Ebony Bland;Austin Bruen;Davis Goolsby;Emilio Manzo;Garfield Murphy

FAMU-FSU College of Engineering  2525 Pottsdamer St. Tallahassee, FL. 32310

Team 510: FPL Remote Control Switching Device

9/8/2022



# Abstract

The goal of this senior design project is to create a device that can switch out broken fuses on power poles from a remote distance. Our sponsor Florida Power and Light is a power company that supplies electricity to residents in Florida. The electricity flows through power lines. Fuses are located on poles that support these power lines. Fuses protect the power lines from experiencing too much current. When the line has too much current, the fuse blows before damaging a residential home or business. The final design for the fuse-switching device is made of a robotic arm connected to an extendable pole. This design was selected by identifying the sponsor’s needs and breaking down the steps needed to replace a fuse. The design addresses the issue of user discomfort caused by the current fuse-switching equipment. It is also transportable and remotely controlled. We plan to start with a full-scale prototype of the robotic arm that can support 5 pounds and two separate telescoping pole prototypes that can reach a height of 5 feet and 10 feet.

*Keywords*: Fuse, fuse switching, telescoping, utility pole, power line.

# Disclaimer

Your sponsor may require a disclaimer on the report. Especially if it is a government sponsored project or confidential project. If a disclaimer is not required delete this section.

# Acknowledgement

These remarks thanks those that helped you complete your senior design project. Especially those who have sponsored the project, provided mentorship advice, and materials. 4

* Paragraph 1 thank sponsor!
* Paragraph 2 thank advisors.
* Paragraph 3 thank those that provided you materials and resources.
* Paragraph 4 thank anyone else who helped you.

Table of Contents

[Abstract ii](#_Toc113549694)

[Disclaimer iii](#_Toc113549695)

[Acknowledgement iv](#_Toc113549696)

[List of Tables viii](#_Toc113549697)

[List of Figures ix](#_Toc113549698)

[Notation x](#_Toc113549699)

[Chapter One: EML 4551C 1](#_Toc113549700)

[1.1 Project Scope 1](#_Toc113549701)

[1.2 Customer Needs 3](#_Toc113549702)

[1.3 Functional Decomposition 5](#_Toc113549703)

[1.4 Target Summary 9](#_Toc113549704)

[1.5 Concept Generation 9](#_Toc113549705)

[Concept 1. 9](#_Toc113549706)

[Concept 2. 10](#_Toc113549707)

[Concept 3. 10](#_Toc113549708)

[Concept 4. 10](#_Toc113549709)

[Concept n+1. 10](#_Toc113549710)

[1.6 Concept Selection 10](#_Toc113549711)

[1.8 Spring Project Plan 10](#_Toc113549712)

[Chapter Two: EML 4552C 11](#_Toc113549713)

[2.1 Spring Plan 11](#_Toc113549714)

[Project Plan. 11](#_Toc113549715)

[Build Plan. 11](#_Toc113549716)

[Appendices 12](#_Toc113549717)

[Appendix A: Code of Conduct 14](#_Toc113549718)

[Mission Statement 14](#_Toc113549719)

[Team Roles 14](#_Toc113549720)

[Communication Standards 14](#_Toc113549721)

[Dress Code 15](#_Toc113549722)

[Attendance Policy 15](#_Toc113549723)

[Team Dynamics 16](#_Toc113549724)

[Statement of Understanding 16](#_Toc113549725)

[Appendix B: Functional Decomposition 18](#_Toc113549726)

[Appendix C: Target Catalog 19](#_Toc113549727)

[Appendix A: APA Headings (delete) 19](#_Toc113549728)

[Heading 1 is Centered, Boldface, Uppercase and Lowercase Heading 19](#_Toc113549729)

[Heading 2 is Flush Left, Boldface, Uppercase and Lowercase Heading 19](#_Toc113549730)

[Heading 3 is indented, boldface lowercase paragraph heading ending with a period. 19](#_Toc113549731)

[Appendix B Figures and Tables (delete) 20](#_Toc113549732)

[Flush Left, Boldface, Uppercase and Lowercase 21](#_Toc113549733)

[References 22](#_Toc113549734)

# List of Tables

[Table 1 *The Word Table and the Table Number are Normal Font and Flush Left. The Caption is Flush Left, Italicized, Uppercase and Lowercase* 21](#_Toc490488643)

# List of Figures

[Figure 1. Flush left, normal font settings, sentence case, and ends with a period. 20](#_Toc490488644)

# Notation

|  |  |
| --- | --- |
| A17 | Steering Column Angle |
| A27 | Pan Angle |
| A40 | Back Angle |
| A42 | Hip Angle |
| AAA | American Automobile Association |
| AARP | American Association of Retired Persons |
| AHP | Accelerator Heel Point |
| ANOVA | Analysis of Variance |
| AOTA | American Occupational Therapy Association |
| ASA | American Society on Aging |
| BA | Back Angle |
| BOF | Ball of Foot |
| BOFRP | Ball of Foot Reference Point |
| CAD | Computer Aided Design |
| CDC | Centers for Disease Control and Prevention |
| CU-ICAR | Clemson University - International Center for Automotive Research |
| DDI | Driver Death per Involvement Ratio |
| DIT | Driver Involvement per Vehicle Mile Traveled |
| Difference | Difference between the calculated and measured BOFRP to H-point |
| DRR | Death Rate Ratio |
| DRS | Driving Rehabilitation Specialist |
| EMM | Estimated Marginal Means |
| FARS | Fatality Analysis Reporting System |
| FMVSS | Federal Motor Vehicle Safety Standard |
| GES | General Estimates System |
| GHS | Greenville Health System |
| H13 | Steering Wheel Thigh Clearance |
| H17 | Wheel Center to Heel Pont |
| H30 | H-point to accelerator heel point |
| HPD | H-point Design Tool |
| HPM | H-point Machine |
| HPM-II | H-point Machine II |
| HT | H-point Travel |
| HX | H-point to Accelerator Heel Point |
| HZ | H-point to Accelerator Heel Point |
| IIHS | Insurance Institute for Highway Safety |
| L6 | BFRP to Steering Wheel Center |
|  |  |
|  |  |
|  |  |

# Chapter One: EML 4551C

# Project Scope

Florida Power and Light is an electrical utility company that provides electrical power to more than 5.7 million residents. The company oversees the installation, operation, and maintenance of the power grid in their service area. This includes utility fuse switching for power restoration. Utility fuses are used to protect equipment on a power line from damage caused by overcurrent. Fuse switching is the process of replacing a blown fuse when overcurrent occurs. . The Work Methods Team at Florida Power and Light has partnered with our team at the FAMU-FSU College of Engineering to optimize the field process of fuse switching.

The project objective is to develop a device that is remotely controlled and can be operated to perform fuse switching operations for restoration purposes. The main goal of this project is to design a device that can reach the location of the fuse on the utility pole. Another primary goal is for the device to remove a blown fuse and replace it with a new one. The device will be able to perform fuse switching in inaccessible areas that bucket trucks cannot reach. Also, the device will be able to be easily transported by line specialists to the job site.

## Some assumptions are considered to guide the scope of the project. One assumption is that the device will be only need to reach heights between 35-45 ft. The device is also assumed to support a fuse link that is 5 pounds or less . In addition, each major component, or subsystem of the device that can be carried individually will weigh no more than 50 lbs. The device is assumed to only be used in fair weather conditions defined by OSHA-regulated guidelines. This excludes hurricane or tropical storm weather. Transportation of the device is assumed to be by a bucket truck or personal vehicle. The device operator will have received adequate training on how to use the device and be physically capable of operating the device. Markets and Stakeholders:

## Markets:

The primary market for this device is investor-owned electric utility companies such as Florida Power and Light. Other primary markets include municipalities that manage their distribution systems, electric cooperatives, and contractors who perform maintenance on electric distribution poles. Secondary markets for this device include companies in public safety and construction that need to unhook items high above the ground.

In addition to markets interested in this project, there are also many stakeholders involved in the project. Stakeholders will invest time, finances, or interest in the project. They are investors, decision-makers, advisors, and receivers. Florida Power and Light and its parent company NextEra Energy are investors in the project through their sponsorship. Our project liaison, Scarlett Luis, is a stakeholder because she will invest time and energy to guide us through the project. Our advisors, Dr. Simone Hruda and Dr. Shayne McConomy, are also stakeholders. They will expend time and effort to assist us with our project by providing guidance and advice. A table portraying stakeholders is shown in the figure below.

### Figure : Stakeholder Chart

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | **Investors** | **Decision-Makers** | **Advisers** | **Receivers** |
| **Sponsor** | Florida Power and Light, NextEra Energy | Florida Power and Light, NextEra Energy | Scarlett Luis (Engineer at FPL) | Florida Power and Light, NextEra Energy |
| **Manager** | Scarlett Luis (Engineer at FPL) | Scarlett Luis (Engineer at FPL) | Dr. McConomy | Florida Power and Light, NextEra Energy |
| **Experts** | Florida Power and Light, NextEra Energy | Kyle Bush (FPL Project Manager) | Dr. Hruda | Florida Power and Light employed Operators |
| **Operators** | Florida Power and Light, NextEra Energy | Kyle Bush (FPL Project Manager) | Kyle Bush (FPL Project Manager) | Florida Power and Light employed Operators |

# Customer Needs

Customer needs establish the requirements for any given design. The project goal is to design a fuse switching device for the customer. The current focus is to find what the customer wants to gain from this design and establish a list of questions and statements from the customer. Interpretations of those needs are shown in the table below.

### Figure : Customer Needs Table

|  |  |  |
| --- | --- | --- |
| **Question** | **Customer Statement** | **Interpreted Needs** |
| 1) What products do you currently use for fuse switching? | A bucket truck and a long extendable pole called an Extendo stick are used for fuse switching. | Multiple tools are used depending on a case-by-case basis. The main product that is used is a long pole called an Extendo stick. |
| 2) What do you like or dislike about these products? | **Problems with Extendo stick:**  -Bends when extend long distances, can be hard to hold still and control  -Requires many steps to achieve the goal of fuse switching.  -Hard to use in some operating environments.  **Problems with bucket truck:**  -Requires a large space to use.  -Some areas are inaccessible by bucket truck. | Issues with Extendo sticks include requiring many steps to switch out fuses and lack of stability when fully extended.  Issues with bucket trucks include the inability to reach areas due to space limitations and places not accessible by road vehicles. |
| 3) What will the operating environment be for this device? | The operating environment will be places that are hard to reach by bucket truck such as residential areas. Design device for ideal weather conditions. | This device will be used in varied operating environments that are hard to reach by bucket truck. This device will be used during safe weather conditions. |
| 4) What level of autonomy is expected for this device? | The device should not be autonomous. “Push a button and [the device] does a few steps”. | While not fully autonomous, the device is expected to automate a few steps of the fuse switching process. |
| 5) What are the current dimensions of the product for transportation | The Extendo stick is approximately 4 feet long when fully collapsed. It is often housed in a PVC sleeve found in the bucket truck. | A bucket truck is used to transport the Extendo stick, and it will be used to transport our device. |
| 6) What pole and fuse sizes does the device need to be used for? | The sponsor will provide a specific pole size and fuse size that the device needs to be designed around. | The initial design focuses on one pole type and standard fuse size dimensions. Later adjust device for different a |
| 7) How do you transport the current device you use for fuse switching? | The Extendo stick is usually transported in a bucket truck. In emergencies, technicians transport the Extendo stick by securing it in personal vehicles using a seatbelt. | The device will be transported in a bucket truck as well as a passenger vehicle. |
| 8) Who is the intended user? | Anyone physically capable may use the device. Typical users are linemen and engineers doing field work. | The device needs to be easy to use and be operable in a field environment. |
| 9) Do you have any safety concerns with the current device? | Repeated use of the Extendo stick leads to soft tissue damage. The repetitive motion required to operate it leads to physical problems for users. | The ergonomic design of the device is a priority. The device will be used multiple times by the same operator. |
| 10) What kind of training do operators receive? | Workers receive extensive training for Extendo stick operation. Anyone who can physically handle the equipment can complete the training. | The current device requires intense physical capabilities. The new device is expected to require less physical work to operate. |

Questions for the customer were brainstormed in a team meeting prior to meeting the customer. The purpose of these questions was to help define the project scope as well as the goals the customer has for this project. Questions were directed to project liaison Scarlett Luis and subject matter expert Kyle Busch over a Microsoft Teams meeting. The interpreted needs of the project will be used to build a fuse-switching device that is transportable in the cabin of a passenger vehicle, is less physically demanding for operators than the current technology and has a simple process of use for linemen.

