** | **2** |

## Appendix D: Testing Results

The battery has a voltage reading of 25.6 V at full charge. The nominal current reading under no load is 2.79 A. Maximum loading current is set and protected via circuit breaker to not exceed 10.00 A.

## Appendix E: Operation Manual

### Overview

The Robotic Trash Cart (RTC) is a device that carries two waste containers and transports them from the home base to the curb for waste removal. This process is non strenuous for the user because the user controls the RTC using a wireless controller. The RTC is designed to be easy to control and safe to use. The RTC is a patent-pending product developed by Artists in Waste Removal (AWR).

### Component/Module Description

The frame of the Robotic Trash Cart (RTC) is made from aluminum due to its lightweight, high strength, and anti-corrosive properties. It is powered by a 24 V battery source supplying two center mounted motors. Each motor is controlled separately enabling zero point turning. There are caster wheels on the front and back of the RTC. It is equipped with a gate which lowers to allow easy access to the containers. To operate the RTC, a wireless controller is used to steer by varying the speed of each motor. Figure 4 below shows the dimension of the RTC in inches. The RTC is 5.617 feet in length, 2.279 feet in height, and 2.292 feet wide. The caster wheels are seen on either end of the RTC with a motorized wheel in the middle of the RTC. The gates are seen on either side of the middle wheel allowing easy access to the waste bins.

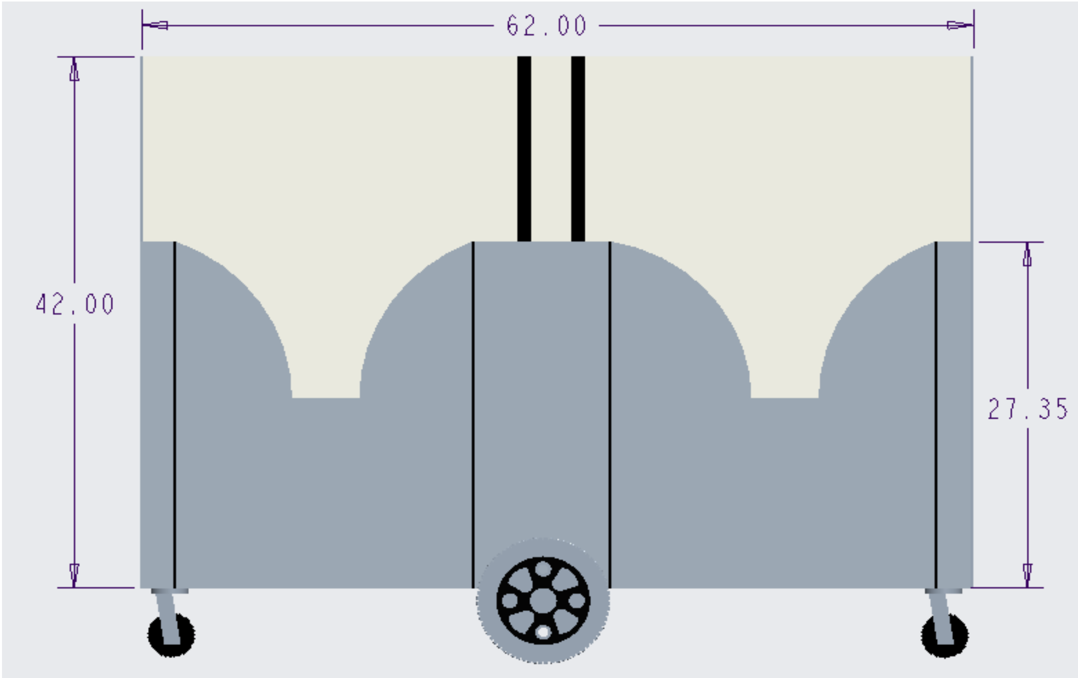



Figure 4 *Front View of the RTC*

The width of the RTC is shown below in Figure 5. The caster wheels can be seen at the bottom of the frame in the center of the RTC.

