Brush Clearing Tool -- Trimmer Assembly

Senior Project Report

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Statement of Disclaimer

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Abstract
The Final Design Review (FDR), this report, encompasses the work done by three Cal Poly Mechanical Engineering seniors along with two other teams of four (members each) for Brian Rois-Mendez. Originally, Dr. Mendez presented his idea to clear overgrown brush along trails. Our main purpose was to eliminate the drawbacks of his prototype and improve where we saw fit. For our team specifically, to reduce the workload of clearing brush, we focused on designing a seamless vertical and horizontal adjustment as well as increasing the trimmer’s cutting power. This report will cover the details of said evolutions.

Since the Critical Design Review (CDR), there have been a few design changes and a significant number of additions – all of which have reasons explained further in this report. We found a lot of alternatives for future recommendations as well. After going through this document, the reader should walk away with an understanding of how our subassembly well enough to be able to theoretically build it themselves given the necessary tools.
Introduction

Our team is composed of three mechanical engineering students attending California Polytechnic State University, San Luis Obispo: Juan Martinez, Paula X. Ortiz-Arango, Jayson R. Salvador. This FDR contains the prototype we presented to our sponsor, Brian Rois-Mendez. The main objective of our trimmers was to be able to cut between one to two inches thickness of wet and/or dry brush while adjusting vertically and horizontally while moving forward effectively with little to no effort from the user. Besides the final design, this report provides the justification behind the design choices. Additionally, we report everything we learned from building the prototype and draw conclusions for future manufacturing planning.

To fully encompass our year-long process, four parts, each with a report, are included below: Scope of Work, Preliminary Design Review, Critical Design Review, and Final Design Review. The SoW describes the background and research and established the needs, desired functions, objectives, constraints, and planned deliverables for the project. The goal of the Preliminary Design Review report was to obtain our sponsor’s approval to move forward; the PDR contains our first chosen design direction and the justifications supporting our decisions. The Critical Design Review reports fully fleshed out design details and changes and how our system functions. Along with the failure mode and effects analysis, the CDR has the iterations before coming to our last design. The Final Design Review, part four, contains any new material since the CDR.
Brush Clearing Tool – A. Trimmer Assembly
Part I: Scope of Work

October 13, 2021

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Abstract

This scope of work outlines the engineering process that our team will go through at California Polytechnic State University, San Luis Obispo for Brian Rois-Mendez of Rogue Path. The Rogue Path is an all-electric machine created to easily clear brush across various terrain while keeping the user’s usability and comfort in mind. Our subsystem’s main concern is to innovate the current trimmer system on the Rogue Path. Current issues include the trimmers not having enough power to cut down thick brush and the system’s complex positioning system. Our goal for the Rogue Path would be to clear out common California-based brush; in turn, this will help mitigate wildfires along highways and trail systems.

The final goal of our sub system is to find a way to correct this problem so that it has no problem clearing brush ranging from ½ to 2 inches in diameter. We have also compiled all our research within the scope of work. This research includes and is not limited to competition, components, patents, brush clearing methods, and safety regulations research. We conducted this research to further enhance our understanding of the challenge of clearing brush. Based on this research we have also found the most common plants and their dimensions found along highways and trail systems in California. We will be taking these plants and their dimension in mind for our designs. After discussion our research, we developed the various requirements and benchmarks that we will use to test our design. The scope of work also includes our sponsors constraints and timeline for the completion for the project. These constraints helped in our innovation process of the trimmers and mounting system. Our expectation will be to finalize the project by May 27th, 2022.
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1.0 Introduction
Our team, the Brush Trimmer team, is comprised of three mechanical engineering students studying at California Polytechnic State University, San Luis Obispo. The problem presented by Brian Rois-Mendez, a retired veterinarian, is to redesign a trimmer prototype focused on clearing out brush while walking along a trail. Mr. Mendez proposed that his initial prototype be broken up into three subsections, the trimmer, drivetrain, and chassis. This Scope of Work is specifically for the trimming section on his mechanical system and how they will cut brush effectively. The problem more specifically that we need to tackle is how to trim thick brush with the constraints and criteria presented to us: weight and cost restrictions, safe, limited power supply (rpm), and at least 3 degrees of freedom of motion. The main objective of our team is to design the most effective trimmer head attachment; in other words, the important process of how the trimmer heads will be removing brush as effectively and efficiently as possible.

The purpose of this project is to develop a safe, dependable and easy process of cutting brush to prevent wildfires. Ideally the process developed will cut the man hours required to clear land significantly. This new trimmer head attachments will be a major improvement over the current Rogue Path prototype. It will hopefully have a varying speed feature that will come along with an intuitive display interface.

The team working on this project includes Jayson Salvador, Juan Martinez, and Paula Ortiz-Arango, who are all mechanical engineering majors in their senior year at California Polytechnic State University, San Luis Obispo.

This document includes background information necessary for understanding the problem at hand in better detail, criteria, background research, related patents, competitor information, the results of the preliminary design process, and timeline.

2.0: Background
For our preliminary research about the product, we wanted to start by having a complete understanding of the problem that we are solving. This research was done through interviews with Mr. Mendez about his current product, online records that indicate the rise in fires across California, and an interview with a Southern California forest worker. Based on our findings, there will always be a need for trail maintenance and brush clearance. Our goal with the final design would be to alleviate the current trail management workers from their current methods of brush clearance. All the details in the results of our research can be found in the remainder of this section.
2.0.1 Brush and Plant

First, we needed to learn what type of foliage we plan to cut. According to CalFire, the top twenty largest California wildfires happen in southern California and in the northern bay area. From there, we researched what plants are common amongst these areas [1].

According to the *Physical Characteristics of Some Northern Californian Brush Fuels*, written by the Forest Service of the U.S. Departments of Agriculture, there are five main plants: Greenleaf Manzanita, Snowbrush, Chinkapin, Mountain Whitehorn, and Bitter Cherry. These brush species’ heights range from 1 ft to 8 ft tall. The handbook also describes “the foliage [being] waxy and often sticky…” (page 6) [2]. We need to keep in mind when testing; we will be working with dry, wet, sticky, and other textured plants. There is also a large range in the flexibility of the stems. Some brushes have short, rigid branches and others flexible branchlets.

2.1: Need for the Problem

In 2020, according to the National Interagency Fire Center, California experienced over 10,000 fires that burned over 4,000,000 acres of land [3]. According to the California Department of Forestry and Fire Protection, the 5-year average from 2006 to 2010 was 7,881 fires that burned about 1,000,000 acres [4]. With the increase in fires, there has been a need for fire mitigation through brush clearance. According to LA Fire Department, property owners and forest services must follow guidelines for the distance of cutting brush. For example, native brush must be trimmed 1/3” from the ground or any heavily populated brush shall be 200’ away from structures [5].

Because our team had little experience with brush clearance and the methodology of clearing out California native brush, we interviewed somebody within the forest service. Mr. Solomon has volunteered, interned, and worked with the forest service for over 4 years. He has experience in brush clearance, trail maintenance, invasive species removal, and conservation education. Our meeting with Mr. Solomon was intended to learn about the current methods of clearing brush and issues while utilizing some method.

Based on Mr. Solomon’s experience, the plants that reside in a trail vary depending on the area in which it is located. In Southern California, it is common to see more dry thinner brush; while in Northern California, the plants have more moisture making it difficult to cut. However, in all cases, he encounters brush smaller than 2” of diameter.
There are still specific tools that are dependent on the environment. For example, you cannot utilize a weed-whip for places that contain lots of tangled brush because the string on the head of the weed-whip become stuck within the brush. In terms of working on most sites, there a few common tools that forest workers will bring; this includes a weed-whip for trails that just need cleaning, lawn mowers for flat trails with a large amount of brush, chainsaws/hedgers for brush such as logs or large branches and hand tools such as a Pulaski or a McLeod for any type of work environment. While talking with Mr. Solomon, he discussed how some common problems with the tooling include an occasional hit from the cut brush after utilizing the weed-whips and the long durations under the sun while carrying heavy equipment. Another constraint that he informed us about was the market’s need for electric equipment. Because of the risk of a fire from the gasoline powered equipment, the forest service is looking to find new, effective products powered by electricity. Overall, the discussion with Mr. Solomon provided us with valuable insight in regard to the project’s scope.

2.2: Current Components on the Prototype that Require Improvement

When being presented with the prototype of Rogue Path, there were four primary sections that our sponsor wanted to redesign. These four sections consisted of the trimmer heads, trimmer controls, the motor powering the trimmer, and the adjustment mechanism. All the components currently on Rogue Path are off the shelf parts that anyone can purchase. All current components are all also functional when looked at individually but as a unit they lack friendly usability as well as power.

2.2.1: Trimmer Heads

The current trimmer heads barely cut through wet and heavier brush. One issue that this might be attributed to is having too low of rpms.

There is a significant amount of varying trimmer heads. We decided to eliminate immediately any trimmer head with metal attachments because there are no guaranteed sparks if there are no conductive materials. With the potential of selling to CalFire, it is easiest to comply with Los Angeles Fire Department’s restrictions on the use of certain metal cutting blades (ordinance no. 185789) [6].

With limited material, excluding metal, the options are narrowed further. Trimmer line is also what the current prototype is using because if offers an easy and replaceable option. Although, there is also a limited market on the options of trimmer line material; most being made of reinforced composite nylon materials for extra strength. We will need to conduct tests for our specifications (desired length and rpm) to determine which trimmer line would be the most effective.

Finding the most appropriate trimmer width and profile shape can also have a lot of range. E-Replacements’ website offers a guide outlining a simple table for the optimal options, shown in Table 2.2.
Ideally, our team would match either a pre-cut line or spooled line for very heavy work (which is brush that is above 0.110 inches thick) but there is limited power supply [7]. We are assuming will not be able to have such a thick trimmer line unless we are able to increase the revolutions per minute but will need to test this first.

Table 2.2: Trimmer Line Buying Chart

<table>
<thead>
<tr>
<th></th>
<th>Pre-Cut Line</th>
<th>Spooled Line</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Light to Medium Work</strong></td>
<td>0.065” 5-Sided-Line</td>
<td>0.08” Round Line</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Medium to Heavy Work</strong></td>
<td>0.095” Square Line</td>
<td>0.095” 5-Sided Line</td>
</tr>
<tr>
<td></td>
<td>0.099” Serrated Line</td>
<td>0.105” Square Line</td>
</tr>
<tr>
<td><strong>Very Heavy Work</strong></td>
<td>0.130” Square Line</td>
<td>0.130” Twisted Line</td>
</tr>
<tr>
<td></td>
<td>0.168” Serrated Line</td>
<td>0.170” Square Line</td>
</tr>
</tbody>
</table>

There are a few options to increase RPMs. If speed is constant, then the back-emf must also remain constant. Then, the only way to increase torque is to increase the current increase the supply voltage.

The benefits of a blade that trimmer line does not have is durability, additional strength, and robust. Ideally, the blades would not be replaced anywhere nearly as often. The disadvantages of a brush cutter are that they are generally heavier than string trimmers and therefore more cumbersome.

From our research, we came across an interesting concept that combines the line and blade concept that results in getting the benefits of both (see Fig. 2.1) [8].

![Figure 2.1: PivoTrim Rino String and Bladed Trimmer Head Replacement](image-url)
This option seems to have the potential of meeting out needs because we expect the trimmer line will cut the thinner brush, leaving it exposed and easy to clear thicker brush with hard plastic blades. No runs or research has been conducted on this dual-wielding concept that is available online so tests will have to be made before choosing this route. Using off the shelf parts, there is the potential we simply build a new trimmer that meets out needs more precisely.

2.2.2: Trimmer Controls

The current market has a wide variety of controls that can be considered for motor control. Research based solely on controls was needed to see what would benefit our product. The current version of Rogue Path has thumb throttles that are used to vary the speed of the motor. This type of controller is cheap and easy to manufacture because it does not have any locking mechanisms to hold the speed desire or have an on/off mode [9]. See Figure 2.3 for the current controllers on the prototype.

Currently, the method of controlling the motor speed is based on varying the voltage feed to the trimmer motor. There is a linear relationship between the current and torque as presented in Figure 2.4. In this figure we can see that as we increase current there will be an increase in torque [see Figure 2.4]. This also means that as we increase current, the speed will increase but torque will be lost.
When the voltage to a motor is varied then the torque of the motor is increased. As depicted in Figure 2.5, we can see multiple linear relationships with torque and speed as the voltage is changed. This also means that we can have a fixed speed of the trimmer and if we are varying voltage then we will have control of the torque (see Figure 2.5) [10].

Based on these graphs the speed of the motor is both controlled by the current and the voltage. This is because when we are controlling the speed of the motor the real factor that is being changed is the resistance of power to the motor. According to Ohms law, see Figure 2.6, The resistance relies on both the current and voltage being provided.
2.2.3: Trimmer Motors
The component significant to the performance of our device is the motor. It is the key component that
controls the trimmer head’s speed and the total amount of power that our machine will output. Our current
motor system is a large torque gear motor, shown on Figure 2.7, that is connected directly to a shaft that
spins the trimmer heads [11]. Although stated that the motor has a large torque, based on Mr. Mendez’s
issues with the trimmer not having enough power to cut through thicker branches, the chosen motor
doesn’t provide enough torque to cut the desired brush.

According to Groschopp Engineering, the motor is dependent on numerous factors: the input power
source, the environment of operation, the motor specs, and the motor’s performance. For the input source
of our project, we will be using a DC power supply that ranges from 40 V to 80 V, depending on the
options available. The environment will be dusty, hot and may encounter water. Therefore, the rating for
Ingress Protection rating, a rating that designates the type of environment a motor is intended to operate
in, of the chosen motor should be at least a 6 [12]. The motor’s specs are a flexible consideration, but in
its maximum, the motor should be able to easily conform to the trimmer head’s shaft. Lastly, the chosen
motor should provide high enough torque to remove any branches that is 2” thick or thinner.

The type of motor that we will choose depends on the type of performance that we expect from the
trimming system. According to Groschopp Engineering, there are four types of motors currently on the
market. They include universal, brushed, induction, and brushless motors. For a summary of the different
performances of the motor, refer to Figure 2.8 [12].

![Motor Performance Chart on the 4 Types of Motors.](image)

In summary, because we want more torque of the overall speed of the motor, the expected motor we will
utilize is the DC Brushless motor.
2.2.4: Trimmer Adjustment Mechanism
The current adjustment mechanism on Rogue Path is a circular device with multiple adjustments positions. This current method of adjustment is functional and achieves the goal of being very versatile to any positions, but it does lack the user friend feel. Figure 2.9 depicts the current locking mechanism that Rogue Path current has. As a team we will go through the ideation process to make it a more user friend device.

![Current locking mechanism](image)

**Figure 2.9: Current locking mechanism**

Things that we will need to consider when designing a new locking mechanism is the constraints provided. The trimmer must have at least 3 degrees of freedom. These degrees of freedom are the up and down, side to side and rotation motion of the trimmers. This means that there will be a change in the degrees of freedom that Roque Path current has but making it simpler will result in a more user-friendly product.
A linear track is a piece of material that contains rails where a carriage of some sort can ride on (see Figure 2.10) [13]. This method of adjustability is limited to only an up and down or side to side depending on how it is oriented. A possible way to lock the carriage would be to use a spring-loaded pin as shown in Figure 2.11.

This pin design is a simple one that can make the locking of multiple positions a lot more user friendly. The only issue that will need to be considered will be how much movement will this allow and if it will affect the way the trimmers are mounted [14].

2.3: Product Research

In order to get a base expectation of what our design should be able to achieve, we looked at our competitors.
2.3.1: D R Pulse
According to Mr. Mendez and Mr. Solomon, the DR Pulse, shown on Figure 2.10, is the current mower on the market that has a high efficiency in brush clearance while being operable in some terrains [15]. It is powered by a 62V lithium-ion battery and its 850W motor makes it comparable to many gas-powered mowers on the current market. However, the downside to this product is within its weight and maneuverability. According to Mr. Solomon, the motor’s performance was fantastic in cutting thick branches; however, it was difficult to maneuver within the trail. For front yards, the device works perfectly since everything is flat, but in locations where you will be constantly maneuvering in various terrains it will become a hindrance.