# Functional Decomposition

## Introduction to F.D.

Functional decomposition acts to simplify broad information from the project scope into specific tasks needed for the completion of the project. Each component serves a purpose characterized by the hierarchical chart and cross-reference table found below. The project objective is to develop a mechanized remote-control device that performs powerline fuse switching for restoration purposes. Functions were derived from communication with the customer and derivation of customer needs. Sub-functions are derived by functional breakdown of the primary functions.

## Hierarchy Chart

The functional decomposition hierarchy chart, seen in the figure 3 below, is broken down into three primary categories: fuse switching operation, transportation/storage, and ergonomics.

### Figure : Hierarchy Chart

Diagram

Description automatically generated

Fuse switching operation outlines the ability of the device to complete the fuse switching process. Fuse switching operation contains several sub-functions necessary for the desired process. Primarily, the device needs to extend to the desired height and attach to the lower contact of the fuse tube. The device must then maneuver the fuse from its resting place in the toggle joint and return the fuse back to ground level. Similarly, the device must then hold onto the new fuse and extend it back to the desired position. The device should then maneuver the new fuse to its toggle joint and attach it to the upper contact point.

Transportation/storage highlights the physical dimensions of the device and by what means the device will be transported. Sub-functions for transportation/storage include transportation via bucket truck, and in the case of emergencies, via personal vehicle. Finally, the device should be a comparable size to current market devices or roughly four feet in length.

The final primary function is ergonomics. The device should consider how the user interacts with it, both in ease of use and a heuristic interface. Sub-functions include mitigating soft-tissue damage which is a common byproduct of repeated use of current devices on the market. Furthermore, the device should be remotely controlled, have an aesthetic and minimalistic design, and make system status easily visible to the user.

## Cross Reference Table

The functional decomposition cross reference table relates individual functions to the overall system. The marker, shown as an ‘X’, indicates that the corresponding function relates to the needs of the customer. For instance, ‘Reach Inaccessible Areas’ corresponds to fuse switching operation and ergonomics, but not transportation and storage. The Cross Reference Chart is shown in Figure 4 below.

### Figure : Cross Reference Chart

|  |  |  |  |
| --- | --- | --- | --- |
| **Function Decomposition Cross Reference Chart** | | | |
| **Function** | **Performs Fuse Switching Operation** | **Considers Transportation & Storage** | **Has An Ergonomic Design** |
| Reach inaccessible areas | X | X | X |
| Mitigate soft tissue damage and limits physical strain |  | X | X |
| Can be transported by personal vehicles or bucket truck |  | X |  |
| Compact device design |  | X | X |
| Automatic operation of all or some of the fuse switching process | X |  | X |
| Device that can extend/retract and pivot to perform fuse switching process | X |  |  |

The functional decomposition cross reference chart assists in prioritizing functions of the design based on how each function interacts with the design's systems. For example, consideration of transportation and ergonomics address most customer needs and are likely to be high priority. Conversely, the cross-reference chart also helps to determine design functions that have less priority and may be susceptible to omission.

## Smart Integration

Each of the major functions becomes a system that must integrate and interact with each other to accomplish the needs of the customer. Each primary function addresses several customer needs, with each need often being addressed by several primary functions. For example, the first primary function “Performs Fuse Switching Operation” addresses three of the six customer needs. To complete the fuse-switching process, the device must reach otherwise inaccessible areas, automate some or all of the fuse-switching process, and have the ability to extend, retract, and pivot. When fully extended, the device must also consider physical factors including gravity, wind interference, and bending moments. The second primary function “Considers Transportation & Storage” addresses customer needs corresponding with how the device is transported, stored, and carried to its destination. The first two primary functions overlap in performing the customer need “reach inaccessible areas” because the device must perform fuse switching operation in inaccessible areas and consider the operator's ability to transport the device to the job site. The physical factors in play include volume and overall weight. The final primary factor “Has an ergonomic design” addresses how the operator interacts with the device, for example, how the device is transported, the ease of operation, and the ability to see the device status. There's substantial overlap in the customer needs to be addressed by transportation and storage and ergonomics, specifically in mitigating tissue damage and compact design.

## Actions and Outcomes

direction of the fuse insulator before lowering to the ground. The operator then extends a new fuse up to the toggle joint and places the lower contact of the fuse tube in the toggle joint. The device then attaches to the upper connection of the fuse tube, pushes up in an arc motion to attach the fuse tube to the upper contact point, and releases from the fuse tube's upper contact. Finally, the device retracts and turns off.

## Function Resolution

In short, the device will be able to extend to the top of power lines, in which the device will hook onto the fuse. The device removes the fuse and can return the fuse to the operator. The operator then can perform a similar process to place a new fuse in its correct position.

# Targets and Metrics

Targets and Metrics take the functions derived from functional decomposition and use quantifiable metrics to provide fixed targets to aim for to ensure project success. The table below outlines the interpreted targets and corresponding metrics for each function. Note that some functions are multifaceted and require multiple targets and metrics to address completely. The target chart is color coded by targets relationship to functions, yellow being fuse switching operation, blue being transportation and storage, purple being ergonomics, and red being other.

### Figure : Target Chart

|  |  |  |
| --- | --- | --- |
| **Function** | **Target** | **Metric** |
| Go to Fuse Tube Location | Reach a minimum vertical distance of 30-45 feet. | Feet or Inches |
| Remove and Replace fuse tube | Maximum time to reach vertical distance of fuse location: 5 minutes. | Minutes |
| Maximum time to install the new fuse tube: 5 minutes. | Minutes |
| Maximum time to remove the fuse tube: 5 minutes. | Minutes |
| Support a weight of at least 14 pounds. | Pounds |
| Have a range of motion of at least 3 degrees of freedom (Translate vertically, horizontally and rotate in plane). | Number of DOF |
| Adaptable | Consider three alternative applications. | Applications |
| Fit into a bucket truck | Maximum storage volume of 11.6 cubic feet. | Cubic feet |
| Storability during Transportation | Maximum length in transit 4ft | Feet |
| Mitigates soft tissue damage | Keep soft tissue damage under grade 1. | Grade of Injury |
| Maximum device weight of 50 lbs. | Pounds |
| Remotely controlled | Is able to communicate with the device at maximum extension 50 ft. | Distance (feet) |
| Communication with user | Updates user on fuse switching status at least every 10 seconds. | Seconds |
| Measures power consumption at least every 20 second interval. | Seconds |
| Communicates the power level when below 25 percent, accurate to within 0.5 percent. | Battery percentage |
| Device implements user input within 1 seconds. | Seconds |
| Stop operation on user command within 2 seconds. | Seconds |
| Notifies the user of environmental obstacles within 5 seconds of detection. | Seconds |
| Minimalistic/Aesthetic Design | Contains fewer than 7 elements for user interaction. | Number of elements |
| Device Battery - Life | Device must be operable for a minimum of 30 minutes at a time | Minutes |
| Battery | Has sufficient charge for a minimum of 30 minutes of device operation. | Amp-Hours |
| Power for Motor | Has sufficient power to perform device operation. | Watts |

## Target Summary

The targets listed in the chart above reflect the major and minor functions found in the functional decomposition hierarchy chart. They can be classified by Fuse Switching Operation, Transportation and Storage, and Ergonomics. Other targets are based on requirements for an automatic device, such as a battery requirement.

Different motions and actions are involved in the fuse-switching operation. The device needs to be able to travel to the fuse tube location and can remove and replace the fuse tube. The device is required to support a target load of at least 14 pounds. Standard fuse tubes or links are approximately 14 pounds based on market research conducted on popular utility equipment manufacturers such as Eaton. Some fuse-links are lighter or heavier depending on the type of utility fuse cutout.

The target for the motion range of the device at the fuse switching location is 3 degrees of freedom. This target value is based on observations of current fuse-switching operations performed with an industry-standard telescoping stick. Fuse links are connected to the fuse cutout configuration by a hinge near the bottom and hooks at the top. A loaded spring system at the bottom attachment point keeps the link in place. In the event of an overcurrent and the fuse link blows, the spring is released and detaches the fuse link from the upper attachment hooks of the fuse cutout. The fuse link will hang by the hinge attachment point. The device must disconnect the lower end of the fuse link from the hinge attachment point of the fuse cutout. Also, the device must reconnect the new fuse to the hinge point and push the link upward to connect it to the cutout attachment hooks. This results in an arc path of motion for a device to remove and replace a fuse link from a fuse cutout. At a minimum, 3 degrees of freedom are necessary to complete this motion.

Time targets for the fuse switching operation are divided according to the steps needed to complete the process. The target time for the device to reach the fuse location is a maximum of 5 minutes. Then, the device is required to remove the broken fuse from the cutout within a maximum of 5 minutes and install a new fuse within a maximum of 5 minutes. The events are done separately. The time target durations are based on personal experiences from employees of Florida Power and Light and the personal knowledge of a team member who has experience working at a utility company. These individuals have first-hand experience with fuse switching and how long it takes to switch a fuse manually. Time requirements are not a high priority, but necessary to consider if the design is to compete with current tools used for fuse switching. Finally, the fuse-switching operation will apply to at least three different classes of fuses.

Transportation and Storage define the device's ability to be stored in a bucket truck between uses and carried by the user to the work site. The target for the maximum space the device can occupy during storage is a volume of 11.6 cubic feet. 11.6 cubic feet is a volumetric value based on the cargo space of Ford F550 model trucks commonly used by utility companies for bucket trucks. The cargo space is located behind the front row of seats in the truck. These trucks are single-row-seater vehicles. This information was obtained directly from the Ford website. Another target for storage is that the device will not have a dimension longer than 4 feet while in storage and not in use. This is to avoid creating a bulky device that will be too long to store or awkward for the user to carry to each work site.

Furthermore, an ergonomic design is essential to keep the user safe and not cause long-term damage to the user. Many of the ergonomic features of the device will be qualitative. However, targets were made based on values associated with desired ergonomic features. One ergonomic target for the device to meet is to not cause soft tissue injuries higher than grade one (admin, 2019). Grade one soft tissue injury is caused by the overstretching tissue fibers and displayed by redness and swelling of the injured area. To effectively eliminate soft tissue injury in users, the device will avoid causing tissue fibers to become overstretched.