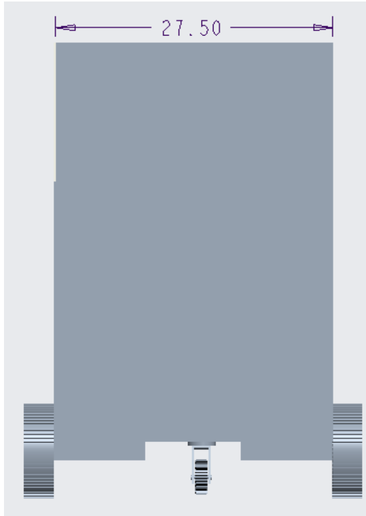



Figure 5 *Side View of the RTC*

Figure 6 shows the top view of the RTC. This view shows the fiberglass grating used for the base. The grating is used to prevent pooling water. The RTC is assumed to be stored outside in South Florida, where rain and humidity are prevalent. Fiberglass is used due to its durability and lightweight properties.

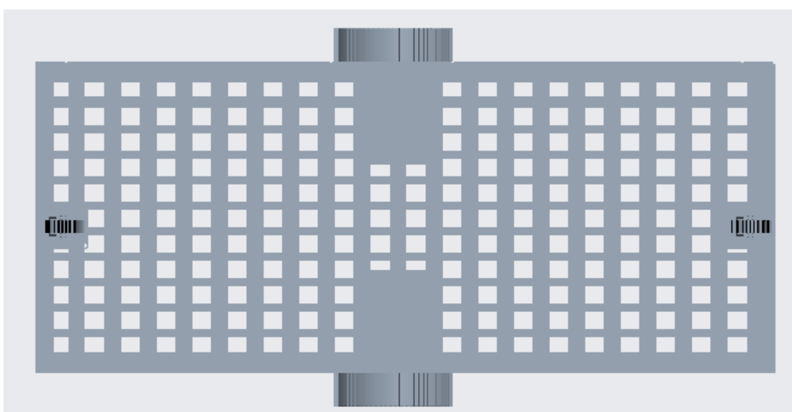


Figure 6 *Top View of the RTC*

Figure 7 below shows a 3D view of the RTC from the front of the cart. The operation controls are stored in junction box J1. It stores the toggle switch that provides power to the control system, the battery fuel gauge display, and the circuit breaker. Junction box J2 stores the control system including the motor controller (Cytron SmartDriveDuo) and the ESP32. Junction box J3 stores the wireless charger and has the motor and battery connections.

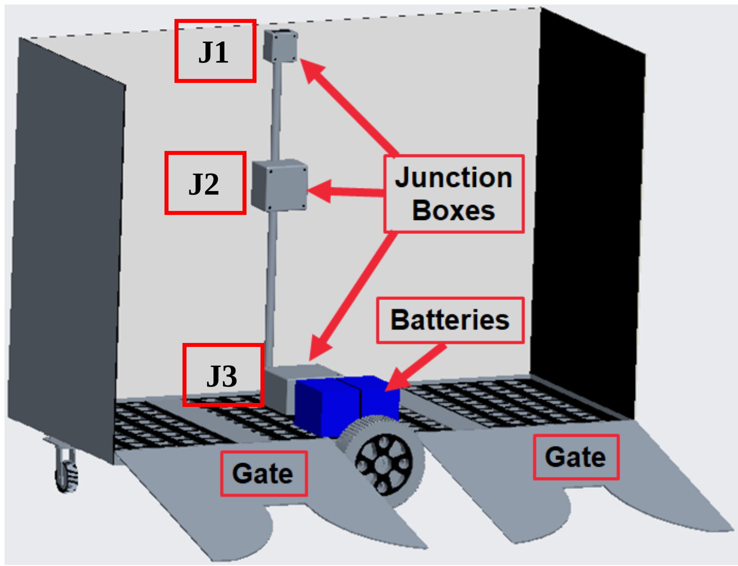



Figure 7 *3D Front View of the RTC with the Gates Lowered*

**General Warnings / Before You Use Your RTC**

The RTC is a battery-operated motor vehicle. The operation of the RTC requires you to exercise caution and consideration for your personal safety and the safety of others around you. Never modify your RTC, and do not use accessories other than those developed for use specifically with your RTC.