![Figure 2.10: DR Pulse 62V Mower](image)

2.3.2: Greenworks 80V 16” Brushless String Trimmer
The Greenworks 80V 16” Brushless String Trimmer, shown on Figure 2.11, is a high-powered electric weed-whip [16]. The following hand-held trimmer operates when the user powers the device with the trigger. Once powered, the operator has complete control of the speed, direction of the device. The head of the device is limited to .095” twisted line; to release more line, the user has to bump the head and power the machine. Based on reviews of the product, the device’s batteries can last upward to ¾ acres. Although effective, the downside is the device weighs about 15 lbs. After long durations of work, the weight of the device may become a hinderance.
2.3.3: Southland 17” Walk Behind String Trimmer

The Southland trimmer, shown in Figure 2.12 is a hybrid between a lawn mower and string trimmer [17]. It has an adjustable trimmer head that swivels and bevels for trimming along walls and fences. The head swivels to 20° and 30° for trimming along fence/wall in a straight line and bevels to 5° and 10° for precision trimming along landscape border. This mower is a typical drive push with recoil start and has a cutting width of 17 inches and a weight of 42 pounds. The Southland trimmer allows you to choose between 0.095” or 0.105” line.

2.3.4: Generac PRO 8.0 Walk Behind Trimmer Mower

According to Tractor Supply’s website, the Generac PRO 8.0, shown in Figure 2.13 has an adjustable height range of 2 – 3.5 inches with a width of 22 inches and is 71 lbs [18]. The walk-behind trimmer operates at 3,600rpm (only one speed) with gas-powered tank that gives 4.96hp. There is a total of four trimmer strings and is meant for up to 1-acre yards. Reviews say it cuts weeds up to 4ft tall and has long lasting coil (which is a Generac specific brand). This mower operates like your typical lawn mower with an OHV engine and recoil start.
2.3.5: DR Field and Brush Mower
The DR Field and Brush Mower, shown in Figure 2.14 claims that it can handle up to 2.5-inch diameter brush [19]. The machine is powered by a 14.5 HP gas engine and has electric starting function. The device also has power steering to allow mowing on slopes. It can cut 4-8-inch-tall weeds and it has a cutting width of 26 inches. Each individual wheel can lock. There are also multiple attachments that can be used on it. This machine comes in at 290 lbs. Users reviews mention that the mower does that work fine, and all the controllers were intuitive. Some mention that it was too heavy and that it was just hard to maneuver in tight spaces.

2.4: Patent Research
In order to get more insight on what not only is currently on the market, patent research will also need to be conducted. It is vital to consider patents because they might not be on the market. Patents can also hold intellecte rights that might limit our design process. We will use the patent research to gain some insights of what others have done to solve similar problems and things to avoid or aim towards. Below are some of the many patents related to our product.
One our main considers along with making the trimmers power and reliable is to ensure that it is safe to operate for the operator. It is also important to consider that Rogue Path's trimmers currently spin in the opposite direction. The left trimmer spins in a counterclockwise direction while the right spins in a clockwise direction. The current trimmers do not have their protective guards on them because they no longer serve their function of cutting the trimmer line if it gets too long. This means if we are going to consider adding back the guard, we will also need to consider how the trimmer line will be cut because the guard contains a single directional blade meant to cut the line. We need to be considering the safety of the user. The guard not only cuts the trimmer line if it is too long, but it also shields the user from rocks or debris that the trimmers can launch. In Figure 2.15 contains a depiction of a guard with a blade that can be turned into a unidirectional [20].

![Figure 2.15: Guard with a Blade.](image)

This patent was filed by Black and Deck and is currently active. The current patent was awarded in 2019 and it will not expire until 2035.
It is also important that when considering the ideation of the trimmers there is a need to make the trimmer hold more line so that the user does not have to constantly replace it. Figures 2.16 and 2.17 are examples of such a device [21] [22]. Both function in a similar way. They can hold multiple feet of line and it is able to release more line on command. They both have a center body that has a loading mechanism that unlocks when the bump switch is hit. The loading device has teeth in only one direction and when the bump switch is pushed the mechanism is able to spin and release more line.

**Figure 2.16:** Trimmer head with wind up line system

This current mechanism was filed by Torvent LLC but was abandoned as of 2019. This means that this current design is available to us. We can base our design on this current model.

**Figure 2.17:** Trimmer head with different bump switch
This trimmer head patent was awarded to MTD Products Inc. in 2019. This patent like the previous was also abandoned as of 2019. This is another design that is available for us to use in our innovation process.

When considering how to ensure that the trimmers cut through the desire brush, we need to look at different ways that others have tried to solve this issue. One of the solutions in a patent was to use a blade and a traditional trimmer line at the same time. This would enable the user to cut through thin brush with the traditional line trimmer. To cut the larger diameter brush the blade would be utilized to cut it. In Figure 2.18 the blade and trimmer line head are both used at once [23].

![Figure 2.18: trimmer head with blades and line](image)

This current patent was filed in 2016 and it was awarded in 2018. The current patent is still active and will not expire until 2036. This means that this exact solution is off the table but can still be used in our innovation process.

The locking mechanism needs to be easy and intuitive for the user and this is a much bigger challenge than the other two but a possible solution from the patent research is the use of a channel lock with a spring-loaded pin. This would provide a quick and intuitive feel for the user. Figure 2.19 provides this design [24].
This current patent was filed in 2019 and is currently still active and will not expire until 2039. This is only a potential way to tackle our locking of positions issues. It was brought up to inspire our innovation and to keep away from doing this design exactly.

### 3.0: Objectives

The following section entails the objectives in the design project. It is structured with an overarching problem statement encompassing the scope of our design followed by a visual representation of theoretical end product. Once the scope is defined, we will describe the overall requirements and needs to constrain our focus of the project.

#### 3.1: Problem Statement

From the increase in fires, there has been an increased need for brush maintenance in California. Current brush clearance methods require extraneous labor from the user. Mr. Mendez presented an initial prototype that utilizes a mowing system utilizing two trimmers on the mechanism’s sides. However, with the current prototype, future users such as landscapers or forest workers would experience inefficient cutting power when encountering thicker plants, a heavy drag when pulling the machine, and tilting wheels when the machine is at rest. Specifically, for the trimming section, it lacks the power to cut thicker branches. Overall, the new design should be able to cut down ½” to 2” diameter brush along trails,
forests, and steep inclines. Figure 3.1 illustrates our team’s boundary system and the environment in which it will perform.

![Figure 3.1: Boundary Sketch of the Project Scope](image)

### 3.2: Needs and Wants Table

Table 3.1 outlines the different customer’s needs and wants for the project. This list was generated from conversations with Mr. Mendez and his personal constraints for the project. In general, the needs column describes the specific constraints that will be the primary source for any design consideration within the project. In terms of the wants column, this list will describe what the best possible product will include when it comes to aesthetics, functionality, etc.

**Table 3.1:** Needs and wants table based on the primary customer Mr. Mendez.

<table>
<thead>
<tr>
<th>Needs</th>
<th>Wants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuts Brush up to 2” in Diameter</td>
<td>Ability to Switch the Heads Depending on Job</td>
</tr>
<tr>
<td>Off the Shelf Components</td>
<td>Inexpensive</td>
</tr>
<tr>
<td>Operates in Dusty/rainy Conditions</td>
<td>Ergonomic</td>
</tr>
<tr>
<td>Have 3 Degrees of Freedom</td>
<td>Voltage Interface Easily Understandable</td>
</tr>
<tr>
<td>Complies with Safety Codes</td>
<td>Lightweight</td>
</tr>
<tr>
<td>Completely Electric</td>
<td>Easy to Assemble</td>
</tr>
</tbody>
</table>
3.3: Quality Function Decomposition (QFD)

After finalizing our problem statement and the direction in which we will take this project, we focused on determining a benchmark for the different needs and wants for our customers. To do this, we utilized a methodology called the Quality Function Decomposition, or the House of Quality. The QFD works by listing all of the possible customers that will interact with the product. From there, all of the needs and wants are listed and graded based on its relation to the customer. After this, any competitive products that is similar to the problem statement are listed and graded. Then, specifications are listed for conducting measurable tests on the correlating need and want. After listing the specifications, a benchmark is developed based on the competitive products’ standard. The benchmarks for the final design are listed in Table 3.2. The complete QFD is shown in Appendix B.

Table 3.2: Engineering Specifications Table

<table>
<thead>
<tr>
<th>Spec.#</th>
<th>Specification Description</th>
<th>Target (units)</th>
<th>Tolerance</th>
<th>Risk*</th>
<th>Compliance**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cuts Wet/Dry Brush</td>
<td>2” Thick</td>
<td>Max</td>
<td>H</td>
<td>A, I, T</td>
</tr>
<tr>
<td>2</td>
<td>RPMs of Trimmer Head</td>
<td>4000 rpms</td>
<td>Min</td>
<td>H</td>
<td>I, S, T</td>
</tr>
<tr>
<td>3</td>
<td>Motor Resistant to Dust</td>
<td>IP #6</td>
<td>Min</td>
<td>M</td>
<td>A</td>
</tr>
<tr>
<td>4</td>
<td>Number of Custom Parts</td>
<td>2</td>
<td>+/- 2</td>
<td>L</td>
<td>I</td>
</tr>
<tr>
<td>5</td>
<td>Cheap</td>
<td>$1000</td>
<td>Max</td>
<td>L</td>
<td>A, I</td>
</tr>
<tr>
<td>6</td>
<td>Comfortability Surveys</td>
<td>80%</td>
<td>Min</td>
<td>L</td>
<td>T</td>
</tr>
<tr>
<td>7</td>
<td>Weight</td>
<td>150 lbs</td>
<td>Max</td>
<td>M</td>
<td>I, T</td>
</tr>
<tr>
<td>8</td>
<td>Number of Components</td>
<td>20</td>
<td>Max</td>
<td>M</td>
<td>A, I</td>
</tr>
</tbody>
</table>

* Risk of meeting specification: (H) High, (M) Medium, (L) Low

** Compliance Methods: (A) Analysis, (I) Inspection, (S) Similar to Existing, (T) Test

For the final product, the end objective would have an efficient cutting mechanism. This would require our product to cut 2” wet/dry brush and meet the minimum RPMs of our competitors. In terms of the other important specifications, anything relating to the functionality of the part will be our preliminary concern followed by the aesthetics and affordability.

4.0: Project Management

An important component for any project will be to plan for the completion of the project. To do this our team will be utilizing the Engineering Design Process presented in Figure 4.1 [25]. It is important to note that this process is not a closed looped; instead, it is iterative. This means that any part of the process can
be revisited no matter the current stage of the process. For example, when we reach a prototype and the tests performed on the prototype fails, then we will go back and redesign until a satisfying final solution is reached.

Figure 4.1: Engineering Design Process

To track the process of where the team is currently at in the Engineering Design Process, we will be utilizing a Gantt Chart. The Gantt Chart will be used to keep records of the completed tasks all the way until the final deliverable. Present in appendix A is the Fall Quarter Gant Chart which displays all of our tasks and important milestones from the start to the delivery of the project. Table 4.1 indicates the most vital deliverables and dates present. This table includes all the dates from Fall to Spring Quarter.

Table 4.1: List of Important Dates and Deliverables

<table>
<thead>
<tr>
<th>Date</th>
<th>Deliverable</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/19/2021</td>
<td>List and Drawings of Ideations</td>
</tr>
<tr>
<td>11/9/2021</td>
<td>Ideation Results and Prototype build</td>
</tr>
<tr>
<td>11/30/2021</td>
<td>Prototype Analysis</td>
</tr>
<tr>
<td>1/27/2022</td>
<td>Plan for Manufacturing</td>
</tr>
<tr>
<td>2/15/2022</td>
<td>Risk Assessment</td>
</tr>
<tr>
<td>3/10/2022</td>
<td>Manufacturing Testing</td>
</tr>
<tr>
<td>4/12/2022</td>
<td>Final Testing Results</td>
</tr>
<tr>
<td>6/3/2022</td>
<td>Final Report and Project Turned in to Sponsor</td>
</tr>
</tbody>
</table>

For the testing and analysis of our prototypes, Finite element analysis (FEA) will be utilized using Fusion 360. Excel iteration tools will also be used to calculate factors of safety (FoS). This will enable us to provide the safest product for the user.
5.0: Conclusion
This statement of work is meant to be an agreement between our trimmer team and Brian Mendez about scope of the project. This document hopefully encompasses and compiles all the information, diagrams, tables, and interviews used in the project thus far. The next major deliverable, the preliminary design review, will be completed on November 18, 2021, and will contain details on our ideation process, lead concept and design choice.

6.0: References


[] “High power large torque motor 775 795 895 DC 12V~24V 3000-12000rpm bracket new,” *eBay*.

[] “Electric bicycle scooter accelerator thumb throttle speed without handlebar,” *Walmart.com*.

7.0: Appendix

Appendix A: GANTT Chart
Appendix B: QFD

![QFD Diagram]

- **Correlations**
  - Strong (+)
  - Moderate (0)
  - Weak (-)

- **Direction of Improvement**
  - Maximum (△)
  - Target (O)
  - Minimize (▼)

- **WHO: Customers**
  - Column #

- **WHAT: Customer Requirements (Weeks/Year)**
  - Column #

- **HOW: Engineering Specifications**

- **HOW MUCH: Target Values**
  - Max Relationship
  - Technical Importance Rating

- **Our Current Product**
  - Relative Weight
  - Car Part Count
  - Weight

- **Our Current Product**
  - Column #
Brush Clearing Tool – A. Trimmer Assembly
Part II: Preliminary Design Review (PDR)

PRESENTED BY

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November 11, 2021
Abstract

The Rogue Path, our sponsor’s company name for his current prototype, is composed of three subsystems: the drivetrain, chassis, and trimmer assembly. Our team’s focus is the trimmer assembly. This assembly consists of three other subsystems that went through ideation. Its subsystems include the adjustment of the trimmers, controlling the power for the trimmer, and the trimmer head.

This document consists of our initial ideations for each of these subsystems. A method called the functional decomposition was the first form of ideation. We used it to find the functions that were necessary for the final product. From there, our ideations focused on those finding ideas for those functions. This led to the team’s first brainstorming session. Using the functional decomposition, we developed “How Might We” questions that were entailed to solve issues the customer may come across. All ideas and suggestions were written in sticky notes and recorded in our team’s notebook.

A debrief session was then held to go over each other’s ideas and remove the ones that were not within our scope. From there, the ideas were placed in a Pugh matrix to ensure that each idea covered a specific function from the functional decomposition. Additionally, this was used to score the ideas based on the current prototype from Rogue Path. We then used a morphological matrix to select a combination of these ideas from each Pugh matrix. This resulted in six unique solutions to the overall problem. To find out what characteristics carry more weight, we had a session where we graded each characteristic. This was vital to our weighted matrix because each of these characteristics help to grade our solutions. The result were concept models that would be the most effective in fulfilling the specifications of the project.

The highest graded model was picked from our weighted matrix. It was solution 3 that took first place. This solution consisted of a 4 bar connect to a linear slide for the up and down motion and a ratcheting locking system for our side-to-side movement. The use of a throttle was included in this solution for the control of the speed of the trimmers, that solid works model was created to test movement and physical constraints. This model was then used to create a functioning concept model that performs the desired function.
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1.0 Introduction

Our team is comprised of three mechanical engineering students studying at California Polytechnic State University, San Luis Obispo. The team working on this project includes Jayson Salvador, Juan Martinez, and Paula Ortiz-Arango, who are all mechanical engineering majors in their senior year at California Polytechnic State University, San Luis Obispo. The problem presented by Brian Rois-Mendez is to redesign a trimmer prototype focused on clearing out brush while walking along a trail. Mr. Mendez proposed that his initial prototype be broken up into three subsections, the trimmer, drivetrain, and chassis. The main objective of our team originally was to design the most effective trimmer head attachment; in other words, the important process of how the trimmer heads will be removing brush as effectively and efficiently as possible. After some concept development, as shown in this report, our focus shifted. Although we will consider ideas for the trimmer head, we want to develop the most effective adjustment system. After developing one that meets our specifications, we will further look into the rest of the trimmer assembly.

This document includes our combined ideas, and our concept ideation processes that lead to our final design concept. The first part of the report is the concept development where we talk about what and how we came up with our initial ideas; essentially, our ideation process. Next, we explain our design concept in greater detail. The team used different matrices to a consensus. We wrap up the report by justifying said choices.
1.1: Concept Development

After fully understanding our scope for the project, we were able to properly attack the problem. In this section, we described the process that resulted in our final solution. The ideation process for our team included performing functional decomposition, having ideation sessions, creating Pugh and weighted matrices, and creating functional prototypes.

1.1.1: Functional Decomposition

Prior to brainstorming any ideas, we developed a functional decomposition graph to grasp the different functions our final device would have to accomplish. The way that a functional decomposition graph works is that the final device is listed on the top. From there, we considered the main functions the graph would have to accomplish. Based on relevant customer needs, we developed subfunctions required to accomplish the main function. Any other subfunctions that are relevant are listed with its correlating subfunction. Our functional decomposition is shown on Figure 1.1.

