Sustainable UTV Final Report
IDD Fall 2021
Oklahoma State University

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2 INTRODUCTION

The purpose of this project was to take the existing design of the Sustainable Utility vehicle and modify components to improve efficiency and ease of use. The budget for this project was specified to be $10,000. To incorporate all redesign components specified by the mentor, the team divided into smaller sub teams to each tackle a portion of the project. There are four main sub teams that include the project management and human factors team, battery cart redesign team, solar cell lockout, speed measurement, and generator team, and the controller upgrade team. Each team’s design and problem description will be discussed in more detail in their respective sections.

The project management and human factor team oversaw, maintaining and organizing all project plans. This included obtaining updated schedules from each team and compiling them into a master schedule. Additionally, they also monitored resource use and task dependency to make sure to eliminate any potential uncertainty. This team also considered human factors and created an intuitive user interface design working with the controller team. The battery cart team redesigned and modified the original battery cart design to allow for dual exchange of batteries. These modifications created safer and faster battery exchanges that will in turn decrease UTV downtime. The solar cell lockout, speed measurement, and generator team has fixed the lockout mechanism for the solar panels and added a device to the vehicle to obtain and accurate speed measurement. This team also designed a solution to fix the problem with the generator running lean. The final team is using a Velocio controller to upgrade the original Arduino and Raspberry Pi setup. The upgraded controller allowed for automatic switching between the sub energy charging systems. The controller also allowed for upgrading the original UI display to a more user-friendly HMI display that will be designed by the human factors team.

Throughout the report each team will discuss the details of their designs and explain the key concepts behind them while providing supporting analysis. Each sub team will also discuss the testing that was conducted to measure the accuracy and validity of the designs. Included after each teams’ discussions of their designs we will discuss our detailed risk management plan that was created to mitigate risks associated with cost and schedule problems as well as potential safety risks to the operator. We will also include a discussion of our project plan and how it changed throughout the semester. The final section of our report will include an overview of all the costs involved. This section will include the detailed bill of materials for each sub team. The costs will include all the components that were needed to complete the fabrication and testing phases of the project.

3 PROJECT MANAGEMENT AND HUMAN FACTORS

3.1 PROBLEM DESCRIPTION

The overall goal of this project is to make modifications to the High Tech Sustainable UTV to increase functionality. The human factors and user interface team worked closely with the controller upgrade team to design a highly intuitive Human-Machine Interface (HMI) considering important human factors concepts. The primary goal of this design was to create a user-friendly display that communicated important information transmitted by the Velocio controller to the operator. Such information includes battery charge level, the vehicles tilt and pitch, solar panel information, as well as key information such as date and time. In addition to a user-friendly display, we wanted our design to increase ergonomic performance by changing the mounting location. When creating the design human factors principles such as the display of visual information, minimizing informational loading, and sizing for alphanumeric characters and labels were used. In addition, calculations for line of sight and reach were used to determine the best mounting location and orientation of the display. Calculations were done for the original location of the display from last semester. These were then compared to the optimal location calculations based on designing for the extremes. Finally, based on both the original and optimal calculations we determined the final mounting location for the HMI based on the restrictions of the UTV itself. Our biggest limitation for the design was the lack of available mounting locations in the UTV. Certain locations would have blocked functionality of the handbrake or blocked the driver's line of sight. These limitations are discussed further in our overall solution section.

3.2 OVERALL SOLUTION AND SUBSYSTEMS

3.2.1 New Mounting Location and Mounting Mechanism

The mounting location of the display is important for driver safety and ergonomics. We relocated the screen to reduce muscle strain and fatigue to the driver due to head movement. The improved mounting location will also reduce the amount the driver has to move their eyes off the road, improving safety, since they will be able to keep the road in their peripheral vision. While our final design is not optimal, it does represent an improvement to the original mounting location. We were limited by multiple practical constraints. One of our main limitations was the lack of available space on the dash for mounting. It is important for the UI not to block any of the buttons or functionality currently on the dash. Another important limitation was that the display could not be mounted in a manner that blocked the driver's view out of the front windshield. Finally, the dash does not have enough stability to support a display that is mounted too far above the dash because this could cause cracking of the dash over time.

In section 3.8 we will go into a detailed discussion of how we came to the final mounting location. We will discuss the original mounting location of the old UI and the optimal location for an HMI display. Here we will show the calculations for line of sight and reach for the new location of the HMI. In figure 1 below you can see the new mounting location that we chose for the HMI.