**Integration:**

The RTC has a box design with an open front face to allow access for the trash cans to roll up. The frame of the RTC was constructed from Aluminum 6061 angle bar, square tubing, and flat bar. Aluminum 6061 is highly corrosion resistant, as well as a high strength to weight ratio. The base of the RTC is made from angle bar formed into a rectangular shape to hold the flooring on it. The four-square tube sides are welded on the four corners vertically with a flat bar running along the top to make three closed sides and secure the trash cans. The floor of the RTC was made of heavy duty fiberglass grating to allow water to pass through without collecting.

There are wires running along the backside of the RTC from the batteries up to the control system. The control system is made up of two development boards, a toggle switch to turn the control system ON/OFF.

**Operation**

A toggle switch turns on the control system. It closes the circuit between the development boards and the batteries. Figure 8 depicts the toggle switch.

Figure 8 *Toggle Switch*

Figure 9 depicts the battery fuel gauge. It turns OFF/ON as you press the toggle the left push button on it. Pressing it once turns it on and displays the amount of charge the batteries have. Pressing it again displays the voltage output by the batteries. Pressing it a third time turns the battery fuel gauge off.


Figure 9 Battery Fuel Gauge

Figure 10 depicts the BLE JoyStick application interface. You connect to the ESP32 using BLE. The left joystick is disabled. The right joystick controls the speed and direction of the RTC. The front of the RTC is the side with the gate attached to it. If you are facing the front of the RTC and turn to the left, this direction is assumed to be the forward direction. If you face the RTC and turn to the right, this direction is assumed to be the reverse direction. The operation of the RTC using the BLE JoyStick App is described below.

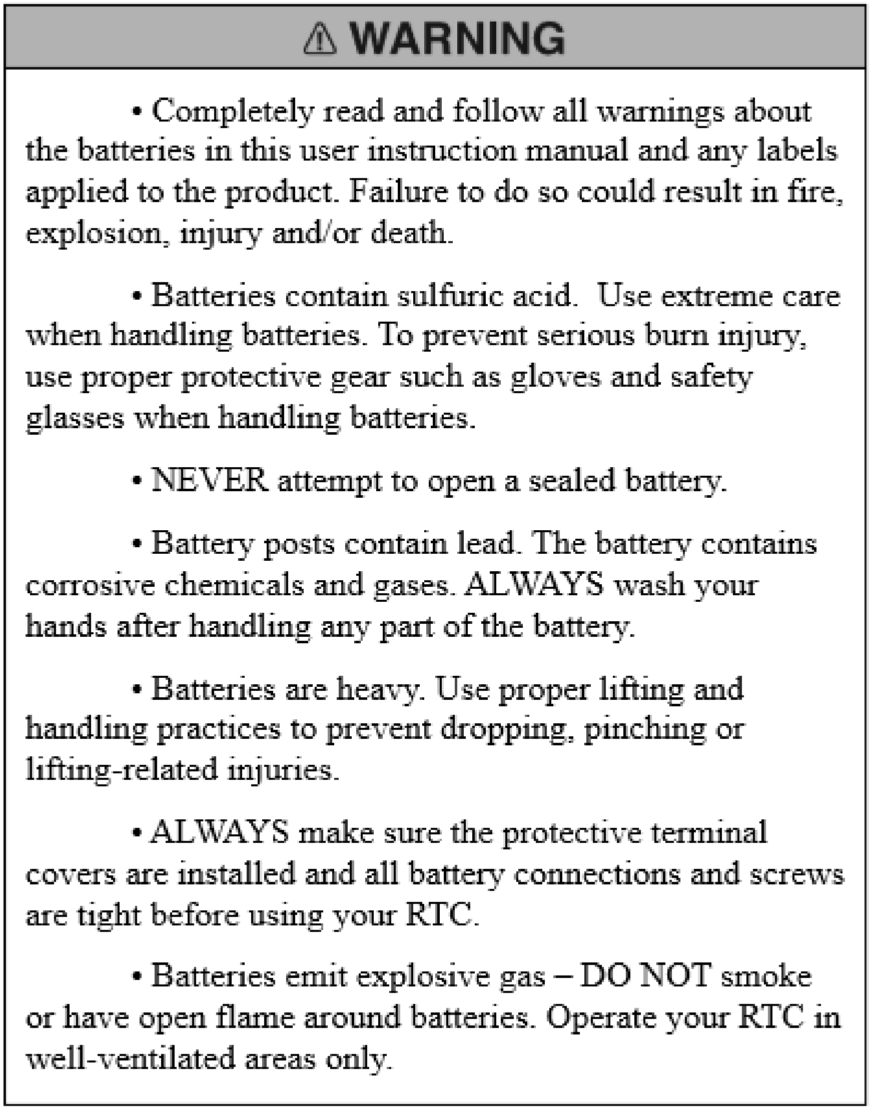
Figure 10 *BLE JoyStick Application Interface*