![Figure 1.1: Functional Decomposition](image)

From the functional decomposition graph, we classified 2 main categories that our device should accomplish. The primary function of the device is to cut brush. While cutting the brush, we want to have the trimmer cut it quickly and effectively and to ensure the user is not affected by the immediately cut brush. The second function the device should be ergonomically adjustable vertically, horizontally, and rotationally. After adjusting, the device should lock in place. From the function decomposition, we focused our brainstorming on finding solutions to these functions.
1.1.2: Ideations

To develop multiple concept ideas for our trimmer head assembly, our team’s ideation processes after the functional decomposition included different kinds of brainstorming sessions: “How Might We?”, individual, and brain dump.

First, the various ideas generated to achieve each of the sub-functions, compiled in Appendix A, were produced because of a “How Might We?” brainstorming session. Essentially, we wrote questions that pertain to the functions we got from out functional decomposition. These questions are also compiled in the appendix. Then, we did five-minute intervals of brainstorming for every three questions. The goal here was to produce numerous ideas regardless of the feasibility or sensibility. The team wrote their ideas on sticky notes and placed them under the corresponding question. For example, a question might be “How might we achieve locking the trimmer head into place?” The sticky notes below it might include a sketch of a mechanical system or a description of an application.

After an initial team brainstorming session, we individually built ideation prototypes. These prototypes were simple and not functional. The sole purpose was to present a visualization of our ideas and hopefully develop new ideas while building those prototypes. For this session, we decided to focus on the trimmer head and mechanical arm adjustment, because these two concepts were the basis for the functionality of our device. Our sponsor put the most emphasis on this system during our meetings. During the simple prototype session, we spent two hours creating simple models out of cardboard or foam. These models and a description about them can be seen in Appendix B. Each model took 15 minutes to create because the purpose of this session was to make as many models as possible.

1.1.3: Pugh Matrixes

Going through the different ideation methods resulted in over a hundred ideas for the whole part. Because judgement on each other’s ideas was neglected throughout the ideation process, many of the ideas were unrealistic; therefore, those ideas were removed. This left us with feasible ideas correlating to one aspect of the device. We separated those ideas based on the function they fulfill. The functions include controls, safety, an adjustment system, and the trimmer head. After having the best ideas for these categories, we utilized a Pugh Matrix to compare each idea to the current prototype.
The Pugh matrix is a method to compare ideas with a “datum”. In our case, the datum, the standard expectation to beat, is Mr. Mendez’s current prototype. Each Pugh matrix will be based on one of the four functions: controls, safety, adjustment system, trimmer head. After separating the ideas into one of these functions, we took the best ideas and added them to the Pugh Matrix to be compared. Each idea will be compared to the datum based on the specification that relates to it. For example, a specification for the adjustment system is that it must be ergonomic. The ranking system for the Pugh Matrix was given as (S), (+), or (-) for same, better, or worse respectively. Therefore, if the brainstormed idea would theoretically perform better than the datum for the chosen specification, that idea would receive a (+) for that specification. All the Pugh Matrixes are shown on Appendix C.

1.1.4: Morphological Matrix

The morphological matrix shown in Table 1.1 displays the various ideas we had for each function of the trimmer head assembly. By choosing one idea from each column, we were able to create complete concepts for our trimmer assembly.

Table 1.1: Morphological Matrix

<table>
<thead>
<tr>
<th>VERTICAL MOTION</th>
<th>HORIZONTAL MOTION</th>
<th>TRIMMER HEAD</th>
<th>CONTROLS</th>
<th>SAFETY</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-Bar Lever</td>
<td>4-Bar Lever</td>
<td>Trimmer Line</td>
<td>Throttle</td>
<td>Heads Spin</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Opposite Ways</td>
</tr>
<tr>
<td>Bevel Gear</td>
<td>Bevel Gear</td>
<td>Line and Plastic Blade</td>
<td>Button</td>
<td>Trimmer Head Guard</td>
</tr>
<tr>
<td>Spur Gears</td>
<td>Spur Gears</td>
<td>Slotted Heads w/ Multiple Lines</td>
<td>Dial</td>
<td>Kill-Switch: Heat Sensor</td>
</tr>
<tr>
<td>Ratchet Gear</td>
<td>Ratchet Gear</td>
<td>Double Trimmer Line</td>
<td></td>
<td>Face Shield Near Handles</td>
</tr>
<tr>
<td>Spring Loaded w/ Fixed Positions</td>
<td>Spring Loaded w/ Fixed Positions</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Each team member came up with two combinations from our matrix and are listed in Table 1.2. The team was meant to consider feasibility and manufacturability as a priority while making their respected combinations. The six full concepts are in the table and figures below.
Table 1.2: Trimmer Assembly Full Concept Ideas

<table>
<thead>
<tr>
<th>Concept Number</th>
<th>VERTICAL MOTION</th>
<th>HORIZONTAL MOTION</th>
<th>TRIMMER HEAD</th>
<th>CONTROLS</th>
<th>SAFETY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bevel Gear</td>
<td>Ratchet Gear</td>
<td>Trimmer Line</td>
<td>Dial</td>
<td>Head Spin Opposite Ways and Trimmer Head Guard</td>
</tr>
<tr>
<td>2</td>
<td>4-Bar</td>
<td>Ratchet Gear</td>
<td>Trimmer Line</td>
<td>Throttle</td>
<td>Guard, Head Spin Opposite</td>
</tr>
<tr>
<td>3</td>
<td>Spur Gear</td>
<td>Rack and Pinion</td>
<td>Trimmer Head with Blade</td>
<td>Dial</td>
<td>Trimmer Head Guard</td>
</tr>
<tr>
<td>4</td>
<td>Bevel Gear</td>
<td>Spur Gear</td>
<td>Trimmer Line</td>
<td>Throttle</td>
<td>Trimmer Head Guard</td>
</tr>
<tr>
<td>5</td>
<td>4-Bar</td>
<td>Spring Loaded w/ Fixed Positions</td>
<td>Trimmer Line</td>
<td>Throttle</td>
<td>Guard, Head Spin Opposite</td>
</tr>
<tr>
<td>6</td>
<td>Spring Loaded w/ Fixed Positions</td>
<td>4-Bar</td>
<td>Double Trimmer Line</td>
<td>Dial</td>
<td>Guard, Head Spin Opposite, Kill-Switch</td>
</tr>
</tbody>
</table>

Figure 1.2: Concept 1

Figure 1.3: Concept 2

Figure 1.4: Concept 3

Figure 1.5: Concept 4
1.1.5: Weighted Decision Matrix

The weighted decision matrix in Appendix D compared the six full concepts against one another using our QFD’s weighted criteria. Each criterion – or specification – was ranked from 1-5, 5 being the best, for each of our combinations. The ranking was multiplied with the “weight” of each specification, and then added for a total value for each full concept combination. The best concept is determined by the highest-ranking total.

2.0: Concept Design

We determined the final concept design based on the concept that was ranked highest based off the specifications in the weighted design matrix.

For the adjustment system, the vertical motion will be controlled by a 4-bar mounted on a linear slide. As the user brings the linear slide up, the trimmer would move in the downward direction; the reverse would occur when the user brings the linear slide down. This is shown on Figure 2.1: For the horizontal motion, the concept utilizes a double rachet gear system. There will be two rachet gears stacked on one another and when the user presses the connecting button, the trimmer will adjust to the left and right. As shown on Figure 2.2, the rachet gear will be controlled with a tab that locks the rachet gear in place. When the button is pressed, the tab is released, and the user can rotate the system left and right. After the system is in its desired position, the user releases a button, and the trimmer locks in place.
Figure 2.1: Vertical Motion Controlled by a 4-Bar Mount on a Linear Slide

As seen on Figure 2.1, as the linear slide is brought downwards, the shaft connected to the trimmer head is brought upwards; however, when the linear slide is brought upwards, the shaft is brought downwards.

Figure 2.2: Horizontal Motion Controlled by a Ratchet Gear System

As for the ratchet gear system, we plan to have a spring-loaded stop in which when it is released, the gear can freely rotate and lock the gear in place when released.

For the cutting mechanism, we plan to utilize traditional trimmer heads because they are reliable and durable. Although traditional trimmer heads are not the most feasible in cutting thicker brush; if given the option, we would conduct future tests with a trimmer head that consists of trimmer line and plastic blades.
Because we want to optimize the effectiveness of the adjustment system, we will utilize traditional trimmer heads as a basis for our calculations. The way that traditional trimmer head works is that they utilize trimmer line that is enclosed inside of the trimmer head. After inserting the spool of trimmer line into the head, the user simply must bump the trimmer head and spin the head to release more trimmer line. Traditional trimmer heads can be seen on Figure 2.3.

![Figure 2.3: Traditional Trimmer](image)

To keep the user safe from the trimmers and the debris our primary safety mechanism has the trimmer heads spin outwards. In other words, the trimmers would be spinning in opposite directions to force the cut brush to be flung away from the user. As an added safety mechanism for the device, we will have trimmer guards mounted on the trimmer head. This will ensure that any debris that may fly inwards will first strike the trimmer guard. The final safety consideration would be to prevent any further damage from occurring when the device would overheat. Therefore, we will attach a kill switch to effectively stop any motion within the device in case it reaches high temperatures. The final assembled design can be seen in Figure 2.4.
2.1: Concept Justification

After going through multiple ideations for all three subsystems our team had to consider 6 unique combinations of solutions for our trimmer assembly. Using the weighted matrix and our intuition we found that solution 3 was the one we wanted to analyze. In each decision, we utilized our engineering intuition because we had no analytical data to judge objectively. Even though physical data and real-world results would be best to grade our solutions we have to consider what the drawbacks are. It would add cost to the overall budget because more research and materials would be needed.

The trimmer adjustment has 3 subsystems that each have specifications that our sponsor wanted to have. These included being able to move the trimmer head up and down, side to side and rotating the trimmers. To meet the up and down motion specification the 4-bar with a linear slide will be integrated into the trimmers. The reasoning behind the 4 bar is that it can carry a good amount of weight without issues. Although it is more complex than other systems, as a team we concluded that this would provide a more stable system for the up and down motion. The next specification that needs to be meet is the side-to-side motion and to accomplish this the use of a ratchet gear will be utilized. This ratcheting locking gear will allow the arm to move freely from the front to either side. Our sponsor also emphasized that these two motions should be done with a single input. To meet this specification the handle of the trimmer will have a button to release the locking mechanism of the ratchet gear. This way all the inputs for both motions will be on a single handle.
The trimmers themselves must be able to rotate along their input shaft axis. This is so that the trimmer head can be angle at whatever angle desired. This specification will be met with the use of a locking collar that requires only one input force to unlock. This will be used because it is much simpler than the bike collars on the prototype currently.

Safety was ranked number one for our weighted matrix and because it is a priority to us, we wanted to ensure that this was a speciation that was met first. We want the trimmer assembly to be as safe as possible for the user and as so the solution that we are moving forward with has this in mind. The trimmer head will have a guard on them to prevent debris from hitting the user. The trimmer heads will also be spun in opposite directions from one another, and ideally, they will be spinning so the debris is thrown in front of the user. This method will also help to clear brush from the front of the machine. The use of a kill switch will be used to prevent the machine from running the trimmers without the operator. This kill switch will stop the power going to the trimmer whenever the operator is not in contact with the machine.

2.1.1: Potential Concept Challenges
Although this is our current decision for our final design concept, we want to conduct further testing to ensure that this will be our finalized product because there were several factors that we did not consider for our system.

One potential issue for our design consists of the weight of the system affecting the adjustment mechanism. The goal for the trimmer assembly is for the adjustment system to carry the load of the trimmer assembly and any potential forces the user will exert on the machine. Therefore, we want to conduct Finite Element Analyses, an analysis method used to illustrate the potential failure points of a device based on critical stress values, on the adjustment systems to ensure that it can withstand any loads from the trimmer and the user.

Another potential issue would be the effectiveness of the locking mechanism. We have not constructed models of our current adjustment system working together, when the user wants to adjust both the vertical and horizontal position. With this, there is no fully defined way to lock and unlock the vertical and horizontal motions. Therefore, we plan to look more into depth with these concepts to develop a way for the adjustment mechanism to be locked.
One constraint we have not fully defined was the rotational motion of the trimmer head. Although we have potential concepts, we have not decided on the way we will rotate the trimmer head. Because this does not need to be adjusted while the trimmer head is operating, we were thinking of making the connection between the shaft and trimmer head rotate.

The final challenge would be the integration to the rest of the subsystems, drivetrain and chassis. Although we have a basic design, we do not know whether this design will obstruct any designs from the drivetrain and chassis. With the next phase of our project, we plan to work more closely with the two other teams to integrate our 3 solutions into one complete solution.

2.1.2: Concept Builds

To further analyze the feasibility of the chosen design, we decided to construct the 4-bar system and compare it with the gear and bevel system. The designs and construction of the designs are shown on the figures below.

![Figure 2.5: CAD Designs of the Spur Gear and Bevel Gear System](image-url)
Based on the following models, we learned that the bevel gear systems would require much more revolutions and the system would act similar to a crank system. Based on Mr. Mendez’s feedback, this system would not be ergonomic for the user. In terms of the spur gear system, the system is more effective than the 4-bar system in terms of changing positions. However, we do not know how it will work with the loads of the system. If the concept of the 4-bar does not work, we may further investigate the spur gear mechanism.

### 2.2: Project Management

The entire project will be done over the course of the school year. Each quarter will be a different step of the engineering design process. We have outlined the important deliverables due each quarter. The final prototype will be presented at the senior project exposition and final design review.

#### 2.2.1: Fall Quarter

For Fall quarter the focus was to identify the problem and how to go about solving it. It was also important for the quality of the solution to spend some time doing team building. It is important to from a team environment where communication is at the core because this will provide an environment where ideas and innovations can flourish. Once the team environment was set, we started to tackle the problem by first doing research about the problem that we are trying to solve. The main goal of Rogue Path is to try to cut down the work hours to clear bush. In doing this task Rogue Path will be helping to reduce the risk of fire hazards. Based on initial interviews with our sponsor we know that he mentions that he would like to potential sell his equipment to Cal Trans. This was important information because now we could understand what his end goal was and his targeted audience. We also used this information to conduct research on native plants in California because we needed to know what size of brush Cal Trans tackles daily. We also conducted interviews to get more insight on what a potential customer would want.
After the base research was completed, we were able to write the scope of work. This included all of research on the needs and background. The scope of work also includes the subsystem that will be focused on, the competition and some initial possible ways to solve the problems. Once this document was submitted to our sponsor and feedback was given from the sponsor, we started the ideation process.

The ideation process started with the decomposition of functions of the trimmer assembly. This was meant to deconstruct the functions that our subsystem needs to be able to do. This then led to the brainstorming sessions where we were then able to construct prototypes to the specific functions of the system. These were rough models that were meant to demonstrate our concept only. More refine ideation was done based on these models and a weighted matrix was used to pick the best one. Based on the weighted matrix a functioning concept model was created. This conceptional model will be used in our Preliminary design report presentation.

The Preliminary report was written to document the ideation process and the various other designs. This will be presented to our sponsor for approval and once it is approved, we will continue with the chosen design to perform basic Finite Element Analysis (FEA). The last task that will be carried out this quarter is will be to start thinking about the manufacturing and assembly design. This last task we will need to start considering materials and cost for such materials.

2.2.2: Winter Quarter

For Winter quarter, we will be doing more design analysis to check out if our chosen solution will satisfy the problem and our sponsor. If not, more ideations will need to happen doing this quarter. We will continue to develop our CAD model and start to deconstruct it to start thinking about ordering parts to construct it. We will also be doing safety and risk analysis on our CAD model. We will be ensuring that our part is as safe as it can be and that it does not provide any risk to the user. Once we are satisfied with the product on the CAD model then we will create a list of materials and costs so that we can start building a full-scale part. The last thing that will need to be done will be to start thinking of ways to test our product to ensure that we are hitting the benchmarks that we set in our House of quality.

2.2.3: Spring Quarter

For Spring quarter, we will continue to test our product and refine our design. Only minimal adjustments will be made after testing has been completed. We will then create our expo poster for the exposition of senior design projects. We will make sure that our area will be clean and clear. We will then present our project at the exposition. The final design review will be turned in to the sponsor. Our entire schedule is laid out in Appendix E.
2.3: Conclusion

This Preliminary Design Review report details our brush trimmer team’s ideation processes that led to our final concept, and briefly restates our objective and our timeline for the rest of the year. These requirements relate directly to the increased efficiency and low-effort input of our trimmer head assembly. Our main goal is to try to limit the input force as much as possible from the user.

