Universal Tread for Power Wheelchairs

ME 430
Senior Design Project
June 2, 2022

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Statement of Disclaimer

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Abstract

This project was centered around developing a fully independently driven powered wheelchair attachment that would allow users to traverse non-wheelchair accessible terrain. The initial goal was to create a full-scale model that would allow our user to use and test as a prototype to get over curbs and some light dirt off-roading. However, as the project progressed and limitations of time and money came up, this project was rescoped to a quarter-scale proof of concept model. The goal of this new project was to create a prototype that would carry a scaled-down load and traverse a scaled-down curb. This was to prove if this concept was possible with the proper specifications and loads that would be scaled up to simulate a full-scale model. In changing the scope to a quarter-scale model, the design of the verification prototype was centered around some critical components and dimensions that would be important when scaled up. Some of these specifications included ground clearance, angle of tilt, and some electronics components.

We designed and built this verification prototype with parts that we found would best be adapted if they were to be scaled up. These components included things like axles and fasteners that could be easily changed to a different size. Also, all of the electronics were chosen so they could be reused with different specifications. When doing all of the design verification testing, we found that this prototype met most of the specifications we set to meet. The main problem we had was our lack of a reliable tread system, and its trouble with durability and ability to grab onto and climb steps. Our testing shows that this concept is possible at a full-scale model with some slight changes. At full-scale, this prototype would have much more durable treads and space to add additional systems for safety and comfort, like a suspension system.
Introduction

The purpose of this senior project was to prove the concept that an independent system could be designed to carry a wheelchair and person over curbs on off-road. Our sponsor, Alex Fung, is intended to be the main beneficiary of the full-scale system; however, because the system is completely independent of the wheelchair many others can benefit from it as long as the design ensures compatibility with a variety of wheelchair standards. For this proof of concept, we chose a quarter-scale system. This meant the system would carry one-quarter the weight we expect in the real system and it would carry it over one-quarter scale curbs.

This report covers the various stages and iterations of the design. This includes the following:

1. Scope of Work

   The scope of work served as a platform to identify goals and criteria that the design is meant to achieve. It shaped the purpose of the design.

2. Preliminary Design Review

   This was the first stage of the design process. The final design itself saw many changes after the preliminary design. However, the preliminary design played a crucial role in establishing what the system would generally look like, how it would aim to achieve the criteria and specifications of interest, and in building an understanding of the physical and financial limitations we would face.

3. Critical Design Review

   The critical design review was the intermediate stage of design. At this point, the group had a better understanding of how to move forward with the design. It also takes into consideration risks and hazards that may result from the design.

4. Final Design Review

   This is the final stage of design. At this stage in the design, all details of the system are finalized. The system prototype is built and used to do real-world tests that show if the design has met the criteria it was set out to achieve.
Part I

Scope of Work
Universal Tread for Power Wheelchairs Scope of Work (SOW)

October 12, 2021

Team F75
Universal Tread

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Abstract

This scope of work document was developed through an in-depth analysis of this project’s research and scope. This document will outline the research and work done by evaluating the stakeholders’ wants and needs, existing similar products, and technical research pertaining to this design challenge. With this research, a problem statement is defined, and a further detailed scope is depicted through a boundary sketch, functional decomposition chart, and quality function deployment sheet. From here, the project scope and objectives are defined in which specifications will be focused as well as the organization and management that will be used to approach this design challenge.

The goal of this project is to develop a fully independent attachment to powered wheelchairs that allow the user to traverse curbs and nonwheelchair-accessible terrain. This document outlines the tasks to be completed through a project scope and deliverable timeline.
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Introduction

Powered wheelchairs that are currently available to patients in need come in different classification groups based on their capabilities. However, none of them give the ease of ability to traverse non-wheelchair accessible areas like unpaved roads and things like curbs and steps. Although there are current powered wheelchairs on the market that can perform such tasks, none of them are offered in the way of a modular attachment that enables multiple wheelchairs to overcome these tasks. This design challenge is centered around designing and building a fully independent external tread-like attachment that allows any user to be able to access these areas without modifying the wheelchair itself.

The main stakeholder of this project is Alex Fung is a fourth-year quadriplegic aerospace student at Cal Poly who is experiencing said difficulties of overcoming non-wheelchair accessible terrain. Other stakeholders include Alex’s assistants and relevant manufacturers. The team working on this design challenge is made up of Aaron Rocha, Brian Song, Daniel Ceja, and Ryan Scarcella, all fourth- and fifth-year mechanical engineering students attending California Polytechnic State University, San Luis Obispo.

The goals of this scope of work report are to communicate the team’s understanding of this project and its goals and to show the steps we are taking in each design decision. This is so Alex has a clear understanding of the team’s project goals and what will be done to achieve them. This Scope of Work document will demonstrate that the team has the required resources and time to take the steps towards achieving a successful design process.

The background of this report will discuss the team’s design research process. This section explains how the customers’ wants and needs are identified. It also shows the existing similar products and relevant patents that were researched. This is to compare different aspects and shortcomings of each product that could be integrated into this project’s final design. The project scope section establishes what the stakeholders want and need, and in what way the team will be interacting with them. This section breaks down the desired final product into basic functions and our specific goals with them. The objective section outlines the clear problem statement and the engineering specifications for what the final product will consist of. This is where the specifications and functions are weighted to best meet everyone’s wants and needs. Lastly, the project management section mentions the strategy and organization methods that the team will be using to stay on track and meet the deadlines for the key milestones and deliverables.
Background

Stakeholder Needs

Alex communicated some of his difficulties with accessibility. He explained how going to a friend's house may be difficult for him when they have a porch. Usually, he will require their assistance to set out plywood and form a ramp he can use to overcome the steps on the porch. This is inconvenient and proves to be hectic when he wants to move in and out of the house freely. Alex has also described to us situations in which he would have liked to be able to scale sidewalk curbs. Though curb cuts are common, there is always that possibility that he may find himself in a situation where he needs to scale a curb, going up or down, to make his route easier. He also mentioned that he used to go on small hikes with this wheelchair but has since lost confidence in the wheelchair. In one scenario, a small rock got caught between his wheels and he was stuck waiting for assistance. He also explained that he would appreciate off-road capabilities in his wheelchair, however it was not a priority to him.

Alex wants an auxiliary system that can easily be attached to an electric wheelchair to improve its accessibility and asks that this system fit in doorways when attached to his wheelchair. The main concern is overcoming small flights of stairs and curbs. The system must have its own power system if any additional propulsion, besides what the wheelchair can already provide, is necessary. The primary reason for this is the fact that Alex wants the design to be simple and easy to set up; a system that would connect to the wheelchair's own power or power delivery system would add complexity. Should the system lift Alex and the wheelchair, thus far presumably on a platform, it must use a commercially available Ez Lock system to hold him and the wheelchair in place. Another requirement is that the system be compatible with all class 4 wheelchairs, because Alex explained to us that he gets a new class 4 wheelchair every 5 years and he wishes to be able to use the system we design with all his wheelchairs. Finally, the system we design must cost no more than $2,500 to produce the first unit.

Existing Solutions

There are a few wheelchairs out there of overcoming steps, rough terrain or stairs. The few models that do exist are very specifically tailored to meet one of these needs and are much more expensive than the wheelchair that Alex uses. There is no auxiliary system that would allow a relatively simple wheelchair to accomplish all of this, so most people who use wheelchairs will lack the enhanced accessibility of the specially designed models.

One of these models was a wheelchair known as the iBot wheelchair. It uses technology much like that of a Segway and has 2 sets of driving wheels. These two wheels can essentially rotate around each other so that the user has the option to have all wheels on the ground or have only two wheels on the ground. When climbing stairs, it rotates these two sets of wheels as if the wheelchair had an integrated suspension system, and because it is four wheel drive it can comfortably overcome grass hills.
Another design used a treadmill like system integrated under the wheelchair. This system had special treads and could be used to scale stairs; the wheelchair was able to tilt relative to the system underneath it to keep the user in the upright position as it scaled the stairs. This chair did not incorporate any features that may help with the off-roading capabilities, and it was not able to turn while going up stairs.

There are also wheelchairs that are designed to be “off-road” wheelchairs, but they do not have any real advantages when it comes to scaling curbs or stairs. These wheelchairs varied greatly. One was just $300 and not electrically powered. Another was $26,000 and was an eclectically powered wheelchair with tank tracks to help with traction and stability in rough terrain.

**Technical Research**

The market for a wheelchair add-on that would improve off-road capabilities or allow the chair to scale a curb is largely uncatered for. Part of the reason for this is the fact that electric wheelchairs weigh well over 400 pounds, not including the operator. Additionally, an add-on like this would have a difficult time reaching a mass market as it would need to be designed to accommodate a variety of wheelchairs. Given that each wheelchair has its own dimensions and specifications, a group of engineers may have a difficult time accommodating all of these specifications. Additionally, this add-on would likely have to have a power unit and power delivery system of its own. It would not be feasible to attach this add on to the wheelchair’s own power unit; ideally the add-on should be easy to attach and detach.

There are accessibility requirements that many buildings, especially on Cal Poly’s campus, must meet. One major piece of information to consider is that for a doorway to be considered accessible it must be a minimum of 32 inches wide. Alex wants his wheelchair to fit in doorways when the auxiliary system is attached, so the system we design must be within these limitations. Additionally, most curbs are 6 inches tall; this means that for the final product to have a system that lifts Alex and his wheelchair on a platform, we will need a minimum ground clearance of 6.5 inches. Finally, the wheelchair manufacturer has a limit to the angle of tilt that is considered safe with the wheelchair. If the system uses a platform, we will need a way to ensure that this platform does not tilt any further than the allowable angle of tilt that the manufacture provides.
Project Scope

As shown in Figure 1 below, the main goal of this project is to develop a completely independent attachment that will not modify the existing wheelchair and any of its current functionalities.

![Boundary Sketch](image)

Figure 1: Boundary Sketch

Wants and Needs

Alex stated that the primary purpose of this project is for him to overcome curbs and potentially small flights of stairs. He gets a new wheelchair once every 5 years, so he specified that he wanted this system to be a completely independent attachment that will also be compatible with other powered wheelchairs of similar specification and dimension (group 4). This also allows the team to target a larger audience with similar problems. He also requires that when attached, the system doesn’t interfere with current mobility capabilities (ex: Fitting through doors). Off-road capabilities like dirt paths are also desirable from this system, though not required. Desired functions of this product include that it is easy to store and deploy for him to use. He wants it to be simple to set up so that ideally, he can set it up himself, or instruct his assistant to do so with little to no trouble. After the system is deployed and attached, he wants to be able to use it easily and integrate it into his current system safely and with ease.

Stakeholder Need

- Overcome curbs
- Be modular for other wheelchairs of similar dimension
- Fully independent attachment (no modifications of the wheelchair itself)
- Not interfere with current mobility (ex: still be able to go through doors)
Stakeholder Wants

- Have some off-road capability
- Easily storable
- Easily deployable for minimal helper involvement
- Easy for independent use

Figure 2: Functional Decomposition

As seen in the functional decomposition in Figure 2 above, the main functions of this final product are broken down into smaller steps. This highlights the different categories of each function and how they interact with each other. Having broken down functions ensures the team does not miss any functions that attribute to the usability of the final product.

Objectives

Mr. Alex Fung currently has a power wheelchair that is designed with limited mobility in non-wheelchair accessible areas. He needs a way to improve the mobility of his power wheelchair with the use of an external attachment thus making him more independent and less reliant on helpers.

To measure the importance of all the user’s needs to their relevance of the team’s engineering specifications a Quality Function Diagram, Appendix A, was used. The team used quality function deployment to translate customer wants and needs into engineering specifications. The first step was to use Alex’s needs and wants that were given to the team during the sponsor meeting to create some specifications for the project. The next step was to relate these specifications’ relevance to each other and to the user’s needs and wants. Each of
Alex’s wants was then weighted by their importance. After this, similar current products were compared to see if they solved any of Alex’s needs and wants. This information was used to learn how these products were able to solve these needs and wants to then apply to our project.

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<th>Risk*</th>
<th>Compliance**</th>
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<tr>
<td>4</td>
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<td>$2500</td>
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</table>

* Risk of meeting specification: (H) High, (M) Medium, (L) Low
** Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

1. **Weight**: The weight of the final product is important because if it is too heavy, then it may be hard to store, and be portable. Weight will be assessed by putting the final product on a scale, and by adding up the weights of each individual smaller piece of our final product.

2. **Traction**: The traction the final product gets is one of the most important specifications. If the treads designed do not give ample traction, then the product will not help Mr. Alex Fung go anywhere. The plan is to assess the traction by using torque analysis and by testing our treads on different surfaces.

3. **Ease of Storage/Portability**: The ease of storage and portability is important to Mr. Alex Fung because he wants to be able to store and take this product with him in his van. The plan is to measure its dimensions to see if it will fit into his van, and the plan is to test to see if most people would be able to move it on their own.

4. **Allowable Angle of Tilt**: The allowable angle of tilt of the final product is a very important specification because this will assure the safety of Mr. Alex Fung or any other user. Allowable angle of tilt will be measured by setting up equations to solve the center of gravity with a user on the final product. The final product will be tested for its allowable angle of tilt once it is constructed.

5. **Ground Clearance**: The ground clearance of the final product is also a very important specification because if the ground clearance is not high enough, then the product will not be able to scale stairs or curbs. Ground clearance will be measured of our product by measuring it at a flat spot.

6. **Power/Torque Output**: The power and torque that the final product puts out is very important because without a high enough torque the user will not be able to climb stairs
or go into rough terrain. Power and Torque will be measured through analysis and testing.

7. Dimensions: The dimensions of the final product are very important because the product must fit most wheelchairs in group 4. This specification will be measured by comparing the average dimensions of a group 4 wheelchair against the final product to see if it would fit them.

8. Cost: The cost is also a very important specification because the team cannot go over the budget or else, the team will have no more money to spend on the project. The team will keep track of our spending through an excel sheet of our purchases.

The allowable angle of tilt and ground clearance are classified as high-risk specifications because they may be hard to meet. The angle of tilt and ground clearance work against each other because the product will be built to be wide enough to still allow it to go in a doorway and not any wider. This means the higher our ground clearance the higher the center of gravity is going to be. This will ultimately cause our allowable angle of tilt to go down, because the width of the base will be the same as the center of gravity raises.

Project Management

The design process begins with background research, then defining the problem and ideating, and finally prototyping and testing. First, the customer's wants and needs need to be defined to obtain a clear problem statement. Background research will be conducted to find existing relevant products as well as other technical topics related to this design challenge. After a problem statement is defined, the team will be conducting an ideation stage to come up with as many new and creative solutions as possible. Following ideation, a weighted decision matrix will be used to narrow down the existing ideas into ones that most closely conform to the user’s wants and needs. After this stage, prototyping and testing will be used to create representations of what the final design will be. These ideas will be tested and used to refine existing ideas and solutions. Following the final designs will be CAD models and final prototypes that will be presented during the final expo.

For organization, the team will be following a timeline template as shown in Appendix B. This Gantt chart shows all the team’s weekly goals as well as bigger milestones (as indicated by a yellow diamond). For documentation and information, the team will be using Microsoft Teams as well as OneNote to log any notes or research that will be used and shared across the team. All these organizational resources are to enable the team to plan work efficiently and meet deliverable deadlines. This project process will be documented for the stakeholders and other interested individuals through four major milestones. The corresponding reports and deliverable dates are presented in Table 1 below.
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<th>Key Milestones</th>
<th>Sponsor Deliverable Date</th>
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</tr>
<tr>
<td>Preliminary Design Review</td>
<td>November 18, 2021</td>
</tr>
<tr>
<td>Critical Design Review</td>
<td>February 11, 2022</td>
</tr>
<tr>
<td>Final Design Review</td>
<td>June 3, 2022</td>
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**Conclusion**

The Universal Treads team proposes a challenge to develop a fully independent auxiliary system to allow powered wheelchair users to improve ground clearance and accessibility. The purpose of this document is to demonstrate the team’s understanding of the scope of the project and receive the stakeholders’ agreement. This report defines the problem statement that addresses the user’s wants and needs, as well as the background and technical research that is relevant to the development of this product. In addition, this report defines each goal and the processes and methods that the team will be using to achieve said goals. Finally, key milestones and deliverable dates are listed for the stakeholder to know when and what to expect for each design review.
References


*Be Mechanical Engineering Final Year Project* - Smart ... https://www.youtube.com/watch?v=Tt9et4TSCEI.