Additionally, the device requirements include avoiding putting the user in uncomfortable positions and strenuous physical activity. The device will be operable from a remote location within a radial distance of 50 feet of the user. A radial distance of 50 feet comes from considering if the device is at a vertical distance of 40 feet at the top of the utility pole and assuming the user is 30 feet horizontally from the base of the utility pole. In this situation, the device would need to be operable at a radial distance of 50 feet from the user based on the Pythagorean theorem.

A minimalist design is another essential ergonomic function that requires targets to ensure the device is easy to use. The device will be required to have no more than 7 user interface features (such as buttons, joysticks, triggers, screens, and lights). This limit was selected because the average adult can remember 5-9 items at one time (Saul, 2009). The device should not cause excessive mental fatigue to the user or require a steep learning curve.

Battery life is essential to both device performance and device practicality. Battery life relates to both battery size and time per use on a single charge. The target for minutes of operation is thirty minutes to remove and replace two fuse tubes. This is based on the target of a maximum of 15 minutes for one fuse-switching operation. This target is also dependent upon motor strength. As such, a target was defined to address the desired motor power to perform the fuse-switching process, measured in Watts. Finally, motor power and minutes of operation depend on battery size. The function of battery charge in Amp-hours is necessary to ensure that desired power is sustained over the desired thirty minutes of operation time.

## Critical Targets and Metrics

Critical targets are vital to project success and reflect the values of our sponsor. Our sponsor company, Florida Power and Light wants to develop a safe, ergonomic, and transportable device that automates the process of fuse switching. Our primary goal is to develop a design that minimizes long term strain on users and ensures their safety. In addition, the design needs to be capable of removing a fuse tube from a utility pole and replacing it with a new fuse tube in areas where large equipment cannot be used. Lastly, the device needs to be able to be easily transported from work sites and able to be stored in the user’s work vehicle, a bucket truck.

To ensure user safety and prevent physical strain, the device needs to address the issue of soft tissue damage. Soft tissue damage is common with telescoping poles currently used for fuse switching. Injuries related to proper use of our device should be limited to grade 1 injuries in accordance with Accident Claims Advice and the National Institute of Neurological Disorders and Stroke, with symptoms including mild swelling and tenderness. In addition, the device should weigh no more than 50 pounds. 50 pounds is a standard lifting weight requirement of line specialists that perform fuse switching as shown on many job postings on Indeed.

Furthermore, the device needs to constantly communicate with the user and respond quickly to ensure the user's safety while operating the device. It is essential that the device communicates the status of the fuse switching process at least every 10 seconds, alerts the user of obstacles within 5 seconds of detection, and responds to any stop command within 2 seconds. This gives the user the same sense of control as they would have with a manual device and allows them to react to an emergency. Additionally, the device is required to be operable by the user from a remote location of within a range of 50 feet from the fuse. This allows the user to be a safe distance away from the area.

Secondary to user safety and ergonomics is the ability to perform the fuse switching operation. To perform the fuse switching process, the device is required to reach the location of a fuse on an average utility pole and support the weight of the fuse tube. The device also needs to at least be able to translate vertically, horizontally, and rotate to remove and replace a fuse tube from its fuse cutout. Critical targets related to the process include the device being able to meet a minimum distance of 35-40 feet, support a load of at least 14 pounds, and have at least 3 degrees of freedom for motion.

Finally, the device must meet the size requirements to allow it to be transportable in a line specialist’s bucket truck and easily carried from the vehicle to the work site. When not in use, the device needs to have a maximum storage volume of 11.6 cubic feet and not have a dimension larger than 4 ft.

## Method of Validation

* A method of testing the minimum distance required to be reached by the device is the use of a distance-measuring device such as a tape measure. This test can be performed by using a tape measure during the fuse switching operation and measuring the vertical height.
* A method of testing the time it takes the device to reach the fuse location is to measure the length of time using a stopwatch. This test can be performed by starting a stopwatch at the beginning of the fuse switching process and stopping it when the device reaches the fuse tube location.
* A method of testing how fast the device takes to remove a fuse is the use of a stopwatch. This test can be performed by starting a stopwatch at the beginning of the fuse switching process and stopping it when the fuse is detached from the fuse cutout.
* A method of testing how fast the device takes to install a new fuse is the use of a stopwatch. This test can be performed by starting a stopwatch at the beginning of the fuse replacement process and stopping it when the new fuse is connected to the fuse cutout.
* A method of testing the weight that the device can support is to perform a stress and deflection test. This test will measure the amount of force per unit area on the device structure due to an external load. The amount of deflection or bending due to the external force will also be measured. This test will be conducted on a CAD model first. The physical prototype can be tested by physically applying the desired force or torque and measuring any physical deflection or bending produced.
* A method of testing the physical range of motion would be using a goniometer. The goniometer will be placed on the device and measure how much the device can move in each direction while in motion. The degrees of freedom on the design and range of motion can also be simulated before prototyping using kinematic equations.
* A method of testing the adaptability of the device is using three different fuses. This can be done by attempting the fuse switching process with our device for three different types of utility fuses. All target methods of validation will be performed using each type of utility fuse to verify the device's ability to meet standard requirements.
* A method of validating the device's ability to fit into a bucket is the use of a tape measure. This can be done by using the measurements of length, width, and height to find the volume of the device and comparing it to the dimensions of the storage space in a bucket truck.
* A method of testing the storability during the transportation of the device will be the use of a tape measure. This can be done when the device is in a storage stage and not in use. The tape measure will measure the overall length, width and height of the device.
* A method of measuring soft tissue damage is the grade of the injury. This can be tested by the user seeing swelling and visible bruising. Also, soft tissue damage can be measured using force sensors to determine the magnitude of the force exerted on the users while interacting with the device.
* A method of validating the weight of the device is to use a scale. This can be done by placing all parts of the device on a scale. The components will be measured individually if needed.
* A method of testing the device's remote-control capabilities is the use of a tape measure and a radio wave frequency signal sensor. The signal strength will be measured with the sensor and the distance at which the signal is tested can be measured with the tape measure.
* A method of testing the communication of system status with the user is testing how frequently updates are communicated with the user. This can be tested by programming the device and manually sending updates and measuring how long it takes the device to update the user.
* A method of testing the communication of power consumption with the user is testing how frequently updates are communicated with the user. This can be tested by programming the device and manually sending updates and measuring how long it takes the device to update the user.
* A method of testing the communication of power level with the user is testing how frequently updates are communicated with the user. This can be tested by programming the device and manually sending updates and measuring how long it takes the device to update the user.
* A method of testing the implementation of user input is testing how quickly the device responds to the desired input method. This can be tested by supplying a device command and measuring response time.
* A method of testing the response to a stop command is testing how quickly the device responds to a user-input stop command. This can be tested by running a stop command and measuring response time.
* A method of testing the response to environmental obstacles is testing how quickly the device responds to an obstruction. This can be tested by imposing an obstacle and measuring response time.
* A method of testing the Minimalist design is by quantifying the number of interfaces features present on the remote. This can be tested by the remote having a maximum of 7 elements for user interaction.
* A method of testing the device's battery is the use of a multimeter. This can be done by hooking up the battery to a multimeter during operation. The user can find out the voltage of the battery and can measure how long it takes for the battery’s voltage to deplete.
* A method of testing the battery is the use of a multimeter. This can be done by hooking up the battery to a multimeter. The user then can use voltage to find the Amp-hours of the battery.
* A method of testing the power of the motor is the use of a multimeter. This can be done by hooking the motor of the device to a multimeter and seeing how many volts, amps, and Watts the motor consumes.

# Concept Generation

## Methods for Concept Generation

100 concepts for an automatic fuse switching device to meet our customer needs were generated over the course of a week. 100 Concepts were chosen because it gives intentionality and engagement to the problem-solving process. Each of the 5 team members created 20 concepts individually using any method of the member's choosing. The team reconvened later and evaluated concepts with overlap and did further ideation to fill out any missing concepts. The list of all concepts created is found in Appendix D.

Functional decomposition acted as a guide for concept generation as each concept needed to address each major function in some way. Targets and metrics were also used to guide the concept generating process. However, consideration was taken to not make the targets constrain the concepts.

The first tool every group member used in their concept generation was brainstorming: recording any idea that came to mind to solve the problem. Brainstorming methods were used throughout the entire concept generation process. The rule all team members abided by during the concept generation process was: “No comment, No judgment”. Each member had free reign to say any idea they came up with no matter how outlandish. Ideas were then presented in a team meeting, and a group brainstorming session took place.

Biomimicry was used as a method of ideation. The team looked at how similar functions are performed in nature. This acted as a basis for many proposed concepts. An example of this ideation method is the gecko robotic switching device, which proposes a fuse switching device that reaches the fuse switching location through suction cup devices like how geckos climb walls. Another example of biomimicry is the drone bird lander design. This design uses a drone device that lands on a surface neighboring the desired location and performs the fuse switching process while stationary. This is similar to how a bird flies and perches. The use of biomimicry also expanded the way the team thought about ways to achieve the major functions.

Crapshoot was also used to come up with ideas. Categories that reflect the functions of the device were created. For example, there was a category for traveling to the fuse tube location and back to the user, removing the fuse tube and installing a new fuse tube, transportability, and ergonomics. For each category, a list of several items was made, such as climbing, flying, and shooting for the category of traveling to the desired location. Each member took turns selecting items from each category and proposing ideas of how to replace a blown utility fuse with a new one. An example of a concept created through crapshoot was shooting the fuse tube with a grappling hook claw to remove the fuse tube.

The concept generation process was an informal and free-thinking process, so many of the concepts were unconventional and impractical. However, the discussion of these ideas became a productive space to discuss different methods of solving the problem. Ideas that multiple group members thought of independently became good candidates for high and medium-fidelity concepts. The concept generation process also acted as a springboard to the concept selection process by highlighting promising features and key problems. Five medium fidelity and three high fidelity concepts were chosen from the 100 concepts generated. They are described in the following sections.

## Medium Fidelity Concepts

**1.** Inverted Slider Crank:

This is a mechanical mechanism that has 5 links. The five components include a ground link, crank, rocker, connecting rod, and slider block. The ground link is placed along the utility pole where the rocker and crank mount to. Other options for the ground link are along the earth with two stands for the crank and rocker portions, or vertically along a structure away from the utility pole. For either option, the structures holding the crank and rocker would be removable from the surface they are placed on. All components are connected with revolute joints.

The crank is connected to a motor that is remotely controlled. The crank has an angular range of motion of 180 degrees with respect to the utility pole or earth. The crank drives the linkage motion. As the crank rotates counterclockwise, the rocker and slider are pushed toward the fuse cutout location. A mechanism attached to the slider, such as a hook or arm, removes the blown fuse during the slider’s maximum position.

As the crank rotates in the opposite direction, the rocker lowers the slider down the connecting rod. The fuse tube is lowered down for the user to be switched out for a new fuse. As the crank rotates counterclockwise again, it installs the new fuse tube.

**2.** External Support and Extension Mechanism for Telescoping Stick:

This design focuses on creating a structure to support a telescoping stick while it extends to reduce the need for the user to handle the stick. A support stand would hold the currently used telescoping stick design. A motorized mechanism would be added to the telescoping stick to extend it to the desired height. The telescoping stick could then be removed from the tripod and used for fuse switching. The support stand could also collapse the telescoping stick using a motor. This design is more ergonomic than the currently used telescoping stick because the user does have to manually extend and collapse the stick.

**3.** Crane:

A Device that mounts on the fuse cutout and acts like a crane. The device would be remote-controlled. An extendable telescoping and manually operated device would bring it up to the fuse cutout location. This device should lock on to the cutout and be sturdy while being able to withstand wind and rain. Special consideration should be given to how the device would be removed in the case of failure, and how to electrically isolate it from nearby tree branches.