Our final concept, for the foreseeable future, will be comprised of controls, an adjustment mechanism system, and the trimmer head itself. The trimmer head will be a traditional one with trimmer line as they have shown their effectiveness. The controls will also be kept as throttles as they have shown their intuitiveness and ergonomic effectiveness to the public. Lastly, the most complex part of the assembly, the adjustment arms. The arms will be controlled by a 4-bar member and a ratchet gear system for the vertical and horizontal motions respectively. The trimmer head will be able to rotate as well. All three of these movements should be able to operate from the users standing position.

Our team will perform further tests to decide best user interface and most efficient trimmer head and line. Moving further, we will need to contact the chassis team to further figure out the details for mounting our adjustment arms. We will also need to run analysis on the forces created by the trimmer head and make sure the trimmer head is not too heavy for the supporting bars when operating.
3.0: Appendix

Appendix A: “How Might We” Questions
F-42: B-Trimmers 17

1. HMW: dispense trimmer line
   - How might we feed the string to the head?

2. Button: trigger
   - What other feedback will you provide?

3. Have fun:
   - Good humor and fun

4. OFF THE SHELF:
   - Parts! Consumers will be more transferrable with these parts

5. Color-coded:
   - Make things more readable, clearer
   - Match trimmer to parts

6. Keep it simple:
   - Keep it simple, stupid

7. Symbole:
   - Same meaning

8. Context:
   - More context to make it relevant
F-42: B-Trimmers 20

- Both speeds of trimmer head on one display.
- Speeds are the same for both.
- Display the speed/battery.
- Which of the displays we can swap at home depot or Lowe's.

- Touch screen.
- 100%_ready.
- Voltage meter.
- Status/light to show low voltage.

- Decreasing torque.
- Bigger/motor.
- Smaller/motor.

- Increase voltage.
- Current in motor.

- Capacitors vs.
- Inductors.

- Increase battery speed.
- Feedback.
- Score 5 star.
F-42: B-Trimmers 21

- HMW: Have varying speed settings
  - Controls: Matlab code, buttons, display
  - Attachment: Do match

- Self setting speed by changing pie, depend on what a beta tool
- Have a hi/lo couple of predetermined speeds instead of a sliding option
- Touch screen display

- HMW... dispense trimmer line
  - How much
  - Feed the trimmer to the head

- Bump trigger

- Action plan: Remove the flyer

- Present time: Feed it in how that is in hand and can be released to gain more and it broken
- Remove as many impracticalities as possible, e.g., friction, oiling, etc.
- How may power be improved efficiently?

**HMW:**
- Decrease power required to trimmer.

Choose:
- Lower good powers.

- Ball joints:
  - Some of the joints at trimmer heads for inclination feature.
- Simple knee joint for 3 DOF freedom (mechanism of arm):
  - r, θ, z
## Appendix B: Concept Prototypes

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<th>DESCRIPTION</th>
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<td><img src="image1.png" alt="Image" /></td>
<td>The first concept was a double trimmer-line head. Essentially, the idea would be to stack two normal trimmer heads on top of each other. This would allow for different trimmer line’s length and strength.</td>
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<tr>
<td><img src="image2.png" alt="Image" /></td>
<td>The second concept prototype shown demonstrates a <em>bendable</em> adjustment arm. This would allow for all degrees of freedom and theoretically, able to move while running. Think of a desk lamp for this prototype. The wires for the trimmer head would be encased with in the shaft. This concept was taken from observing a desk lamp.</td>
</tr>
<tr>
<td><img src="image3.png" alt="Image" /></td>
<td>The following is also an adjustment arm mechanism, and somehow, is simpler. Although the photographed picture is incredibly simple, the concept is the same. With only members and pins, we could build a system that gives <em>one</em> direction of motion.</td>
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</table>
While keeping points of contact in mind, a ball-joint arm was also considered. Using a ball-joint would allow two directions of motion with only one input. Although this is already a concept, a small prototype was created to visualize it with a shaft arm.

The following idea was to focus on redesigning the trimmer head. A popular head that another teammate described was a trimmer head with blades and string. However, utilizing plastic blades would be inefficient in the long run. Therefore, I wanted to utilize metal blades. I created an idea that covers the blade when the operator is not cutting thick brush, and when the operator has to cut thick brush; they can simply roll down the cover as shown. The difficulties with this design is that there will be a difficult way to constantly adjust the guard.

One idea that I had was to create a custom-designed trimmer head that has chamfers so the string can easily rest on the head. Also, with those chamfers, we can put multiple strings onto one trimmer head allowing for multiple strikes to the brush in fewer seconds. Therefore, instead of increasing the rpms, we can simply increase the amount of torque and make sure each of the strings can hit with that amount of torque. Also, maybe to lock it, we can have a spool in the back of it and housing that goes over the whole design.
The following idea was to redesign the adjustment mechanism for the machine. As you can see, the shaft of the trimmer will have fixed adjustments that the user will be able to lock in place with a kind of locking mechanism. To adjust the user will simply unlock it, place it in the desired adjustment and then continue to trim. The biggest downside to this design is that it restricts the control of the user. The user would not be able to rotate the trimmers. The user only has 3 angles that can be trimmed. Overall, with this design, the user is restricted.

The following idea was to redesign the adjustment mechanism for the machine. A significant want for the design was to make the adjustment system easy with a spring-loaded system that returns the trimmer to the body after adjusting it. Therefore, the green piece symbolizes a possible spring that returns the trimmer to its resting position. On top of that, I wanted to focus on adjusting the way the part rotates. Therefore, I added a gear system that when a shaft is rotated, the trimmer heads rotate. One idea I came up with to add to this was to add some kind of stopping mechanism that holds the position of the trimmer. I would say that the largest problem with this design is the integration with this to the system as a whole.
Combination of a traditional trimmer headline and blade. The purpose of this prototype is to demonstrate how the blade and traditional trimmer line would align.

This prototype is a combination of traditional trimmer headline and blade but with a different style blade. This blade design cuts more efficiently because it has three blades in a curved design.

This is a trimmer head ideation with a blade and traditional trimmer line integrated into one. The idea behind this was that the blade and the trimmer line combination is made simpler because the blade does not need to be included on top of the trimmer head.
This is a more complex idea that is aimed to create rational motion into horizontal motion. The center moves the whole tower and a pin on the outer circle is held still with a pin in it to hold it in a different position.

This is another trimmer head idea with the trimmer line having counterweights at the end of the line. This is aiming to maybe improve the response of the traditional trimmer line.

This is to solve the up and down motion of the subsystem. The center is still while the outer disc moves and is locked with a screw in the center.
## Appendix C: Pugh Matrices

### Adjustments System

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**TOTALS**

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**System Options**

- Spur gear for vertical motion; radial rack and pinion for horizontal motion; trimmer head with blade; dial controller
- Bevel gear box for vertical motion; horizontal motion; traditional trimmer head; throttle controller
- 4bar lever for vertical motion and ratchet gear for horizontal motion; line trimmer head w/opposite spinning; throttle controls
- Bevel gear for vertical motion & ratchet gear for horizontal motion; Trimmer head that spin opposite ways and trimmer guard; dial controls
- Fixed positions for vertical motion, 4-bar lever for horizontal; Double trimmer head that spin opposite ways; button controls
- 4-bar lever for vertical motion; spring loaded w/ fixed positions; horizontal motion, trimmer head with guard; throttle

**Appendix E: Yearly Schedule**
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Brush Clearing Tool – A. Trimmer Assembly
Part III: Critical Design Review (CDR)

PRESENTED BY
SENIOR PROJECT MEMBERS:
Juan Martinez
Jayson Reyes Salvador
Paula Xochitl Ortiz-Arango

Trimmersb42@gmail.com

SPONSOR
Brian Rois-Mendez

ADVISOR
Elghandour, Eltahry I.

PHD

February 02, 2022

BUSH
Abstract
The Critical Design Review (CDR) reports summarizes the work done by a Cal Poly Mechanical Engineering senior project team for Brian-Rois Mendez. Mr. Mendez proposed his idea for reducing the workload it takes for clearing overgrown brush along trails. The overall purpose of the project is to redesign his current prototype to be more effective and user-friendly while clearing brush. For our team, we will be focusing on redesigning his trimmer assembly to improve the cutting power and adjustment of the trimmer assembly.

Since the last design review, there have been lots of design changes. Within this critical design review provides a full description of the trimmer sub-assembly designs and the reasonings behind design choices. Essentially, the purpose of this document should provide readers with the opportunity to recreate our design given all of the materials.
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1. Table 1. Summary of Costs
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1.0: Introduction

This report holds our final selected design and the justification behind the design choices. There’s justification for the trimmer head and line, the trimmer shaft, material choice, the rail and carriage, motor, and the locking mechanisms. The final selected design section within this report will additionally include the safety, shipping, and repair considerations we prioritized. There will be a section highlighting the major changes we made to our system since the preliminary design report as well. These major updates include the final integration of the locking mechanism, motor mount, and the rotational adjustment. We also changed the design of the vertical and horizontal adjustment. Included in the appendixes is a detailed breakdown of our analysis cost, design verification plan, and detailed manufacturing drawings. The manufacturing plan sections outlines the steps required to build our entire trimmer assembly. Theoretically, if given the appropriate access to tools, the reader could build it at home! This section includes our plan for material procurement, and the assembly of all the subassemblies: trimmer attachment, motor and trimmer mounts, rail and carriage. The design verification plan section of this report details the functions, safety, and ergonomics we want to achieve. The final sections wraps up the report without scheduled follow-up steps we intend to meet.
2.0: Final Design

This section outlines the final design for our trimmer assembly. Specifically, this section includes the design changes since the PDR, the Final Design with the reasonings behind it, and the breakdown of every component’s cost. Although this will be the prototype that we will be constructing and testing with, this section will describe further modifications that can be made to potentially decrease mass production costs and increase marketability to customers.

2.1: Changes Since PDR

Since the PDR we have gone through numerous design changes for the overall system. Some reasons for these design changes were to combine our ideas with the drivetrain and chassis teams, to further support some of the loads on the machine, and to decrease the amount of moving parts. The reasonings for making each design change will be briefly described in this section. Further description of the components will not be on this specific section.

2.1.1: Integration of the Locking Mechanism, Motor Mount, and Rotational Adjustment

During the PDR there was no specific way of locking the vertical and adjustment mechanisms. Because locking the mechanism is a significant aspect of our device, we did further design work on choosing a functional and secure method for locking our device. The biggest constraint when designing for the locking mechanism was making sure that both the vertical and horizontal locks could release from the same component. The final locking mechanisms can be seen in section 2.2.5.

One important design consideration we did not have during the PDR was the decision on the trimmer’s motor. After researching different types of motors and comparing the different specifications on each, we decided on the motor and its way of attaching to our system. The motor details are described in section 2.2.6.

Another undetermined mechanic from the PDR was the rotational movement for the device. Being able to rotate the trimmers was a necessity when trimming brush along slopes. Therefore, we initiated design work on a rotational adjustment system. The resulting rotational adjustment is detailed in section 2.2.7.

2.1.2: Changing the Design of the Vertical and Horizontal Adjustment.

During the PDR, we had 2 concepts for our vertical and horizontal adjustment.

The vertical was a 4-bar system that translated up and down based on a lever. The change that we made to this system was the removal of one of the members. When constructing another concept prototype for the vertical adjustment, we realized there were too many moving parts for the 4-bar system. Therefore, we began redesigning to find a system that reduced the number of moving parts. With the change from the 4-bar to a 3-bar system, we were able to get a larger range of motion for the trimmers. The resulting vertical adjustment can be seen in section 1.1.

The horizontal was a ratchet gear that included a spring-loaded pin to lock the gear in place. The change we made was from using a gear to a rotating pipe system. The reasoning for this change was the concern for the gear supporting our trimmer assembly. The ratchet gear system also did not have a reasonable mounting place for the chassis team. After further redesign, the result was a cheaper and stronger horizontal adjustment. The result can be seen in section 1.1.
2.1: Final Selected Design
The final trimmer assembly is divided mainly into four main categories: the trimmer head/shaft, the vertical adjustment, horizontal adjustment, and rotational adjustment. The entire trimmer assembly is shown in Figure 2.1 and the complete trimmer device including the drivetrain and chassis team is shown in Figure 2.2. The complete bill of materials, drawings, and specifications are shown on Appendix A.

Figure 2.1: The full trimmer assembly separated into its four main subassemblies.

Figure 2.2: Full brush-clearing device mounted on the chassis and drivetrain.

The trimmer head/shaft assembly is composed of the universal trimmer shaft, a new trimmer head, and a thicker trimmer line. The overall design reasonings for the trimmer head/shaft was to make an easily replaceable trimmer head/shaft. The current head required the trimmer to be bumped on the ground to release the line. We changed this to be an automatic pull system.
For the vertical, we went from a four-bar linear system to an integrated two-bar system. From results with our concept prototypes, we saw that there were numerous moving parts, pinch points, and not much range for the trimmer shaft. After redesigning, we solved for many of these issues. The final vertical adjustment can be seen on Figure 2.3. The locking mechanism will be controlled with a brake lever at the handles that controls a spring-loaded plunder at the carriage.

![Figure 2.3: Final vertical adjustment design.](image)

The horizontal adjustment changed from the use of a ratchet gear to an inner tube that will rotate within a mounted flat-plate. This change was because of the concern for locking the ratchet gear as well as the support the horizontal adjustment needs to provide. The final design is shown in Figure 2.4. The locking mechanism will utilize the same method as the vertical adjustment to fulfill Mr. Mendez’s need for the lock to be on one input.

![Figure 2.4: Final horizontal adjustment design.](image)
The final section is the rotational which includes the mechanism to rotate the trimmer shaft, the motor and its mount, and the coupler to connect the motor with the shaft. The design for the lock is to use the universal trimmer’s built-in spring-loaded release where the user needs to push the spring and rotate the shaft. The rotational system includes a universal female coupler that will allow the user to use hedgers, blowers, and other products that fit the universal coupler. The motor is a brushed CIM motor that provides a 335W power at 60 amps. The final design is shown in Figure 2.5.

![Figure 2.5: Final rotational adjustment design.](image)

The wiring for the system involves powering the trimmer head with the drive train team’s battery. The electrical wire will be protected by being carefully placed along the rail. The shifting cable for the brakes will be protected by housing and run along the paths of least movement. This is shown in Figure 2.6.

![Figure 2.6: A representative drawing of where the braking cables will be placed and connected to the handle bars.](image)
2.2: Material and Part Selection Justification

2.2.1 Trimmer Head and Line
Our new trimmer head, the Echo 450 trimmer head is shown on Figure 2.7. The head is a speed feed trimmer head that operates by installing the line and cranking the head. Compared to the bump release head, this head is an automatic release head; therefore, when the line gets shorter, it will release more line. It also holds up to 20ft of trimmer line in the housing and fits the desired line thickness: 0.105-inch twisted square-profile trimmer line. The decisions on this line is that thicker heads can cut thicker brush, but will limit your housed trimmer line.

Figure 2.7: Echo High-Capacity Speed Feed 450 trimmer head and our chosen trimmer line.

2.2.2 Trimmer Shaft
The trimmer shaft we decided to go with is the universal straight shaft attachment shown on Figure 2.8. We chose this trimmer shaft because it fits most standard trimmer heads. Also at the end of the shaft, there’s a spring-loaded release button we will be using to secure the shaft; this feature is also the fundamental part of our rotational adjustment.

Figure 2.8: The universal 0.105in fixed line, 34in extended straight shaft string trimmer attachment can be purchased at Home Depot.

To connect the trimmer shaft and motor, we are using an aluminum coupler. As seen on Figure 2.5, the trimmer shaft will connect to a universal female coupler and the motor will connect to the aluminum coupler. The female coupler will then attach to the aluminum coupler completing the trimmer head/shaft assembly. The decisions for these couplers were to create an effective method to lock the shaft after being rotated.
2.2.6 Motor
The trimmer’s motor determines whether the trimmer will have enough power to cut the brush. The largest challenge when choosing a motor was considering a motor that provides enough torque and speed to trim down the brush. In estimating a torque for the trimmers, we calculated how much shear force the trimmer line needs to deliver to cut a ¾” diameter brush. To calculate this, we used the shear stress equation \( \sigma = \frac{F}{A} \). Based on our calculations, we determined that the trimmers would need around 556.8 oz-in to trim a ¾” diameter brush in one swing. Assuming that it would take about 10 swings for the trimmer line to cut the brush, we reduced the value to 55.6 oz-in. With this torque, we researched various motors that have around a 50 oz-in rated torque at about 3000 rpms. We decided on the am-0255 CIM motor that provides 42 oz-in at 4500 rpms (at max efficiency) or 169 oz-in at 2500 rpms (at max power). The following motor was priced at $35. Although the ideal type of motor is a high-powered brushless DC motor, the cost of these types of motors was not comparable to the am-0255 CIM.