The basic operation is described below. It is assumed that the RTC is off.

- Turning the RTC on: Press the toggle switch to turn the control system on
- Connecting to the BLE JoyStick App: Open the app and connect to RTC Service device
- Pressing the triangle button: Moves the RTC forward direction
- Pressing the X button: Moves the RTC in the reverse direction
- Pressing the circle button: Moves the RTC to the right
- Pressing the square button: Moves the RTC to the left

**Caring for Your Batteries**

The RTC uses two Sealed Lead Acid (SLA) 12-Volt batteries of the UI size. The battery pair is connected in a series configuration to provide 24-Volts of power. The batteries supplied by AWR are of the sealed-type that require no maintenance. These batteries are classified as "wet-non-spill" and may be transported by air, land or sea. They are deep cycle rechargeable batteries. Figure 11 below depicts the warning label from AWR.



⚠ WARNING

• Completely read and follow all warnings about the batteries in this user instruction manual and any labels applied to the product. Failure to do so could result in fire, explosion, injury and/or death.

• Batteries contain sulfuric acid. Use extreme care when handling batteries. To prevent serious burn injury, use proper protective gear such as gloves and safety glasses when handling batteries.

• NEVER attempt to open a sealed battery.

• Battery posts contain lead. The battery contains corrosive chemicals and gases. ALWAYS wash your hands after handling any part of the battery.

• Batteries are heavy. Use proper lifting and handling practices to prevent dropping, pinching or lifting-related injuries.

• ALWAYS make sure the protective terminal covers are installed and all battery connections and screws are tight before using your RTC.

• Batteries emit explosive gas – DO NOT smoke or have open flame around batteries. Operate your RTC in well-ventilated areas only.

Figure 11 *Battery Warning Label from AWR*

**Battery Replacement**

ALWAYS refer to the supplied wiring diagram located on the base of your RTC when installing the batteries.

• ALWAYS install and use the correct fuse as specified on the battery label. This will prevent battery and wire overload.

• ALWAYS dispose of batteries in accordance with EPA regulations.

• Do not leave the battery charger connected to a power source when not charging.

• Do not let your batteries run down.

When it becomes necessary to replace batteries, consult with AWR Technical Support. We will provide you with the replacement battery to ensure the proper operation.

**Charging Precautions**

Your RTC is equipped with an on-board charger. Please follow the operating instructions for the appropriate charger. The charging time for the batteries will vary based on the amount of use the RTC has had. It may take up to 8 hours for a full recharge. The battery fuel gauge depicts the amount of charge your batteries currently have. We recommend an overnight charge after 8 days of use or if the gauge reads below 25%. Figure 12 depicts the battery charger warning label from AWR summarizing the precautions you must take.

⚠ **WARNING**

• ALWAYS use the charger and connectors supplied with your RTC.
• DO NOT use the charger while raining or in areas unsheltered from the weather.
• ALWAYS charge your RTC in a well-ventilated area free of any sparks, high heat or open flame. Explosive gas is emitted during the charging process.
• DO NOT smoke around your RTC or charger when charging.
• DO NOT attempt to repair or open the charger.
• ALWAYS use a grounded,120-volt household power outlet.
• NEVER connect the charger to a 240-volt power source.
• DO NOT use the charger if the cables or connectors are damaged.

Figure 12 *Battery Charger Warning Label from AWR*

Cables and connectors can be damaged by:

- Stepping and rolling objects over the cable or connectors.
- Yanking the cable out of the wall outlet.
- Pinching the cable.
- Handling sharp objects such as knives and/or scissors in close proximity to the cable or connectors.
- DO NOT attempt to charge a frozen battery.