Appendix B: Project Gantt Chart
Part II

Preliminary Design Review
Universal Tread for Power Wheelchairs Preliminary Design Report

November 12, 2021

**ME 428**

Senior Design Project

Team F75

Universal Tread

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Abstract

This preliminary design review document consists of a breakdown of the ideation process and in-depth analysis used to further develop the best ideas from ideation. This document will outline the work done to come up with a design through ideation, selection, and the justifications of each step. Lastly, this document will address the management and development plan for the rest of this project until the Critical Design Review.

The initial ideation sessions resulted in many ideas. These ideas were then narrowed down within four different function level categories with the use of Pugh matrices. The categories that seemed most important and relevant were suspension, contact to ground, attachment to chair, and deployment/storage. The Pugh matrices narrowed the ideas down into a small handful of ideas which were further reduced with the use of a weighted decision matrix. The weighted decision matrix combined the function level ideas into different system level ideas.

This process resulted in two main designs with interchangeable components that will be developed further in detail. Narrowing down the ideas will allow the team to do further detailed design and testing to make these said ideas work.
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**Introduction**

Powered wheelchairs that are currently available to patients in need come in different classification groups based on their capabilities. However, none of them give the ease of ability to traverse non-wheelchair accessible areas like unpaved roads and things like curbs and steps. Although there are current powered wheelchairs on the market that can perform such tasks, none of them are offered in the way of a modular attachment that enables multiple wheelchairs to overcome these tasks. This design challenge is centered around designing and building a fully independent external tread-like attachment that allows any user to be able to access these areas without modifying the wheelchair itself.

Since the Scope of Work, the research and design of this project has been more focused on ideation and narrowing these ideas into more flushed-out designs. Moving forward, the team has a clearer goal in terms of design direction and specific things to build and test. The main focus of this document is the project concept development, design, and justification. This describes the steps taken to narrow the large quantity of ideas down to a select few with the use of different matrices and selection techniques. It explains the designs with more detail and descriptions. It will also address how the design process will be done, including preliminary calculations, safety plans, and current challenges with the concept design. Finally, this document will address the project plan for the rest of the development of this project.

**Concept Development**

The concept development process consisted of creating functional decompositions and evaluating the different ideas with matrices to narrow down the top design. The final concept for the attachment to the wheelchair is shown in figure 1 below.

![Figure 1 Final Concept Design for Power Wheelchairs](image)

The concept ideation process involved the team in participating in different ideation methods. In between ideation methods the team would participate in Stoke activities, usually involving physical activities like Ping Pong or walks around campus to avoid mental blocks. Some of the methods that were used were creating functional decompositions, brainstorming, brainwriting, worst idea and how might we questions. In the functional decompositions we created a function tree outlining the wheelchair attachment’s main functions and sub-functions for each one. Below in figure 2 is the Functional decomposition that the team developed for the Power wheelchair attachment with the main functions of the attachment being to provide safety, facilitate movement, ensure drivability and make transportable.
After we recorded enough ideas, we created function prototypes and evaluated the different ideas using Pugh and Morphological matrices to narrow our designs. The Pugh matrix compared the different ideas we had developed in the ideation session and compared them to a set of criteria. Each idea was compared to a selected datum and assigned values of +, - and S depending on how each design compared to the datum with each symbol representing better, worse or the same performance, respectively. The total amount of values was summed and compared to the datum. Negative total values indicated that the datum meets the criteria better than the idea that was being compared to it. Similarly, positive values meant that the idea met the criteria better than the datum and a zero-value meant they met them equally. The Pugh matrices that were created for the wheelchair attachment can be found in the appendix D. The Pugh matrices results showed that the Trailing-arm, Push Rod and the leaf concepts best met the criteria for the Suspension system while the Front-Back Tread, Tread-Wheel Hybrid and the four wheel best fit the criteria for the Contact to Ground. The full concepts were chosen by generating a morphological matrix with the possible ideas from the Pugh matrices and selecting one idea from each row. Five full concept configurations were chosen using the morphological matrix below in figure 3.

Figure 2 Functional Decomposition Function Tree
The team then created in-depth sketches and descriptions of the five concept configurations. The first design, shown below in Figure 4, uses a Pushrod Suspension on four wheels which are attached to a DC motor engine box. The engine box has a platform attached to the top of it with engine mounts serving as both dampers and as securing points. The wheelchair is secured to the platform. This design is greatly inspired by motorsport vehicles like Baja and formula 1 cars. This design configuration would give the wheelchair more clearance and allow it to overcome steps and off-road.
The second design shown below in figure 5 is very similar to the one that is described above. The one thing that has changed in this design is how the system will be stored more easily. We planned to use Ez-up Buttons to help store the wheels and such of the system. An Ez-up Button is similar to what you would find on a crutch that is used to adjust for height. If we were to go through with this design, it may be hard for Alex to use the Ez-up Buttons.
The third design, shown below in figure 6, uses a trailing arm for the suspension system. The contact to ground is a front and back tread system that is angled to be able to grab onto stairs/curbs. There are pivot points where the treads attach to allow up and down tilt. The four different tread systems allow for left and right movement. The front/back frame is an easily detachable frame system that detaches into four separate frames. They all click together using a similar technology seen in how “easy-ups” or crutches change the lengths of their pieces. This makes it easy to disassemble and store cleanly.
The fourth design, shown below in figure 7, uses Leaf suspension attached to the platform of the wheelchair for added support and comfort. The main suspension design, the suspension that will be in contact with the wheels and treads will be trailing arm suspension much like we see in airplanes. Essentially, there are two rigid rods attached with a pivot point, and there is a spring and damper system between the two that counteracts the moment of the 2nd rod.

The treads will be on the front end of our system. They are designed so that they may easily overcome steps. At the front end they are angled upward to make this possible. The wheel at the back end of the system will simply be used to prevent it from tilting too far backwards as the wheelchair transverses stairs.
The weighted decision matrix shown below in figure 8 was constructed using the top four wheelchair attachment designs and comparing them using weights and QFD specifications. Each concept was ranked 1-5 with 5 meaning that the concept met the specifications best. The rank was then multiplied by the weight and a total score was given to each design. Based on the weighted decision matrix the top concept design was the fourth concept choice which consists of a tread/wheel hybrid system connected to a frame on trailing arm suspension.
Figure 8 Weighted Decision Matrix

Concept Design

The design that holds the most value in moving forward was a design that used a combination of treads and wheels; the wheels will support the back end of platform for the electrical wheelchair. The platform will be connected to the rear wheels through independent trailing arm suspension, and the rear wheels will not be driven. This will free them up to rotate about an axis perpendicular to their translational motion and the platform. A simple way to visualize this is to picture the motion of the wheels on a shopping cart. The front end of the platform will be rigidly attached to treads that are shaped like upside-down trapezoids with 45-degree angles. This is meant to help the system when reaching a curb by allowing the treads to make meaningful contact with the edge of the curb before beginning to transverse it. The wheelchair must have a way to get onto the platform of the system; to solve this the system will be equipped with a retractable ramp that will be driven by one of the motors that drives the treads. These motors can engage and disengage with the tread and ramp system by a clutch or pin mechanism that allows the motor to only drive on of these at a time.
Figure 9 A visualization of how the front tracks will rotate to minimize the angle of tilt (theta).

The front tracks will rotate about the axis on which they are attached to the platform. Servo motors can allow this rotation to be controlled as necessary. For example, when going downstairs the tracks can rotate backwards to help level the system and minimize the angle of tilt.

The two treads at the front will be driven by two pulleys attached to two electrical motors. One pulley and motor per tread. This will allow us to vary the input from one tread to another, and this can be used to steer the wheelchair. The primary reason for choosing to drive the treads and not the rear wheels is because we want to ensure that the driving system (whether it be wheels or treads) is in contact with the stairs, or curbs for as long as possible. It is also important to consider that from the point of view that the grip available, the system will have the hardest time overcoming stairs and steps at first contact. At first contact the system will be horizontal and the system will have to elevate itself on the front end to begin to climb. Once the entire system is at the angle of the stairs, the system no longer needs to elevate the front end; it must only progress forward at an incline.

It is necessary to consider a variety of material for this design. There are aspects of the design that will not need more structural security than others. Safety is our highest priority so all components must be able to support their respective loads even after considering fatigue. Our system will be designed for infancy when considering fatigue; this means that the factors of safety used in the design will be used in this design will be relative to a lifetime fatigue. Parts like suspension components are planned to be made of steel. The steel alloys we use will depend mostly on price; it is preferable to use cheaper materials as the budget of the project is a large constraint. The design will be adjusted around these alloys to achieve desirable factors of safety. Other components, like the ramp that will be used to get on the
platform, can be made of aluminum. Finally, rubber will be used for the treads and tries to provide reliable grip.

The geometry of the system is not fully understood yet as a change in any aspect of the system can change the overall geometry of the system. The primary concern of the system is the ability to transverse stairs. The project sponsor has made it clear that the geometry is less important if the system can easily be boarded and onboarded and then be left “parked” outside a doorway. This is something that will be accomplished with the ramp integrated into the system. Additionally, the specific dimensions of the suspension, including the spring stiffness, are not yet decided. The idea is to have stiff enough suspension in the back to support the system and wheelchair as well as level it out to some extent. Further analysis is required to determine this.

**Concept Justification**

Not many calculations have been done to this point; it is important to first understand the system and its functionality well. One calculation that could be done before fully developing the system was how force would have to be applied at the rear suspension to help minimize the angle of tilt. This calculation was initially done assuming that there would be suspension in the front and the back end of the system. Regardless, it did show that a rear suspension that would work to balance the system while going up stairs would work against the system going downstairs; it would increase the angle of tilt instead of decreasing it. The tilting treads at the front-end aim to solve this by tilting the front end backwards.

There is many hazards associated with our design, however there is the primary safety concern of ensuring that the system does not tilt past a chosen angle of tilt going up or down the stairs. The entire design revolves around this safety consideration, and it is an aspect of safety that all the components will work together to achieve. The other safety concern is keeping the wheelchair on the platform. For this the plan is to use either a commercially available EZ lock system, grooves cut into the platform for the wheels or a combination of the two.

One of the current challenges that we have with the concept designs is the dimensions and profile of our design. Powered Wheelchairs already have a size constraint so that they can meet the building code regulations which means that the systems attachment dimension and profile must be minimized to ensure compliance. The team has discussed with the customer that there is a concern with meeting size expectations, and it has been recognized that the team will design to minimize the size of the attachments. The customer understands the challenges and would be okay with having to take off the attachment and “park it” to get through tight spaces like doorways.
Another concern for the concept design is the allowable angle of tilt for the customers while using the attachment. Allowable angles of tilt must meet certain specification to create a low center of gravity and ensure the safety of users. This will be particularly challenging when considering that the systems size will need to be minimized. The system is expected to have about 8 inches of ground clearance. Most of the mechanism, including the two electrical motors will be under the wheelchair, so it can generously be assumed that there will be an addition of at least 8 inches to the height of the center of gravity. Ideally, this higher center of gravity would be accommodated with a wider system to increase stability. However, this may not be an option if the system is designed to fit in doorways. As previously mentioned, the system does not need to fit within doorways; the deciding factor here will be how safe and stable the system can be made while minimizing size.

**Project Management**

After we finished our ideation phase, we started to pick some of the best ideas. A couple of methods that helped us do this were Pugh matrices, and a weighted decision matrix. After finding out what design was the best based on our set criteria, we are now presenting this idea to our sponsor and our project coach through this report. Along with this report we are currently building a concept model out of wood, making a basic CAD model of our concept, and we will be doing a presentation. We will make changes to our concept based on the feedback we get from our project coach and sponsor.

After revising our design, we will also revise our CAD model. After we are confident in the design, we have we will then begin to write our interim design review, IDR. This report will cover what has been changed in our design since the PDR as well as our plans for building a structural prototype. Once the report is finished, we will get into the logistics of what materials we need as well as make a detailed drawing and specifications package. After this, we will then write our critical design review, CDR. This report will go over our manufacturing plan as well as our system design and analyses. Once this is completed and approved, we will go into manufacturing our final design and writing our final design review, FDR.

For organization, the team will be following a timeline template as shown in Appendix A. This Gantt chart shows all the team’s weekly goals as well as bigger milestones (as indicated by a yellow diamond). For documentation and information, the team will be using Microsoft Teams as well as OneNote to log any notes or research that will be used and shared across the team. All these organizational resources are to enable the team to plan work efficiently and meet deliverable deadlines. This project process will be documented for the stakeholders and other interested individuals through four major milestones. The corresponding reports and deliverable dates are presented in Table 1 below.

<table>
<thead>
<tr>
<th>Key Milestones</th>
<th>Sponsor Deliverable Date</th>
</tr>
</thead>
</table>

*Table 1. Key Milestones and Deliverable Dates*
Conclusions

This preliminary design report covered our ideation process, our selection process, our justification process, and our plans for the future. The purpose of this document was to show our ideation process and to convince our sponsor that this design may solve the problem at hand. We hope this document showed how in depth our ideation and selection process were to gain approval from our sponsor to proceed with this design. According to our sponsor’s decision we will either go back and change things based on his comments, or we will go into our next steps. These next steps will include making a more detailed CAD model of our design as well as doing more analysis on the design to find any ways that we can improve.
Appendices

Appendix A: Project Gantt Chart
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<td>Clean out workspaces</td>
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Appendix B: Ideas List and Sketches

Provide Safety
- angle of lift
- safety lock (e.g., lock)
- ramp with loss of traction
- Kill switch
- easy speed
- self brake
- when no input
- wider base
- lower center of gravity

Make Transportable
- collapsible
- lightweight
- easy form to pick up
- collapse to briefcase

Facilitate Movement
- tracks
- tires
- unicycle
- trike
- Stepping leg wheels
- elliptical
- treadmill style tracks
- magnetic
- suspension
- jeep inspired
- BIG TIRES
- All rubber tires
- ownreplaceable
- ramp
- two chassis system
  \_ joint in middle

Ensure Drive-ability
- Have
  - Joystick
  - Braking system
    \_ no joystick
    \_ movement
- Suspension
- Large battery
- life
- More storage
  \_ for Batteries/etc
- Controls to shorten response time
Appendix C: Ideation Model Pictures

**What it is:** Sandcastle with rubber band that simulates suspension

**What was learned:** Although this system would make Alex’s not more durable, but the physics might not make it a feasible option.

**What new ideas:** This model allowed us to start thinking more about comfort and suspension.

---

**What it is:** Tank Tread system with double wheel suspension

**What was learned:** A 4-Tank Tread system with independent suspensions could act like rock crawlers “Jeep Style”

**What new ideas:** After making this model we started considering more common car suspensions like spring but suspension and shocks.
What it is: In this model toothpicks represent potential wheel locations.

What was learned: The wheel location from this model seems to be potentially dangerous as there is a high chance of tipping over. A more straight ahead.

What new ideas were promoted: Different locations for the wheels were considered along with other anti-tipping methods.

What it is: "Air bag suspension" that sits in between the wheel chair platform and tank truck.

What was learned: Air bags would make the ride comfortable but would require additional components like a tank and pump.
What it is: Wheel chair with short trays and back wheel disabled

What was learned: Hybrid systems with tracks and wheels are a good combination of components to prevent tipping and allow the sitter to sit up and show sparse

What new ideas? Idea on how to connect the trays to the center piece, representing the wheelchair, was generated. New thought: Integration of kinetic mechanics was added to design.
Idea 1: Essentially we can give the wheelchair a platform to sit on and then 4 wheels, each with their own independent suspension to facilitate offroading and aid in going up stairs. This model would need large wheels, with a radius greater than 6 inches, because a typical curb is 6 inches and a radius larger than this would facilitate climbing. This method may be expensive as independent suspension is very involved and we would still need to drive at least 2 wheels (front or rear). Here we learned that a platform would be almost absolutely necessary for just about any design that requires wheels because we need a mounting point for the wheels and the suspension. We also learned it may prove difficult to integrate suspension on wheels as we would have two separate points to mount the suspension.