![Figure 2.9: Aluminum Alloy joint connectors can be purchased on Amazon.](image)

2.2.3: Adjustment Members
We decided to go with 6061 aluminum alloy for the majority of our system’s members and plates for one main reason: strength to weight ratio. With the potential of shipping these, we had to keep our system as light as possible. Our sponsor requested that the entire system weigh as little as possible so that two average people can carry our vehicle. Our trimmer assembly is measured to be around 40lbs at the time being. We were able to reduce some of the weight by removing a member from our adjustment mechanism as mentioned earlier.

After manufacturing consultant meeting, we will be doing a cost/strength analysis to see if steel would be as effective using less of it. If we could use less steel and achieve the same power, it’d be beneficial to switch over as steel is more inexpensive.
We also decided to go with a combination of steel and nylon washers. Nylon washers for where we expect movement and material to material interaction. Most of our hardware is either steel or zinc plated due to the low course of it. In the future we would like to have all stainless-steel hardware to prevent wear from the elements.

We were unsure about whether to add extra bracing to our system because of where our current budget was. To analytically determine which would be the best option we ran a couple finite element analysis (FEA) to determine what would best suite our problem. Figures 2.11-2.14 are all FEA models of two separate conditions with the same 6061 aluminum material and the same loading conditions. We know that only one loading on the shorter side of the rail profile is going to be the main cause of failure. This is where it would fail because of how the carriage is mounted to the rail. Only impacts to this side of the rail will cause great forces to the rail. We used these figures to determine our bracing option. In Figure 2.11 we can see that the maximum displacement is 3.19e05 inches and it occurs at the top.

![Figure 2.11: FEA Model showing displacement due to a 300-pound distributed load on shorter profile of the rail](image)

Figure 2.12 is the same model as Figure 2.11 but instead it is showing stresses. We can see that the highest stress occurs along the bottom of the plate where the outer sleeve and plate meet. This was expected but as seen in Figure 3.2 the displacement was not expected.
Figure 2.12: FEA Model showing stresses due to a 300-pound distributed load on the shorter profile of the rail.

Figure 2.13 is the new bracing model that was though about after the CDR presentation to the class. In this configuration we have the 1-inch diameter pipe extend as high as it can before interfering with the railing system. At the top of this we have another plate that will have a slightly larger 1-inch diameter hole. This is where the pipe will move from. This helps to decrease our lever arm and improve our stability of our arm system. In this FEA model we see the that the max displacement is again on top and is max out at 1.98e-08 inches. This is lower than the previous model.

Figure 2.13: New bracing model showing displacement due to a 300-pound distributed load on the shorter profile of the rail.

Figure 2.14 is the same model as that found in Figure 2.13 but with the stresses displayed. This model shows us that the max stress is at the top plate where we expected it to be because of the work that this new brace is doing.
After comparing both of these cases we can confirm that we can stay with the same materials, 6061 aluminums. The only changes we would need to prevent so much displacement is to extend the 1-inch diameter pipe to the maximum and at the top use another ¼ inch plate with slightly larger 1 inch diameter hole. This brace then would be mounted to the chassis with the chassis tubing.

### 2.2.4 Rail and Carriage

The main reason we decided to go with a rail and carriage system is because it’s easy to repair, easy to build, and has movement in both directions. Another reason we decided to go with this specific carriage is it has a locking mechanism we can tweak to achieve our vertical motion. As shown in the pictures below, we will have to modify the carriage by adding a plate to reinforce its ability to hold the trimmer shaft.

**Figure 2.15:** Back and front view of our modified carriage system.

### 2.2.5 Horizontal Adjustments

**Locking Mechanisms**

We already covered the vertical adjustment locking mechanism in the previous section, but there is also the horizontal locking mechanism (Figure 16). This one is located at the base of our railing. Our railing
will be grinded down to fit within the round aluminum tubing which will serve as the inner sleeve. Both the inner and outer sleeve will have holes around their perimeter to allow for the spring-loaded pin to enter. This pin will be connected to braking cable as mentioned in the very beginning. A second bracket was added to ensure the spring can be ‘activated’ – essentially allowing the braking cable to put a force on the pin via a steel line.

The method of which we will achieve having both locking mechanisms released at once is by having a 2-input brake lever (Figure 2.16). With this, the user should theoretically be able to move our trimmer shafts with ease.

![Figure 2.16: Our locking system design to allow for horizontal motion.](image)

![Figure 2.17: The double barrel brake lever for both the locking mechanisms.](image)

### 2.3 Safety, Shipping and Repair Considerations

The safety of the user is of the utmost importance to us. We plan to run several Failure Modes and Effects Analysis to investigate how the design might fail.

Shipping and potential repairs are also the biggest reasons why we decided to go with the locking mechanisms we did. We wanted to be able to disconnect the linear rail from the chassis for easy shipping or if the trimmer assembly needed a repair. A lot of our components can be easily purchased and replaced intentionally and are listed in our bill of materials.
2.4 Cost Analysis Summary
After sourcing components and ensuring we buy from the least expensive competitor, the total cost of the system came out to be around $1200. The table below shows the costs broken down into subsection. For a more in-depth cost analysis, see Appendix A.

<table>
<thead>
<tr>
<th>Sub-Section</th>
<th>Approximate Cost</th>
</tr>
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<tr>
<td>Trimmer</td>
<td>$310</td>
</tr>
<tr>
<td>Electronics</td>
<td>$130</td>
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<tr>
<td>Adjustment</td>
<td>$640</td>
</tr>
<tr>
<td>Fasteners</td>
<td>$150</td>
</tr>
</tbody>
</table>

Table 1. Summary of Costs

3. Manufacturing Plan

3.1 Material Procurement
For the entire assembly, we will be purchasing our parts from online sites. We will be ordering mostly from Home Depot, McMaster, Amazon, and bike shops. This is mostly due to requiring easy repairability and construction. Our budget was a combination of our sponsor and the school – equaling 800 dollars. The bill of material included in Appendix A outlines how we plan on using said budget and where we plan on purchasing specific items. We crossed referenced companies to ensure we were getting the lowest costs and shipping times.

3.3 Trimmer Attachment
1. No modifications (change the trimmer head only).

2.3 Motor and Trimmer Mount

Band Saw
1. Cut 3.5x24 ¼ thick plate into a 3.5x7 plate
2. Cut 3 inches of the upper shaft attachment including the female end adapter within the 3 inches

Drill Press
1. From the 3.5-inch side of the 3.5x7 drill 3 holes that are .5 inches from the 7-inch side of the plate. The first hole will be .5 from the 3.5 side of the plate. The second hole will be 2 inches from the 3.5 side of the plate. The last hole will be 4 inches from the 3.5 side of the plate.
2. Drill 4 holes for 8-32 bolts for the motor bracket. The long side of the bracket should be aligned and butted against the long side of plate. The short side of the bracket should be aligned and butted up against this short side.
3. The flange housing should be aligned with the vertical part of the motor mount and should be covering the 1.5 hole. Drill holes on the flange to match the tapped holes on the motor.
4. Drill 5 more holes around the universal coupler housing that has a knob on it. These holes will be .1 inches from each other.

Assemble
1. Mount the motor mount to the 3.5x7 plate using the 8-32 bolts, washers, and nuts.
2. Mount the motor to the motor mount using tapped holes
3. Put the 8 mm side of the flexible coupler on the motor shaft and slide in about half of the coupler length. tighten the 2 set screws on to shaft.
4. The 3-inch upper shaft attachment should have a 5 mm (about 0.2 in) square end. This end goes on to the flexible coupler. The set screws should be tightened. The 3-inch-long upper shaft should go into the flange until it cannot go in. The flange has a set screw that is tighten on to the upper shaft.

![Figure 3.1: Motor plate and mount attachment](image)

5. Lastly the rotational coupler can be attached using the given hardware.

### 3.4 Rail and Carriage

#### Band Saw

1. Cut a 4x2.5x.25-inch plate form provide plate.
2. Cut the 1000 mm rail into two 500mm rail

#### Drill Press

1. Drill 4 holes on to the 4x2.5x.25-inch plate to align with the tapped holes on the carriage. These holes should be off set from the middle of the plate. The 4 holes should be closer to the shorter side of the plate. It should be 1 inch from the short side to the first hole.
2. Drill a ¼ hole on this 1inch side of the plate from step 1. This hole should be 1.25-inch from the longest side of the plate and .5 from the shortest side.
3. Drill two more ¼ holes on the opposite side of the 1-inch side. These holes rely on the alignment of the spring-loaded pin and the use of spacers. Drill holes wherever the L bracket aligns with pin.
4. Drill holes on the side of the rail where the carriage lock is. From the non-grounded rail Drill .16 holes every .5 inches for 5 inches.

#### Grind

1. Take an angle grinder to one end of the rail and grind down the longest legs of the rail until they can fit inside the 1-inch diameter pipe. 2.5 inches of the rail should fit inside the tubing.
3.5 Assembly

Bandsaw

1. Cut all the 1x1 aluminum tubing to length according to the engineering drawings.
2. Cut available plate to 4x4.5 plate.
3. Cut both 1-inch diameter tubing and the 1.35 tubing into corresponding length according to engineering drawings.
4. Cut all L brackets to corresponding lengths.

Drill

1. Drill ¼ holes on the L brackets so that the brackets line up with the locking pin.
2. Drill a 1.35 diameter hole on the 4x4.5 plate. The hole should be 1.25 from the 4-inch length side of the plate and 2 inches from the 4.5-inch side.
3. Drill more ¼ holes corresponding to the bracket holes on to the plate.
4. Drill ten .16-inch holes halfway around both tubing at the same time. Do this by taking both the 1.35 diameter and 1 diameter tubing and insert on into the other. The holes should be .5 form the top of the 1.35 tube.

Weld

1. Weld 7/8 tubing to the end of the longest square tubing where it has no ¼ holes.
2. Weld the 1.35 tubing to flat plate ensuring that 1.25 inches stick out from the ¼ holes.
Assemble

1. Using locknuts and washers, attach the 9in and 19in tubes to the 90-degree gusset. The shortest end of the now L shape member should be attached to the rail with a 10-32 bolt, washer and nut.

Figure 3.3: L shape handle and rail from back side

2. The brake and grip can now be inserted on to the 7/8 tubing at the end of the L shape member.
3. The carriage can be slid onto the rail as well.
4. The plate with the motor bracket and trimmer attachment can now be bolted on to the short square tubing via 1/4-20 bolts, washer, and nuts. This conjoined part can also be attached to the carriage plate with the same fasteners and spacers. Finally, this part can also be connected to the middle of the short end of the L member with the same fasteners and spacers.
5. The end of the grinded rail can now be inserted into the 1-inch diameter pipe. Making sure that the holes around the pipe are away from the flattest part of the rail.
6. This whole unit can now be inserted into the larger 1.35 tubing.
7. The plate with the 1.35 tubing should be attached to the chassis and have the brackets already installed and bolted down.
8. You can now feed wires from motor through tubing and along the rail to the chassis.
9. Brake lines can also now be fed through tubing and along rail.
4.0: Design Verification Plan

The design verification plan details how we are going to test all the specifications detailed in our SOW. The plan is outlined to describe which specification we are testing, how it will be tested/graded and who is responsible for the completion of that test. A complete updated design verification plan can be seen in Appendix D. In terms of the general aspect of our design verification plan, there are three categories that we aim to test: functionality, ergonomics, and safety of the user.

4.1: Functionality

The primary specification that we are aiming to meet is cutting the 1” diameter brush whether it is dead or alive. This test will be a numerical test conducted in 3 trials to determine the overall performance of our trimmers. Each of the three tests will have the throttle fully engaged to have a constant power between each test. The first is cutting a patch of ½” diameter dead brush packed closely together. Not only will this inform us whether our device is capable of cutting ½” diameter dead brush, we will be able to determine if this device can handle trails requiring lots of maintenance. In other words, trails that have dead brush overlap one another. The second test will verify our limitation for cutting an individual 1” dead brush. If our trimmers are successful, we will continue to increase the diameter of the brush until we reach 2” in diameter. The final test is cutting ¾” diameter live brush. From this test, we will learn the finalized diameter the trimmers can cut.

The other specification that we plan on testing is the functionality of the adjustment systems. The major concern that we have is whether our 2-input brake lever will have any delay or issues when unlocking both the vertical and horizontal adjustment at the same time. For this test, we plan to set up a structural prototype that will have the brake lever attached to a stationary PVC pipe. While attached, the brake lever will have both the functionality of vertical and horizontal movement. When testing, we will attach the brake cables to 2 different stationary points, each at different distances and heights. We will then use the brake lever to inspect if there is a delay and then translate the lever to see if the locking mechanism would still function at different locations.

The final specification that we plan to test is the directional capabilities of our device. Currently, we know that the vertical and horizontal systems are able to move individually; however, we want to test how our system will behave when both the vertical and horizontal adjustments move at the same time. This test will be conducted at the final stage of our project when the trimmer assembly is complete. At this stage, the locking mechanisms are installed, the weight of the trimmer will be considered, and the effect that this motion will have on the other teams can also be observed. The expected result for this test will have the trimmer head translate diagonally without affecting the other parts of the machine.

3.2: Ergonomics

The primary test for the ergonomics of our machine is how intuitive the adjustment system will be. Therefore, we plan to test the time it takes for 10 different users to successfully unlock, translate and lock the trimmer head in place. The results of this test will detail if the customers easily understand the functionality of our machine. As a safety precaution, individuals will be given a brief instruction manual describing how the adjustment systems work. To conduct the experiment, 10 random individuals will be given the instruction manual for the device. One by one they will be tasked to unlock the vertical and horizontal then translate them left, up, down, and right then will lock the adjustments. The final test will be to have them rotate the shaft. If each task is completed within 30 seconds, it will be considered a success. We will then survey them how comfortable adjusting the machine was.
4.3: Safety
The final category that we plan on testing is the safety of the device. One of the safety tests that we will conduct is testing the pinch points on the machine. The pinch point we are referring to is the vertical adjustment system. When some member cross, we do not want this motion to cut the user’s finger. To complete this test, we will be using carrots to simulate an individual’s finger. Based on research (need to find and cite), we found that a carrot has the same shear strength as a human finger. Therefore, we will place a carrot at the pinch point and see if the carrot will cut. The results of this test will determine if we must add housing around the vertical adjustment to avoid any hazards.

Because the following individual will be cutting dead brush, we want to avoid the number of debris hitting the user’s face. Therefore, one of the final tests that we will do on the completed prototype is to test exactly that. This test requires us to use the final prototype with the Drivetrain and Chassis. This is because we want to test how much debris will be hitting the user while cutting for about 10 min. To conduct this test, we will attach a plastic face shield on the user and begin cutting dead brush. After 10 minutes of consistent working, we will inspect the scratches on the plastic face shield from the flying debris. Based on the damage, we will integrate more guards to reduce the debris.

5.0: Project Management
This section provides a full timeline of the planned deliverables and dates that they will be delivered. In Appendix C details Gantt chart with the remaining timeline and goals. Our current main goal is to revisit and revise our FEA analysis to confirm our expected analysis. After final confirmations, we will begin the manufacturing phase of the project.

Table 5.1: Primary deliverables and dates for the remainder of the project.

<table>
<thead>
<tr>
<th>Deliverable</th>
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<tr>
<td>Manufacturing &amp; Test Review</td>
<td>March 10th, 2022</td>
</tr>
<tr>
<td>Test Procedures</td>
<td>April 5th, 2022</td>
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<tr>
<td>Senior Project Expo</td>
<td>May 27th, 2022</td>
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5.1 Further Analysis
We have finalized our design to a system that we believe will accomplish all the movements that our sponsor wanted. We still need to perform in-depth FEA on our system as a whole to ensure that any failure points are addressed. We also want to perform ergonomic tests to see if our handle will be comfortable enough to be used for long periods of time. We want to get a solid figure on how much force our pins will actually require to release the locks and how much force the brake levels will require. Overall, we intend to conduct a design verification plan to confirm our analysis and collect the mentioned results for our project.
Appendix
Appendix A: Bill of Materials
Appendix B: Drawings and Specs
Appendix C: Gantt Chart
Appendix D: Design Verification Plan
## F42: Brush Clearing Tool: Trimmers

### Appendix A: Indented Bill of Material (IBOM)

<table>
<thead>
<tr>
<th>Assy Level</th>
<th>Part Number</th>
<th>Descriptive Part Name</th>
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Universal 0.105 in. Fixed Line 34 in. Extended Straight Shaft String Trimmer Attachment

$70.73

- Connects to most attachment-capable trimmers
- Fixed line head design uses 18 in. long 0.105 in. trimmer line
- 34 in. Extended boom allows for greater reach

How to Get It

We'll send up to 700 to San Luis Obispo for free pickup

Add to Cart

Getting ready for your move?
Calculate how many supplies you need

- or -

Buy now with PayPal
Echo 78890-21001E High Capacity Speed Feed 450 Trimmer Head

Visit the Echo Store

471 ratings

$42.93

✓prime

& FREE Returns

Thank you for being a Prime member. Get a $150 Gift Card: Pay $0.00 upon approval for the Amazon Prime Rewards Visa Card.