**4.** Drone:

A remotely controlled drone flies up to the fuse. The drone perches on the utility pole and has a robotic arm to remove and install the fuse. This allows the device to perform the fuse switching process. The device is remotely operated by the user. The drone has a camera on it that helps the user view the fuse switching process. After the drone has performed the fuse switching process, it lands safely in a nearby area to return the damaged fuse to the user. The user then puts a new fuse in the robotic arm. The user controls the drone to put the new fuse back into its cutout.

**5.** Multiple-fuse box:

This concept offers an adjustment to power line designs, implementing multiple fuses ready to replace a broken fuse automatically in the event of a fuse break. Multiple fuses would be held in the device close to or on the fuse cutout of the utility pole. The multiple-fuse box could communicate how many fuses are operational and how many fuses are blown to users using different colored lights.

## High Fidelity Concepts

1. Automated telescoping Stick with a Foldable Robotic Arm:

This design is based on automating the current tool used for fuse switching, the telescoping “Hot Stick” or “Extendo Stick”. The device is a pole that can extend to heights between 5-40 ft. The device reaches this height through manual telescoping by the user. The intended design would use the same telescoping concept to reach the desired height between 35-45 feet. However, the user remotely activates the telescoping function of the device through a user interface on the intended device or with a separate controller. The controller could have visual or haptic feedback to alert the user of issues. In addition, the automated telescoping stick would have a manipulator arm on the end. The arm would fold up when not in use and extend with the rest of the stick links. The extending section of the device would have a way to stabilize, such as by attaching it to the earth or the pole for support.

The extendable mechanism would extend to the desired height and the manipulator arm would extend out and unfold. The arm is made up of 3 pin joints and 4 links that provide the user with 3 DOF to position the hand and grab the fuse. The manipulator's hand is also linked. The hand has a claw-like mechanism that will be controlled by a motor to extend and unextend, resulting in one degree of freedom. The arm and hand would be controlled using the same interface or controller as the extending components.

1. Pole Climber Device:

This device is made up of a structure that climbs up the pole with an extendable 3 DOF arm and a 1 DOF hand as shown in the automated telescoping stick concept. The Pole climber will roll up the pole to the desired location and the arm will be controlled by the user to grab the fuse. It can be controlled with an analog controller with visual feedback. The arm would fold up for storage.

The climber device would surround the utility pole and use multiple wheels controlled by a motor to roll up the utility pole. The climber section of the device will have a structure that holds an axle with at least two wheels on both sides of the pole. The axle lengths and the length between each axle on the outer structure are adjustable to fit different pole diameters and shapes. A motor will be connected to one axle and generate enough torque to drive the entire configuration up the pole. The motor driving mechanism would be controlled by the same controller used for the arm.

1. Inflatable Tube Device:

This device would be an inflatable tube-like structure. This device would be inflated using an air pump to extend to 35-45 ft. The materials of the device would be sturdy enough to not puncture or wobble in the wind when the device is fully inflated. The device would also include a camera and a hook near the top. The hook would be used for fuse-switching and the camera would be used to assist the user in positioning the hook to perform fuse removal or restoration.

# Concept Selection

Concept Selection is the process that takes our medium and high-fidelity concepts and quantitatively decides what is the best choice. Our customer requirements and engineering characteristics are quantitatively assessed. Medium and high-fidelity concepts are reduced to 2 or 3 concepts through binary pairwise comparison, house of quality, and Pugh charts. These 2 or 3 concepts are then quantitatively assessed during the Analytical Hierarchy Process to select a final concept

## Binary Pairwise Comparison

We used a Binary Pairwise Comparison Matrix to decide what are the most important customer requirements, based on our customer needs. The Binary Pairwise Comparison chart, shown in Figure 6, was used to rank the relative importance of the customer requirements. This data was used to determine the importance weight factors in the house of quality.

### V Figure : Binary Pairwise Comparison



## House of Quality

The house of quality compares engineering characteristics based on how well they fulfill customer requirements. Each engineering characteristic was ranked from 0 to 9 by how much it correlates with each customer requirement. The metrics associated with engineering characteristics were used to aid in this process. Important weight factors from the binary comparison matrix were then applied to rank engineering characteristics in order of importance. These rankings were used to determine which engineering characteristics should be considered as selection criteria when comparing concepts in our Pugh charts. Additionally, the relative weight of each engineering characteristic was computed and used during the Analytical Hierarchy Process.

From the house of quality, we decided that the engineering characteristics we will use to compare concepts are: reaching fuse tube location, maximum installation time of 15 minutes, three degrees of freedom, maximum storage of 4 ft, minimum communication length of 50 ft, implementation of commands within 1 second, stops operation within 2 seconds of command, operable for 30 minutes at a time, and sufficient power to perform device operation. The engineering characteristics “Measures power consumption every 20 seconds” and “contains 7 user interaction elements” had comparatively small weight percentages to the rest of the engineering characteristics and were eliminated for consideration in concept selection.

### Figure 7 : House of Quality



## Pugh Charts

Pugh charts are useful in determining the most promising design concepts by comparing each concept to a datum, where the datum is typically a popular market device. The concepts and datum are compared relative to several selection criteria to determine if the concept in question is better than, the same as, or better than the datum. Furthermore, Pugh charts are iterative in that a new datum can be defined to gain further information about potential concepts. The popular market device used in the first iteration of the Pugh chart is the telescoping stick developed by BLUE STRIPE. The promising design concepts and the medium and high-fidelity concepts derived from concept generation, and the selection criteria are engineering characteristics derived from the house of quality. The wording of the engineering characteristics was simplified to make up the selection criteria for the Pugh Charts: reach fuse tube location, installation time, degrees of freedom, storage length, communication distance, device responsiveness, emergency stop time, operation time on a single charge, and motor power. Additionally, the selection criteria of “support fuse weight” was added from customer requirements because it is an important factor to consider when comparing concepts.

After the first iteration of the Pugh chart, the fuse box and inflatable telescoping stick were eliminated because of their poor scores compared to the currently used telescoping stick. The fuse box concept, while prolonging how often an overhead line specialist needed to be present, does not address the safety and ergonomic issue with the currently used telescoping stick. Likewise, the inflatable telescoping stick led to concerns about supporting the load of a fuse when fully extended as well as stability and longevity. Due to a balance of even distribution of positives and negatives, the slider-crank based mechanism was defined as the new datum for the second Pugh chart iteration.

In the second iteration of the Pugh chart, the pole climbing robot, crane, and slider crank concepts were eliminated. The high scores of the external support system, drone, and robot arm on a telescoping stick concepts eliminated the slider crank datum concept. The relatively poor scores of the pole climbing robot and crane concepts eliminated these concepts.

The pole climbing robot had concerns with using a battery that had enough charge to perform multiple fuse switching operations and being able to reach the fuse cutout when there are obstacles attached to the pole. The crane concept was removed due to limited motion, battery concerns, and response in the event of an emergency. Finally, the slider crank was removed due to difficulty reaching fuse cutouts at inaccessible locations as well as potentially unreasonable installation times.

The three remaining concepts were the external support system, drone, and robot arm on a telescoping stick. These three concepts were determined to be the most feasible for performing the required functions using Pugh charts. Because of this, these three concepts moved on to the Analytical Hierarchy Process.

### Figure 8: Pugh Chart Legend

|  |  |
| --- | --- |
| **Concept Number** | **Concept Description** |
| 2 | Pole climbing robot. |
| 4 | External support mechanism for existing telescoping stick. |
| 5 | Drone with ability to perform fuse switching operation. |
| 41 | Fuse box containing a series of fuses that diverts power when a fuse blows. |
| 52 | Inflatable telescoping stick that uses an air compressor to automatically extend and contract. |
| 57 | Crane used to automatically raise fuses to fuse cutout location. |
| 64 | Slider crank mechanism to aid in the fuse switching process. |
| 80 | Robotic arm on the end of a telescoping stick. |

Figure 9: Pugh Chart First Iteration

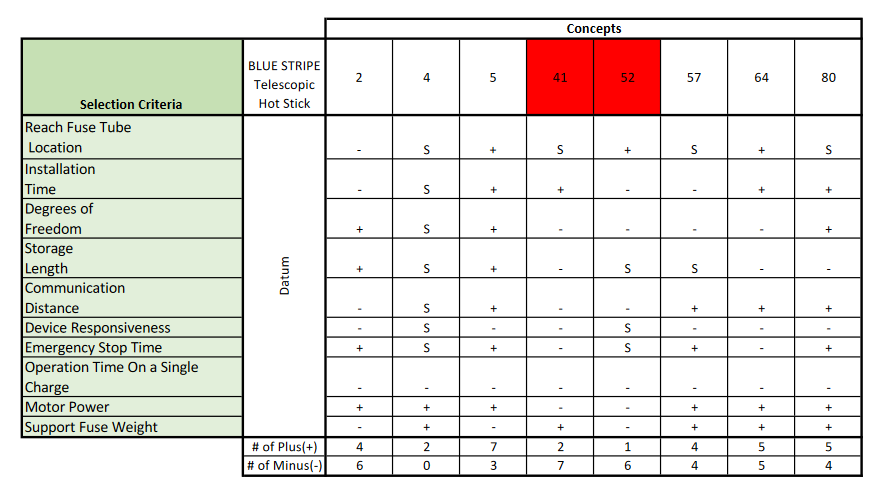
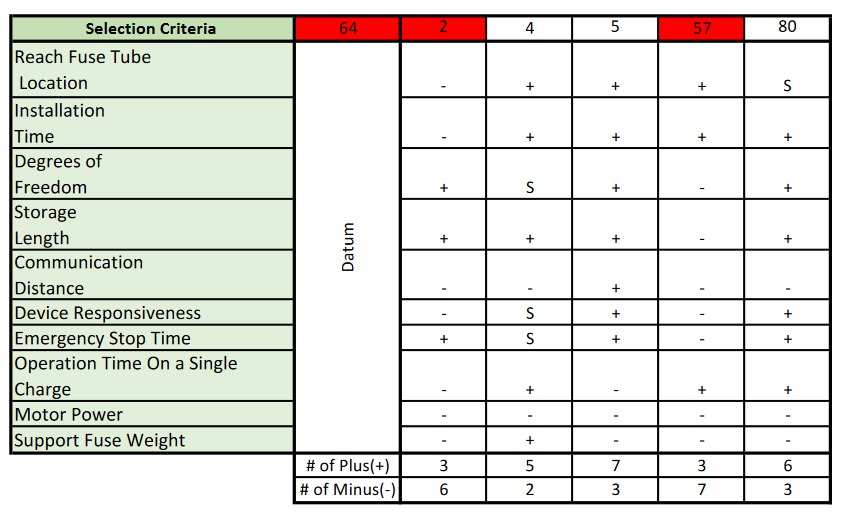


Figure 10: Pugh Chart Second Iteration



## Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) is a decision-making matrix methodology that provides a quantitative comparison of two or three concepts. AHP was used to narrow down from the three concepts remaining from the Pugh charts to the final concept.

The first step of the process was to formulate a criteria comparison matrix of all the engineering characteristics that were used to judge each concept. Our engineering characteristics included eight objectives summarized from the house of quality. The characteristics were as follows: Reach Fuse Tube Location, Fuse Removal, and Installation Time of 15 minutes, have 3 Degrees of Freedom, have a Maximum Storage Length of 4ft, Have Communication Distance between Device and User of 50 ft, Device Responsiveness, Emergency Stop Time, Ability to Support Fuse Tube Weight, Operation Time per Charge. A pairwise comparison was performed to rank the engineering characteristics. These values were used to find which criteria were most important for a design concept.