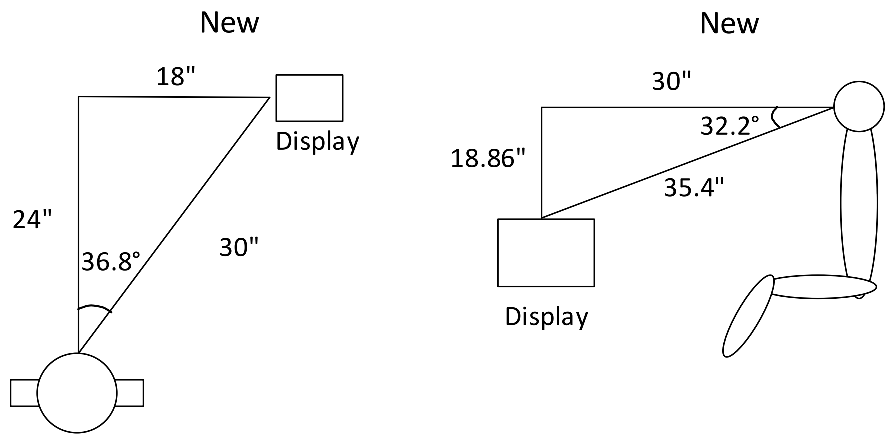


Figure 1: New HMI mounting location calculations

For the final location, we had to make several compromises for practicality. To get a 15-degree neck rotation angle, the display would obstruct the handbrake and part of the steering wheel the best angle we are able to achieve is 38 degrees. Since the interface will not be manipulated as much as it will be looked at, it is more important to have a smaller angle than for it to be closer. Having the display closer to the user would have required a long arm for it to be mounted to. We estimate that the display and its housing will weigh about 5 lbs. together, so we were worried that the moment that it creates would be enough to cause it to crack the plastic dashboard of the UTV over time. For the neck flexion angle, we were not able to mount it high enough to give an optimal angle. It would be too high off the dash, creating large moment, as well as blocking forward line of sight for shorter people. Our final position reduces neck twisting by 3 degrees, neck flexion by 4 degrees, and reach by about 2 inches. These measurements are taken in reference to the 95^{th} percentile male who will be taller than most of the population. This means that for the average person the neck flexion and rotation angles will be smaller and thus closer to the optimal range. This analysis represents the worst-case scenario for an operator of the UTV.

We were not able to mount the display as close to the operator as we had initially hoped due to the limited space on the dash. Additionally, the mount we ended up using would not be able to be adjusted if we mounted it in the optimal location due to the front screen of the UTV interfering with the adjustment knob. Having access to the adjustable knob will give the operator some flexibility to change the angle and height of the HMI screen. The new mounting location is shown in figure 2 below.

Figure 2: New mounting location

The mounting mechanism chosen for the HMI was a ball and socket mount from McMaster-Carr. The explanation behind why this option was picked and the analysis behind it is discussed next. The ball and socket mounting arm was attached to the dash using steel bolts and locknuts on the underside of the dash. The other side of the mount was attached to the display housing using the steel screws and nuts that came with the mounting ball. The adjustable arm that was chosen is 5 and 5/8 inches. We chose this arm length so that the HMI would have some clearance from the front screen of the UTV without being too far off the dash to avoid creating a large moment arm. Figure 3 below shows the mount attached to the dash and the HMI housing.

Figure 3: HMI housing and mount

3.2.2 Housing Design

The purpose of the box is to house the Velocio HMI display so that it could be mounted to an adjustable arm inside of the UTV. The manufacturer provides a data sheet that includes the dimension for the Velocio display being used. This was used to figure out the proper dimensions for the model of the mounting box. The front and back plates are aluminum sheets. The middle section was 3D printed using ABS plastic. To make the front and back plates we cut 16-gauge aluminum sheets into the shapes that we needed using the waterjet with the help of the NCL staff. The front and back plates were then attached to the 3D printed piece with a screw in each corner. The CAD drawings for the housing can be found in the human factors section of the appendix section 11.1.2

Using aluminum and plastic for the housing served two purposes. The first being that they are corrosion resistant. The previous display mounting box was constructed out of unfinished steel that was very corroded by the time we took over the project. The other purpose is that they are relatively lightweight compared to steel. The dashboard of the UTV is made from a thin plastic and since the display on its mount creates a moment on the dash, we needed the housing to be as light as possible to prevent cracking the dash. A rendering of the housing can be seen in figure 4.