May be available at a lower price from other sellers, potentially without free Prime shipping.

- Genuine OEM Echo Part; Does not fit curved-shaft trimmers
- PLEASE NOTE: Consult owner's manual for proper part number identification and proper installation. It may look like the right part, but it may not fit your particular machine
- Holds 20' of .095" line. Max line size .130"
- Reload in 30 seconds or less, no disassembly required; Recommended for trimmers with engines 25cc and larger
- Includes adapters to fit most premium trimmer brands like Stihl, Husqvarna, Tanaka, Echo, Shindaiwa, Redmax, Maruyama & Honda; Included adapters are: 8mm x 1.25 LHF (Left Hand thread Female), 10mm x 1.0 LHF, 10mm x 1.25 LHF, 10mm x 1.25 LHF Extended, 7mm LHM (Left Hand thread Male) and 8mm LHM
ECHO
.105" Black Diamond Trimmer Line (217 ft.) Large Clam

**4.5** (1360) Questions & Answers (26)

- Unique square, twisted line is razor sharp for ultra-fast cutting
- Designed for one-pass cutting to maximize efficiency
- Best suited for medium to heavy grass and weeds
- View More Details

San Luis Obispo Store
- 10 in stock
- Aisle 51, Bay 011
- Text to Me

Line Diameter (in.): .105
Line Length (ft.): 217

How to Get It

- Store Pickup: Available
- Ship to Home: Get it by Wed, Feb 23 FREE
- Scheduled Delivery: As soon as Tomorrow $89.00

46 available for delivery to 93405
Delivery Options

One-Time Purchase
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Member 2: Handlebar

DIMENSIONS ARE IN INCHES
TOLERANCES:
- FRACTIONAL ±
- ANGULAR: MACH ± BEND ±
- TWO PLACE DECIMAL ±
- THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
FINISH

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McMaster-Carr® CAD PART NUMBER 3249K2

Locking Sleeve Bearing Carriage

http://www.mcmaster.com
© 2022 McMaster-Carr Supply Company

For 15mm Rail Wd.
2X Ø0.25 THRU

1.50

.50

3.50

.25

9.00

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES:

FRACTIONAL ±

ANGULAR: MACH ±, BEND ±

TWO PLACE DECIMAL ±

THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

SOLIDWORKS Educational Product. For Instructional Use Only.
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http://www.mcmaster.com

T-Slotted Framing

McMaster-Carr®
Thread-Locking Element

Nose Diameter: 0.16"

1/4"-20 Thread: 0.31"

0.62" Length

0.75" Overall Length
Mounting screws included.
PROBLEM SOLVERS DOUBLE BARREL BRAKE LEVER

$14.99  MSRP $20.00  SAVE 25%

FREE 1-DAY SHIPPING TO CALIFORNIA on orders over $60

Only 2 Left - Ready to Ship

ADD TO CART

+ Add Accident Protection from Extend

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<td>3 Year</td>
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Add to Wishlist ➤
GPMTER Bike Handlebar Grips, Single Lock on Bicycle Handle Bar, for BMX, Mountain, MTB, Beach Cruiser, Scooter, Folding Bike, Soft Non-Slip Rubber Grip Comfortable Ergonomic

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Not suitable for road bike

Roll over image to zoom in
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Information in this drawing is provided for reference only.

1.315" For 1 Pipe Size

1.049"

0.133" Wall Thickness

12"

PART NUMBER 5038K231

Standard-Wall Aluminum Pipe

http://www.mcmaster.com

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Your payment method is no longer active. Update your payment method

Baby Black Handle Brake Part Lever Adjusting Screws Aluminum MTB Bike Bicycle M10 Fastener Bolt Brake Accessories (4 Pcs)

Brand: Fox Baby
Color: 4 Pcs
Handle Type: Lever
Material: Aluminum

About this item
- Quality Material: The brake lever adjustment screw is made of high quality aluminium material, which is durable, highly strength and corrosion-resistant.
- Exquisite Workmanship: Sophisticated production, with good performance and higher work

$8.99

In Stock.
FREE delivery Wednesday, February 16. Order within 1 hr
Deliver to Jayson - San Luis Ob... 93401

Secure transaction
Ships from Amazon
Sold by Fox baby

Return policy: Eligible for Return, Refund or Replacement

Quantity: 1
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Buy Now

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Repair Parts Home > Lawn Equipment Parts > Troy-Bilt Parts > 753-06682 Upper Drive Shaft Housing Assembly

**Upper Drive Shaft Housing Assembly**

Part Number: 753-06682

- **5 Reviews**

**Availability:** 1 in stock

- **Price:** $17.07
- **Quantity:** [ ]

**Add to Cart**

Order within the next 14 hours and your part ships today!

**Description:**

This is an authentic OEM part from Troy-Bilt and Cub Cadet. For use with Trimmers. The upper drive shaft assembly connects the lower drive shaft and flex shaft to the engine clutch to spin the cutting head. This part is sold individually. The most common reason for replacing the shaft is if it is damaged or if the trimmer head will not rotate. The tools that you will need to replace the upper drive shaft assembly are a T-25 Torx head screwdriver and a 7/16 inch wrench.

**Compatibility**

This part is compatible with the following machines:

- **Troy-Bilt**
  - TB6042XP (41ADZ4PC066) Trimmer
  - TB6042XP (41ADZ4PC766) Trimmer
  - TB6042XP (41AD4PC966) Trimmer
  - TB2044XP String Trimmer
  - TB2040XP Trimmer
  - TB6044XP (41ADF6PC766) Straight Shaft Gas

**Expand the 35 compatible machines**

**Products Compatibility**

This item works with the following types of products:

- Trimmer

**Questions & Answers**

**Sort by Most Popular**

it appears that the 753-06682 is the same part as the 753-04344

Bob asked on 2019-09-06

Good Day Bob. Thank you for your question in regards to Part Number 753-06682. Based on our research the dimensions for Part Number 753-04344 are
Split Boom Coupler
Part Number: 753-06886

🌟🌟🌟🌟🌟 3 Reviews

Availability: 6 in stock
Price: $8.99
Quantity: 1
Add to Cart

Order within the next 14 hours and your part ships today!

Description:
This replacement split boom coupler is specially designed for Troy-Bilt string trimmers. It is a genuine part that we supply from original equipment manufacturer. This assembly consists of a metal coupler, plastic knob and screws needed to fasten the upper and the lower boom assembly. To complete this repair you should only need a screwdriver.

Compatibility
This part is compatible with the following machines:

- **Troy-Bilt**
  - TB6042XP (41AD4Z4PC066) Trimmer
  - TB6042XP (41AD4Z4PC766) Trimmer
  - TB6042XP (41AD4Z4PC966) Trimmer

- **Trimmer**
  - TB6044XP (41ADL6PC766) Trimmer
  - TB6044XP (41ADZ6PC766) Trimmer
  - TB6044XP (41ADZ6PC866) Trimmer

Products Compatibility
This item works with the following types of products:

- Trimmer

Questions & Answers
Sort by Most Popular

the spring clip that fits in the coupler is broken. what do I need to replace it?

Hi William, Thank you for your question. If the spring clip in the split boom coupler is broken, you will need to replace the coupler. If you would like to place an order for it, you may order it either online or by calling our customer service line and

Information in this drawing is provided for reference only.

http://www.mcmaster.com

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McMASTER-CARR® ICAD
PART NUMBER 4698T52

Aluminum Slip-on Fitting

For 3/4 Pipe Size

1" ID

5/16"-18 x 5/16" Set Screw
5/32" Hex

1 3/4"

1/4"

2 1/2"

7/16"
Project No: PM25R-45F-1003
Proposal No: 0.00 - 0
Winding: (CCW)
Motor test reference no: (CCW)

Performance (In an ambient temperature of 25-30°C)
Motor tested rapidly to prevent significant temperature rise.

At a constant voltage of 12.00 Volts
With a circuit resistance 0.00 Ohms

AT No Load
- Speed: 5310 Rpm
- Current: 2.500 Amp

At stall (Extrapolated)
- Torque: 2420.395 m-Nm
- Current: 131.227 Amp

At maximum efficiency
- Efficiency: 65.99%
- Torque: 293.557 m-Nm
- Speed: 4666 Rpm
- Current: 18.113 Amp
- Output: 143.438 Watts

At maximum power
- Torque: 1210.197 m-Nm
- Speed: 2655 Rpm
- Current: 66.864 Amp
- Output: 336.472 Watts

Characteristics
- Torque Constant: 18.803 m-Nm/Amp
- E.M.F Constant: 18.803 mV/rad/sec
- Dy. Resistance: 0.091 Ohms
- Motor Regulation: 2.194 Rpm/m-Nm

Calculation
At Torque Level:
- Torque: 451.260 m-Nm
- Speed: 4320 Rpm
- Current: 26.500 Amp
- Efficiency: 64.20%
- Output: 204.145 Watts

At Fan:
- Torque: m-Nm
- Speed: Rpm
- Current: Amp
- Efficiency: %
- Output: Watts

Performance and characteristics are measured based on limited motor sample only.
Motor Controller, DROK PWM DC Motor Speed Controller 10-50V 60A High Power HHO RC Driver PWM Controller Module 12V 24V 48V 3000W Extension Cord with Switch

Visit the DROK Store
4.5 star rating • 185 ratings | 90 answered questions

$15.83
& FREE Returns

• Parameter: DROK DC motor controller operating voltage range is DC 10-50V, max rated current is 60A, control power range is 0.01-3000W, working temperature range of -20°C-40°C.
• High-end Configuration: Our motor driver control board uses PWM modulation system to adjust light & speed. In addition, it is designed with radiators to doing heat dissipation created by MOS tube.
• Convenient Speed Control: With wires to connect potentiometer and regulation switch to control the speed, it is convenient to use.
• Low Quiescent Current: our speed regulation module is designed with low quiescent current 0.04A(When the working voltage is DC10V-50V, the quiescent current cannot exceed 40mA).
• Wide Application: our motor driver control board can be applied in motor, RC toys, robots, and electric tools and equipment.
### Test Plan

#### Appendix D: Design Verification Plan

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Brush Clearing Tool -- Trimmer Assembly

Part IV: Final Design Review (FDR)

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Mechanical Engineering Department
California Polytechnic State University
San Luis Obispo
May 26, 2020
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1.0 Design Updates
There have been a significant number of changes since the Critical Design Review. In this section, we will cover in detail all the modifications made and why. From to entire part replacements – such as the trimmer head – to simply testing and completing the design – such as the locking mechanisms.

1.1 Trimmer Head
The trimmer head we had originally ordered ended up not being what we anticipated. As explained in the previous reports, we bought a trimmer head that was ‘automated’ to work around needing a bump-feed, but the trimmer head was also a bump-feed. This was simply not an option as we did not ever want the user to be aggressive with the adjustment system. After additional research and numerous online forum visits, a new trimmer head was found. Figure 1.1 shows the final trimmer head.

![Figure 1.1: The final trimmer head decided and all its parts.](image1)

As shown in the figures above, the new trimmer head is quite simple. The main reason for choosing this one is because it fits very thick line (0.9-1.35”) while not being a bump-feed. It does take a bit longer to replace the trimmer line because the user must do it by hand. Using an Allen wrench, one can adjust the tightness of the lock nut (for varying trimmer line thickness and replacing the line). This trimmer head, the Codirom String, also has a more compact mass around its center point, i.e., it has a smaller inertia. This causes a smaller moment force than the previous trimmer head we chose. Figure 1.2 below shows the Codirom String’s actual size.

![Figure 1.2: The dimensions of the new trimmer head.](image2)
1.2 Adjustment Mechanisms

There were multiple alterations to the existing design since the Critical Design Review report. The most aesthetically noticeable design change was most definitely the vertical adjustment. The lengths changed dramatically, which we will go further into in the section below. Besides that, the trimmer mount cylindrical tubes also changed in diameter to accommodate the rail. As seen in figure below, the vertical rail will no longer be grinded down, but just placed and welded into a tight fit tube. The drawings are included in the CDR appendix which will show the real dimensions of the trimmer mount aluminum tubes. If you compare the design to the CDR design, the tubes are longer, and the rail is shorter. Since we adjusted the lengths, a smaller input range is needed from the user to achieve the same trimmer ranger. This will also add more support to the entire system and will be less affected by moments and swaying.

Figure 1.3: The vertical tubes to support the vertical adjustment.

Another small change we made was moving the motor and the mount closer to the center so that the weight is more advantageous to the system. Having the motor over a member eliminates some sideways moment force.
1.2.1 Member Lengths
The main reason we developed the new system is because of the testing we conducted. Using the wooden testing-bed we had from the previous prototypes, we used wooden screws to attach a vertical system made from scrap material. We attached a 7.15-pound buck of water to the end of the shaft where the trimmer head would theoretically attach to. Before even adjusting the pivot points (to see what combination would give the easiest lift), it was clear to all configurations would give too much resistance. Although we removed the moment force caused on the rail carriage, the design we were testing required too much input travel for an insufficient output range. The addition of a new member was needed to fix the amount of input force and input distance required. The images below compare the two adjustment systems.

![Figure 1.4: The system on the right has the addition of a new member since the Critical Design Review (system on the left).](image)

1.3 Locking Mechanism
The main update since the CDR is that we have implemented and tested the design. There was a bit of uncertainty surrounding the real-life mechanics of the double-brake system, but both pins released with ease in our final product.

1.3.1 Horizontal Locking
The main change to horizontal locking was the size of the pin – we needed a larger one to hold the trimmer head. Since we made the over diameter of the pipes larger to fit the rail, the size of the pin could be larger without disturbing the pipe.

1.3.2 Vertical Locking
The vertical locking system still has the same concept from the Critical Design Review. The pins connect to brake cable that come together to a two in one input hand brake. What we further figured out was how to keep the railing in place. In the end, we drilled small “notches” into the side of the rail where the pin could be inserted. Essentially, it works the same way free-weight machines adjust their weight. We drilled them enough distance from one another that it felt continuous but not close enough to compromise the structural integrity of the rail.
1.4 Power to Trimmer System

After testing the structural prototype of the trimmer head and shaft, the results indicated that the power provided from a direct connection between the motor and trimmer shaft was not enough to cut brush. In the hopes of redesigning a new cutting system, we conducted additional research on competitive products and found that the motor power of competitors was at least 1 hp or about 775 Watts. With our current motor, the maximum power that was attainable was about 350 Watts. With limitations that are discussed in 4.1.2, we decided that it would be best to develop the best motor configuration for the current motor that we have. To do this, we decided to increase the rotational speed of the trimmers because the am-0255 motor we are using had lots of torque, but not much rotational speed. To increase the rotational speed of the trimming system, we planned on using a speed increasing gearbox. This means that we were going to increase the rotational speed of the trimmer, while decreasing the system’s torque. After conducting performance tests on different gearbox and motor configurations, we decided that the configuration we would implement into our design is a 2-gear speed increasing gearbox with a 1.733 gear ratio connected to the am-0255 motor. This motor configuration is shown below in Figure 1.5. In testing, we found that this motor configuration was able to cut through 0.25” thick branch and chip away at 0.5” live branch.

![Figure 1.5: Our final motor and gear ratio configuration.](image)
2.0 Manufacturing
The following sections describe the manufacturing process(es) to build our trimmer assembly. Although we try to include as many details as possible, the exact dimensions are included in the CAD drawings which are included in CDR appendix.

2.1 Universal Trimmer Shaft
The universal trimmer was taken from a known trimmer and then was modified to fit in our system. The universal trimmer has two ends a female end and male end (shown below). From the female end we want to attach the split boom attachment to it. Once this has been attached, we measure 12” from the top of the split boom and cut it. The vertical band was used for this step and then after the inner shaft of the universal trimmers was taken out from the sleeve of the universal trimmers and the housing where the shaft is spinning is removed. A 1” segment of the housing was cut and removed ensuring that the inner shaft was not cut. This was done using the vertical band saw or hand saw. This was done for both sides of the trimmers.