**Charging Your Batteries**

1. Select a clean, dry, cool, well ventilated area to use the charger.

2. Make sure the RTC is in the OFF position.

3. Connect the charger output port into the AC extension power cord connected to a 120-volt grounded household power outlet. The charger port is located in the rear port of the RTC. Align the three pins on the plug with the three holes on the port and push the plug in place. Make sure the plug is fully seated in the charger port. If it is not pushed all the way, the batteries will not charge or the plug may become hot.

4. Plug the AC power cord into the back of the charger.

5. Plug the other end of the AC power cord into a 120-volt grounded household power outlet.

6. When the batteries are charged, and/or you are ready to use the RTC:

- Unplug the charger from the household power outlet.
- Unplug the AC extension power cord from the charger port.

**Manual Brake Release Levers**

On occasion, it may be necessary to push your RTC. Each motor has a manual brake release lever. To locate the manual brake release levers on your RTC, check the rear of each motor. The levers move downward to release the brake on the motor. When both manual brake release levers are released, and the power is turned OFF, the RTC can be pushed. Pull both manual brake release levers upward to re-engage the brakes.

**Owner Maintenance/Troubleshooting**

**Daily Maintenance:**

• Check drive tires for tread wear and tire pressure.

• Charge batteries as needed per guidelines below.

• Check that the gate latches do not show signs of wear.

**Weekly Maintenance:**

• Check tire treads and pressure. (Should be 45-50 psi.).

• Check that casters are free to pivot.

• Check that caster wheels rotate freely.

• Check manual brake releases. Release each brake separately to ensure they disengage.

• Check charger cords and connectors for loose connections, damaged cables or signs of electrical damage.

• Clean the RTC.

If problems arise with your RTC, please call customer service for technical assistance.

*Note* Motor operational noise is normal. Audible noise levels will normally increase as the RTC ages.

**Caster Wheel Replacement**

1. Remove both sides of the base fiberglass grating from the RTC.

2. Locate and remove 2 sets of 2 ⅜" X 1 ½" hex bolts and washers on each side of the RTC.

3. Remove each set of 4 ⅜" X 1" hex bolt and washer from the caster wheel plate attached in between RTC frame and caster wheel.

4. Replace caster wheels and reinstall the caster wheel plate in between the RTC frame and caster wheel with the 4 ⅜" X 1" hex bolt and washer.