Idea 2: This idea involved using treads on a pivot point on the front of the platform and a set of large wheels at the back end of the platform. The treads, if designed correctly, can facilitate going over stairs and curbs while the wheels in the rear can have relatively stiff suspension that can be used to balance the wheelchair as it goes over the stairs. We learned that we can use a mixture of treads and wheels to balance price and performance. We should not use treads where it is not necessary but they definitely have their advantages.
**Idea 3:** This idea was hard to visualize with our limited supplies but the idea is simple. We use a large tread under the wheelchair that can pivot around the center of gravity and be used to climb stairs while a small wheel in the back with stiff suspension is used to create a moment that would add force between the tread and ground and simultaneously balance the angle of tilt. We learned that single tread may be the easiest way to ensure maximum grip going up stairs but the system that would manage the angle of tilt is sure to be the more complex part of the project as it would require some controls and intelligence to adjust the angle appropriately.

![Image of single tread](image1.jpg)

**Idea 4:** Again, the idea is to use treads but in this case we use treads on either side of the wheelchair, with a more intricate design than I was able to show here, to have large amounts of grip on both sides. The greatest down side of this may be that there is no integrated system that would help reduce the angle of tilt as the wheelchair goes up stairs and integrating this type of system to the threads could be challenging and pricey. Also treads and the mechanism that drives them are very expensive as it is. We learned that rigidly attaching any form of a drivetrain to the wheelchair or platform would not be feasible as it would not address the problem of our limited angle of tilt.

![Image of dual treads](image2.jpg)
Idea 5: A simple design much like idea 2 but using only wheels that pivot about a point on the front and back ends of the platform where the wheelchair sits. This could keep prices down and do the exact same function as idea 2; wheels are cheaper than threads.

Here we learned that wheels can do just about as much as treads can and for less money.
Idea 1. This ideation model has many components. The first is a platform for Alex to park his wheelchair on top of. This platform also has a ramp-up to it. On the front of the platform, there is also a box for electrical stuff like batteries. Below the platform, there is a suspension made up of leaf springs. Below this, there is a hydraulic leveling kit that can lower and raise the four separate sets of tracks. One thing I did not think about was how and where the motors would fit, possibly right under the platform, but I was not sure.
Idea 2: This idea is similar to the first but utilizes a different type of suspension. This suspension has a spring that lowers the platform according to the force that is being put on it. The problem with this suspension is that it only effectively lowers one side of the platform. This can possibly work with more types of suspension, like hydraulics, added to it.
1. Front/back tread attachment

This model features two tread systems, one in front and one in the back. There are pivot points where the two systems meet the middle structure to allow them to tilt upwards and downwards. I learned that the placement and pivot point of these tread systems matter a lot to how they move. This also made me think about the dimensions of the tread system itself in order to fit the attachment system of the wheelchair.

2. Extended back-support

This model features another front-back system. The front features two points connected by a pin and a slot. The curvature of the spoon makes it so when extended, the system moves both out and up. The back of this system features a clip system that extends out. This is supposed to simulate a wheel or weight support for when the wheelchair system is imbalanced. This idea taught me that our extension system could mount in a pivot point that doesn’t have to be linear. This upward and out motion could be used as stairs/steps have both elevation and depth to them. For the back, this type of deployment could save space for the actual system.
3. Front Clawarm

This model features a claw-like system as its front mechanism. This mechanism is designed to "grab" onto the higher elevation and retract to pull itself up. There would be two pivot points, one at the connection to the wheelchair system and one on the arm itself. This idea made me think of ideas of how that could be implemented, like adding some sort of friction on the end of the arm to provide a better grip. This sparked ideas like using techniques like "mantling" to climb up steps.

4. Attachment/baseplate system

This model represents the "easy to attach/display" requirement of our design challenge. The pin at the bottom of the wheelchair model represents the "ez-lock" system that we will be designing our product around. The system consists of one half that attaches to the ez-lock and has another lock system for the second half to pin onto. This design made me think of different ways the system would attach to the existing wheelchair and the shape/structure of the overall base.

5. Tread Pin/spoke system

This model represents the outer tread system. The foil represents the outer tread/grip-like material attached to a roller system. The pins represent how it will be easily attachable to the wheel or chair system. This model sparked the idea of having spoke-like pins sticking out instead of a flat tread, to grab on to the step but still be closer to the center of rotation.
## Appendix D: Pugh and Morphological Matrices

![Matrix Image]

### Driver

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## Appendix E: Design Hazard Checklist

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<th>Planned Corrective Action</th>
<th>Planned Date</th>
<th>Actual Date</th>
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<tr>
<td>Our design contains a DC motor as well as rotating wheels/tracks.</td>
<td>We plan to be careful and wear gloves when working with any areas of our design that have pinch points. We also plan to create a warning manual to highlight these pinch points.</td>
<td>3/22</td>
<td></td>
</tr>
<tr>
<td>The motor as well as the wheels of our design can undergo high acceleration.</td>
<td>We plan to keep at least 6 inches of distance between ourselves and the rotating parts of our design.</td>
<td>3/22</td>
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<tr>
<td>Our system in operation will be moving as a large mass.</td>
<td>We plan to make sure that the center of gravity of the system is safe enough for the mass to not be an issue.</td>
<td>3/22</td>
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<tr>
<td>Description</td>
<td>Plan</td>
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<td>----------------------------------------------------------------------</td>
<td>------</td>
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</tr>
<tr>
<td>Our system can fall due to gravity and may cause injury.</td>
<td>We plan to make sure our system has a high enough allowable angle of tilt so that it is safe for use.</td>
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<tr>
<td>Our battery to our motor may be ungrounded.</td>
<td>We plan to make sure that all the electrical system of our design is grounded.</td>
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<tr>
<td>Our system will have a DC motor which will require a large battery.</td>
<td>We plan to make sure all electrical connections are kept in a safe place in order to stop electrical hazards.</td>
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<td>Our system will have the stored energy in the battery.</td>
<td>We plan to store the battery in a watertight container to stop any electrical hazards from occurring.</td>
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<tr>
<td>The battery will either be lithium or have battery acid in it.</td>
<td>The battery acid is harmful to humans, so we will make sure to install a battery that has preventive measures to stop leaking.</td>
<td>3/22</td>
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<tr>
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<td>-------</td>
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<tr>
<td>The motor and tracks of our system may cause loud noise.</td>
<td>We plan to use rubber tracks to reduce the noise created by them while the system is in motion.</td>
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<tr>
<td>Our device may be in all conditions because it is also meant for off roading.</td>
<td>We plan to use a watertight case for the battery and motor of our system to stop water damage.</td>
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<tr>
<td>Our system can possibly be used in an unsafe manner.</td>
<td>We plan to provide warnings for what can and cannot be done with our system.</td>
<td>3/22</td>
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Part III

Critical Design Review
Universal Tread for Power Wheelchairs

Critical Design Review

ME 429
Senior Design Project
February 17, 2022

Team F75
Universal Tread

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Abstract

This critical design review document is a continuation of our work since the Preliminary Design Report. It consists of a breakdown of the final system design and its justification, the manufacturing plan, and the prototyping and testing plan. Since the Preliminary Design Report in November, the scope of this project has been changed to a quarter scale model. This done to meet a more realistic goal with the given time and budget of the project.

Following this change, our Failure Mode and Effects Analysis (FMEA) was modified to list out any potential failures to our new design. Next, a manufacturing plan was created to account for how each component was going to be made, and how the final design will be assembled. This then resulted in the Indented Bill of Materials (iBOM) for the design, and a Drawing and Specifications Package that contains the specification sheets or drawings for all our components. These documentations will be used for creating our structural prototype and later our verification prototype. Lastly, this document will address the management and development plan for the rest of this project until the Final Design Review.
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1. Introduction

Alex Fung, a fourth-year aerospace engineering student at Cal Poly, has a power wheelchair that is designed with limited mobility in non-wheelchair accessible areas. He needs a way to improve the mobility of his power wheelchair with the use of an external attachment thus making him more independent and less reliant on helpers. Currently, very few powered wheelchairs give the ease of ability to traverse non-wheelchair accessible areas like unpaved roads and obstacles like curbs and steps. Although there are current powered wheelchairs on the market that can perform such tasks, none of them are offered in the way of a modular attachment that enables multiple wheelchairs to overcome these tasks. This design challenge is centered around designing and building a fully independent external tread-like attachment that allows any user to be able to access these areas without modifying the wheelchair itself. The team of students working on this project are Aaron Rocha, Brian Song, Daniel Ceja, and Ryan Scarcella. All students working on this project are mechanical engineering majors, with a mix of different concentrations.

Since the Preliminary Design Report, the biggest change is that the project scope was changed from a full-scale model to a quarter scale model. The biggest limitations towards making a full-scale model was time, money, and feasibility. Key limitations and dimensions like ground clearance were kept true to the quarter scale, while some other dimensions like platform size were modified for simplicity or feasibility. For example, motors do not scale linearly with output torque to size; a motor that produces four times the amount of torque as the motors used in this project is not 4 times the size. For scope change, the implementation of a ramp was also removed. The problem of the user getting on and off the final product will be tackled by future teams that pick up this project. For the design, the drive system was changed to have full treads on both sides rather than a front-back tread-wheel system. This was done to increase the contact points of the ground and curbs being traversed.

This document will fully describe the final proposed system, explain the justification behind the design and key decisions made, and provide confirmation that the final project will meet the specifications detailed in the specification tables. It will outline the team’s plan for manufacturing and break down the processes and costs for each component as well as assembly. Finally, it will outline the planned tests that will be conducted for the structural prototype and design verification prototype.
2. System Design

Our design has three main systems, the platform system, drive system, and electronics system. The platform system is the main base to our design and holds the other two systems together. This platform will be an 18” x 12” metal platform with sets of holes drilled on either side of it. These holes will be used to secure different parts of our other systems.

The electronics system is placed on top of the platform. This system consists of the batteries, motor driver, RC receiver, fans, circuit breaker and the electronics box. These components will be housed in a 3-D printed box that will be placed on top of the platform.

The drive system will partially be contained on top of the platform, while the other parts will be on either side of the platform. The parts of the drive system that are attached to the top of the platform are the motors, sprocket, and drive train. The treads and the idler wheels will be on either side of the platform. The idler wheels will be on 5/16” thickness shafts that will be supported by pillow blocks. To sustain axial loads, shaft collars will be used. A CAD design of our final system is shown below in Figure 1.

![Figure 1: CAD of final system design](image)
2.1 Platform System

The final design is a platform that uses a mechanism much like tank treads to move. There are four idler wheels on both sides; each are attached to the platform with axles supported by two bearing pillow blocks each, totaling eight bearing pillow blocks. The axles will be constrained with shaft collars. The 4 idler wheels all contact the ground, and there is one pinion that is used to the tread on either side. These pinions are held by a second pillow block, sized to fit the largest diameter of the driveshaft that is attached to the top side of the platform. The pinions are in the center of the platform and subsequently, they are equally spaced between the 2nd and 3rd set of idler wheels. This was done so that the pinions could sit lower and closer to the platform. If the pinion was placed above any of the idler wheels, as was originally planned, then the pinion must be a minimum distance above the platform to avoid contact with the idler wheel. The platform system with its components can be seen below in Figure 2.

![CAD of platform system](image)

These motors are mounted on the back of the platform on motor mounts. The sprocket on the motor shaft will drive an identical sprocket on the shaft that holds the pinion. These sprockets will be connected with high strength bike chains that will be covered by 3-D printed covers to minimize the risk of injury from the mechanism.

The batteries that will power the motors, two 12V batteries in series, will be on the opposite end of the platform to balance the weight. They will not be mounted as far forward on the platform as is possible because this can create an uneven teeter as the system transverses curbs. It is ideal that a larger proportion of the weight is biased forward rather than backward; this will give the platform a tendency to lean forward and touch the ground more readily when going down curbs. When going up curbs the front wheels will lighten up as more weight will be
transferred to the back half of the system, by having a larger proportion of weight in the front, 
the system can counteract this to some extent.

2.2 Drive System

The platform will be driven by two 24V 350-Watt motors with internal gear ratios that 
can output a stall torque of about 40 ft-lbf each. The gear ratio will be one to one because the 
motors being used have internal gearboxes that already output a favorable torque and 
rotational speed for the design. However, this gear ratio will serve as a method to transfer 
power from the motor to the driving shaft. It is not feasible to use the motor to directly drive 
the pinion, because the forces on the drive shaft are significant and require a very thick, and 
subsequently strong, drive shaft. Additionally, there is not enough room to fit the pinion on the 
drive shaft itself.

Only 2.6 ft-lbf total is required to move the system at an acceleration of two ft/s². It is 
important to note that the 24V motors were chosen instead of smaller 12V motors to keep the 
operating amperage as low as possible. One of the main concerns was that the amperage 
required to run the motors would be too high if 12V motors were used. These motors come 
with sprockets attached to them, and there will be another of the same sprocket attached to 
the drive shaft. The two sprockets will then be attached with a chain (this chain is not depicted 
in the CAD). The drive shafts will also be attached to the sprocket that drives the tread system.

There are four idler wheels; all are at the same vertical height and held by their own 
individual shaft. These wheels will contact the tread that will then contact the ground; they are 
load bearing. There are two pillow blocks for every axle, one is meant to sustain a vertical load 
and the other is meant to sustain a moment. The drive system with its components can be seen 
below in Figure 3.
2.3 Electronics system

The two motors will be connected to a dual-channel Cytron Motor Driver that is designed for controlling differential drive using a RC controller. This motor driver will be powered by the two 12V batteries in series to produce the required 24V for the motors. This motor driver is rated for 30 Amps with a peak current of 80 Amps. In addition to having features like regenerative braking, the motor driver has thermal and current limit protection. As a safety precaution, a circuit breaker will be placed to as to protect all the components from overload and act as an emergency kill switch.

The wiring diagram shown in Figure 4 demonstrates how each component is connected to each other. An RC receiver will be connected to the motor driver allowing us to control the system using the Flysky FS-i6X RC controller transmitter which can be see in Appendix A. The RC receiver is connected to two channels out of the total 6 giving us the option for added functionality using the same controller. The RC controller comes with throttle response adjustment and safety features for when there is a sudden loss of connection between the transmitter and receiver. These electrical components will be enclosed in a 3D Box equipped with fans shown in Figure 5 to ensure that the motor driver does not overheat. The fans will be
powered and directly controlled by the motor driver as needed to keep the motor driver at an operable temperature.

Figure 4. Wiring Diagram of our Components

Figure 5: Isometric view of the Electronics Box
2.4 Summary Cost Breakdown

Currently, the total cost of the final system is $1,465.57. This value accounts for all the components that will be going into the final design verification prototype. Table 1 below shows a breakdown of each subsystem cost. The specific components that will be bought for each subsystem will be displayed in the Indented Bill of Materials (iBOM) in Appendix B.

Table 1. Cost breakdown of each subsystem

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Platform System</td>
<td>$426.63</td>
</tr>
<tr>
<td>Drive System</td>
<td>$547.30</td>
</tr>
<tr>
<td>Electronics System</td>
<td>$518.33</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$1,465.57</strong></td>
</tr>
</tbody>
</table>

3. Design Justification

The drive system design uses only one tread system for two primary reasons: simplicity and for continued contact with the obstacle to overcome. This means that if this system is traversing a curb (to scale), it will be contacting the curb from the time it first meets it to the time it has completely overcome the curb. The original idea called for three idler wheels on either side, however, there was a concern that an idler wheel in the middle of the platform may cause it to teeter about that wheel when facing elevation changes. For this reason, the design was modified to include four idler wheels on either side. The tread will be tensioned by moving one of the idler wheels on the edge of the platform forward or backward on the slots that will be used to hold them in place. This tension will keep the tread from deflecting large amounts as it makes contact with the curb in areas where the idler wheels will not make contact. For example, halfway up a curb, it is expected that the two front wheels will be beyond the curb and the two back wheels will be yet to reach the curb. This means that the tread in between the two middle idler wheels will be supporting some weight and subsequently deflecting some amount.