### Figure : AHP pairwise comparison



After the pairwise comparison was performed to determine the most important criteria, each design concept was ranked against one of the other three concepts based on each design criteria. The ideas were ranked using values of 1/3, 1/5,1/7,1, 3,5,7, or 9. These values were normalized, and the criteria weights were established. A sample of these tables is shown in the figure below, and calculations for all characteristics are found in Appendix E.

### Figure : Sample Criteria Weights



After the Criteria Weights were found, we checked for consistency bias in choosing each concept. This was done by computing the weighted sum, *Ws,* and consistency vectors for each normalized matrix (Dieter, Consistency Check Process for AHP , 2013). Using the weighted sum and consistency vectors, we found the average consistency, consistency index, and consistency ratio of each normalized matrix. A sample of these calculations are shown in the figure below, and all calculations are shown in Appendix E.

### Figure : Consistency check

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Consistency Check** | |  | **Consistency Comparison** | | |
| Ws | Cons V |  | Avg Consist | Con Index | Con Ratio |
| 1.43 | 3.21 |  | 3.208 | 0.104 | 0.200 |
| 0.35 | 3.20 |  |  |  |  |
| 1.43 | 3.21 |  |  |  |  |

After two iterations of AHP, there were no egregious outliers in the consistency averages, so it was concluded that consistency bias was negligible. With consistency bias accounted for, we moved on to the final selection matrix and the alternative values.

In the final selection matrix, criteria weights for the design were recorded by the respective engineering characteristic they correspond to. These values were then used in a matrix multiplication with averages of the criteria weights to give alternative values for each Concept. The final Matrix and alternative values are shown in the figure below.

### Figure : Final Rating Matrix



To make the final rating matrix and alternative values more readable, a simple bar chart was made. This bar chart gives a visual indication of the difference between the alternative values calculated.

### Figure : Alternative Value Bar chart

The alternative value assessment indicated that concept 5, the drone, would be the best design based on engineering characteristics. After deliberation with the group, the drone concept was eliminated despite winning an alternative value due to the feasibility problems due to the physics involved that are not considered in the AHP. One of the major issues with the drone is the inability for the drone to generate enough torque to perform fuse switching and still be lightweight enough to fly. In addition, it would be difficult to stabilize a drone while supporting a heavy weight. The final concept was then decided to be concept 80, the robotic arm attached to a pole. The group decided to add valuable design elements from the other concepts. However, the focus of the project going forward will be to realize a design based on concept 80.

## Final Selection

The final concept selected is a telescoping stick with a robot arm that uses an external support mechanism to anchor itself to the ground. This support mechanism can also manipulate the tilt angle of the stick to allow for fuse switching from a distance. This mechanism was chosen because it can fulfill all engineering characteristics. It can perform fuse switching 10 feet away from the pole on uneven ground. It can telescope to a desired length and collapse to a transportable length. The robot arm can provide three degrees of freedom to successfully remove and replace utility fuses up to 14 lb weight. Finally, this design can provide users with ergonomic fuse-switching experience. By combining the best parts of the best concepts generated, an even better concept was created.

# Spring Project Plan

# Chapter Two: EML 4552C

## 2.1 Spring Plan

### Project Plan.

### Build Plan.

# Appendices

# Appendix A: Code of Conduct

## Mission Statement

Team 510 is committed to putting forth our best work on a new Engineering Project. Team 510 seeks to create an environment conducive to effective engineering design, by communicating well, applying consistent effort to the project, and respecting our team and the project.

## Team Roles

Fluids Engineer: Davis Goolsby

Fluids engineer is responsible for all matters related to fluid flow and heat transfer. In addition, this role is tasked with recording and organizing digital copies of meeting minutes.

Controls Engineer: Ebony Bland

Controls engineer is responsible for all matters related to robotics and controls. In addition, this role is tasked with being the point of contact for the team

Materials Engineer: Garfield Murphy

Materials engineer is responsible for all matters related to material properties. In addition, this role is tasked with organizing meetings and coordinating internal meetings.

Power/Design Engineer: Emilio Manzo

Power/Design engineer is responsible for all matters related to electrical design, including PCB design and bread boards. In addition, this role is tasked with being the web master.

Power/Test Engineer: Austin Bruen

Power/Test engineer is responsible for all matters related to testing of electrical systems. In addition, this role is responsible for accounting and procurement.

Individual team roles reflect each member's expertise and ability to direct the project during stages that reflect to their experience. All team members are responsible for tasks that fall under their nature of expertise. For other tasks that don’t directly align with any team member’s duties, the team will decide together who is best suited for each task during our weekly meetings. All tasks will be divided fairly. Each member is encouraged to ask for help we needed. All team members should show support for everyone is the team and help when able.

## Communication Standards

Microsoft Teams is the primary mode of communication between Teammates, written messages, as well as video calls, will be used for on-the-fly communication. Text messages will be used for informal, or time-sensitive information Regular Meetings will be held in person, or via video chat, if needed. Meetings will take place at the College of Engineering on Wednesdays from 2 pm to 3 pm.

Formal Documents will be shared with Teammates and sponsors via Microsoft Teams, drafted documents will be shared using Google drive.

Microsoft teams must be checked regularly by each Teammate for updates to projects and any sudden changes. Teammates are given a maximum of 48 hours to respond to direct messages formal or informal.

## Dress Code

Dress code will be as followed:

* Informal casual clothing for standard team and/or faculty advisor meetings is appropriate.
* Business casual clothing is required at minimum for biweekly sponsor meetings
* Business professional clothing is required for all official presentations for the senior design class and sponsor presentations.

## Attendance Policy

Official team meetings will be held once a week for one hour in person or via video call (Teams or Zoom). The meeting time will be based on each team member's availability each semester. Additional meetings may occur if needed and will be scheduled at least 2-3 days in advance. The attendance of each team member will be recorded in sign-in sheet documents for all team meetings, presentations, and meetings with sponsors and advisors. Attendance to official team meetings, presentations, sponsor, and advisor meetings is mandatory unless it notice is provided 24 hours prior or an emergency arises. If an emergency arises, that person is required to notify the group at their earliest convenience. An emergency is defined according to the FAMU-FSU College of Engineering Policy for emergencies and unexcused absences.

Failure to attend more than 3 meetings of any kind without notice will result in a team intervention meeting. If the issue persists with that person, the team will present the situation to Dr. McConomy for guidance. Attendance for additional team meetings is required unless a team member has time conflicts. All team members are expected to be on time for all team meetings, sponsor and advisor meetings, and presentations. If a member knows they will be late to a meeting, they are expected to provide notice unless it is an emergency. If an emergency arises, the individual is expected to notify the team at their earliest convince. Any outside obligations that will present time conflicts need to be discussed in advance. Communication with all team members is essential for success. The team will work to accommodate any team member within reason.

## Team Dynamics

All team members are to be treated equally and with respect. This includes not cutting people off and not discrediting the ideas and opinions of others. Furthermore, team members should be open to criticism and work to provide open, non-destructive modes of communication. Team members are expected to put in similar levels of effort and be proactive in finding ways of aiding the team. If a team member is found to put in disproportionately low levels of effort compared to the other members of the team, this should be brought up readily and, in a manner, consistent with the above style of communication. If the problem persists, Dr. McConomy should be informed.

## Statement of Understanding

All team members have read and understand the expectations and responsibilities listed above.

Davis Goolsby      \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Davis Goolsby\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Garfield Murphy  \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Garfield Murphy\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Ebony Bland       \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ Ebony Bland\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Emilio Manzo    \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Emilio Manzo\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Austin Bruen       \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_Austin Bruen\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