5. Reinstall the 2 sets of 2 ⅜" X 1 ½" hex bolts and washers on each side of the RTC.

**Appendix G: Software**

There were multiple scripts made to control the motors using the BLE JoyStick App and the ESP32. The final design was unable to properly control the motors using the smartphone app. The motors would run but not how we had predicted. We suspect that there is an issue with the PWM. The digital pins on the Cytron SmartDriveDuo control the direction of the motors. A low signal stops the motors and a high signal sends maximum current to the motors. The analog pins on the Cytron SmartDriveDuo control the speed of the motors. We were attempting to use PWM to control the motors; however, the motors were not functioning as expected. We took out the PWM and attempted to control the motors full throttle first and then add the PWM, but we were unable to do this. If we were to do this project again, we would use an Arduino UNO or Arduino MEGA with an HC-10 BLE module rather than the ESP-32. The Arduino UNO and MEGA are directly compatible with the Cytron SmartDriveDuo. The HC-10 BLE module is compatible with the RemoteXY app, which is also a free application like the BLE JoyStick App. The RemoteXY App has more features than the BLE JoyStick App. The script below is the most basic program we were able to get some motor controls functioning, but not in the manner we wanted to.

```
#include <BLEDevice.h>

#include <BLEServer.h>

#include <BLEUtils.h>

#include <BLE2902.h>

#define MOT_1F 23

#define MOT_1R 22
```

```
#define MOT_2F 18
#define MOT_2R 19

BLECharacteristic *pCharacteristic;
BLEDescriptor *pDescriptor;
bool deviceConnected = false;
bool deviceNotifying = false;
uint8_t txValue = 0;

// See the following for generating UUIDs:
// https://www.uuidgenerator.net/

#define SERVICE_UUID           "6E400001-B5A3-F393-E0A9-E50E24DCCA9E" // UART
service UUID
#define CHARACTERISTIC_UUID_RX "6E400002-B5A3-F393-E0A9-E50E24DCCA9E"
#define CHARACTERISTIC_UUID_TX "6E400003-B5A3-F393-E0A9-E50E24DCCA9E"

void mot_up() {
  digitalWrite(MOT_1F, 1); // turn on
  digitalWrite(MOT_2F, 1); // turn on
  delay(500);              // wait
  digitalWrite(MOT_1F, 0); // turn off
```

```
  digitalWrite(MOT_2F, 0); // turn off
 }
void mot_down() {
  digitalWrite(MOT_1R, 1); // turn on
  digitalWrite(MOT_2R, 1); // turn on
  delay(500);              // wait
  digitalWrite(MOT_1R, 0); // turn off
  digitalWrite(MOT_2R, 0); // turn off
}
void mot_left() {
  digitalWrite(MOT_1R, 1); // turn on
  digitalWrite(MOT_2F, 1); // turn on
  delay(500);              // wait
  digitalWrite(MOT_1R, 0); // turn off
  digitalWrite(MOT_2F, 0); // turn off
}
void mot_right() {
  digitalWrite(MOT_1F, 1); // turn on
  digitalWrite(MOT_2R, 1); // turn on
  delay(500);              // wait
  digitalWrite(MOT_1F, 0); // turn off
  digitalWrite(MOT_2R, 0); // turn off
```

```
}
class MyServerCallbacks: public BLEServerCallbacks {
    void onConnect(BLEServer* pServer) {
      deviceConnected = true;
    };

    void onDisconnect(BLEServer* pServer) {
      deviceConnected = false;
    }
};

class MyCallbacks: public BLECharacteristicCallbacks {
    void onWrite(BLECharacteristic *pCharacteristic) {
      std::string rxValue = pCharacteristic->getValue();

      if (rxValue.length() > 0) {
        Serial.println("*********");
        Serial.print("Received Value: ");
        for (int i = 0; i < rxValue.length(); i++)
          Serial.print(rxValue[i]);

        if (rxValue=="up") {
```

```
        mot_up();
      }
      if (rxValue=="down") {
        mot_down();
      }
      if (rxValue=="right") {
        mot_right();
      }
      if (rxValue=="left") {
        mot_left();
      }

      Serial.println();
      Serial.println("*********");
    }
  }
};


class MyDisCallbacks: public BLEDescriptorCallbacks {
  void onWrite(BLEDescriptor *pDescriptor) {
    uint8_t* rxValue = pDescriptor->getValue();
```

```
      if (pDescriptor->getLength() > 0) {
        if (rxValue[0]==1) {
          //deviceNotifying=true;
        } else {
          deviceNotifying=false;
        }
        Serial.println("*********");
        Serial.print("Received Descriptor Value: ");
        for (int i = 0; i < pDescriptor->getLength(); i++)
          Serial.print(rxValue[i]);

        Serial.println();
        Serial.println("*********");
      }
    }
};
void setup() {
  Serial.begin(115200);
    pinMode(MOT_1F, OUTPUT);
    pinMode(MOT_1R, OUTPUT);
    pinMode(MOT_2F, OUTPUT);
```

```
  pinMode(MOT_2R, OUTPUT);


// Create the BLE Device

BLEDevice::init("UART Service");


// Create the BLE Server

BLEServer *pServer = BLEDevice::createServer();

pServer->setCallbacks(new MyServerCallbacks());


// Create the BLE Service

BLEService *pService = pServer->createService(SERVICE_UUID);


// Create a BLE Characteristic

pCharacteristic = pService->createCharacteristic(

                    CHARACTERISTIC_UUID_TX,

                    BLECharacteristic::PROPERTY_NOTIFY

                  );


pDescriptor = new BLE2902();

pCharacteristic->addDescriptor(pDescriptor);


BLECharacteristic *pCharacteristic = pService->createCharacteristic(
```

```
                                CHARACTERISTIC_UUID_RX,
                                BLECharacteristic::PROPERTY_WRITE
                              );
  pCharacteristic->setCallbacks(new MyCallbacks());
  pDescriptor->setCallbacks(new MyDisCallbacks());

  // Start the service
  pService->start();
  // Start advertising
  pServer->getAdvertising()->start();
  Serial.println("Waiting a client connection to notify...");
}

void loop() {
  if (deviceConnected && deviceNotifying) {
    Serial.printf("*** Sent Value: %d ***\n", txValue);
    pCharacteristic->setValue(&txValue, 1);
    pCharacteristic->notify();
    txValue++;
  }
  delay(1000);
}
```