Multiple changes have been made since our PDR with our specifications table. With the change in scope to make a quarter-scale model, specifications like portability and collapsibility were removed. The remaining specifications like the dimensions, required torque, weight, and ground clearance were scaled down to a quarter of the original specifications. Table 2 below lists our new specifications.
Table 2. Specification Table

<table>
<thead>
<tr>
<th>Spec. #</th>
<th>Specification Description</th>
<th>Requirement or Target (Units)</th>
<th>Tolerance</th>
<th>Risk*</th>
<th>Compliance**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Carrying Capacity</td>
<td>200 lbs</td>
<td>Max</td>
<td>H</td>
<td>A,T</td>
</tr>
<tr>
<td>2</td>
<td>Weight</td>
<td>125 lbs</td>
<td>±25 lbs</td>
<td>L</td>
<td>A,I</td>
</tr>
<tr>
<td>3</td>
<td>Ability from point A to B at 15 degree grade</td>
<td>Ability to go from point A to B</td>
<td>Min</td>
<td>M</td>
<td>A,T</td>
</tr>
<tr>
<td>4</td>
<td>Allowable Angle of Tilt</td>
<td>30 degrees</td>
<td>Max</td>
<td>H</td>
<td>A,T</td>
</tr>
<tr>
<td>5</td>
<td>Ground Clearance</td>
<td>2 inches</td>
<td>Min</td>
<td>H</td>
<td>I,T</td>
</tr>
<tr>
<td>6</td>
<td>Required Power/Torque Output</td>
<td>2.5 lbf-ft</td>
<td>Max</td>
<td>H</td>
<td>A,T</td>
</tr>
<tr>
<td>7</td>
<td>Dimensions</td>
<td>18”x12”</td>
<td>Min</td>
<td>M</td>
<td>A,I</td>
</tr>
</tbody>
</table>

FEA was done on all the shafts and all shafts have factors of safety of two or greater; the material being used is purchased from McMaster-Carr and has a yield strength of 60 kpsi. To verify the FEA conducted, hand calculations were also done, as shown below in Figure 6. The shaft is loaded at 75 lbf to account for moments when only a few wheels will be supporting the 200lbs. For example, while down a curb there will be a point where only the two front wheels and the two back wheels are in contact with the ground. The middle two sets of idler wheels will be able to touch the ground; this will happen when just the rear set of wheels is on the curb. This calculation can be altered to find the point at which the shafts for the idler wheels are expected to yield. This happens when one wheel is loaded with 180 lbf.

The driveshaft is a step-down shaft from a ¾ diameter to a 5/16 diameter shaft. This is because the shaft was having a difficult time sustaining loads from the torque that is expected from the sprocket that will be driven by the motor and the sprocket that will drive the tread. It was important to have a larger diameter closer to the area where the shaft is being held so that it can sustain the large moments. The driveshaft is designed to hold 22 ft-lbf output from the motor with a factor of safety of about 2.5. This shaft could be designed to sustain greater loads, such as the 40 ft-lbf of torque that the motors are capable of. However, calculations on how much torque it takes to move the system do not reveal a scenario where the system will require more than 22 ft-lbf. This includes the system traveling at a maximum incline of 28 degrees. Though the motors are capable of 40 ft-lbf, the system will not encounter a scenario where it will require this amount of torque. This clears our required torque laid out in Table 2 by a large margin.
FEA was done for all of the parts that will manufactured, and all parts are designed to hold conservatively hold a load of 200 lbf. Impact has been taken into consideration for these parts; the factors of safety are still larger than one. Figure 7 below shows that the platform as specified for the design will be sufficiently strong enough to hold the weight necessary with a large factor of safety.

Figure 6: Hand calculations for the bending stress of idler wheel shafts.

Figure 7: FEA of the platform with 200 lbf being held by 16 pillow blocks
The 200 lbf force for this FEA was localized at the center of the platform, as may be expected in a more realistic loading case, but this made not a significant difference. In this case is larger than ten, so it may seem that a thinner sheet of metal may be better. However, the FEA shown here does not consider all the parts bolted to the platform and the loads each of those parts must withstand. Because the loads that can be expected from the bolted parts are not understood on a very technical level it is best to have a large factor of safety. Every component of the system will be bolted to the platform; it is difficult to predict a worst-case scenario loading when everything is considered.

Figure 8: Drive shaft with force from max expected torque of 11 ft-lbf of torque.

Figure 8 above shows the FEA on our top axle. The material in this case has a yield strength of 5.3e+8 N/m² (77,000 psi) and the maximum von Mises stress is 2.6e+8 N/m² (38,000 psi). Two main concerns with the design were the drive shaft strength and platform deflection. No major deflections are expected from any of the parts. The smallest factor of safety expected is the factor of safety associated with the drive shaft seen above. At a worst case scenario of 200 lbf loading and climbing a 28 degree incline it is expected the system will require 22 ft-lbf to accelerate at 2 ft/s². The forces induced on the shaft from this torque are applied to the shaft above and result in a factor of safety of approximately two.

For the material choice of our platform, we wanted to use high-strength and low-bowing steel. The two options that we had in mind were stainless steel and mid carbon steel. We ended up deciding to use stainless steel for our platform because stainless steel has chromium content in it, which makes it less prone to cracking and failure. For our axles, we decided to use low carbon steel for its strength and toughness compared to mid carbon steel. Low carbon steel can plastically deform without failure compared to mid carbon steel. The pillow blocks chosen are rated for significantly higher load and angular velocities than expected.
for this system. Both the loads and angular velocities for which the pillow blocks are rated are more than ten times larger for each respective pillow block.

For our electronics system, to reduce the amperage in our electrical system, 24 Volt motors were chosen to drive the tank treads instead of 12 Volt motors. The electronics will be enclosed in a 3D printed box. The enclosure will not be load bearing so 3D printing offers us the ability to easily manufacture an inexpensive box to protect both users and components.
4. Manufacturing Plan

The design for this system was designed heavily around off-the-shelf parts with the number of manufactured parts at a minimum. This would eliminate as much error due to manufacturing as possible. Most of the parts will be bought and used as-is from online vendors. However, some housing units will be 3-D printed. The manufacturing plan for this project can be seen below in Appendix D. This covers our three main systems, the platform system, drive system, and electronics system. The drawings for each component can be found in the Drawings and Specifications Package in Appendix A.

4.1 Material Procurement

Most of the parts for this project will be bought through McMaster-Carr. We will be buying the platform, axles, and both types of pillow blocks required. Most of these raw material purchases will have to be modified into our final components. The remaining parts will be purchased from Pitsco, and all of the electronics components will be bought on Amazon. The full details for these components and purchases can be found below in the iBOM in Appendix B. These ordering of these parts will be done by Meredith Rubin, using our budget which is sponsored by the Tech-E club at Cal Poly.

4.2 Fabrication

The following manufacturing plan provides a numbered list of how each component will be modified and/or built. Each section of the fabrication process is broken down into the main assemblies. This manufacturing plan in Appendix D will be checked over by and approved by the Cal Poly Machine Shop technicians to ensure that the plans are feasible and provide enough detail.

4.2.1 Platform System

**Platform**

1. Run the waterjet machine to cut out the mounting holes and slots in the platform (#111000).

**Motor Bracket**

1. Use the bandsaw to cut the top bracket (#114000) into a 4.5-inch length.
2. Use the manual mill to face off each face of the bracket piece.
3. Use the manual mill to mill off 1/2” off both lengths parallel to the axle hole.
4. Use the manual mill to mill off 1” from both sides from the middle to a depth of 3/4” creating a channel in the middle.
5. Use a 1/4” drill bit to drill out the bottom two mounting holes
6. Use a wire wheel or grinder to get rid of any burrs and smoothen any sharp edges or corners.
7. Repeat steps 1 through 6 for one more part to result in two parts.

4.2.2 Drive System

**Bottom axle**
1. Use the bandsaw to cut the axle stock (#122100) into a 3-inch length.
2. Use a wire wheel or grinder to get rid of any burrs and smoothen any sharp edges.
3. Repeat steps 1 and 2 seven more times to result in eight axles.

**Top axle**
1. Use the bandsaw to cut the axle stock (#122200) into a 4-inch length.
2. Turn one side of the shaft down on the lathe to a 1.5-inch length of 5/16 diameter.
3. Use a wire wheel or grinder to get rid of any burrs and smoothen any sharp edges.
4. Repeat steps 1 through 3 for one more part to result in two parts.

**Chain Cover**
1. 3D Print chain cover at Mustang 60

4.2.3 Electronics System
1. 3D Print Electronics box at Mustang 60

4.3 Assembly
The final assembly consists of three main assemblies- the platform system, drive system, and electronics system. Each section of this assembly section is broken down into the main assemblies. These are the parts that were procured that don’t need any fabrication or modification.

4.3.1 Platform Assembly
1. Use fasteners (#115000) and nuts (#116000) to fasten all 16 bottom pillow blocks (#113000) to the side holes of the platform.
2. Use fasteners (#115000) and nuts (#116000) to fasten both top pillow blocks (#112000) to the top of the platform.
3. Use fasteners (#115000) and nuts (#116000) to fasten both motor brackets (#114000) to the top of the platform.

4.3.2 Drive Assembly
1. Place the top axle (#122200) in the top pillow blocks with the smaller 5/16” diameter side facing the outside.
2. Attach the motor sprockets (#121500) to the 3/4” diameter side of both top shafts.
3. Lock the motor sprocket onto the shaft with the included set screw.
4. Lock in two top shaft collars (#123200) on either side of the sprocket with a hex-key.
5. Repeat steps one through four for the other top axle.
6. Slide a tread sprocket (#121200) onto the 5/16” diameter side of the top shaft axle.
7. Slide a shaft hub adapter (#121300) onto the 5/16” diameter side of the top shaft axle.
8. Tighten the shaft hub adapter onto the tread sprocket with the given fasteners.
9. Repeat steps six through eight for the other top axle.
10. Slide the fabricated bottom axles (#122100) in the bottom pillow blocks underneath the platform.
11. Lock in two bottom shaft collars (#123100) on either side of the bearings with a hex-key.
12. Repeat steps 10 and 11 for the remaining seven axles and bottom pillow blocks.
13. Assemble the tread with the tread links package (#121400) by linking together 99 tread links.
14. Place the assembled tread links over the sprocket and wheel hubs.
15. Repeat steps 13 and 14 for the other tread side.

Note: To tension the tread links, add or subtract links from the tread assembly and slide the front pillow blocks down along the respective slot in the platform.

4.3.3 Electronics Assembly
1. Secure motor driver (#133000) using self-tapping screws to the center of the 3D printed electronics box with the power pins facing the three holes of the box.
2. Secure RC receiver (#134000) on outside on the box opposite to the three holes.
3. Connect RC receiver channels one and two to the RC pins on the motor driver.
4. Connect the two 12V batteries (#132000) in series to create a 24V power source.
5. Connect the positive power source terminal wire to one of the circuit breakers terminals using the provided wire lugs and copper washer.
6. Connect the second circuit breaker terminal to the positive terminal of the motor driver.
7. Connect the negative terminal from the power source to the negative terminal on the motor driver.
   a. It is imperative that the power source terminals are connected to the correct motor driver as this motor driver does not have polarity protection.
8. Connect one motors positive and negative terminals to the motor driver’s channel A.
9. Repeat step eight with second motor by connecting terminals to channel B.
10. Place each component in their respective spots in the 3-D printed housing

11. Connect the motor (131000) to the electronics box and mount it on the motor bracket (#114000).

5. Design Verification Plan

The design verification plan tabulates the detailed tests that we plan to conduct for each of our specifications. The plan includes a description of each test, their acceptance criteria, who has responsibility for the test, and any special equipment that will be used in the testing. A complete design verification plan can be found in Appendix E. Most of our tests will be performed in the Tech-E lab at Cal Poly. In Appendix F, our Gantt chart lists the dates that we plan to do these tests. We can categorize our tests into three groups, functionality, durability, and safety.

5.1 Functionality

One of the primary functions that we want our system to accomplish is being able to produce enough torque to move the load that is being applied to it. To test this, we will first set up our motors and connect them to our batteries and radio remote control. We must then attach a beam of a known length to one of the motors. The motor will then be turned on and the force at the end of the beam will be measured by using a scale. This measurement will then be used to calculate the torque. If the combined torque out of both motors is equal to or over 2.5 lb-ft of torque, then the test will be a success. We plan to do an uncertainty calculation on the data that we collect during this test as well.

Another test that we plan to perform is to load our platform with the load to verify that there is no deformation. To test this, we plan to set up our platform between two tables, with about half an inch over on each side. This will recreate the vertical forces being put on the platform from the pillow blocks. We will then apply the load to the platform and measure if there is any deformation or not. If no deformation occurs when the load is applied, then the test will be a success. We planned to do this test prior to our CDR for our structural prototype, but we could not get the parts in time. We will order the necessary parts and complete the test in the coming weeks.

One test that we plan to perform on our final prototype is to see if it will be able to go up model-sized “stairs” or “curbs”. To perform this test, we will create ¼ scale model curbs and stairs using pieces of wood. We will then weigh these down and allow our fully loaded final prototype to attempt to traverse these obstacles. If the final prototype can traverse these model-sized obstacles, then the test will be a success.
Another functionality test that we plan to do is on our battery life. Once our final prototype is complete, we will fully charge the batteries and put them into our design. We will then take our prototype out and run it until the battery dies, while timing how long it takes. If the batteries last 15 minutes long, then the test will be a success. This test will be vital to us for the final expo at the end of the spring quarter. Depending on the results of this test, we may have to get extra batteries to make it through the expo.

The last functionality test that we plan to do with our final prototype is to see if it can traverse over an incline while loaded. To test this, we will first build a ramp out of wood that has an angle of about 15 degrees. We will then load our final prototype with 100 pounds and approach the ramp. If the final prototype can traverse this slope without visible slippage while fully loaded, then the test will be a success.

5.2 Durability
To test the durability of the components in our design we plan to do multiple tests on them. One of the components that we plan to test this on is our treads. To test if the treads are strong enough to support the load that will be on the device, we plan to have our final prototype fully built. We will then slowly start adding parts of the load while the machine is in motion. If the 100-pound load has been fully added onto the machine and the treads are handling fine without any deformations, then the test will be a success.

One part of our design that we plan to test is the durability and strength of our pillow blocks. These pillow blocks will be supporting the 100-pound load between the eight of them, so we want to make sure they don’t shear or deform when the load is applied. To test this, we will assemble our platform with pillow blocks and axles. We will then load our platform and observe what happens with the pillow blocks and axles. If there is no deformation in the pillow blocks or axles, then the test will be a success.

The driving shaft on our design is one point of interest where we believe there could possibly be failure. The driving shaft must endure massive forces and moments from the motor to be able to transfer movement to the treads. To test to make sure that the shaft can endure the moments from the motor we plan on putting together the motor, platform, and driving shaft altogether. We then plan to keep one end of the driving shaft still while fully loading the motor. If the driving shaft handles the moments and force from the motor without deformation, then the test will be a success.

5.3 Safety
Another test that we plan to do is to make sure our radio connected operating unit has safety precautions, and that they work properly. To test this, we plan to set our system up and start to move our device. Once the device is moving, we will then interrupt the radio signal on
purpose. If the device successfully stops movement when the radio signal is interrupted, then we will verify that the auto shut off feature is working correctly, and the test will be a success. If the test is a failure, then we can make changes to our prototype to allow it to stop movement once the radio controller disconnects.

The electronic box, which will be storing our motor driver controller and wiring will slowly gain heat after use. To prevent this system from overheating we plan to add two mini fans to cool it down on top of the motor drivers heatsink. To test if the fan is appropriate for cooling down the system, we plan to verify that the electronic box stays at an operable temperature. We will first power the system and use it for a bit. We will then check the temperature of the box with a temp gun. The temperature will keep being checked every five seconds until stability has been reached. If the steady-state temperature is under that of the operable temperature, then the test will have been a success.

6. Project Management

The project management section provides a timeline for the rest of our plans with this project. This section will include our future deliverables and the dates that they will be finished. All of our upcoming milestones and their corresponding deliverable dates are presented below in Table 3. We have also attached our Gantt Chart in Appendix G for a more detailed look at our plans.

<table>
<thead>
<tr>
<th>Key Milestones</th>
<th>Sponsor Deliverable Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety Review/ Order Parts</td>
<td>March 8, 2022</td>
</tr>
<tr>
<td>Manufacturing &amp; Test Review</td>
<td>March 15, 2022</td>
</tr>
<tr>
<td>Test Procedures</td>
<td>April 4, 2022</td>
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<tr>
<td>Expo</td>
<td>May 27, 2022</td>
</tr>
<tr>
<td>Final Design Review Submission</td>
<td>June 3, 2022</td>
</tr>
</tbody>
</table>

6.1 Next Steps

We are currently waiting for the materials to work on our Structural Prototype. The plan is to receive the materials to construct our structural prototype. This will include our platform, our pillow blocks, and axles. The test format will follow what was described in the Design Verification Plan section for testing the platform. The parts will be assembled, and the platform will be loaded to make sure there is no deformation in any of the parts while loaded.