# Appendix B: Functional Decomposition

# Appendix C: Work Breakdown Structure

# Appendix D: Concept Generation list

1. The standard pole is motorized and can go to the top of the pole, the user can manually do fusing and restoration.
2. A robot that climbs the pole and can change out the fuse. All of this would be automated. The user would have to click a button on a remote to do all the movements.
3. The Tripod pole extends up based on the height of the pole and the user can take control of the device and manually do fuse switching.
4. A Tripod pole extends up based on the height of the pole and the user can push a button and fusing gets done as well as restoration.
5. A drone device with a hook that can fly in takes the fuse out and does fuse restoration. The user would be trained in drone flying prior. This would be flown by the user to the designated height and the addition of a hook would remove the move and have the ability to put a fuse back in.
6. An automated device in which the user pushes a button the stick extends up and automatically does fuse switching and can place a fuse back in.
7. A hot stick that the user controls from an app on their phone. The device can go to the user's height based on what they entered and does fuse switching.
8. A hot stick with a rotary motor which when you press down the device extends and you press another button to perform fuse switching.
9. A hot stick in which there are joins between each gap that expand on each other. Basically, like a pocketknife mechanism.
10. The inflatable motion in which the stick inflates up and can be inflated to the desired height of the user. The user would then perform fuse switching and restoration manually.
11. A hot stick has a pull system that gets to the desired height based on the user input. The device pulls the old fuse down and the new fuse can be pulled up.
12. Stick that can fold up like a lawn chair type of thing. It sits on 4 legs and has a button the user pushes to the stick to go to the desired height. The user can then manually do fusing.
13. A stick that folds in on itself, this way it can fold to the desired space. The user is then able to perform the fuse manually.
14. A fuse box is placed at the ground of the pole so that the user doesn’t have to go to the desired height and the user can perform fuse switching.
15. A bucket truck that is put to the pole height can perform fuse switching and restoration.
16. A device that is spring loaded at the top of the pole, when a fuse blows will pop the blown one out and add a new one to the pole.
17. A ladder in which the motorized pole in which it goes up to the desired height manually and does the fuse switching manually.
18. A ladder in which the regular pole is used to switch the fuse manually (Ladder and the process they use now)
19. A motor-like system in which the user places the base down on the ground below the pole. The user can then use a reel system for the hot stick to extend to the top of the pole. The user can do fusing and restoration.
20. A device that anchors to the ground, the user can rotate a crank around and this would extend the device to the desired height. The user can then manually fuse or replace the fuse.
21. Self-tensioning rope to scale utility pole (Mulan - I’ll make a man out of your pole)
22. Air-tight telescoping pole with an air compressor to extend.
23. Inflatable snake extending mechanism.
24. Extendable ladder with rigid base.
25. Drone with the ability to clamp to utility poles.
26. Drone with the complete ability to perform a fuse-switching process.
27. Rigid stand to assist in using the current hot stick.
28. Alternating clamps to scale the pole.
29. Alternating clamps to extend the hot stick.
30. New hot stick that takes fuse up with it on the first extension (Cuts extending and descending in half).
31. Attachment to a hot stick that performs the steps in concept 30.
32. A remote-controlled snake coils the pole.
33. A device that mimics pole climbing shoes.
34. Rope pulls down to extend the hot stick (more ergonomic motion).
35. Air cannon to rapidly extend the hot stick.
36. A device that automatically repairs fuse tubes in the air.
37. A device that automatically repairs a fuse still hanging from lower contact.
38. Holster for a hot stick that extends as you pull it out.
39. Elevated anchor point on the truck to extend the hot stick via pulling, then push to elevate.
40. Extending anchor point on truck or tripod to achieve above^
41. Fuse array: 3 fuses in a box.
42. Automated pole climbing shoes.
43. Inflatable AC-tube-like structure that extends up to 35-45 ft. Made of materials sturdy enough to not puncture or wobble in the wind when fully extended. Has a camera and a hook near the top used to perform fuse switching. Extending/collapsing function performed by an air pump.
44. Extendable/collapsible robot with a hook and a camera at the end. Tripod shape grips the ground, and the insulating extendable rod is sturdy enough not to sway in the wind. The top has a camera and a rod that can extend horizontally independently of the main rod. To be placed on the ground right next to the utility pole and extend upwards. Extends through telescoping using motors at the bottom of the design. Controlled with a remote similar to that of a crane.
45. Adapting a drone-like flying device with a hook and a camera. It needs to be able to stay roughly in place even with a light wind and be accurate in its movements.
46. Diagonal telescoping pole extendable using motors. It supports that drop to the ground as it extends like a roller coaster. Maneuverable by operators from its base like a hot stick but cutting out the repetitive extending and collapsing motion. Special attention should be given to hilly terrain.
47. Climbing robot. A robot that climbs up a utility pole and can perform fuse switching. Remote-controlled. Users can control it as it goes up and down, and as it performs fuse switching. To avoid scaling up and down multiple times per pole, the robot can drop the fuse using a rope, and a pulley system can pull the new fuse up.
48. Extendable telescoping mechanism using motors that support itself against the utility pole. A complex, remote-controlled, fuse-switching mechanism is found on top that can go around the pole finding and removing the fuse.
49. Hot stick extended/self-extending hot stick. Uses current hot sticks as a base, but simply extends it automatically to avoid repetitive motion of users.
50. The balloon carries up a pulley that can attach/suction to the pole. Through the pulley, a device is raised/lowered that can remove the fuse. This device is remote-controlled.
51. Diagonal extendable ladder. First placed horizontally, one of the sides (close to the utility pole) telescopes upwards using a motor. The ladder ends at a diagonal position. Special care should be taken with hills. A device we create can use the ladder rails as tracks to move up. Once it is up, it can use a horizontally extendable hook to grab the fuse. The hook can roll up to hook or straighten out to unhook. Remote-controlled device.
52. Inflatable 35-45 ft long tube. It’s like the AC-vent idea except less automized. This device is simply made from tough, resistant material like inflatable kayaks. It extends up and has a hook at the end just like the hot stick. It should extend vertically and will be only slightly wider than a hot stick. It will be held and used by users in a very similar way to a hot stick. The experience should be user-friendly, and the stick should be about as easy to control as a hot stick.
53. A grappling hook/hook gun. You aim at the fuse and fire to make a rope shoot out with a system that fastens to the fuse cutout. A hook near the top of the rope can be angled to attach to the fuse. A pulley system allows the hook to go down, and then go back up to replace the fuse.
54. The extendable telescoping pole has a “finger” that can be curled up or extended. Lightweight enough to be manually operated. Telescoping is extendable by using motors.
55. Telescoping extendable ladder idea but vertical. Remote-controlled hooking mechanism near the top. Has a camera. The two poles help with maintaining a good grip on the ground and with being resistant to the wind.
56. Joined caterpillar-like device that can suction to the side of the pole. It can “walk” up the pole as an earthworm walks on the ground.
57. A device that mounts on the fuse cutout and acts like a crane. Remote-controlled. Need an extendable (maybe telescoping?) device to bring it up there, probably manually operated to put it on the fuse cutout. Should lock on and be sturdy, while being able to withstand wind and rain. Special consideration should be given to how the device would be removed in the case of failure, and how to electrically isolate it from nearby tree branches.
58. Extendable stick that supports itself on a utility pole, but it stays there. It goes up to the fuse and has a pulley and a hook. These must be cheap materials to be put on many poles. Pulley is remote-controlled.
59. Flexible extendable stick that is attached to a balloon to extend. Once extended to the desired level, it can be made to become stiff. This stick can be used to switch the fuse with a hook at the end. Could be a rollable jointed design that can have its joint become stiff after receiving a remote signal. Also, the balloon can be deflated with a remote signal.
60. The same idea as number 17 but instead of a jointed design, could be an inflatable design. Inflating the design can make it stiff.
61. The rocket that you point up to the fuse and it can attach like a hand. The end of the design has a rope that can be used to remove the device. Once the blown fuse is removed, a new fuse can also be rocketed up and the end attaches to the empty cutout like a hand. In case of a miss, a motor can quickly revert the direction of motion of the flying fuse. A net should be set up below so that a new fuse does not break once it falls.
62. A wheeled robot that rolls up the pole due to high friction and attaches to the fuse cutout. A pulley system can be used to switch the fuse. A net might be necessary below to catch the robot in case of failure. Safety hats are necessary!
63. The little robotic guy that zips lines across the power lines and smoothly changes fuses. Controllable only by my Xbox controller.
64. Slider crank- Attached to the pole rotational motion brings the fuse up, keeping the device stable.
65. Tripod
66. Roller with pole
67. Gecko suction robot
68. Voice command UI robot
69. Folding mechanism with robot
70. Camera feature
71. Fuse switch conveyor belt
72. Mini RC Bucket truck
73. Touch Screen interface
74. Hook Gripper Structure
75. Gear Trains for different motions
76. Net For old fuse
77. Scorpion Design
78. Drone design Bird or Insect
79. Tripod on wheels
80. Robotic hot stick
81. Folding structure
82. Fuse switching device attached to the pole
83. Grapple gun fuse switching arms
84. An automated telescoping hot stick with a manipulator arm on the end. The extendable mechanism transfers the arm to the desired location. The manipulator's arm is the last link to telescope out. It is made up of 3 pin joints and 4 links for the arm that allows the user to have 3 DOF to position the hand to grab the fuse. The manipulator's hand is linked 4. The hand has a claw-like mechanism that will be controlled by a motor to extend in and out (1 DOF).  Could be controlled with an analog controller or a controller with visual feedback. The Analog controller could have haptic feedback. The arm folds up and collapses into the telescoping configuration.
85. Pole climber device that rolls up the pole with an extendable 3 DOF arm with a 1 DOF hand as shown in concept one. The Pole climber will roll up the pole to the desired location and the arm will be manipulated by the user to grab the fuse. Could be controlled with an analog controller or a controller with visual feedback. The arm would fold up. Adjustable axle lengths
86. A device that can mount to a pole and has a  3DOF arm that is retractable and can fold up for storage. But can still perform fuse switching. Same as concept 1 but the bottom of the telescoping mechanism would mount to the utility pole.
87. Small lightweight lift for a lines specialist to rise to the desired height to perform fuse switching easily. Could mount to the pole. Remote controlled by the user on the lift with up and down controls.
88. Snake climber robot that climbs utility poles by coiling up the pole. Could have the manipulator's hand attached to the head to grab the fuse. Or a lamprey robot.
89. Crane device (construction crane or toy machine). Analog controller (with or w/o visual input) to control colored joints to get the hook onto the fuse tube. Could mount to a pole and have a revolute joint at the base for more range of motion.
90. A drone that could be remotely controlled and would have an arm and claw to grab the fuse tube.
91. Large sticky hand rope that the user would lasso onto the fuse to remove. Or have an automated mechanism that extends to the fuse location and lassos the fuse with sticky adhesive rope. (Think like spiderman's webs)
92. Automatic grappling hook gun that the user can aim from the ground and will shoot a hook to capture the fuse tube. The hook would be a claw that would close once around the fuse tube.
93. The ladder that folds up when not in use.
94. Shoot the fuse down with a gun and use an air balloon to float a new one back up to the location.
95. A controlled hot air balloon machine with a manipulator claw to grab the fuse tube. Have a component that controls the amount of hot air being released into the balloon. Could add sails or structures that could “steer the balloon forward and backward”.
96. Hover platform with arm
97. Put steps on the pole
98. Suction cup crane
99. Make the fuse tube magnetic and have a device remove it and hold it with a magnetic field. That can turn the field off when it needs to be released.
100. A pulley-like system.
101. A pulley system with a mechanical arm.
102. An inflatable device.
103. A crane that is operable by the user in a chair mounted to the pole or in a remote location.
104. Chick Fil A delivery system to remove the fuse.

# Appendix E: Concept Selection tables

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Binary Piecewise Comparison** | | | | | | | | | | | | |
| **Customer Needs** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **Total** |
| **1) Automates Fuse Switching** | - | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 6 |
| **2) Reach Areas Inaccessible by Bucket Truck** | 1 | - | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 7 |
| **3) Operate in Multiple Operating Environments** | 0 | 0 | - | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 2 |
| **4) Transportable via Bucket Truck** | 0 | 0 | 1 | - | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 5 |
| **5) Transportable via Passenger Vehicle** | 0 | 0 | 0 | 0 | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **6) Mitigate Soft Tissue Damage** | 1 | 1 | 1 | 1 | 1 | - | 1 | 1 | 0 | 0 | 1 | 8 |
| **7) Maintain a Device Weight < 50 lbs.** | 0 | 0 | 1 | 0 | 1 | 0 | - | 1 | 0 | 0 | 1 | 4 |
| **8) Ergonomic Carrying Design** | 0 | 0 | 0 | 0 | 1 | 0 | 0 | - | 0 | 0 | 0 | 1 |
| **9) Minimum Length of 40 ft.** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | - | 1 | 1 | 10 |
| **10) Support a Weight of 14 lbs.** | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | - | 1 | 9 |
| **11) Operable from 10 ft. Away** | 0 | 0 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | - | 3 |
| **Total** | 4 | 3 | 8 | 5 | 10 | 2 | 6 | 9 | 0 | 1 | 7 | n-1=10 |

**House Of Quality**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Engineering Characteristics** | | | | | | | | | | | | | | | | | | |
| **Improvement Direction** | ↑ | ↑ | ↑ | | ↓ | | ↑ | | ↓ | ↓ | | ↓ | | ↓ | | ↑ | | ↑ |
| **Units** | ft | lbf | DOF | | ft | | ft | | s | s | | s | | n/a | | min. | | W |
| **Customer Requirements** | **Importance  Weight Factor** | **Reach Fuse Tube  Location** | | **Maximum Installation Time of 15 Minutes** | | **Have 3 Degrees of  Freedom** | | **Max Storage length of 4 feet** | **Min. Communication  Length of 50 ft.** | | **Measures Power  Consumption Every 20 Seconds** | | **Device Implements User  Commands Within 1 Second** | | **Device Stops Operation Within  2 Seconds of Stop Command** | | **Contains 7 User-Interaction  Elements** | **Operable for 30 Min. at a Time** | **Motor has sufficient Power  to Perform Device Operation** |
| **1) Automates Fuse Switching** | 6 |  | | 5 | | 5 | |  | 3 | |  | | 3 | |  | |  | 5 | 9 |
| **2) Reach Areas Inaccessible by Bucket Truck** | 7 |  | |  | |  | |  |  | |  | |  | |  | |  | 3 |  |
| **3) Operate in Multiple Operating Environments** | 2 |  | |  | | 3 | |  | 5 | |  | | 1 | |  | |  |  |  |
| **4) Transportable via Bucket Truck** | 5 | 3 | |  | |  | | 9 |  | |  | |  | |  | |  |  |  |
| **5) Transportable via Passenger Vehicle** | 0 | 1 | |  | |  | | 9 |  | |  | |  | |  | |  |  |  |
| **6) Mitigate Soft Tissue Damage** | 8 |  | | 1 | |  | |  |  | |  | | 1 | | 3 | |  | 1 |  |
| **7) Maintain a Device Weight < 50 lbs.** | 4 |  | |  | |  | |  |  | |  | |  | |  | |  |  |  |
| **8) Ergonomic Design** | 1 |  | |  | |  | | 3 |  | |  | |  | |  | | 9 |  |  |
| **9) Minimum Length of 40 ft.** | 10 | 9 | |  | |  | |  |  | |  | |  | |  | |  |  |  |
| **10) Support a Weight of 14 lbs.** | 9 | 3 | |  | | 1 | |  |  | |  | |  | |  | |  |  |  |
| **11) Operable from 10 ft. Away** | 3 | 3 | |  | |  | |  | 9 | |  | | 5 | | 5 | |  |  |  |
| **Raw Score** | **531** | 141 | | 38 | | 45 | | 48 | 55 | | 0 | | 43 | | 39 | | 9 | 59 | 54 |
| **Relative Weight %** | 26.554 | 7.156 | 8.475 | | 9.040 | | 10.358 | | 0.000 | 8.098 | | 7.345 | | 1.695 | | 11.111 | | 10.169 |
| **Rank Order** | 1 | 9 | 6 | | 5 | | 3 | | 11 | 7 | | 8 | | 10 | | 2 | | 4 |