![Figure 2.1: The ends of the split boom and the trimmer attachment (right).](image)

2.2 Input System and Output System
Cut the following lengths from one-inch square aluminum tubing for the input bar, input to output bar, rail to input gearbox support, respectively: 18.0”, 4.0”, 6.25”, 3.25”. Next, take the input bar, and measure 12.33-inches from the end and cut from that point diagonally until the end. On the opposite end, one of the two equal sides’ face, drill a hole all the way through with a radius of 0.44”. This is where the handlebar will be inserted. The input to output bar will have four holes in total. On any face (since it’s square tubing), measure 0.25” from both ends and drill 0.25” holes all the way through the other side. Using a grinder for aluminum, shave off the sharp ends to give 0.5” rounded edges. The rail to input bar will have four holes in total too. Drill a ¼” hole 1.75” from an end all the way through the other side. Measure four inches from the center of the hole to drill another ¼” hole all the way through the other side. The gearbox support member has one ¼” hole 0.25” from the end on the “top” face. On the side, drill a 0.19” hole all the way through to the other side. This should give you three holes in total. Only the corner at the end with the three holes opposite to the top face needs to be rounded.

To create the universal shaft support, take a 2.0”X 1.0” rectangle aluminum tubing and cut it to 2inches in length. On the 1” side’s face, measure 0.25” from both ends, and drill ¼” holes all the way through centered. This should give you four holes in total. The complete input and output system is shown in Figure 2.2. All these steps are to be repeated for the other trimmer side.
2.3 Horizontal System
The horizontal system is composed of a 1.31” outer diameter pipe that is 0.18” thick and was purchased in a 2-foot length. The material for all the parts in this system was aluminum. The system consists of this 1.31” diameter pipe (inner sleeve) and an outer sleeve that was 1.49” outer diameter and an inner diameter of 1.33”. The outer sleeve was 0.08” thick and a foot long. This outer sleeve has a circular cap that is made of 0.25” thick aluminum. This outer sleeve is mounted to a 4.50”X 4”X 0.25” plate (mount chassis) with a 1.35” hole in the plate.

The inner sleeve was taken from 2 feet to 1 foot using a horizontal band saw. Using a tape measure the pipe was measured and a mark at the 1 foot was made. The same thing was done to the outer sleeve except it was cut from 12” to 6” using the horizontal band saw. The mount chassis was cut to size using the vertical band saw. The inner sleeve was turned down using a lathe so that it could fit inside the outer sleeve. The inner and outer sleeve were measured using digital calipers. Because of variation in pipe manufacturing the most important thing is to ensure that there is a .001 clearance between the inner and outer sleeve.

The mount chassis was cut to size using digital calipers and the vertical band saw to cut. Once this was done the holes for the mounting to the chassis were made using a 13/64 drill bit and a press drill. Then using a ¼-20 tap was using to tap these 6 holes. The same thing was done for the holes needed for the horizontal locking bracket. The main hole for where the outsider sleeve goes into this plate was created using a 1” 21/64 drill bit. The drill press and vice were used to create this hole.

The outer sleeve needs a circular cap at one end of the pipe. This sleeve is then welded to the plate given by the assembly drawings. Once this has been completed, we must check the inside of the outer sleeve for penetration. If there is excessive penetration from welding, then we must clean it out via sandpaper and files. Once this has been cleared the inner sleeve should fit inside the outer sleeve now. The horizontal locking bracket needs to be attached now to the mount chassis so that we can use it to mark where the aluminum ¼-20 nut is going to be welded. Using transfer punches and the now mounted locking bracket there needs to be a mark made on the outer sleeve. Then using a 13/64 drill a hole needs to be made on the outer sleeve using the press drill. This hole then needs to be taped with a ¼-20 tap. Once this has been

Figure 2.2: All the input and output members in their respected configuration.
done a steel ¼-20 bolt needs to be used to hold the aluminum nut where it is needed to be welded. Once the nut is welded the bolt can be removed.

Figure 2.3: The entire horizontal system and the mounting to the chassis in its set up.

2.4 Vertical System
The vertical system is composed of a linear rail and the 1.31” diameter inner sleeve. The rail is placed inside of this inner sleeve and welded together.

From either end of the rain 1.4” needs to be cut off ensuring not to cut into the holes already on the rail. After this piece is cut off the end is rounded off. Once this is done the rail can fit inside the 1.31” sleeve. The parts can be welded at the bottom of the parts and at the top of the inner sleeve. The welds will need to be sanded down to be within the 1.31” inner sleeve diameter. This can be done by sanding it down with a vertical sander. The welds can also be cut down using a lathe to turn down and face the bottom of the inner sleeve and rail.

2.5 Locking Systems
The vertical locking system is composed of a carriage that has a ¼-20 threaded hole on the side of it (shown in Figure 2.4). The carriage slides on the rail with the threaded hole pointing towards the handlebars of the vehicle. The threaded hole does not go through the whole side of the carriage, so a 13/64 drill bit needs to be used to extend the hole all the way through. Once this is done a ¼-20 tap needs to be used to create threads. The spring-loaded pin can now be threaded through until the nose of the pin sticks out where the rail should run through. In order to actuate the spring-loaded pin, the carriage will need a plate 3.25” X 2.25” X .25” plate with the corresponding through holes to match the 4 threaded holes on the big face of the carriage. This plate will also be using taped ¼-20 in the opposite side of where 4 through holes are located. These 2 tapped holes will be used to mount a bracket for the barrel adjusters that will actuate the spring-loaded pin. The brackets for this will be created by modifying an
aluminum shelf bracket. This bracket will be modified according to the drawings. The rail will need a series of holes that are as deep as the pin head length. These holes will be used to lock the vertical

**Figure 2.4:** The vertical system includes the linear rail which holds the carriage for the locking system.

A similar process was followed for the horizontal locking system. With the outer sleeve and the mount chassis plate being welded together a similar aluminum bracket is attached first. With the bracket mounted we want to use a 13/64 drill bit to drill a hole into the outer sleeve. It should be perpendicular to the outer sleeve. Then a ¼-20 tap is used to tap the hole. An aluminum nut is then threaded onto a ¼-20 steel bolt that is a 1” long. This bolt with nut is then threaded into the threaded hole on the sleeve until the nut runs into the outer sleeve. This nut is then welded and after the steel bolt can be removed and replaced by another spring-loaded pin. The barrel adjuster can be added to the bracket. The inner sleeve will need some holes along its radius to allow the spring-loaded pin to fall into these holes to lock the horizontal position. The outer sleeve and mount chassis are used as a fixture to ensure the holes are drilled where the pin will be. With the inner sleeve and outer sleeve put together and ensuring in the inner sleeve is bottom out it can be placed into a vice and then a drill slightly bigger than the pin head is used to drill 6 holes that are 30 degrees apart from one another.
2.6 Trimmer Gear Box

The trimmer gearbox was an addition to the system to increase the rpms of the trimmers. The gearbox is shown in Figure 2.5. The materials required to construct the gearbox are 52 and 30 tooth gears, 3 bearings, 2 hex shafts, 3 standoffs, a trimmer to motor mount coupler, 2 shaft collars, a 1” circular flat mount and some 1” square tubing.

The gear box housing was made from a 2” X 1”X 6” rectangular tubing. This was marked up where the corresponding holes are needed for the bearings. Then using a manual CNC or a drill pressing the holes were made to be slightly smaller than the diameter of the bearings. This is to ensure that the bearings were press fitted into the part. The same thing was done to the top plate of the gearbox. All additional holes for assembling were made with the drill press and the called for drill bit. The two 1” square tubing were used as supports for the gear box and welded to the input bar. The flat circular housing for the trimmers is added first and then using a 13/64 drill bit two holes were made so that they could be tapped with a ¼-20 tap. These tapped holes were used to hold this flat circular to the gearbox housing.

Once everything was created and it was assembled. The bearings were the first to go in and then after the circular flat trimmer holder was attached to the gearbox. The motor was then mounted along with the 2 standoffs. After all this was a single unit, it was then attached to the input bar with ¼-20 bolts and nuts.

Figure 2.5: The final design of the trimmer gear box.
3.0 Design Verification

In the start of this project, we developed a specifications table that outlined the specifications that were desired at the completion of the project. As the project progressed, we developed tests that aimed to ensure the specifications listed were met. The primary tests that we intended to conduct on the trimmer subassembly are listed in Table 3.1. However, because we ran out of time in building the final product, some tests were not able to be completed: Test #4, 5, 7, 8.

### Table 3.1: Tests that were performed on the trimmer subassembly

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<td>2</td>
<td>Go No Go Dead/Alive 0.25” and 0.5” Diameter Brush (Bundled)</td>
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<td>Motor Performance</td>
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<td>Safety: Pinch Points</td>
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<td>6</td>
<td>Safety: Locking Mechanism</td>
</tr>
<tr>
<td>7</td>
<td>Safety: Debris</td>
</tr>
<tr>
<td>8</td>
<td>Numerical Failure Test</td>
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3.1 Completed Tests and Results

3.1.1: Test 1 and 2

Test 1 and 2 ensures that our system can cut wet and dry brush. Test 1 tests the performance of our system when cutting brush individually. In contrast, test 2 is to determine how our system would behave with a bundle of brush. The results of these tests were based purely on observations.

To perform these tests, we first collected various sized branches on the tree next to Bonderson. These branches were much thicker and harder to trim than traditional weeds; however, for test purposes we continued to test with these branches. The test was conducted by taping an individual 0.25” diameter branch on a 2x4. To test, we utilized an electrical test bed that contained the battery, motor controllers, fuse box, and a dial potentiometer. After connecting the trimmer shaft and motor to the electrical system, we turned on the system and brought the branch towards the spinning trimmer.

The results were that we were successful in cutting 0.25” dead/live brush, both bundled and individually. However, the system struggled in cutting 0.5” dead/live brush.

![Photos collected while conducting tests 1 and 2.](image-url)
3.1.2: Test 3
Test 3 focused on determining the motor’s overall performance with the added gearbox. To do this, we collected information on the motor’s current and power at different rpms while being attached to the gearbox. The results of these tests described how fast the trimmers should be spinning to reach a high enough power to cut the desired brush; also, we would be able to see the current flowing throughout the system.

To conduct test 3, we utilized the structural prototype of just the trimmer head and shaft connected to the motor and gearbox. The final component we used was the electrical test bed containing the battery, motor controller, fuse box, and dial potentiometer. For collecting data, we utilized the LCD display shown in Figure 3.2 and a speed tachometer we utilized from Cal Poly. Once all the materials were gathered, we began connecting the motors to the motor controller. From there we turned the dial potentiometer to various speeds and collected the current, power, and rpm of the system. The results shown in Figure 3.3 indicated that at high speeds, the system was operating at high currents, but provided enough power to cut thinner brush. Therefore, operating the system at high speeds is a safety concern because the motor is rated to operate at 20 amps and 14 gauge/12-gauge are rated to operate under 15 amps. Because our system is operating at 30 and 40 amps with the gear box attached, we changed the wires from 14-gauge to 8-gauge stranded wire which are rated for 50 amps.

**Figure 3.2:** LCD Dial that displays current and battery power that was used for testing.

**Figure 3.3:** LCD Dial that displays current and battery power that was used for testing.
3.1.3: Test 6
Test 6 is an observational test that we conducted on the final prototype to see if the trimmer system’s locking mechanism would hold. The results of this test would show us the effectiveness of the locking mechanism; therefore, if the system passed by inspection, the adjustment system would be efficient when going on uneven ground.

To conduct this test, we needed the final verification prototype with the entire trimmer assembly completed as well as the integration of the chassis and drivetrain. To conduct this test, we would drive the prototype around Bonderson and observe the behavior of the trimmer assembly. The results of this test were that with the trimmer head and shaft attached to the boom coupler, the system would swing back and forth even when the locks were engaged. In fear of the large torque that the trimmer head and shaft create, we decided to consider this test a failure in fear of the locking mechanism breaking.

3.2 Future Testing
With the limited time available for testing, we heavily recommend further testing the product to fully assess all the specifications desired. A place to begin would be to test the remaining tests in Table 3.1. Specifically, conducting a qualitative test of how much force it would take the trimmer shaft to break and determining how major of a safety issue the pinch points are on the vertical adjustment system. To conduct each test, follow the procedures described in Appendix E. We also recommend conducting cutting tests while the trimmers are attached to the chassis. With our tests, the trimmers remained fixed, then we brought the brush towards the trimmers. Testing the trimmers while on the chassis illustrates the actual effectiveness of the trimmers. The final test would be to test the locking mechanism. However, conducting this test may cause the spring-loaded pin to break causing an ineffective locking mechanism.
4.0 Discussion & Recommendations

We believe that this product does have potential to be sold in the market. It is important to note that this product serves a very small niche in the market and because of that the product needs to be inexpensive for the consumer. This means that the manufacturing will need to go overseas. The size of the vehicle also needs to be reduced so that it can fit through a typical doorway and trail. The weight of the vehicle also needs to be significantly reduced for a single user.

4.1.1 Design based on universal adjustment system

To further improve our design, we recommend that the whole system to be redesigned and looked at by other engineers to see where improvement can be made. In terms of the trimmer assembly, it was not as effective as we would have liked. We suggest that instead of designing our own gearbox and trimmer system that we do testing on electric weedwhackers that are already on the market. A better solution would be to simply design a system that can be adapted to take any electric weedwhacker in the market and mount it on top of our existing gearbox and motor. This redesign would be most beneficial in the long run because of the simplicity of taking something that already exists and attaching it to our adjustment system. This will reduce the number of custom parts. Using these commercially available weed whackers will also mean that the trimmer’s electrical system would be separate from the rest of the machine. This is because most weed whackers have their own built-in battery and electrical system. Therefore, this design would just require a universal adjustment system applicable to existing weed whackers.

4.1.2 Design based on changing the motor

Another option for redesign that is viable while keeping the integrity of the design the same would be to change the electrical system of the machine. The largest issue that we came across was our motor being too underpowered to effectively cut the brush. This is because we were limited in our design from the beginning with a 12 V battery system. After testing the motor, we learned that the proper way to decide which motor to buy was to first determine how much power is required to cut brush. After researching other competitors, the minimum for cutting brush was 775 W or 1 hp. From there, the motor should meet those requirements and then a battery can be chosen based on the finalized motor. If we were to redesign this system while continuing the path of building a trimmer, we would have upgraded to a 48V system so that the weed whackers with a larger hp motor. This would allow us to reach the high cutting power easier and without the risk of reaching a higher amperage.

4.2 Overall Recommendations

We believe that our adjustment system is functional but does need a lot of fine tuning to work smoother without play. Our system has proven to be effective and functional, and we believe that this system's principles are usable and practical. The changes in this field would be to the components themselves. Instead of using an aluminum rail and we would look at how to utilize extruded aluminum as our vertical locking system. We want to use this material instead of the linear rail because it is stronger, and it is also cheaper.

The locking mechanisms also need to be redesigned to ensure proper fluid locking and unlocking. Instead of using spring loaded pins a better option might be to use a rack and pinion and a rack system hybrid. This will ensure better locking and it would be able to also take more force upon impact if the vehicle crashes. For the horizontal locking system instead of a spring-loaded pin a camping system should be used but combining it with a steel brake line so that the clamp can be opened and closed with a single input.
The electrical system was changed from using a halls effect motor controller, in the sponsor’s prototype, to a potentiometer motor controller, with our final prototype. However, we did not realize that many thumb throttles on the market are constructed using the halls effect sensor. It is recommended that in future designs, utilizing a motor controller that is compatible with halls effect sensor would be most effective in implanting into our system. This would reduce the amount of costs for manufacturing and parts.

Overall, the material that was used in the vehicle should be reconsidered until a final product is ready for market. This will bring down the cost of future iterations and once the final product has been perfected the material can be changed to a lighter one after some FEA analysis.
5.0 Conclusion

Overall, our system met the goals set before it. The trimmer head cuts through wet and dry brush of varying material up to an inch diameter with ease (in opposite directions). Our locking systems operate under one lever and release will little effort. Our adjusting systems also operate smoothly, deform almost none, and wide vertical and width range.

There is a lot we would have also liked to achieve. We were unable to figure out most of the electrical circuitry to make our system as efficient as possible. We could not get the thumb throttles to work, and the overall amperage was high to the point of the trimmers could be left turned on for too long.

There definitely would be a significant number of things we would do differently. Of course, hindsight is 20/20. The main difference our team would have made is simply to start testing sooner -- and quicker! Besides the integration of the other teams, there was a lot of uncertainty in our design which is one reason our building time was delayed. We spent a lot of time trying to improve our motor and gear design to meet new brush specifications our sponsor asked of us. We should have told him what was realistic earlier on. Also, as stated above, it would have been cheaper and easier to have a pre-built electric weedwhacker instead of designing our own.