There will be more FEA done on the gears to make sure they can sustain the torque from the motor. This FEA will push us into buying the parts for our final prototype, which will
then send us into our test procedures. We also plan to schedule a safety review with shop techs on campus and go over our design with them.

Additionally, some of the parts for the manufacturing plan have not yet been verified by the shop techs at Cal Poly. This was due to many design changes and iterations that changed the specific properties needed to determine how and where our parts could be fabricated. This will be discussed and necessary changes will be made make the manufacturing process ideal.

7. Conclusion

After a rescope of our project to a quarter-scale model, we have been focused on redesigning and analyzing our design for this senior project. This document shows our new system design along with the justification for the components that we chose. It highlights the manufacturing plan and assembly of each component and the different subsystems and lists the cost breakdown of each part. Lastly, it lays out the tests we plan on conducting to verify the validity of our project and its specifications. Going forward we will start to order the parts listed in this document and build the design verification prototype to perform the listed tests.

To the project stakeholder, Alex Fung, will you agree to the defined design presented by this document and authorize the team’s continuation onto the next step in the design process?

_______________________________________________________  ________________
Please sign above for approval.                             Today’s Date
Appendix

Appendix A: Drawing & Spec Package
Appendix B: Project Budget & iBOM
Appendix C: Failure Modes & Effects Analysis (FMEA)
Appendix D: Manufacturing Plan
Appendix E: Design Hazard Checklist
Appendix F: Design Verification Plan (DVP)
Appendix G: Gantt Chart
Appendix A: Drawing & Spec Package

Notes:
1. All dimensions in inches
2. Tolerances:
   X.XX ± 0.05
   X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max
Top Pillow Block

Notes:
1. All dimensions in inches
2. Tolerances:
   - X.XX ± 0.05
   - X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max
Notes:
Unless otherwise specified:
1. All dimensions in inches
2. Tolerances:
   X.XXX ± 0.05
   X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max

Bottom Pillow Block
113000
Notes:
1. All dimensions in inches
2. Tolerances:
   X.XX ± 0.05
   X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max

Motor Bracket
114000
Notes:

1. All dimensions in inches
2. Tolerances:
   - X.XXX ± 0.05
   - X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max

Tread Sprocket

121200
Notes:
Unless otherwise specified:
1. All dimensions in inches
2. Tolerances:
   - X.XX ± 0.05
   - X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max

Shaft Hub Adaptor
121300
Notes:
1. All dimensions in inches
2. Tolerances:
   - X.XX ± 0.05
   - X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max

Tread Link Package (individual link)

121400
Motor Sprocket

Notes:
Unless otherwise specified:
1. All dimensions in inches
2. Tolerances:
   X.XXX ± 0.05
   X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max
Notes:
Unless otherwise specified:
1. All dimensions in inches
2. Tolerances:
   X.XX ± 0.05
   X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max

Bottom Axles

122100
Top Axles

Notes:

Unless otherwise specified:
1. All dimensions in inches
2. Tolerances:
   X.XXX ± 0.05
   X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max
1. All dimensions in inches
2. Tolerances:
   - X.XX ± 0.05
   - X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max
Notes:
Unless otherwise specified:
1. All dimensions in inches
2. Tolerances:
   XXX ± 0.05
   X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max
Notes:
Unless otherwise specified:
1. All dimensions in inches
2. Tolerances:
   X.XX ± 0.05
   X.XXX ± 0.005
3. Inside tool radius 0.01 max
4. Break sharp edges 0.01 max
Cytron SmartDriveDuo-30 MDDS30

MDDS30 bottom cover:

Absolute Maximum Rating of SmartDriveDuo-30:

<table>
<thead>
<tr>
<th>No</th>
<th>PARAMETERS</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Input Voltage (Motor Supply Voltage)</td>
<td>7</td>
<td>–</td>
<td>35</td>
<td>V</td>
</tr>
<tr>
<td>2</td>
<td>$I_{\text{MAX}}$ (Max Continuous Motor Current)*</td>
<td>–</td>
<td>–</td>
<td>30</td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>$I_{\text{PEAK}}$ (Peak Motor Current)**</td>
<td>–</td>
<td>–</td>
<td>80</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>$V_{\text{IOH}}$ (Logic Input – HIGH Level)</td>
<td>1.3</td>
<td>–</td>
<td>5</td>
<td>V</td>
</tr>
<tr>
<td>5</td>
<td>$V_{\text{IOL}}$ (Logic Input – LOW Level)</td>
<td>0</td>
<td>–</td>
<td>0.7</td>
<td>V</td>
</tr>
</tbody>
</table>

* Depends on the room temperature.
** Must not exceed 1 second.
Dimension (unit in mm):

- MDDS30 main board.
- MDDS30 height.
Battery Construction

<table>
<thead>
<tr>
<th>Component</th>
<th>Positive plate</th>
<th>Negative plate</th>
<th>Container</th>
<th>Cover</th>
<th>Safety valve</th>
<th>Terminal</th>
<th>Separator</th>
<th>Electrolyte</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>Lead dioxide</td>
<td>Lead</td>
<td>ABS</td>
<td>ABS</td>
<td>Rubber</td>
<td>NB</td>
<td>Fiberglass</td>
<td>Sulfuric acid</td>
</tr>
</tbody>
</table>

**General Feature**

- Absorbent Glass Mat (AGM) technology for efficient gas recombination of up to 99% and freedom from electrolyte maintenance or water adding.
- Computer designed lead, calcium tin alloy grid for high power density.
- Long service life, float or cyclic applications.
- Maintenance-free operation.
- Low self discharge.

**Performance Characteristics**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Capacity 77°F (25°C)</td>
<td>20 hour rate (1.85A · 10.8V) 37Ah</td>
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<tr>
<td></td>
<td>10 hour rate (3.5A · 10.8V) 35Ah</td>
</tr>
<tr>
<td></td>
<td>5 hour rate (5.7A · 10.5V) 28.5Ah</td>
</tr>
<tr>
<td></td>
<td>1 hour rate (20A · 9.6V) 20Ah</td>
</tr>
<tr>
<td>Internal Resistance</td>
<td>Full charged Battery 77°F (25°C): 10mA</td>
</tr>
<tr>
<td>Capacity affected by Temperature (10 hour rate)</td>
<td>104°F (40°C) 102%</td>
</tr>
<tr>
<td></td>
<td>77°F (25°C) 100%</td>
</tr>
<tr>
<td></td>
<td>32°F (10°C) 85%</td>
</tr>
<tr>
<td></td>
<td>5°F (-15°C) 65%</td>
</tr>
<tr>
<td>Self-Discharge 68°F (20°C)</td>
<td>Capacity after 3 month storage 90%</td>
</tr>
<tr>
<td></td>
<td>Capacity after 6 month storage 80%</td>
</tr>
<tr>
<td></td>
<td>Capacity after 12 month storage 60%</td>
</tr>
<tr>
<td>Max. discharge current 77°F (25°C):</td>
<td>330A (5S)</td>
</tr>
<tr>
<td>Charge (Constant Voltage) Max. Current:</td>
<td>10.5A</td>
</tr>
</tbody>
</table>

**SPECIFICATION**

- Nominal voltage: 12V
- Number of cell: 6
- Length (mm/inch): 195/7.68
- Width (mm/inch): 130/5.12
- Height (mm/inch): 155/6.10
- Total Height (mm/inch): 180/7.09
- Approx. Weight (kg/lbs): 10.5/23.1

Discharge Constant Current (Amperes at 77°F 25°C)

<table>
<thead>
<tr>
<th>End Point Volts/Cell</th>
<th>5 sec</th>
<th>10 sec</th>
<th>30 sec</th>
<th>60 sec</th>
<th>1 hr</th>
<th>2 hrs</th>
<th>5 hrs</th>
<th>10 hrs</th>
<th>24 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4V</td>
<td>114</td>
<td>94</td>
<td>42</td>
<td>18</td>
<td>6.41</td>
<td>6.41</td>
<td>6.41</td>
<td>6.41</td>
<td>6.41</td>
</tr>
<tr>
<td>1.6V</td>
<td>102</td>
<td>85</td>
<td>36</td>
<td>14</td>
<td>5.79</td>
<td>5.79</td>
<td>5.79</td>
<td>5.79</td>
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<tr>
<td>1.8V</td>
<td>94</td>
<td>75</td>
<td>32</td>
<td>11</td>
<td>5.33</td>
<td>5.33</td>
<td>5.33</td>
<td>5.33</td>
<td>5.33</td>
</tr>
<tr>
<td>2.0V</td>
<td>86.5</td>
<td>66.5</td>
<td>28</td>
<td>9.8</td>
<td>4.91</td>
<td>4.91</td>
<td>4.91</td>
<td>4.91</td>
<td>4.91</td>
</tr>
<tr>
<td>2.5V</td>
<td>135</td>
<td>104</td>
<td>42</td>
<td>18</td>
<td>6.41</td>
<td>6.41</td>
<td>6.41</td>
<td>6.41</td>
<td>6.41</td>
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</table>

Discharge Constant Power (watts at 77°F 25°C)

<table>
<thead>
<tr>
<th>End Point Volts/Cell</th>
<th>5 sec</th>
<th>10 sec</th>
<th>30 sec</th>
<th>60 sec</th>
<th>1 hr</th>
<th>2 hrs</th>
<th>5 hrs</th>
<th>10 hrs</th>
<th>24 hrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4V</td>
<td>215</td>
<td>152</td>
<td>67</td>
<td>28</td>
<td>13.7</td>
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<td>13.7</td>
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<tr>
<td>1.6V</td>
<td>200</td>
<td>142</td>
<td>60</td>
<td>25</td>
<td>13.4</td>
<td>13.4</td>
<td>13.4</td>
<td>13.4</td>
<td>13.4</td>
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<tr>
<td>1.8V</td>
<td>185</td>
<td>133</td>
<td>60</td>
<td>25</td>
<td>13.3</td>
<td>13.3</td>
<td>13.3</td>
<td>13.3</td>
<td>13.3</td>
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<tr>
<td>2.0V</td>
<td>175</td>
<td>125</td>
<td>50</td>
<td>20</td>
<td>13.1</td>
<td>13.1</td>
<td>13.1</td>
<td>13.1</td>
<td>13.1</td>
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<tr>
<td>2.5V</td>
<td>160</td>
<td>110</td>
<td>45</td>
<td>18.5</td>
<td>12.8</td>
<td>12.8</td>
<td>12.8</td>
<td>12.8</td>
<td>12.8</td>
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</table>

(Note) The above characteristics data are average values obtained within three charge/discharge cycles not the minimum values.
HiLetgo 40mm CPU Fan

Pin definition:

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<th>Color</th>
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<tbody>
<tr>
<td>(+)</td>
<td>Red</td>
</tr>
<tr>
<td>(-)</td>
<td>Black</td>
</tr>
</tbody>
</table>

Rotation:

- 40.0 ± 0.5
- 32.0 ± 0.3

Air Flow:

- 10.5 ± 0.3

Connection:

- BLACK (-)
- RED (+)
- 2.5/2P
- 150 ± 10
Erayco 40 Amp Circuit Breaker

Structure Size

Operating Temperature: -32 °C to 82 °C ( -25 °F to 180 °F )
Storage Temperature: -34 °C to 149 °C ( -30 °F to 300 °F )

Stud Size 1/4 " -28

Stud size A: 1/4" -28

Dimensions:
- 2.9 inch / 74 mm
- 1.8 inch / 46 mm
- 1.7 inch / 44 mm

Addendum:
- 36.70 (1.4449)
- 57.00 (2.2441)
- 24.00 (0.9449)

Dimensions given in millimeters (mm) and inches ("").
Senior Design Tank Treads

Electronics Box

All Dimensions in [mm]
Scale 1:3

PROJ
ECT

TITLE

PROJECT

Title:

Electronic Box

All Dimensions in [mm]
Scale 1:3

Approved

Checked

Drawn: Daniel Cela

2/25/2022

Scale: 1:3

Sheet: 1/1
FlySky Is6b Receiver

All Dimension in [mm]
Scale 1:1.5

Created by Daniel Ceja 2/25/2022

Sheet 1/1
Appendix B: Project Budget

**Materials Budget for Senior Project**

- **Title of Senior Project:** F75 Universal Treads for Wheelchair
- **Team members:** Ryan Scarcella, Brian Song, Aaron Rocha, Daniel Ceja
- **Designated Team Treasurer:** Aaron Rocha
- **Faculty Advisor:** Sarah Harding
- **Sponsor:** Alex Fung
- **Quarter and year project began:** Fall 2021

**Materials budget given for this project:** $2,500.00

<table>
<thead>
<tr>
<th>Date purchased</th>
<th>Vendor</th>
<th>Description of items purchased</th>
<th>Transaction amount</th>
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</thead>
<tbody>
<tr>
<td>03/01/22</td>
<td>Amazon</td>
<td>Motors(2)</td>
<td>$193.75</td>
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<td>Motor Driver</td>
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<td>03/01/22</td>
<td>Amazon</td>
<td>RC Transmitter Controller</td>
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<tr>
<td>03/01/22</td>
<td>Amazon</td>
<td>Mini CPU Fans</td>
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<tr>
<td>03/01/22</td>
<td>Amazon</td>
<td>Dust Proof Fan Shield</td>
<td>$6.99</td>
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<td>Amazon</td>
<td>Battery Charger</td>
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<td>Amazon</td>
<td>Metric Screw Assortment</td>
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<td>Pitco</td>
<td>Tank Tread Chain Links</td>
<td>$101.85</td>
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<td>Top Pillow Blocks</td>
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<td>03/01/22</td>
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<td>Bottom Pillow Blocks</td>
<td>$171.84</td>
</tr>
<tr>
<td>Date</td>
<td>Vendor</td>
<td>Item Description</td>
<td>Rate</td>
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<td>--------</td>
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<td>03/03/22</td>
<td>McMaster-Carr</td>
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<td>Motor Sprocket</td>
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<td>McMaster-Carr</td>
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<tr>
<td>03/10/22</td>
<td>McMaster-Carr</td>
<td><strong>Tax/Shipping &amp; Handling</strong></td>
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<table>
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<tr>
<th>Description</th>
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<tr>
<td>Total expenses</td>
<td>$1,793.76</td>
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<tr>
<td>budget</td>
<td>$2,500.00</td>
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<td>actual expenses</td>
<td>$1,793.76</td>
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<td>remaining balance</td>
<td>$706.24</td>
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# Appendix B: iBOM

## F75 Universal Tread Project

### Indented Bill of Material (iBOM)

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<thead>
<tr>
<th>Asy Level</th>
<th>Part Number</th>
<th>Descriptive Part Name</th>
<th>Qty</th>
<th>Mat'1 Cost</th>
<th>Production Cost</th>
<th>Total Cost</th>
<th>Part Source</th>
<th>More Info</th>
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<tbody>
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<td>100000</td>
<td>Final Assembly</td>
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<tr>
<td>1</td>
<td>110000</td>
<td>Platform</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
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<td>111000</td>
<td>Platform Block</td>
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<td>139000</td>
<td>8 Gauge Wire</td>
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**Total Parts**: 94, **Total Cost**: $1,466.71
## Appendix C: Failure Modes & Effects Analysis (FMEA)