**Pugh Chart 1**

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  | **Concepts** | | | | | | | |
| **Selection Criteria** | BLUE STRIPE  Telescopic Hot Stick | 2 | 4 | 5 | 41 | 52 | 57 | 64 | 80 |
| Reach Fuse Tube  Location | Datum | - | S | + | S | + | S | + | S |
| Installation Time | - | S | + | + | - | - | + | + |
| Degrees of  Freedom | + | S | + | - | - | - | - | + |
| Storage  Length | + | S | + | - | S | S | - | - |
| Communication  Distance | - | S | + | - | - | + | + | + |
| Device Responsiveness | - | S | - | - | S | - | - | - |
| Emergency Stop Time | + | S | + | - | S | + | - | + |
| Operation Time On a Single Charge | - | - | - | - | - | - | - | - |
| Motor Power | + | + | + | - | - | + | + | + |
| Support Fuse Weight | - | + | - | + | - | + | + | + |
|  | # of Plus(+) | 4 | 2 | 7 | 2 | 1 | 4 | 5 | 5 |
|  | # of Minus(-) | 6 | 0 | 3 | 7 | 6 | 4 | 5 | 4 |

**Pugh Chart 2**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  |  | **Concepts** | | | | |
| **Selection Criteria** | 64 | 2 | 4 | 5 | 57 | 80 |
| Reach Fuse Tube  Location | Datum | - | + | + | + | S |
| Installation Time | - | + | + | + | + |
| Degrees of  Freedom | + | S | + | - | + |
| Storage  Length | + | + | + | - | + |
| Communication  Distance | - | - | + | - | - |
| Device Responsiveness | - | S | + | - | + |
| Emergency Stop Time | + | S | + | - | + |
| Operation Time On a Single Charge | - | + | - | + | + |
| Motor Power | - | - | - | - | - |
| Support Fuse Weight | - | + | - | - | - |
|  | # of Plus(+) | 3 | 5 | 7 | 3 | 6 |
|  | # of Minus(-) | 6 | 2 | 3 | 7 | 3 |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Criteria Comparison Matrix [C] | | | | | | | | | |
| **Engineering Characteristics** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| Reach Fuse Tube  Location | 1.00 | 0.11 | 0.33 | 0.33 | 0.20 | 0.11 | 0.11 | 0.33 | 0.20 |
| Maximum Installation Time of 15 Minutes | 9.00 | 1.00 | 9.00 | 5.00 | 0.33 | 7.00 | 3.00 | 3.00 | 3.00 |
| Have 3 Degrees of  Freedom | 3.00 | 0.11 | 1.00 | 3.00 | 3.00 | 0.33 | 0.33 | 3.00 | 3.00 |
| Maximum Collapsed  Length of 4 ft. | 3.00 | 0.20 | 0.33 | 1.00 | 0.20 | 0.20 | 0.14 | 3.00 | 0.14 |
| Min. Communication  Length of 50 ft. | 5.00 | 3.00 | 0.33 | 5.00 | 1.00 | 3.00 | 0.20 | 3.00 | 5.00 |
| Device Implements User  Commands Within 1 Second | 9.00 | 0.14 | 3.00 | 5.00 | 0.33 | 1.00 | 3.00 | 3.00 | 3.00 |
| Device Stops Operation Within  2 Seconds of Stop Command | 9.00 | 0.33 | 3.00 | 7.00 | 5.00 | 0.33 | 1.00 | 3.00 | 3.00 |
| Operable for 30 Min. at a Time | 3.00 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 0.33 | 1.00 | 0.20 |
| Motor has sufficient Power  to Perform Device Operation | 5.00 | 0.33 | 0.33 | 7.00 | 0.20 | 0.33 | 0.33 | 5.00 | 1.00 |
| **Total** | 47.00 | 5.57 | 17.67 | 33.67 | 10.60 | 12.64 | 8.45 | 24.33 | 18.54 |

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Normalized Criteria Comparison Matrix [NormC] | | | | | | | | | | |
| **Engineering Characteristics** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | Criteria Weights |
| Reach Fuse Tube  Location | 0.021 | 0.020 | 0.019 | 0.010 | 0.019 | 0.009 | 0.013 | 0.014 | 0.011 | 0.015 |
| Maximum Installation Time of 15 Minutes | 0.191 | 0.180 | 0.509 | 0.149 | 0.031 | 0.554 | 0.355 | 0.123 | 0.162 | 0.250 |
| Have 3 Degrees of  Freedom | 0.064 | 0.020 | 0.057 | 0.089 | 0.283 | 0.026 | 0.039 | 0.123 | 0.162 | 0.096 |
| Maximum Collapsed  Length of 4 ft. | 0.064 | 0.036 | 0.019 | 0.030 | 0.019 | 0.016 | 0.017 | 0.123 | 0.008 | 0.037 |
| Min. Communication  Length of 50 ft. | 0.106 | 0.539 | 0.019 | 0.149 | 0.094 | 0.237 | 0.024 | 0.123 | 0.270 | 0.173 |
| Device Implements User  Commands Within 1 Second | 0.191 | 0.026 | 0.170 | 0.149 | 0.031 | 0.079 | 0.355 | 0.123 | 0.162 | 0.143 |
| Device Stops Operation Within  2 Seconds of Stop Command | 0.191 | 0.060 | 0.170 | 0.208 | 0.472 | 0.026 | 0.118 | 0.123 | 0.162 | 0.170 |
| Operable for 30 Min. at a Time | 0.064 | 0.060 | 0.019 | 0.010 | 0.031 | 0.026 | 0.039 | 0.041 | 0.011 | 0.034 |
| Motor has sufficient Power  to Perform Device Operation | 0.106 | 0.060 | 0.019 | 0.208 | 0.019 | 0.026 | 0.039 | 0.205 | 0.054 | 0.082 |
| **Total** | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |

**Criteria Weights**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **Reach Fuse Tube** | | |  |  |  | **Normalized Reach Fuse Tube** | | | |
| **Concepts** | **# 4** | **# 5** | **# 80** | **Avg** |  | **Concepts** | **# 4** | **# 5** | **# 80** | **Critical Weight** |
| **# 4** | 1.00 | 5.00 | 1.00 | 2.33 |  | **# 4** | 0.45 | 0.45 | 0.45 | 0.45 |
| **# 5** | 0.20 | 1.00 | 0.20 | 0.47 |  | **# 5** | 0.09 | 0.09 | 0.09 | 0.09 |
| **# 80** | 1.00 | 5.00 | 1.00 | 2.33 |  | **# 80** | 0.45 | 0.45 | 0.45 | 0.45 |
| **Total** | 2.2 | 11 | 2.2 |  |  | **Total** | 1 | 1 | 1 | 1 |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | **Installation Time** | | |  |  |  | **Normalized Installation Time** | | | |
| **Concepts** | **# 4** | **# 5** | **# 80** | **Avg** |  | **Concepts** | **# 4** | **# 5** | **# 80** | **Critical Weight** |
| **# 4** | 1.00 | 3.00 | 0.20 | 1.40 |  | **# 4** | 0.45 | 0.27 | 0.09 | 0.27 |
| **# 5** | 0.33 | 1.00 | 0.20 | 0.51 |  | **# 5** | 0.15 | 0.09 | 0.09 | 0.11 |
| **# 80** | 5.00 | 5.00 | 1.00 | 3.67 |  | **# 80** | 2.27 | 0.45 | 0.45 | 1.06 |
| **Total** | 6.33 | 9 | 1.4 |  |  | **Total** | 2.88 | 0.82 | 0.64 | 1.44 |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | **DoF** | | |  |  |  | **Normalized DoF** | | | |
| **Concepts** | **# 4** | **# 5** | **# 80** | **Avg** |  | **Concepts** | **# 4** | **# 5** | **# 80** | **Critical Weight** |
| **# 4** | 1.00 | 5.00 | 5.00 | 3.67 |  | **# 4** | 0.45 | 0.45 | 2.27 | 1.06 |
| **# 5** | 0.20 | 1.00 | 3.00 | 1.40 |  | **# 5** | 0.09 | 0.09 | 1.36 | 0.52 |
| **# 80** | 0.20 | 0.33 | 1.00 | 0.51 |  | **# 80** | 0.09 | 0.03 | 0.45 | 0.19 |
| **Total** | 1.40 | 6.33 | 9.00 |  |  | **Total** | 0.64 | 0.58 | 4.09 | 1.77 |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | **Storage Length** | | |  |  |  | **Normalized Storage Length** | | | |
| **Concepts** | **# 4** | **# 5** | **# 80** | **Avg** |  | **Concepts** | **# 4** | **# 5** | **# 80** | **Critical Weight** |
| **# 4** | 1.00 | 3.00 | 1.00 | 1.67 |  | **# 4** | 0.45 | 0.27 | 0.45 | 0.39 |
| **# 5** | 0.33 | 1.00 | 3.00 | 1.44 |  | **# 5** | 0.15 | 0.09 | 1.36 | 0.54 |
| **# 80** | 1.00 | 0.33 | 1.00 | 0.78 |  | **# 80** | 0.45 | 0.03 | 0.45 | 0.31 |
| **Total** | 2.33 | 4.33 | 5.00 |  |  | **Total** | 1.06 | 0.39 | 2.27 | 1.24 |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | **Communication Distance** | | |  |  |  | **Normalized Communication Distance** | | | |
| **Concepts** | **# 4** | **# 5** | **# 80** | **Avg** |  | **Concepts** | **# 4** | **# 5** | **# 80** | **Critical Weight** |
| **# 4** | 1.00 | 0.33 | 0.33 | 0.56 |  | **# 4** | 0.45 | 0.03 | 0.15 | 0.21 |
| **# 5** | 3.00 | 1.00 | 3.00 | 2.33 |  | **# 5** | 1.36 | 0.09 | 1.36 | 0.94 |
| **# 80** | 3.00 | 0.33 | 1.00 | 1.44 |  | **# 80** | 1.36 | 0.03 | 0.45 | 0.62 |
| **Total** | 7.00 | 1.67 | 4.33 |  |  | **Total** | 3.18 | 0.15 | 1.97 | 1.77 |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | **Responsiveness** | | |  |  |  | **Normalized Responsiveness** | | | |
| **Concepts** | **# 4** | **# 5** | **# 80** | **Avg** |  | **Concepts** | **# 4** | **# 5** | **# 80** | **Critical Weight** |
| **# 4** | 1.00 | 3.00 | 3.00 | 2.33 |  | **# 4** | 0.45 | 0.27 | 1.36 | 0.70 |
| **# 5** | 0.33 | 1.00 | 0.33 | 0.56 |  | **# 5** | 0.15 | 0.09 | 0.15 | 0.13 |
| **# 80** | 0.33 | 3.00 | 1.00 | 1.44 |  | **# 80** | 0.15 | 0.27 | 0.45 | 0.29 |
| **Total** | 1.67 | 7.00 | 4.33 |  |  | **Total** | 0.76 | 0.64 | 1.97 | 1.12 |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | **Emergency Stop time** | | |  |  |  | **Normalized Emergency Stop time** | | | |
| **Concepts** | **# 4** | **# 5** | **# 80** | **Avg** |  | **Concepts** | **# 4** | **# 5** | **# 80** | **Critical Weight** |
| **# 4** | 1.00 | 0.11 | 0.20 | 0.44 |  | **# 4** | 0.45 | 0.01 | 0.09 | 0.19 |
| **# 5** | 9.00 | 1.00 | 3.00 | 4.33 |  | **# 5** | 4.09 | 0.09 | 1.36 | 1.85 |
| **# 80** | 5.00 | 0.33 | 1.00 | 2.11 |  | **# 80** | 2.27 | 0.03 | 0.45 | 0.92 |
| **Total** | 15.00 | 1.44 | 4.20 |  |  | **Total** | 6.82 | 0.13 | 1.91 | 2.95 |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | **Support fuse weight** | | |  |  |  | **Normalized Support fuse weight** | | | |
| **Concepts** | **# 4** | **# 5** | **# 80** | **Avg** |  | **Concepts** | **# 4** | **# 5** | **# 80** | **Critical Weight** |
| **# 4** | 1.00 | 0.20 | 0.20 | 0.47 |  | **# 4** | 0.45 | 0.02 | 0.09 | 0.19 |
| **# 5** | 5.00 | 1.00 | 0.33 | 2.11 |  | **# 5** | 2.27 | 0.09 | 0.15 | 0.84 |
| **# 80** | 5.00 | 0.11 | 1.00 | 2.04 |  | **# 80** | 2.27 | 0.01 | 0.45 | 0.91 |
| **Total** | 11.00 | 1.31 | 1.53 |  |  | **Total** | 5.00 | 0.12 | 0.70 | 1.94 |
|  |  |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
|  | **Operation on Charge** | | |  |  |  | **Normalized Operation on Charge** | | | |
| **Concepts** | **# 4** | **# 5** | **# 80** | **Avg** |  | **Concepts** | **# 4** | **# 5** | **# 80** | **Critical Weight** |
| **# 4** | 1.00 | 0.14 | 0.14 | 0.43 |  | **# 4** | 0.45 | 0.01 | 0.06 | 0.18 |
| **# 5** | 7.00 | 1.00 | 7.00 | 5.00 |  | **# 5** | 3.18 | 0.09 | 3.18 | 2.15 |
| **# 80** | 7.00 | 0.14 | 1.00 | 2.71 |  | **# 80** | 3.18 | 0.01 | 0.45 | 1.22 |
| **Total** | 15.00 | 1.29 | 8.14 |  |  | **Total** | 6.82 | 0.12 | 3.70 | 3.55 |