## Appendix H: InNOLEvation Challenge Application

The robotic trash cart is a fully autonomous device that carries the recycling and waste bins to the curb for pick up and returns home. The elderly, disabled community, and people with limited strength and mobility in their extremities struggle to push or pull heavy objects, such as waste bins. This problem is magnified if their driveways are sloped, uneven, or become slick due to rain. The robotic trash cart consists of an aluminum frame with an HDPE plastic base, which will hold the trash and recycling bins, using an array of sensors to autonomously transport the bins from the user's home to the curb for waste removal and back to the user's home. A gate in the frame of the robotic trash cart provides waste engineers easy access to the bins for quick trash removal. The primary markets for the robotic trash cart are waste management companies that can rent out the equipment to homeowners for a monthly fee and individual homeowners. Secondary markets include amusement parks, outdoor shopping centers, and transportation hubs, such as airports, train and bus stations, and waterway entries. These secondary markets have the greatest commercial applications for the robotic trash cart due to their dense foot traffic. Here, an autonomous system of multiple robotic trash carts can be implemented. Once a robotic trash cart senses that it is full of trash, it will autonomously navigate to the central waste site, where it can be emptied and return to its original location. The business model canvas below explains our expenditures, revenue stream, and key partnerships.

**Lean Business Model /Business Model Canvas** Organization/Project Name: Robotic Trash Cart

**Key Resources (6 )**

- Storage facilities
- Distribution network for sales team
- Manufacturing of RTC
- Design and development of RTC and autonomous systems
- Mobile support
- Component parts (repairs)

**Key Partners (7 )**

- Waste Management Companies
- Retirement communities
- Amusement Parks
- Outlet malls
- AARP
- Homeowners Association

**Key Activities (5)**

- Design and develop product
- Code that enables user control of the RTC and autonomous functions
- Arrange for a contract manufacturer (or we could assemble ourselves)
- Technicians to provide maintenance services
- Telephone and online chat operators to offer technical support

**Value Proposition (1)**

1. Waste Management Companies
   a. No more pick up of trash bins from the backyard
   b. Additional revenue stream leasing RTCs to customers.
2. Home Owners
   a. Alleviate stress from pulling/pushing heavy bins
   b. Avoids rain/cold/snow when taking trash out (convenience)
   c. Automates the trash dispensing to the curb allowing home owners to be away during trash collection weeks
3. Amusement Parks/Locales with dense foot traffic
   a. Trash cart can be strategically placed as foot traffic changes throughout the day
   b. Trash carts move to the primary dumpster when they are full

**Customer Relationships (4)**

Possible Partnership with waste management companies/amusement parks to train technicians on maintenance of the RTC or provide maintenance services (warranty). Client managers familiar with a user's trash dispensing system will provide personal assistance for troubleshooting problems. We will offer customer service support for individual homeowners.

**Channels (3)**

- Direct sales to waste management companies/home owners/amusement parks
- Online sales to the home owners

**Customer Segments (2)**

1. Waste Management Companies
2. Home Owners
3. Amusement Parks
4. Local, state, and national parks
5. Locales with dense foot traffic, such as outlet malls, transportation hubs, sporting events/stadiums

**Expenditures (8)**

(Cost Structure) ⟶

- Manufacturing costs of the RTC (wholesale price if using contract manufacturer)
- Distribution costs for deliveries of RTC
- Design and development
- Storage costs
- Company operating costs

**Revenues (9)** ⟶

- Selling or leasing of the RTC
- Consulting services for customization of RTC and/or autonomous system for trash dispensing
- Mobile support for mechanical failures
- Maintenance agreements
- Replacement Parts

Figure 13 *Business Model Canvas*

# References

**There are no sources for this document.**