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>Support System(Platform)/Support User</td>
<td>bowing/breaking may occur from too much weight or not enough support</td>
<td>load falls through platform if not strong enough</td>
<td>5</td>
<td>1) wrong material 2) Not enough supports 3) geometry of platform 4) overloading platform</td>
<td>1) FEA analysis 2) Choosing the right material 3) Design well</td>
<td>1</td>
<td>1) Visual inspection 2) User sense</td>
<td>9</td>
<td>45</td>
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<tr>
<td>Support (Brackets)/ Support Force from Platform</td>
<td>Brackets break and platform is not secured</td>
<td>Device breaks, and falls over</td>
<td>5</td>
<td>1) not strong enough 2) quantity of attachment points 3) materials 4) fatigue/load</td>
<td>1) FEA/Design</td>
<td>1</td>
<td>1) Feel 2) Sound</td>
<td>9</td>
<td>45</td>
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<tr>
<td>Propulsion (Motor)/ Provide Motion</td>
<td>Motor can seize/overheating</td>
<td>Device stops moving</td>
<td>4</td>
<td>1) Overload 2) Electrical Compatibility</td>
<td>1) Choose the right motor 2) Check motor compatibility with electronics 1) Insulate 2) Design appropriate electrical system 3) Overcharging prevention</td>
<td>1</td>
<td>1) Loss of power 2) Smell 3) Sound</td>
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<td>Propulsion (Battery)/ Provide Power</td>
<td>Battery may malfunction</td>
<td>Potential damage to user</td>
<td>7</td>
<td>1) Wet Conditions 2) Electrical Surges 3) Overcharging</td>
<td>1) FEA 2) Set recommended weight limit</td>
<td>1</td>
<td>1) Smell 2) Loss of power</td>
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<td>Propulsion (Power-Train)/ Transfer Power</td>
<td>Gear Slippage/ Gives Out</td>
<td>Device stops moving</td>
<td>4</td>
<td>1) Too much load 2) Worn out parts 3) Breakage</td>
<td>1) Ensure tread stability before use</td>
<td>1</td>
<td>1) Loss of power (slippage) 2) Sound 3) Feel</td>
<td>7</td>
<td>28</td>
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<tr>
<td>Propulsion (Tracks)/ Provide Traction</td>
<td>Loses Traction</td>
<td>Device slips</td>
<td>3</td>
<td>1) Worn out, 2) Running something over 3) Bad Driving Conditions</td>
<td>1) Ensure tread stability before use</td>
<td>2</td>
<td>1) See slip 2) Loss of control</td>
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## Appendix D: Manufacturing Plan

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<tr>
<th>Subsystem</th>
<th>Component</th>
<th>Purchase (P) Modify (M) Build (B)</th>
<th>Raw Materials Needed to make/modify the part (only M &amp; B)</th>
<th>Where/how procured?</th>
<th>Equipment and Operations anticipate using to make the component</th>
<th>Key limitations of this operation places on any parts made from it</th>
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<tbody>
<tr>
<td><strong>Platform</strong></td>
<td>Platform</td>
<td>M</td>
<td>304 Stainless Steel Sheet</td>
<td>Purchase raw material from McMaster-Carr</td>
<td>Waterjet Cutter</td>
<td>Machine bed size</td>
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<td>Motor Bracket B</td>
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<td>6061 T6 Aluminum Block</td>
<td>Purchase raw material from McMaster-Carr</td>
<td>Bandsaw/Chop saw, Mill/Drill:</td>
<td>Size of mill fixture</td>
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<td>Fasteners P</td>
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<td>Bike Chain P</td>
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<td><strong>Drive System</strong></td>
<td>Top Axle M</td>
<td></td>
<td>1045 Carbon Steel 3/4&quot; Diameter, 24&quot; Long</td>
<td>Purchase raw material from McMaster-Carr</td>
<td>Bandsaw/Chop Saw:</td>
<td>Size of lathe fixture</td>
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<td>Bottom Axle M</td>
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<td>12L14 Carbon Steel 5/16&quot; Diameter, 24&quot;</td>
<td>Purchase raw material from McMaster-Carr</td>
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<td>Top Shaft Collar P</td>
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<td>-</td>
<td>1) Cut axle stock to length</td>
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<td>Bottom Shaft Collar P</td>
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<td>-</td>
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<td>2) Turn down one side to 5/16 diameter</td>
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<td>Chain Cover B</td>
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<td>3D Printed</td>
<td>3D Printed</td>
<td>3) Deburr sharp corners/edges</td>
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<td>Battery P</td>
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<td>3D Printed</td>
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<td>Assembly Screws P</td>
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## Appendix E: Design Hazard Checklist

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<th>N</th>
<th>Question</th>
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<td>✔</td>
<td></td>
<td>1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?</td>
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<td>✔</td>
<td></td>
<td>2. Can any part of the design undergo high accelerations/decelerations?</td>
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<tr>
<td>✔</td>
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<td>3. Will the system have any large moving masses or large forces?</td>
</tr>
<tr>
<td>✔</td>
<td></td>
<td>4. Will the system produce a projectile?</td>
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<tr>
<td>✔</td>
<td></td>
<td>5. Would it be possible for the system to fall under gravity creating injury?</td>
</tr>
<tr>
<td>✔</td>
<td></td>
<td>6. Will a user be exposed to overhanging weights as part of the design?</td>
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<tr>
<td>✔</td>
<td></td>
<td>7. Will the system have any sharp edges?</td>
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<tr>
<td>✔</td>
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<td>8. Will any part of the electrical systems not be grounded?</td>
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<td>9. Will there be any large batteries or electrical voltage in the system above 40 V?</td>
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<tr>
<td>✔</td>
<td></td>
<td>10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?</td>
</tr>
<tr>
<td>✔</td>
<td></td>
<td>11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?</td>
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<tr>
<td>✔</td>
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<td>12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?</td>
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<tr>
<td>✔</td>
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<td>13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?</td>
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<tr>
<td>✔</td>
<td></td>
<td>14. Can the system generate high levels of noise?</td>
</tr>
<tr>
<td>✔</td>
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<td>15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?</td>
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<tr>
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<td></td>
<td>16. Is it possible for the system to be used in an unsafe manner?</td>
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<tr>
<td>✔</td>
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<td>17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.</td>
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<tr>
<td>Description of Hazard</td>
<td>Planned Corrective Action</td>
<td>Planned Date</td>
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<tr>
<td>-------------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>--------------</td>
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<tr>
<td>Our design contains two motors with two gearboxes that will be spinning. These may cause pinch points.</td>
<td>We plan to add covers over our gearboxes and motors so that nobody can reach the pinch points.</td>
<td>3/29/22</td>
</tr>
<tr>
<td>Our motors can accelerate and decelerate very quickly, causing our whole drive train to follow suit.</td>
<td>To mitigate the risk of acceleration and deceleration we plan to add safety warnings in our manual to alert users of the capabilities of the device.</td>
<td>3/29/22</td>
</tr>
<tr>
<td>Our system will carry a load of at least 100 lbs, so it will be moving a large mass.</td>
<td>To mitigate the risk of the movement of the large mass, we plan to secure the mass with straps so that it cannot fall off.</td>
<td>3/29/22</td>
</tr>
<tr>
<td>We will have two 12 V batteries on our system.</td>
<td>To mitigate the risk of the stored energy in the batteries, we plan to create battery boxes for them to protect them from the outside conditions.</td>
<td>3/29/22</td>
</tr>
<tr>
<td>Our system can be used in an unsafe manner.</td>
<td>To mitigate the risk of our system being used in an unsafe manner, we plan to add warnings in our manual to warn users of improper usage of the device.</td>
<td>3/29/22</td>
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### Appendix F: Design Verification Plan (DVP&R)

#### TEST PLAN

<table>
<thead>
<tr>
<th>Item No</th>
<th>Specification #</th>
<th>Test Description</th>
<th>Acceptance Criteria</th>
<th>Test Responsibility</th>
<th>Test Stage</th>
<th>SAMPLES TESTED</th>
<th>TIMING</th>
<th>TEST REPORT</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Load Platform with weight</td>
<td>Holds 100 lb load without deformation</td>
<td>Ryan</td>
<td>SP</td>
<td>1</td>
<td>Sys</td>
<td>3/6/2022</td>
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<tr>
<td>2</td>
<td>2</td>
<td>Test Radio Disconnect Safety</td>
<td>If radio signal is interrupted the machine will stop movement.</td>
<td>Daniel</td>
<td>VP</td>
<td>1</td>
<td>Sub</td>
<td>4/10/2022</td>
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<tr>
<td>3</td>
<td>3</td>
<td>Bracket/Roll Strength Test</td>
<td>Holds 100 lbs load without deforming due to shear/force.</td>
<td>Aaron Brien</td>
<td>VP</td>
<td>1</td>
<td>Sub</td>
<td>4/10/2022</td>
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<tr>
<td>4</td>
<td>4</td>
<td>Motor RPM/Torque Test</td>
<td>Motors must produce 2 lb-ft of torque combined.</td>
<td>Daniel</td>
<td>VP</td>
<td>1</td>
<td>Sub</td>
<td>4/10/2022</td>
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<tr>
<td>5</td>
<td>5</td>
<td>Going-up &quot;Stair&quot;</td>
<td>Device successfully traverses 2 inch vertical motor &quot;stair&quot;.</td>
<td>Aaron Daniel/ Brian Ryan</td>
<td>VP</td>
<td>1</td>
<td>Sys</td>
<td>4/10/2022</td>
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<tr>
<td>6</td>
<td>6</td>
<td>Wheel/Thread Stability Strength Test</td>
<td>The treads will sustain 100 lb load while in motion without deformation or succumbing to stress.</td>
<td>Ryan/Braden</td>
<td>VP</td>
<td>1</td>
<td>Sys</td>
<td>4/10/2022</td>
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<tr>
<td>7</td>
<td>7</td>
<td>Battery Life</td>
<td>The device must stay operational for 15 minutes long while loaded with 100 lbs.</td>
<td>Daniel</td>
<td>VP</td>
<td>1</td>
<td>Sub</td>
<td>4/10/2022</td>
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<tr>
<td>8</td>
<td>8</td>
<td>Tread Traction Test</td>
<td>The design is able to go up a 15-20 degree grade while loaded without slipping.</td>
<td>Ryan</td>
<td>VP</td>
<td>1</td>
<td>Sys</td>
<td>4/10/2022</td>
</tr>
<tr>
<td>9</td>
<td>9</td>
<td>Driving Shaft Strength Test</td>
<td>The driving shaft must uphold the torque produced by the motors without failure.</td>
<td>Brian</td>
<td>VP</td>
<td>1</td>
<td>Sub</td>
<td>4/10/2022</td>
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<td>The electronics box must not exceed the operable temperature.</td>
<td>Daniel</td>
<td>VP</td>
<td>1</td>
<td>Sub</td>
<td>4/10/2022</td>
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Appendix G: Gantt Chart
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</tr>
<tr>
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</tr>
<tr>
<td>Write Design Verification Plan</td>
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<tr>
<td>Write Project Management</td>
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<td>Write Intro/Conclusion</td>
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<td>DVP</td>
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<tr>
<td>Receive Electronics System</td>
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<tr>
<td>Order Platform/Treads</td>
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</tr>
<tr>
<td>Receive Platform/Treads</td>
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<td>Go Through Manufacturing Plan</td>
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<td><strong>Building Process</strong></td>
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<td>Build Electronics System</td>
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<td>Manufacture Platform/Axles</td>
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</tr>
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<td>Build Tread System</td>
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<td>Assemble Components</td>
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<tr>
<td><strong>Test Prototype</strong></td>
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<td></td>
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<tr>
<td>Test Radio Disconnection Safety</td>
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<td>0%</td>
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<tr>
<td>Test Bracket/Axle Strength</td>
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</tr>
<tr>
<td>Test RPM/Torque</td>
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<td>0%</td>
</tr>
<tr>
<td>Test Going Up Stairs</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Test Tread Stability</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Test Battery Life</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Test Traction</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Test Driving Shaft Strength</td>
<td>0</td>
<td>0%</td>
</tr>
<tr>
<td>Test Electronics Box Heat</td>
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<td>0%</td>
</tr>
<tr>
<td>Revise if Necessary</td>
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<td>0%</td>
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<td><strong>Verification Prototype Sign-Off</strong></td>
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<td></td>
</tr>
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<td>FMEA</td>
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<td>0%</td>
</tr>
</tbody>
</table>
Part IV

Final Design Review
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1. Manufacturing

This manufacturing section will cover the part procurement process, outsourcing, the manufacturing processes and tools used, and the assembly of each system. It also covers the challenges faced and lessons learned after finishing the manufacturing process.

1.1 Part Procurement

Throughout our part procurement process, we ordered through McMaster Carr, Amazon, and Pitsco. Through Amazon, we ordered the electronics, batteries, RC controller, bike chain, battery chargers, and motors. Through Pitsco, we ordered our whole tread system which included our treads, idler wheels, driving sprocket, and motor shaft hub. Through McMaster Carr, we ordered all our metal parts, which included the platform, pillow blocks, axles, shaft collars, and aluminum stock. All these orders were done through Meredith Rubin.

We also procured some parts locally at Home Depot. From Home Depot we bought fasteners, Velcro, and extra wire for the electronics. We then used the reimbursement process to forward our payments to our account. A detailed list of our final expenses is shown in Appendix A.

1.2 Manufacturing Used

All the manufacturing for this project was done at the machine shops at Cal Poly – Mustang 60 and the Aero Hangar. The parts done at these machine shops were the top and bottom axles, the motor mount blocks, and the platform plate. The platform plate came as a solid stainless-steel sheet, and the holes were made at the waterjet at Mustang 60. The plate with the holes is shown below in figure 1.1.

![Figure 1.1: Platform plate with the water-jetted holes](image)
The top and bottom axles were manually done at Mustang 60 with the horizontal bandsaw and lathe. The bottom axle pieces were cut to length with the horizontal bandsaw, and the top axle stock pieces were cut to size to be turned on the lathe. The lathe was used to make a step-down shaft diameter to fit the tread sprocket and its fastening hub attachment. The process and final parts are shown below in figures 1.2 and 1.3.

Figure 1.1: Turning down the step-down diameter on the top axle with a lathe

Figure 1.2: Bottom and top axle parts
Finally, the motor mount block was done at Mustang 60 with the horizontal bandsaw, drill press, and manual mill. The stock part had to be cut on the horizontal bandsaw to achieve a rough size of the block size. Then, all the faces were faced on the mill to achieve the motor block size. The result of these two processes is shown below in figure 1.3.

![Figure 1.3: Motor mount blocks](image)

Next, the holes in these blocks were drilled using the drill press, and the bottom and top slots were milled using the manual mill. The final part is shown below in figure 1.4.

![Figure 1.4: Motor mount part](image)
1.3 Challenges

One of the main problems we ran into during the manufacturing stage was how long the processes took. Some primary operations, like making the motor mount blocks, could have been much more simplified and standardized to save time while still having a good part function how it was designed to function. This part was not designed very well for manufacturability, requiring extra operations. For example, the stock size of the block was 4.33” x 2.17”. This dimension required additional steps in cutting the block to size with the horizontal bandsaw and using the mill to face each side to size. The cutting and facing process could have been skipped if this part were designed to standardized stock size. If we had the chance to re-do this part, we would think further down the line for manufacturability while designing the parts of our project.

Another problem we ran into was after assembling our first design, shown in figure 1.5. We tested it and noticed that the treads kept slipping on the drive sprocket. In the first iteration of our design, the sprocket was only in contact with about 2 or 3 of the treads, and it lacked the tension to stay on the teeth. The motor’s torque was too much for the tread and sprocket to maintain constant contact.

To fix this, we needed the sprocket to contact the treads more. As seen in Figure 1.6, we decided to raise our top axle using longer bolts. After changing this, our top sprocket was now in contact with about six of the treads, and it had an upward force that was keeping it in contact with the treads. This increases the tension of the tread while also reducing slippage between the treads and the drive sprocket.
Figure 1.6: Design after raising the top axle
2. Design Verification

2.1 Meeting Specifications

Below is our specifications table, which we planned to use for the quarter-scale model verification prototype.

Table 1: Specifications Table

<table>
<thead>
<tr>
<th>Spec. #</th>
<th>Specification Description</th>
<th>Requirement or Target (Units)</th>
<th>Tolerance</th>
<th>Risk*</th>
<th>Compliance**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Carrying Capacity</td>
<td>200 lbs</td>
<td>Max</td>
<td>H</td>
<td>A,T</td>
</tr>
<tr>
<td>2</td>
<td>Weight</td>
<td>125 lbs</td>
<td>±25 lbs</td>
<td>L</td>
<td>A,I</td>
</tr>
<tr>
<td>3</td>
<td>Ability from point A to B at 15-degree grade</td>
<td>Ability to go from point A to B</td>
<td>Min</td>
<td>M</td>
<td>A,T</td>
</tr>
<tr>
<td>4</td>
<td>Allowable Angle of Tilt</td>
<td>30 degrees</td>
<td>Max</td>
<td>H</td>
<td>A,T</td>
</tr>
<tr>
<td>5</td>
<td>Ground Clearance</td>
<td>2 inches</td>
<td>Min</td>
<td>H</td>
<td>I,T</td>
</tr>
<tr>
<td>6</td>
<td>Required Power/Torque Output</td>
<td>2.5 lbf-ft</td>
<td>Max</td>
<td>H</td>
<td>A,T</td>
</tr>
<tr>
<td>7</td>
<td>Dimensions</td>
<td>18”x12”</td>
<td>Min</td>
<td>M</td>
<td>A,I</td>
</tr>
</tbody>
</table>

2.2 Tests and Results

To verify that our system met the specifications that we set at the beginning of the project, we set up 10 different tests, listed below in table 2. After the table is a more detailed description of each test and their results.