**Consitency Checks**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  |  |  |  |  |  |
| Consistency Check |  |  | Consistency Comparison |  |  |
| Ws | Cons V |  | Avg Consis | Con Index | Con Ratio |
| 1.36 | 3.00 |  | 3.000 | 0.000 | 0.000 |
| 0.27 | 3.00 |  |  |  |  |
| 1.36 | 3.00 |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| Consistency Check |  |  | Consistency Comparison |  |  |
| Ws | Cons V |  | Avg Consis | Con Index | Con Ratio |
| 0.82 | 3.00 |  | 3.179 | 0.089 | 0.172 |
| 0.41 | 3.73 |  |  |  |  |
| 2.98 | 2.81 |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| Consistency Check |  |  | Consistency Comparison |  |  |
| Ws | Cons V |  | Avg Consis | Con Index | Con Ratio |
| 4.60 | 4.33 |  | 3.288 | 0.144 | 0.277 |
| 1.30 | 2.53 |  |  |  |  |
| 0.58 | 3.00 |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| Consistency Check |  |  | Consistency Comparison |  |  |
| Ws | Cons V |  | Avg Consis | Con Index | Con Ratio |
| 2.31 | 5.87 |  | 3.900 | 0.450 | 0.865 |
| 1.61 | 3.00 |  |  |  |  |
| 0.89 | 2.83 |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| Consistency Check |  |  | Consistency Comparison |  |  |
| Ws | Cons V |  | Avg Consis | Con Index | Con Ratio |
| 0.73 | 3.44 |  | 3.210 | 0.105 | 0.202 |
| 3.42 | 3.65 |  |  |  |  |
| 1.57 | 2.54 |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| Consistency Check |  |  | Consistency Comparison |  |  |
| Ws | Cons V |  | Avg Consis | Con Index | Con Ratio |
| 1.97 | 2.83 |  | 3.159 | 0.079 | 0.153 |
| 0.46 | 3.51 |  |  |  |  |
| 0.92 | 3.14 |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| Consistency Check |  |  | Consistency Comparison |  |  |
| Ws | Cons V |  | Avg Consis | Con Index | Con Ratio |
| 0.57 | 3.10 |  | 3.058 | 0.029 | 0.055 |
| 6.27 | 3.39 |  |  |  |  |
| 2.46 | 2.68 |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| Consistency Check |  |  | Consistency Comparison |  |  |
| Ws | Cons V |  | Avg Consis | Con Index | Con Ratio |
| 0.54 | 2.86 |  | 2.493 | -0.254 | -0.488 |
| 2.08 | 2.48 |  |  |  |  |
| 1.95 | 2.13 |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
|  |  |  |  |  |  |
| Consistency Check |  |  | Consistency Comparison |  |  |
| Ws | Cons V |  | Avg Consis | Con Index | Con Ratio |
| 0.66 | 3.71 |  | 3.840 | 0.420 | 0.808 |
| 11.91 | 5.54 |  |  |  |  |
| 2.77 | 2.27 |  |  |  |  |
|  |  |  |  |  |  |

**Consistencies for each Engineering Characteristics**

|  |  |
| --- | --- |
| Engineering Characteristic | Consistency ratio |
| Reach Fuse Tube | 0.000 |
| Installation Time | 0.172 |
| DoF | 0.277 |
| Storage Length | 0.865 |
| Communication Distance | 0.202 |
| Responsiveness | 0.153 |
|  |  |
| Norm Matrix Consistency Check | |
| Ws | Cons V |
| 0.18 | 12.25 |
| 3.35 | 13.37 |
| 1.25 | 13.03 |
| 0.36 | 9.89 |
| 2.19 | 12.62 |
| 1.70 | 11.90 |
| 2.20 | 12.91 |
| 0.38 | 11.48 |
| 0.84 | 10.21 |

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Final Rating Matrix | | | | |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |
| Concept | Reach Fuse Tube | Installation Time | DoF | Storage Length | Communication Distance | Responsiveness | Emergency Stop time | Support fuse weight | Operation on Charge |
| # 4 | 0.45 | 0.27 | 1.06 | 0.39 | 0.21 | 0.70 | 0.19 | 0.19 | 0.18 |
| # 5 | 0.09 | 0.11 | 0.52 | 0.54 | 0.94 | 0.13 | 1.85 | 0.84 | 2.15 |
| # 80 | 0.45 | 1.06 | 0.19 | 0.31 | 0.62 | 0.29 | 0.92 | 0.91 | 1.22 |

**Criteria Weights and alternative values**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| E char | Criteria Weights |  | Concept | Alternate Value |
| 1 | 0.33 |  | # 4 | 1.97 |
| 2 | 0.48 |  | # 5 | 6.12 |
| 3 | 0.59 |  | # 80 | 4.31 |
| 4 | 0.41 |  |  |  |
| 5 | 0.59 |  |  |  |
| 6 | 0.37 |  |  |  |
| 7 | 0.98 |  |  |  |
| 8 | 0.65 |  |  |  |
| 9 | 1.18 |  |  |  |

# Appendix A: APA Headings (delete)

# Heading 1 is Centered, Boldface, Uppercase and Lowercase Heading

## Heading 2 is Flush Left, Boldface, Uppercase and Lowercase Heading

### Heading 3 is indented, boldface lowercase paragraph heading ending with a period.

#### Heading 4 is indented, boldface, italicized, lowercase paragraph heading ending with a period.

##### Heading 5 is indented, italicized, lowercase paragraph heading ending with a period.

See publication manual of the American Psychological Association page 62

# Appendix B Figures and Tables (delete)

The text above the cation always introduces the reference material such as a figure or table. You should never show reference material then present the discussion. You can split the discussion around the reference material, but you should always introduce the reference material in your text first then show the information. If you look at the Figure 5 below the caption has a period after the figure number and is left justified whereas the figure itself is centered.



Figure . Flush left, normal font settings, sentence case, and ends with a period.

In addition, table captions are placed above the table and have a return after the table number. The second line of the caption provided the description. Note, there is a difference between a return and enter. A return is accomplished with the shortcut key shift + enter. Last, unlike the caption for a figure, a table caption does not end with a period, nor is there a period after the table number.

Table 1  
The Word Table and the Table Number are Normal Font and Flush Left. The Caption is Flush Left, Italicized, Uppercase and Lowercase

|  |  |
| --- | --- |
| Level of heading | Format |
| 1 | **Centered, Boldface, Uppercase and Lowercase Heading** |
| 2 | Flush Left, Boldface, Uppercase and Lowercase |
| 3 | Indented, boldface lowercase paragraph heading ending with a period |
| 4 | Indented, boldface, italicized, lowercase paragraph heading ending with a period. |
| 5 | Indented, italicized, lowercase paragraph heading ending with a period. |

# References

admin. (2019, june 19). *Soft Tissue Injury: Types, Causes, and Treatments*. Retrieved from https://www.accidentclaimsadvice.org.uk/soft-tissue-injury-types-causes-and-treatments/

Alibaba. (2022, October). *Distribution power dropout fuses cutout*. Retrieved from Alibaba: https://www.alibaba.com/product-detail/Distribution-power-dropout-fuses-cutout\_1600064214572.html

Eaton. (2021, February). *ELSG full-range current-limiting fuse*. Retrieved from Eaton: https://www.eaton.com/content/dam/eaton/products/medium-voltage-power-distribution-control-systems/line-installation-and-protective-equipment/elsg-full-range-current-limiting-fuse-catalog-ca132020en.pdf

*Hastings 40 Telescoping Hot Stick*. (2022, 10 27). Retrieved from Linesmenssupply: https://linemenssupply.com/products/hastings-40-telescopic-hot-stick-53-hv-240

*Journeyman Lineman OH Distribution in Multiple FL locations*. (2022, October 27). Retrieved from Indeed: https://www.indeed.com/viewjob?from=app-tracker-saved-appcard&hl=en&jk=b3245b0b6250140d&tk=1gg6j5laghvde802

Saul, M. (2009). *Short Term Memory.* Retrieved from Simply Psychology Organization: https://www.simplypsychology.org/short-term-memory.html#:~:text=Most%20adults%20can%20store%20between,which%20items%20could%20be%20stored