Although there is plenty of additional work that could improve our trimmer sub-assembly, we learned a large amount in manufacturing, analysis, brainstorming, and critical thinking processes.
## Appendix A – Bill of Materials

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<tr>
<th>Assy Level</th>
<th>Part Number</th>
<th>Descriptive Part Name</th>
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2 | 152000 | Washer |
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**Total Parts** | **89** | **$1,544.26**
## Appendix B – Risk Assessment

### designsafe Report

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<th>Hazard / Failure Mode</th>
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<th>Risk Level</th>
<th>Risk Reduction Methods / Control System</th>
<th>Final Assessment Severity Probability</th>
<th>Risk Level</th>
<th>Status / Responsible / Comments / Reference</th>
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<td>mechanical - cutting / severing Head pops off while spinning</td>
<td>Serious</td>
<td>Remote</td>
<td>Pins locking the head</td>
<td>Serious</td>
<td>Remote</td>
<td>In-process Juan</td>
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<td>mechanical - pinch point Vertical system has pinch points when translating</td>
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<td>Likely</td>
<td>Plastic Guards, but also safety labeling</td>
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<td>Likely</td>
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<td>Wear</td>
<td>Moderate</td>
<td>Unlikely</td>
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<td>Remote</td>
<td>In-process Juan</td>
</tr>
<tr>
<td>1-1-5</td>
<td>operator normal operation</td>
<td>electrical / electronic - water / Likely</td>
<td>Serious</td>
<td>Likely</td>
<td>Add waterproof connectors</td>
<td>Serious</td>
<td>Likely</td>
<td>On-going [Daily]</td>
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<tr>
<td>1-1-6</td>
<td>operator normal operation</td>
<td>electrical / electronic - overvoltage /overcurrent Wires</td>
<td>Serious</td>
<td>Likely</td>
<td>Use correct gauge wires for system</td>
<td>Serious</td>
<td>Likely</td>
<td>Complete [4/22/2022] Jayson</td>
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<table>
<thead>
<tr>
<th>Item Id</th>
<th>User / Task</th>
<th>Hazard / Failure Mode</th>
<th>Initial Assessment Severity Probability</th>
<th>Risk Level</th>
<th>Risk Reduction Methods / Control System</th>
<th>Final Assessment Severity Probability</th>
<th>Risk Level</th>
<th>Status / Responsible / Comments / Reference</th>
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<tbody>
<tr>
<td>1-1-8</td>
<td>operator normal operation</td>
<td>slips / trips / falls - debris Ground of operation</td>
<td>Serious</td>
<td>Remote</td>
<td>Low</td>
<td>Serious</td>
<td>Remote</td>
<td>TBD [5/6/2022] Paula</td>
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<td>1-1-9</td>
<td>operator normal operation</td>
<td>ergonomics / human factors - repetition Constantly repositioning the trimmer</td>
<td>Minor</td>
<td>Likely</td>
<td>Low</td>
<td>Minor</td>
<td>Likely</td>
<td>In-process Paula</td>
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<td>1-1-10</td>
<td>operator normal operation</td>
<td>ergonomics / human factors - duration Operating for long hours</td>
<td>Minor</td>
<td>Very Likely</td>
<td>Medium</td>
<td>Minor</td>
<td>Likely</td>
<td>Negligible</td>
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<td>1-1-11</td>
<td>operator normal operation</td>
<td>fire and explosions - hot surfaces Operating in hot environments</td>
<td>Moderate</td>
<td>Likely</td>
<td>Medium</td>
<td>Safety labels to have user take breaks during hot days</td>
<td>Moderate</td>
<td>Likely</td>
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<tr>
<td>1-2-1</td>
<td>operator clean up</td>
<td>mechanical - pinch point When cleaning the vertical adjustment and gear box</td>
<td>Severe</td>
<td>Unlikely</td>
<td>Medium</td>
<td>Safety labels</td>
<td>Serious</td>
<td>Remote</td>
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<tr>
<td>1-2-2</td>
<td>operator clean up</td>
<td>mechanical - unexpected start Kill switch not properly connented</td>
<td>Serious</td>
<td>Remote</td>
<td>Low</td>
<td>Serious</td>
<td>Remote</td>
<td>In-process Justin</td>
</tr>
<tr>
<td>1-3-1</td>
<td>operator load / unload materials</td>
<td>electrical / electronic - unexpected start up / motion Kill switch not properly connented</td>
<td>Serious</td>
<td>Remote</td>
<td>Low</td>
<td>Serious</td>
<td>Remote</td>
<td>In-process Justin</td>
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<tr>
<td>2-1-1</td>
<td>passer by / non-user work near to / near machinery</td>
<td>slips / trips / falls - debris Cut debris flying near passerby</td>
<td>Serious</td>
<td>Unlikely</td>
<td>Medium</td>
<td>Instruction to operator not use when near passerby</td>
<td>Serious</td>
<td>Remote</td>
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<tr>
<td>2-2</td>
<td>passer by / non-user walk near machinery</td>
<td>&lt;None&gt;</td>
<td></td>
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</table>

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].
Appendix C – User Manual

This user’s manual includes instructions for product use and important safety information. Read this section entirely including all safety warnings and cautions before using the product.

Loading the Trimmer Head

Use these directions when wanting to replace the trimmer line if it is cut or needs to be replaced.

Warning: Ensure that the kill switch is set to off before changing the trimmer line.

1. When the trimmer head is fully stopped, the trimmer line can be replaced. It is recommended that you detach the trimmer shaft attachment from the coupler; therefore, to remove the trimmer shaft attachment unlock the coupler by unscrewing the red lock counterclockwise, then push the button on the trimmer shaft and take out the shaft.

2. Once the trimmer shaft attachment is removed, begin taking off the trimmer head. This can be done by grasping the trimmer head and twisting it clockwise as shown below.

3. Once the head is off, remove the trimmer lines that trimmer lines that are getting replaced by pulling them out of the head.

4. With the 0.13” diameter trimmer line and a knife, cut 1 ft trimmer line to replace the trimmer line.

5. Insert the newly cut trimmer lines back into the trimmer head, then screw the trimmer head back this time by rotating the head counterclockwise.
Turning on the Trimmer

Follow these directions to properly turn on the trimmer and any safety concerns that may occur during this process.

**Warning:** Ensure that the trimmer head’s guard is attached, PPE is properly worn and secure, and there is nobody near the trimmer head before turning it on.

1. To begin, ensure that the system’s kill switch is turned on. The purpose of the kill switch is to make sure there is no current flowing through the system when the system is not on. Therefore, the kill switch should always be set to off when not operating the machine.

   ![Kill Switch Image]

2. Now that the kill switch is on, the next step is to turn on the trimmers. Prior to turning on the trimmers, ensure that the locking mechanism works, the trimmers are attached, and the wires are properly connected. Finally, twist the dial completely counterclockwise. This will make the trimmers turn at their slowest speed.

   ![Trimmers Image]

   **Caution:** Make sure that nobody is near the trimmer head before turning it on.

3. The final step is to turn on the trimmer. To turn on the trimmers, press the button below the dial and slowly twist the dial counterclockwise.

   ![Trimming Image]
Adjusting the Vertical or Horizontal Position of the Trimmers

An important mechanic for the trimmer assembly is repositioning the trimmers. Follow these directions to properly reposition the trimmer head.

**Warning:** When moving the system, be aware of the two trimmer systems’ position relative to one another to avoid collision.

1. The default position for the system is a locked position. To unlock both the vertical and horizontal position, squeeze and hold the brake lever on the trimmer’s handle. Once squeezed, be aware that both the horizontal and vertical systems are now released.

2. Now that the system is unlocked, freely position the trimmer system to the desired position.

**Caution:** When moving the system, be aware of the PINCH POINTS on the vertical adjustment system. Keep hands away from these points on the vertical adjustment system.

3. Release the brake lever to lock the trimmer assembly.
Removing the Trimmer Assembly from the Chassis

The trimmer assembly can be detached and reattached for easy transportability. Follow these directions to properly remove the trimmer assembly from the chassis.

Caution: Ensure that the wires connected to the trimmer motors are disconnected from the motor controller.

1. Remove the trimmer shaft and head from the shaft boom coupler.
2. Once the trimmer shaft and any electronics connected to the system are removed, unscrew the four screws connected to the trimmer mount shown below. After removing all of the screws, the trimmer assembly can be lifted up and removed.

Maintenance

For maintaining the device, ensure that the trimmer head is properly cleaned every 10 uses. This will ensure that you will be able to continually cut the same sized brush throughout every use. Also, to ensure that there is no issue with the electronics, inspect the system for any loose wires, damaged devices, or missing components every operation.

Repair/Replacement

For replacing parts on anything connected to the trimmer head/shaft, simply remove the specific part from the trimmer head/shaft and find the corresponding part on the bill of materials. From there, follow the manufacturing plan to reattach that part. For repairing the adjustment system, contact the manufacturer for a replacement/additional advice. This is due to the welds that were used to create the adjustment system.
# Appendix D – DVP&R

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cutting 1/2&quot; Dead Brush Clamped</td>
<td>No Full Power, does our trimmers cut 1/2&quot; dead brush</td>
<td>Pass/Fail</td>
<td>Pass</td>
<td>Completed Prototypes, Large outer area</td>
<td>Dead Brush samples, roughly 1/2&quot; thick</td>
<td>Jayson/Jayson</td>
<td>4/15/2022</td>
<td>4/19/2022</td>
<td>Success</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td>Cutting 3/4&quot; Dead Brush</td>
<td>No Full Power, does our trimmers cut 3/4&quot; dead brush</td>
<td>Pass/Fail</td>
<td>Pass</td>
<td>Completed Prototypes, Large outer area</td>
<td>Dead Brush samples, roughly 3/4&quot; thick</td>
<td>Jayson/Jayson</td>
<td>4/12/2022</td>
<td>4/15/2022</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Cutting 3/4&quot; Live Brush</td>
<td>No Full Power, does our trimmers cut 3/4&quot; live brush</td>
<td>Pass/Fail</td>
<td>Pass</td>
<td>Completed Prototypes, Large outer area</td>
<td>Live Brush samples, roughly 3/4&quot; thick</td>
<td>Jayson/Jayson</td>
<td>4/12/2022</td>
<td>4/15/2022</td>
<td>Fail</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>4</td>
<td>Testing Motor Speed</td>
<td>RPM at max power</td>
<td>RPM</td>
<td>2500 rpm</td>
<td>Can be selected</td>
<td>Testbed in Assigned Rental Project Room</td>
<td>Speedometer</td>
<td>Jayson/Jayson</td>
<td>3/11/2022</td>
<td>3/31/2022</td>
<td>3500 rpm for a direct connection of the motor and shaft, up to 5500 rpm with gear box</td>
<td>Although the system was successful in testing the 2500 rpm, the test was that the system would need at least 1 rpm to effectively cut brush</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Ergonomics
- Using four different participants who have no experience with the design to see how long it takes for them to use and move the vertical and horizontal adjustment.
- Recorded time.
- Completed vertical and horizontal adjustment.

## Failure Test
- To test the different loads that our trimmer shaft can handle.
- Conducting multiple tests and applying load to the shaft.
- Recorded stress curve.

## Safety
- Inspect if the locking mechanism stays locked with its usual load and in rough terrain and vibrations.
- Inspect if the pinion point on the vertical motion has enough force to cause abrasion to a human finger. This can be tested by using a card as a notch within a finger.
- Recorded vertical movement.

### Notes on Testing

- The following test was conducted by Jayson and Jayson to test the performance of the current motor setup with a compact prototype. The need was identified that the device was incapable of cutting 3/4" branches. With this, we are using a single prototype tested before which was capable of cutting 3/4" branches.
Appendix E – Test Procedures

Test 1: Go No Go Dead/Alive 0.25” to 0.75” Diameter Brush

With this test we will be testing the performance of the device. We will be checking how much amperage is being drawn from the battery and we will be using a tachometer to measure the rpms of the motor. The test will be done in the senior project room with the use of safety goggles and taping the individual brush on a 2x4 piece of wood.

- Wire the motor to the electrical circuit with the thumb throttle and the motor controllers.
- Attach a 0.25” diameter dead brush onto a long wooden bar with tape
- Begin to apply current to the motor from the throttle
- Slowly bring the brush to the trimmer line
- **Record the rpms, no-load current, loaded current, and whether the machine cut the brush**
- Repeat the process for a 0.5” and 0.75” dead brush and a live brush

Test 2: Go No Go Dead/Alive bundle of 0.25” to 0.5” brush

We will be testing the performance of the trimmer system with various sized brush. The test will be done in the senior project room with the use of safety goggles.

1. Wire the motor to the electrical circuit with the thumb throttle and the motor controllers.
2. Attach a handful of varying diameter brush and attach them onto a long wooden bar with tape
3. Begin to apply current to the motor from the throttle
4. Slowly bring the brush to the trimmer line
5. **Record the rpms, no-load current, loaded current, and whether the machine cut the brush**
Test 3: Testing Motor Power

To get the best power out of the trimmers, we want to test the overall performance of our simple gear box motor configuration and compare it with other motor configurations. The following test will collect the no-load amperage, loaded amperage, input power of batteries, and rpms of different motor configurations. Using the input power and the rpms, we can calculate the theoretical power output of the motor at 100% efficiency.

1. Different motor configurations:
   a. Motor to Shaft connection
   b. Motor with Simple Gearbox
   c. Motor with Compound Gearbox
2. Install one of the motor configurations to the trimmer assembly
3. Power and calibrate to collect the rpms of the trimmer
4. Connect the motor to the electrical test bed
5. Connect the batteries turning on the test bed
6. Turn off the Kill Switch
7. Slowly Dial up the Throttle
8. **Record the Amps, Power, and Rpms of the system at max power**
9. Repeat with different motor configurations.
Test 4: Ergonomics of Assembly

With a complete trimmer assembly and adjustment mechanism, we want to test how easy it is for an agricultural individual (the primary customer) to understand the system. When one side of the trimmer assembly is completed, we will ask 4 different agriculture students to test our product in the senior project room. They will test the vertical/horizontal/rotational adjustments, the locking mechanisms, and the throttles of the system. After it is completed, they will complete a survey detailing their experience with the product.

1. Request for 4 different agricultural students to come test our product.
2. Have them test the adjustment systems when unlocked.
3. **Answer questions on how the weight was, position of handles, and any recommendations.**
4. Have them test the locking mechanism.
5. **Answer questions on the 1 input unlocking both systems and their recommendations.**
6. Have them test the throttles.
7. **Answer questions on safety concerns, position of throttles, and type of throttles.**
8. Ask their opinion on the overall product.
**Test 6: Safety Tests**

The important tests that we plan on testing are the safety tests. The primary results we are looking to test are the pinch points from the vertical system, whether the locking mechanism will stay locked when the system is experiencing vibrations from the ground, and how much debris will the user experience from our system. These tests will occur in the later stage of the process when at least one trimmer assembly is complete and will occur at Architecture Graveyard and the senior project room.

**Testing Pinch Points**

1. Install adjustment system to the chassis structural prototype.
2. Adjust the vertical system to locate the pinch points.
3. Place a hot dog in the pinch point to simulate a finger
4. Rapidly adjust the vertical system activating the pinch point
5. **Record whether the hot dog was cut**
6. If cut, consider designing housing or labeling at the pinch point.

**Locking Mechanism**

1. With a completed system, install the trimmer assembly to the completed chassis
2. Without unlocking the system, go over bumps and different terrain in the area
3. Record if the locking mechanism unexpectedly broke or unlocked.

**Debris**

1. Bring the completed product to Architectural Graveyard.
2. Wear any necessary PPE gear to protect the user. It is recommended to install acrylic sheet near the handles.
3. Turn the system on
4. Begin cutting the brush
5. **Observe how much debris scratches the acrylic sheet.**
6. If too much debris consider additional protection.
Test 7: Numerical Failure Test

For our numerical test we will test how much force it will take to break the trimmer shaft to simulate getting hit at high speeds. This will be done with Mr. Mendez’s first prototype and tested in the senior project room. We hope to get a graph showcasing force and deflection.

1. Set up a test bed for deflection
2. Using weights, attach various known weights to the end of the trimmer
3. **Record the Deflection if any occurs.**
4. Continue to record until the shaft breaks.
Test 8: Final Test with DriveTrain and Chassis products.

With this test we will be testing the performance of the device. With the completion of the project we will be testing how our machine handles brush while mounted on the chassis and drivetrain. This test will be conducted on the trail leading to Architecture graveyard

1. Mount the trimmers onto the completed machine.

2. Power the device

3. While going up the trail, use the trimming mechanism to determine if the device works while on the trail.
   a. Does the device bend while being mounted?
   b. Is the electrical system being affected by bumps on the trail?
   c. Is the adjustment system operating properly?
   d. Is the brush getting cut?