Table 2: Overview of Completed Verification Tests

<table>
<thead>
<tr>
<th>Tests</th>
<th>Date Completed</th>
<th>Pass/Fail</th>
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</thead>
<tbody>
<tr>
<td>Electronics Heat</td>
<td>5/17/2022</td>
<td>Pass</td>
</tr>
<tr>
<td>Radio Disconnect</td>
<td>5/5/2022</td>
<td>Pass</td>
</tr>
<tr>
<td>Load Platform</td>
<td>5/5/2022</td>
<td>Pass</td>
</tr>
<tr>
<td>Battery Life</td>
<td>5/10/2022</td>
<td>Pass</td>
</tr>
<tr>
<td>Tread Traction</td>
<td>5/10/2022</td>
<td>Pass</td>
</tr>
<tr>
<td>¼ Scale Curb</td>
<td>5/10/2022</td>
<td>Pass</td>
</tr>
<tr>
<td>Motor/Torque</td>
<td>5/17/2022</td>
<td>Pass</td>
</tr>
<tr>
<td>Wheel/Tread Stability, Strength</td>
<td>5/5/2022</td>
<td>Pass</td>
</tr>
<tr>
<td>Driving Shaft Strength</td>
<td>5/17/2022</td>
<td>Pass</td>
</tr>
<tr>
<td>Bracket/Axle Strength</td>
<td>5/5/2022</td>
<td>Pass</td>
</tr>
</tbody>
</table>
2.2.1 Electronics Heat

The purpose of the electronics operating temperature test was to observe and record the temperature of the Cytron Motor Controller at a steady state. The goal of this test was to ensure that the motor driver would stay in optimal condition while the device was in use. The test checked the cooling effectiveness inside the electronics box and checked the motor driver's thermal protection features.

The team followed PPE, which included Safety Glasses and a fire extinguisher, as high amperage and fire hazards were associated with the test to complete the test. The team took an initial reading of the motor controller using a thermocouple which registered a reading of 77.7 °C as shown in figure 2.1. A fan was connected to the motor controller to ensure that the device would not be damaged in case of overheating. The device was then driven around the parking lot, and after 30 minutes, the temperature was re-recorded. After 30 minutes, the temperature rose 2°C and immediately started cooling down as we measured the temperature on the heat sink. Since the temperature rose very little, the overheating protocol on the motor controller was never activated, and the fan remained off. As a result, the device passed the temperature test.

![Figure 2.1: Thermocouple Initial Reading](image)

2.2.2 Radio Disconnect

The radio disconnect test aimed to ensure that the device would halt if the radio connection signal between the receiver and transmitter was lost. The test checked the built-in failsafe protocols of the Cytron motor controller, which were activated through the remote controller by associating a zero-duty cycle in case of a signal loss for the joystick that controlled the movement of the motors (Figure 2.2).
The device was placed in an open area to mitigate any hazards created by the device, not stopping with a radio disconnect. The device was turned on and moved forward using the radio controller. After a couple of seconds of continuous movement, the radio controller was turned off, and the motors were observed to ensure that they would cease after the signal loss. Five runs were conducted, and each passed the failsafe activation criteria. One thing that the team observed was that the failsafe feature has a delay of approximately 1 second.

2.2.3 Load Platform

This test aims to ensure that our system can sustain the 200 lbf load it is meant to carry. Several components are responsible for this load, and all of them must be reliable. The shafts that hold the idler wheels and the platform have been designed to carry this load with substantial factors of safety; however, it was unclear whether purchased components, such as the idler wheels and treads, would be capable of sustaining the load. To complete this test, three members of the senior design group stood on the platform. This was a total of 550 lbf loaded on the platform (fully assembled); all load-bearing components showed no signs of deformation or damage.

2.2.4 Battery Life

The purpose of the battery life test was to quantify how long the device would remain operational on a full battery. The criteria for the device to pass was to stay functional for a minimum of 15 minutes. After moving the prototype continuously, the team found that the average battery life was greater than 1 hour. This result is to be expected as the equipped batteries are rated for 35 Amp Hours and the device runs at a maximum of 30 amps.
2.2.5 Tread Traction

This test aims to give us a qualitative understanding of how much traction is available for our system as it attempts to traverse inclines. Ideally, we do not want the treads to slip any amount as the system makes its way up an incline because once the system starts to slip, the friction coefficient decreases, and it may prove difficult to stop the system from slipping further down an incline.

To test this, we constructed a small ramp with wooden blocks propping it up on one end and the other end was contacting the ground. To adjust the ramp’s angle, we were able to add or remove wooden blocks from the end of the ramp that was propped up. We then used the angle measuring tool available on iPhones to measure the angle. Finally, the system was slowly driven onto the ramp. The test was successful if it did not slip as it moved onto and over the ramp. We learned that the largest angle the system was capable of traversing was a 15-degree incline, as shown in figure 2.3.

![Prototype Traversing 15 Degree Grade](image)

Figure 2.3: Prototype Traversing 15 Degree Grade

2.2.6 Going Up “Curbs” (Angle)

The system is meant to traverse a curb at full scale. Curbs are on average 6 inches tall; translated to our quarter scale, our system should be able to traverse a curb that is an inch and a half tall.

To test this, we used thin pieces of wood and laid them flat on the floor. We then drove the system over the wood. Progressively, we added more layers of wood to increase the size of our model curb. The maximum height of the model curb that our system was able to climb was a 1.75-inch curb. This translates to a full-scale curb of 7.5 inches.

We realized during the test that the model could not climb a 1.5-inch model curb in the form of a two-by-four because the two-by-four wood piece had rounded edges. The model had trouble
gripping the rounded edges. However, using wood with sharper edges, the system had no trouble overcoming the 1.5-inch model curb. We do not believe this will be a problem with the full-scale system because it will use rubber treads on concrete. This will give it a much higher coefficient of friction.

2.2.7 Motor RPM/ Torque

This test is designed to give us a quantitative understanding of how much torque our motors produce; this is particularly important because the motors did not come with a torque specification. We estimated the system would need a total of 44 lbf-ft of torque to climb a 20-degree incline with a maximum acceleration of 1 ft/s^2 when fully loaded with 200 lbf. This means each motor needs to produce 22 lbf-ft. Additionally, the drive shaft was designed to withstand the loads corresponding to being driven with 22 lbf-ft. They were designed with a factor of safety; however, ideally, we do not want to exceed this torque rating.

To test the torque output of each motor, we first needed to disconnect the motors from the chain that drives them. Then, we connected a socket and wrench to the nut that holds the sprocket on the motor shaft. We used a force gauge and leverage from the wrench to hold the motor shaft still (stalled) while applying maximum input from the controller. This means that the force read from the force gauge multiplied by the distance from the motor shaft from which it was read is our stall torque for the motor.

We took several measurements and got an average of 26.4 lbf-ft of torque for each motor. This measurement averaged to 47 lbf force read at 6.75 inches from the center of the motor shaft. The sources of error from this measurement could come from the force gauge itself and the tolerance of the fitting between the wrench and the motor nut. The error propagation from these two would be the square root of the sum of the uncertainties of each. This comes out to an error range of approximately ±1 lbf-ft of torque.

2.2.8 Wheel/ Tread Stability, Strength Test

Our system has eight idler wheels set up on top of our treads. These treads and idler wheels are meant to be used for toys with little to no load. To test if our idler wheels and treads could withstand a full load being applied to them, we decided to load our system and drive it along flat land.

After changing the tension of our treads, they performed fantastically. One issue that we ran into while testing was if our system were to run off a ledge and then try to crawl out, usually, a singular tread would break (Figure 2.4). We placed this cause due to the amount of stress that was being placed on a singular tread when trying to crawl out. If a tread were to break, they were very easy to replace and tension again.
2.2.9 Driving Shaft Strength Test

Our driving shaft, which was located on the top of our platform and was connected to our motor, would withstand an exceptionally large moment if the motor were to ever stall while in operation. We designed our driving shaft to withstand this moment, but we wanted to ensure that it would withstand it in action.

To test this, we held our driving shaft so that the motor would end up being at its stall torque. After performing the test, we saw that no deformation occurred in the driving shaft. This confirmed that we designed our driving shaft appropriately for the motors that we were using.

2.2.10 Bracket/Axle Strength Test

The system has a total of 8 brackets (pillow blocks), and 8 axles on the underside of the platform, shown in figure 2.5. To confirm that these brackets and axles would be able to withstand a load without deforming, we decided to test them out in a comparable way to that of the wheel/tread stability test. Once the system was fully built we applied a load to the system and visually saw that there was no deformation in either the brackets or the axles. This showed that our brackets and axles would not deform due to the load that we would be applying to it.
2.3 Specifications Not Met

We did not meet the specifications we set out to achieve for our test to experimentally determine the maximum slope that the system could traverse. However, the conditions were not ideal, and we have reason to believe that a full-scale model would perform much better than this. To begin, we used wood to make our make ramp, and concrete has much higher coefficients of static and kinetic friction. Additionally, the treads we used were not designed for this use; they are plastic treads with very limited grip. A system that uses rubber treads will also result in higher coefficients of friction. Specifically, the coefficient of static friction between plastic and wood is approximately 0.4, and the coefficient of static friction between rubber and concrete varies between 1.0 and 4.0.

2.4 Challenges & Lessons

There was one specification that we were not able to test. This is the strength specification for the drive shaft. The drive shaft is designed to sustain the loads associated with driving the system, loaded with 200lbf, at an acceleration of 1 ft/s^2 at an incline of 25 degrees. For this, we estimate about 22 ft-lbf of torque required from each motor, and we know that our motors were each producing 26 ft-lbf. Because the drive shafts were designed with a factor of safety of 2; it is reasonable to assume that they can safely withstand the maximum load conditions they were designed for. However, we could not test this because our system had difficulty climbing slopes of greater than 20 degrees because of the limited traction from the plastic treads.

The next time we design a test, it is important to understand if the success or failure of any test will affect our ability to proceed with other tests. In this case, because the system failed the incline test, we were unable to proceed with the drive shaft strength test. In retrospect, we should have a plan in place to test the drive shaft strength regardless of the system’s ability to successfully complete any of the other tests.
3. Discussions & Recommendations

When starting this project, we set out to build a full-scale model of the product. After realizing that the budget and time needed to build a full-scale model was too little, we changed the scope of our project to a ¼ scale model to verify that the design would work at full-scale. We have gathered some recommendations if the design were to go to a full-scale model.

3.1 Learning & Continuing Design

After completing our ¼ scale model verification prototype, we learned a couple of things about the overall design. One of these things was the tensioning on the treads and the chain. This was a struggle when we first started assembling our verification prototype because the chains and treads were always too tight or too loose. After some design workarounds, we decided to have the driving axle raised on longer bolts so that when we raised the driving axles, it would also tension the treads. This also ended up allowing our treads to be in more contact with the gear that drove them as well.

Since this was only a ¼ scale model, we had to find treads that would fit this size. The only treads that we were able to find were made for toy RC cars. These treads were very slick and offered little to no traction. They also broke whenever there was any force coming in from the side. If this project gets sized up, I do not think that this will be an issue because there will be more access to real rubber treads.

3.2 Design Changes

As we said in the section beforehand, we had a hard time tensioning the chains. To fix this in the full-scale model, we thought that something similar to a bike chain tensioner could be used to tension the chains. Another part that we never added to our ¼ scale model was chain covers. These chain covers were supposed to be used for protection against pinch hazards. Since our treads would break occasionally, we decided to leave these out of the ¼ scale design because fixing the treads would have required the chain covers to be removed.

When going to full scale with this project, we thought of a couple of design changes and design additions. One of these changes would be to keep all the electronics stored in the front of the prototype, either in between the motors or on top of the motors. This would save a lot of space that could be used for securing the user to the platform.

Another design change would be to correctly size the platform. When building this prototype, we over-specified the requirements and got a 3/8” thick steel platform. Even with more than the load we designed for being applied to it, the platform would not deform at all.
Since this platform was so thick, it took up the majority of what the prototype weighed. If this project were to go to full scale, we would suggest using a platform with a different material, like carbon fiber, to lower the weight and keep the strength.

Another design change that we discussed was adding a specific box for where the batteries would go. For this ¼ scale model, we were only running it during optimal conditions, but at full scale, this device should be able to be used at any time in most weather conditions. Adding a battery box would protect the batteries from these conditions.

3.3 Manufacturing Changes

While going through the manufacturing process, there were a couple of challenges that we faced that could be optimized if we had to build it again. Throughout the design process, we continually reduced the complexity of the parts and the necessity for manufacturing, so most of our components were off-the-shelf parts by the end of the design phase. However, the parts that did need to be manufactured could have been designed in a way that is optimized for manufacturing. Some of the dimensions of the parts were very specific dimensions that demanded additional manufacturing processes. Had these been designed to standard stock part dimensions, this could have cut down on a lot of machining time and opportunity for error.

When converting this to a full-scale model, ideally the parts that would need to be manufactured are also designed in a way that would make machining and assembly easier. This would include standardized parts and part dimensions.

3.4 Recommendations for Future

Some other recommendations for the future have also been talked about in our group. If the design were to go full scale, we recommend that the controller be changed to closely resemble the one that Alex already has on his wheelchair. We also recommend that an attachment be made so that the controller can be easily attached to the wheelchair. This single joystick design would make it very easy for Alex to adjust to using it.

The full-scale model will also need two additions to the design: a ramp to get the user onto the platform and a way to secure the user. When we were still designing for full-scale, we came up with multiple ideas for both. For the ramp, we had the idea of building a ramp that was long enough for the user to get up onto the platform without it being too steep or to use something like a curb to help load the user onto the platform. In our opinion, the latter made more sense because any ramp that would be able to load the user would be way too long to practically store anywhere. We believed that if the prototype were backed up to a raised surface, the process would be much easier. Even if the raised surface was not high enough to get the user onto the platform, a much shorter ramp can be used to assist.
We had one main idea for securing the user to the platform, the EZ-Lock. This was an already existing product that is used to lock wheelchair users in place while in a car. The problem with this product was that it is costly, and it can only be installed by a professional in an actual car. When talking with one of their salesmen, they said that “Sadly, we cannot install the EZ-Lock in anything except pre-approved vehicles.” There are many other companies with similar technologies that might be of use when trying to solve this problem, but for the moment, we were never able to solve the problem of securing the user to the platform entirely.
4. Conclusion

This project began as a full scale; it was then changed to be a quarter-scale proof of concept. The idea is that if we could design a system to meet the specifications set out for the full-scale project after being adjusted to our quarter-scale project, it is reasonable to assume that a full-scale would have similar success. I think the fact that we were able to meet just about all our specifications is a very good sign. The only specification we did not meet was the specification for the incline we wanted the system to be able to climb; however, as we talked about in this report, that is unlikely to be an issue at full scale. We would argue that the success of this project warrants further development of the system. The only shortcoming of the system came from the fact that the only commercially available treads were not meant to carry so much weight at such angles of incline.

If we could do this project again, we would take much more time for open-ended design. There are various subsystems to the design, and we left out the suspension and platform subsystems. Changes to one subsystem affect nearly every other subsystem. We would begin by choosing what we believe to be the most important subsystems and making the design and function of those paramount. The other subsystems can then be designed to work well with what we believe the project needs most. One of the subsystems of major importance when carrying a person on the system is suspension, the addition of which can have a major effect on the other subsystems that are integrated.
References

*Student Success Guide*. Department of Mechanical Engineering. (2022, April).
Appendix

A. Final Project Budget

B. Risk Assessment

C. User Manual

D. DVP&R

E. Test Procedures
Appendix A: Final Project Budget

Materials Budget for Senior Project

Title of Senior Project: F75 Universal Treads for Wheelchair
Team members: Ryan Scarcella, Brian Song, Aaron Rocha, Daniel Ceja
Designated Team Treasurer: Aaron Rocha
Faculty Advisor: Sarah Harding
Sponsor: Alex Fung
Quarter and year project began: Fall 2021
Materials budget given for this project: $2,500.00

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All transactions were made through the $2500 budget granted to us by Tech-E.
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Total expenses: $2,022.48

budget: $2,500.00
actual expenses: $2,022.48
remaining balance: $477.52
## Appendix B: Risk Assessment

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Appendix C: User Manual

Universal Wheelchair Tread Quarter Scale Model
User Manual
By Brian Song, Ryan Scarcella, Aaron Rocha, Daniel Ceja

Potential hazards:
Mechanical: The system has several pinching points. These include any points where the tread contacts idler wheels and the driving sprocket of the ground. Additionally, any points where the chain contacts the sprockets are potentially hazardous. Finally, the chain and tread have very little clearance between them; they move simultaneously at a ratio of 1.1:1. In other words, the chain moves 1.1 times faster than the tread, because of the gear ratio. There is the possibility that the chain can push something towards the tread and jam it in the clearance between both. One should also be careful not to run into any persons while operating the system. Unloaded, the system weighs about 50lbs and could traverse someone’s foot with relative ease. Loaded, the system can weigh up to 250lbs and could hurt a bystander.

Electrical: There are exposed battery terminals. One should be very careful not to create any contact between the two terminals; this could shock them.

Page Break

Set Up Sequence:
Connecting Power Supply
1. Use the quick connect cables coming connected to the battery and coming out of the electronics box to power the system (Figure 1). The radio receiver, attached to the electronics box, should have an LED flash on (Figure 2).
   a. If the light fails to turn on check the fuse in the battery side of the quick connect and make sure that the fuse is intact (Figure 3).
Figure 1: Connecting Quick Connect Power Cables

Figure 2: LED Power Indicator
Turning on the Radio Controller

1. Once the system has power and the LED on the receiver is turned on proceed to set up the radio controller. Place the radio controller switches and joysticks to the position shown in Figure 4.
   
a. Failure to configure controller before powering up will result in an alarm being set up with a warning on the digital display stating to configure the remote as stated before. The controller will not be operational until this step is completed.

1. To power the controller place the switch located at the bottom right corner of the display to the upward position.
Operating B.R.A.D:
Driving Device with Controller

1. Use the right joystick to drive the device. The controller is set up so that it can be completely driven by a single joystick in a tank-style directional configuration.

Maintenance:
Treads

1. To remove the treads, one needs to loosen the nuts that clamp the top pillow blocks to the platform. Particularly, you must loosen the top nuts that clamp the top pillow blocks to the platform.

In the figure we can see there are 3 nuts and one lock washer per bolt. The topmost nut is to hold the pillow block mated to the bolt. The next two bolts are on either side of the platform and are used to clamp the bolts in place relative to the platform. Notice that there is a lock washer between one of the bolts and the platform; this is to ensure the bolts do not loosen with vibrations that the system may be experiencing. The top nut of the two that are used to clamp the bolt to the platform can be loosened to relieve tension from the tread. This allows the pillow block to move down; subsequently, the pinion that drives the tread will move down and relieve tension. The treads can then be removed from the system.
Figure 5: The nuts used to clamp the bolts to the platform have been loosened to remove the tread.

Figure 6: The un-tensioned tread ready to be removed.

There should be 99 tread links on either side of the system. This is important when tensioning the treads. With 99 links the ideal tension happens when the bottom nuts are flush with the bolt and the top nuts are tightened to the platform.

Motors/Chain
1. Removing the motors will require removing the chain. To remove the chain, one must simply remove the tread link that holds the chain together.
2. Now that the chain is removed one can begin to remove the bolts that hold the motor to the motor bracket.
3. After these bolts are removed, one can remove the bolts that hold on the motor bracket.
   a. Removing the motor bracket will be necessary if one wants to remove all of the bottom side pillow blocks, because one bolt for those pillow blocks is under the motor bracket and can not be removed or placed with the motor bracket in place.
Figure 7: An illustration of the bolts holding the motor and motor bracket.

Drive Shaft

1. The drive shaft is the shaft that holds the pinion that drives the treads. Each drive shaft is held by two pillow blocks. To disassemble the drive shaft, one must first relieve the tension in the tread (see Treads section).
2. Remove the specially designed shaft collar that attaches the pinion to the drive shaft. Each is held in place with 4 bolts, 4 nuts, and one set screw. The pinion can now be removed.
3. The nuts that mate the top pillow mated to the bolts must be loosened.
4. The pillow blocks can now be separated into their components: top housing, bottom housing, and bearing.
5. There are 2 set screws per bearing (2 bearings) holding the shaft and 1 set setscrew holding the gear on the shaft. All must be loosened so the shaft can be removed.
   a. Note, when removing the gear, the keyway will also be removed. Do not lose this.

Figure 8: The top housing, bottom housing, and bearing separated to remove the drive shaft.
Idler Wheels and Shafts

1. The idler wheels are mated to shafts that are held by pillow blocks. Shaft collars ensure that the correct distance between the wheels, the platform and the pillow blocks. To remove the idler wheels one can simply remove the shaft collar on the outer edge of these shafts and then remove the wheels.

1. To remove the shafts, continue by removing the second shaft collar on the outer side of the platform. The shaft should now be able to slide out of the pillow block towards the center of the platform.

   a. Note: when reassembling, one must ensure that the idler wheels line up with the pinion above them. For them to line up appropriately the shaft collars will on the outer edges of the shafts will need to be half engaged on the shaft only.

Figure 9: An illustration of the shaft collars on the edge of the shafts that hold the idler wheels.
## Appendix D: DVP&R

### TEST PLAN

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### NOTES

- The electronics box must not exceed the allowable temperature.
- The platform could hold excess of 100 lb without deformation.
- The battery was used for up to 40 hours of continuous movement.
- The device was able to traverse at an angle of 15 degrees.
- The device was able to traverse 1-1/2 inch “obstacles” but not 2 inch.
- One motor was able to produce 20.4 lbs of torque with 3/8 V power supply.
- The treaps did not deform under load, while in movement.
- The device could hold up to 150 lb load without deformation of the motors without failure.
- The axle did not deform under load.
Appendix E: Test Procedures

Test Name: Electronics Box Operating Temperatures

Purpose:
The goal of this test is to observe the operating temperature of the electronics box, specifically the motor driver, and record its temperature at steady state. The purpose of this is to ensure that the motor driver will stay at optimal conditions while the device is in use.

Scope: (Defines what feature or function the test is for)
This test will check the thermal protection features on the motor driver and effectiveness of the cooling components in the electronics box. This includes the heat sink, filters, and the overall airflow created by the fans.

Equipment:
- Digital Infrared Thermometer

Hazards: (list hazards associated with the test)
- Fire Hazard
- High Amperage

PPE Requirements: (e.g. safety goggles, respirators)
- Fire Extinguisher
- Safety Goggles

Facility: (Where the test should occur)
The test should be performed outside, away from fire hazards like dry vegetation. A parking lot can serve as a testing location.

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):
1) Take initial reference temperature of the motor driver
2) Drive the device for 15 mins taking temperature readings at the motor driver every 3 mins using the infrared thermometer.

Results: Pass Criteria, Fail Criteria, Number of samples to test
The electronics box will pass the test if the motor driver does not trip the thermal protection feature and the steady state operating temperature of the motor driver stays under the recommended operating temperature specified by the manufacturer.

Test Date(s): 4/19/2022

Test Results:

Performed By: Daniel Ceja G
Team: F75 Universal Treads

Test Name: Radio Disconnection Safety Test

Purpose: The purpose of this test is to make sure our device does not keep moving if the radio connection disconnects.

Equipment: Fully built electronics system

Hazards: Prototype might not stop moving, so when radio disc

Facility: Tech-E Lab

Procedure: (List number steps of how to run the test, can include sketches and/or pictures):
1) Build the full electronics system.
2) Activate prebuilt program on motor driver.
3) Set up motors/electronics system in a safe space.
4) Turn on system and run motors with radio controller.
5) Disconnect radio controller.
6) Observe the motors to make sure movement has ceased.

Results: Pass Criteria, Fail Criteria, Number of samples to test

After testing our device, the test will be passed if the device stops when the radio controller is disconnected.

Test Date(s): March 31, 2022

Test Results:

Performed By:
**Team:** F75 Universal Treads

**Test Name:** Platform Stress Test

**Purpose:** The purpose of this test is to see how much deflection occurred while our platform is loaded with 100 lb load. If there is too much deflection, then the platform will need added supports.

**Equipment:** 100 lb weight, platform (cut to size), 2 tables, yardstick

**Hazards:** Heavy weights can cause pinching. Suspended mass may fall. Heavy weight must be lifted by at least two people.

**PPE Requirements:** Work gloves to hold 100 lb load

**Facility:** Tech-E Lab

**Procedure:** (List number steps of how to run the test, can include sketches and/or pictures):

1) Acquire materials needed for test.
2) Set two tables up parallel to each other with a 10-inch gap in between them.
3) Place platform in between tables so that 1 inch of the platform is over each side of the tables.
4) Measure the height of the middle point of the platform before loading with the yard stick. Record data.
5) Carefully load 100 lb load onto center of platform.
6) Measure the height of the middle point of the platform after loading. Record data.
7) Carefully remove weight from platform.
8) Repeat steps 4-7 two more times.
9) Clean up area.

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Height Before Loading</th>
<th>Height After Loading</th>
<th>Comments</th>
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<tr>
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</table>
Results: Pass Criteria, Fail Criteria, Number of samples to test

After collecting the three samples the total deflection will be calculated and averaged. If the beam deflects by more than .07 inches then the platform will fail. The .07 inches was calculated using North American rack design standards. This standard calls for the deflection having to be less than the length divided by 180.

Test Date(s): March 31, 2022
Test Results:
Performed By:

Team: F75 Universal Treads

Test Name: Battery Life Test

Purpose: The purpose of this test is to see how long our batteries will last on a charge during expo.

Equipment: Final Prototype fully built, timer, fully charged batteries, battery charger

Hazards: Tipping may occur, weights falling

PPE Requirements: N/A

Facility: Tech-E Lab

Procedure:

1. Set up final prototype with fully charged battery inserted.
2. Start timer when final prototype starts movement.
3. Keep prototype in movement until the device stops moving from the battery losing charge.
4. When the prototype fully ceases movement stop the timer.
5. Repeat steps 2-4 with a new, fully charged battery.
6. If the results differ from the first two tests by more than 10%, steps 2-4 will be repeated again.

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<thead>
<tr>
<th>Test Number</th>
<th>Test Results</th>
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</table>
Results:
If our final prototype stays operational for about 15 minutes on one fully charged battery, then our prototype will have been a success.

Test Date:
Test Results:
Preformed By:

Team: F75 Universal Treads

Test Name: Traction Test

Purpose: The purpose of this test is to see if the final prototype will be able to traverse an incline of 15 degrees.

Equipment: Final Prototype fully built, 15 degree angle wooden ramp

Hazards: Tipping may occur, weights falling

PPE Requirements: N/A

Facility: Tech-E Lab/Mustang 60

Procedure:
1. Arrive at mustang 60 and begin to assemble 15 degree angle wooden ramp
2. Once complete, take the assembled ramp to the Tech-E Lab.
3. Set up ramp in front of prototype and see if it will traverse them.
4. Record if the final prototype is able to traverse the ramp or not.
5. Repeat steps 3 and 4 about five times.
6. Clean up area and save the ramp for expo.

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</table>
Results:

After collecting the five test results, the test will be a success if the final prototype is able to traverse the 15 degree incline every time.

Test Date:

Test Results:

Preformed By:

Team: F75 Universal Treads

Test Name: “Stair” Test

Purpose: The purpose of this test is to see if our final prototype will be able to traverse ¼ scale model stairs.

Equipment: Final Prototype fully built, ¼ scale model wooden stairs/curbs

Hazards: Tipping may occur, weights falling

PPE Requirements: N/A

Facility: Tech-E Lab/Mustang 60

Procedure:

1. Arrive at mustang 60 and begin to assemble ¼ scale model steps out of 2"x4"s.
2. Once complete, take the assembled ¼ scale model steps to the Tech-E Lab.
3. Set up steps in front of prototype and see if it will traverse them.
4. Record if the final prototype is able to traverse the steps or not.
5. Repeat steps 3 and 4 about five times.
6. Clean up area and save ¼ scale model stairs for expo.

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Results:

After collecting the five test results, the test will be a success if the final prototype is able to traverse the \(\frac{3}{4}\) scale model stairs every time.

Test Date:

Test Results:

Preformed By:
Team: F7S Universal Treads

Test Name: “Torque” Test

Purpose: The purpose of this test is to have a real world value for the maximum amount of torque that the motors can output when connected to one 12 V battery vs when connected to two 12V batteries in series.

Equipment: Final Prototype fully built, force gauge, torque wrench, socket to fit on the motor nut

Hazards: Force gauge slipping from its place

PPE Requirements: Safety glasses

Facility: Tech-E Lab/Mustang 60

Procedure:
1. Arrive at mustang 60 and with motors attached to the platform.
2. Use the platform to constrain the motors.
3. Attach the motor to a sing 12V battery
4. Attach a socket and wrench to the nut at the output shaft of the motor.
5. Activate the one motor to spin.
6. Hold the wrench to stall the motor.
7. Attach a force gauge one foot away from the motor shaft.
8. Slowly reduce amount of force applied against the motor so that the force gauge can apply this force itself (to keep the motor stalled).
9. Measure the force at one foot from the motor shaft at stall conditions.
10. Repeat for the same motor attached to two 12V batteries in series.

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Results:
After we have a force required to stall the motor at one foot from the motor shaft, we can calculate the torque output. The torque output will the force measured times 1 foot. We have two of these motors, so our total output is two time the output of one motor driven at a given voltage.
Team: F75 Universal Treads

Test Name: Wheel/Tread Strength Test

Purpose: The purpose of this test is to see if the wheels and treads on our final prototype can sustain the load that it will carry.

Equipment: Final Prototype fully built

Hazards: Tipping may occur, weights falling

PPE Requirements: gloves, eye protection

Facility: Tech-E Lab

Procedure:

1. Finish building final prototype.
2. Set on ground with load placed on top and allow the device to move around.
3. Move the final prototype around for about five minutes.
4. After five minutes have passed, check for deformations, strains in the wheels and treads.
5. Record Observations

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Wheel Integrity Notes</th>
<th>Tread Integrity Notes</th>
</tr>
</thead>
</table>

After observing the tread and wheel integrity, the final prototype will have passed this test if there is little to no damage taken by the treads and wheels. If the treads or wheels break then the test will be a failure.

Test Date:

Test Results:

Performed By:
Team: F75 Universal Treads

Test Name: Driving Shaft Strength Test

Purpose: The purpose of this test is to see if the driving shaft can withstand the torque that is being supplied by the motor.

Equipment: Motors and drive shaft assembled on platform, Locking mechanism for drive shaft

Hazards: Pinch Points, Moving Parts

PPE Requirements: gloves, eye protection

Facility: Tech-E Lab

Procedure:
1. Finish assembling the motors and drive shaft.
2. Lock the end of the drive shaft, so no movement can occur.
3. Startup motor and slowly increase until at full torque.
4. Turn off the motor and observe the drive shaft to see if any changes have occurred.
5. Record Observations.

<table>
<thead>
<tr>
<th>Test #</th>
<th>Observations</th>
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<tbody>
<tr>
<td>1</td>
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</table>

Results:
After observing the drive shaft integrity, the drive shaft will have passed this test if there is no damage that occurred. If the drive shaft breaks then the test will be a failure.

Test Date:
Test Results:
Performed By:
**Team:** F75 Universal Treads

**Test Name:** Bracket/Axle strength test

**Purpose:** The purpose of this test is to verify how much weight the bracket and axles can hold without deforming due to strain/stress.

**Equipment:** Top pillow block, shaft collar, and axle,
   Bottom pillow block, shaft collar, and axle.
   Scrap platform
   Fasteners
   String
   Varying weights

**Hazards:** Heavy weights can cause pinching. Suspended weights may fall. Heavy weights must be lifted properly and by two people.

**PPE Requirements:** Work gloves to hold heavy loads, close toed shoes.

**Facility:** Tech-E lab

**Procedure:**
1) Acquire materials needed for test.
2) Set up the test apparatus by fastening the pillow blocks to the test platform.
3) Insert the axles in the respective pillow block and constraint them with shaft collars.
4) Attach string to different weights and hang them by the cantilevered axle.
5) Repeat step 4 with increasing weights.

**Results:** Pass Criteria, Fail Criteria, Number of samples to test

This test will be a pass/fail criteria test. If the axles and pillow blocks can suspend increasing weight up to the specified weight determined through calculations, this test will pass.

**Test Date(s):** March 31, 2022

**Test Results:**

**Performed By:**