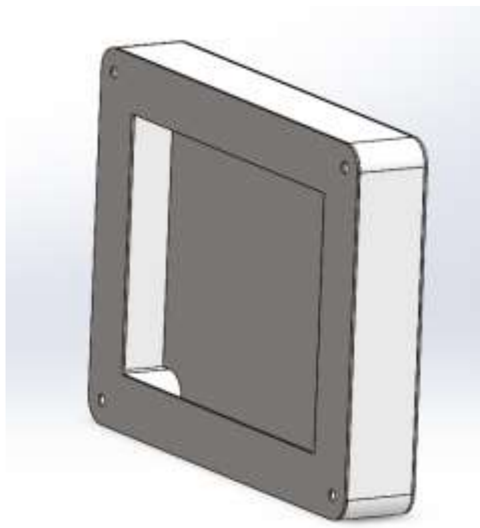


Figure 4: HMI housing model

Water ingress was a big concern that was considered when designing the box. The UTV will be outside, potentially in the elements, so the display and its connections needed to be protected from water to prevent damage. The front of the display has an IP65 rating (Command HMIs, n.d.), however the back of the display needs to be protected. The seams of the box were sealed with silicon. This will keep water from getting in from the front and sides. Since the bottom of the box is open to allow for access to the display's I/O, a piece of foam was cut to insert into the bottom of the display housing. This will prevent water from splashing up onto the I/O ports of the display. Due to the porosity of the surface of the 3D printed plastic, we spray painted the surface to seal it against water.

Mounting the display housing to the dash of the UTV was done using a ball-and-socket arm mount from McMaster-Carr as seen in figure 5. This will allow for the user to orient the display however they need.

Figure 5: A ball mount and socket arm from McMaster-Carr (McMaster-Carr, n.d.)

3.2.3 HMI Layout

The final HMI layout that we decided on is shown below in figure 6. We made some adjustments to the original design that is discussed in section 3.8.4. The home screen remained the same with only a few minor adjustments on text size. The second screen also had some adjustments made for text size. The main change is that we changed the range for our tilt sensors. Based on the information and calculations from last year's solar structure team we determined that the maximum tilt with the addition of the solar panels was approximately 36 degrees. This value was obtained from the Spring 2021 solar structure team's final report. We adjusted our scale to have a red box indicating that you are reaching the maximum tilt value and should take corrective action. The red boxes on the scale indicate where this limit starts for the operator and gives them a good visual indicator. The rest of the functionality has remained the same and is described further in section 3.8.4.

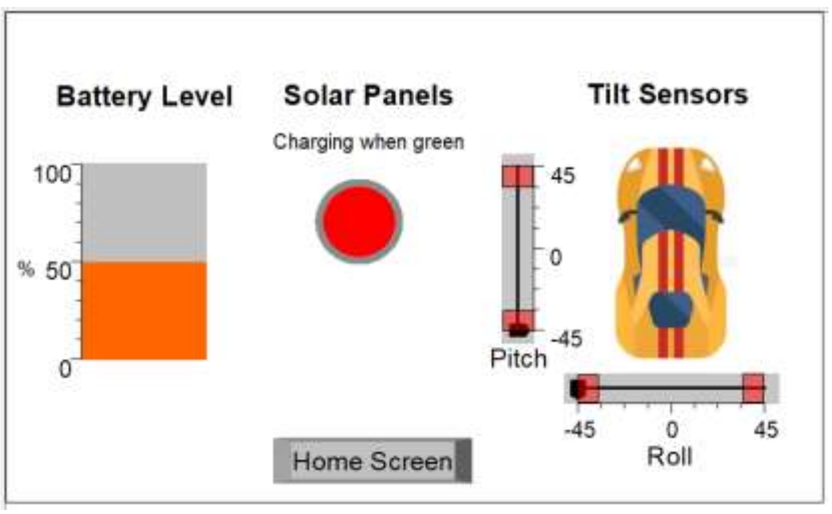


Figure 6: HMI information screen

3.2.4 Noise Exposure

The final solution to protect UTV users from noise exposure is to insulate the compartment under the seat with insulation. The surfaces insulated are between the compartment and the seat, as seen in figure 7. The other surface insulated is between the compartment and the footwell as seen in figure 8. In our testing section we will discuss the difference in noise level with and without insulation in the generator compartment.

Figure 7: Insulation between compartment and seat

Figure 8: Insulation between footwell and compartment

The insulation used is Micro-Aire duct board from Johns Manville. We are using this material because it has a relatively high service temperature at 250 degrees Fahrenheit, it is flame resistant, and it is inexpensive. Automotive sound insulation was also considered; however, it is hard to find in small quantities and it is expensive. The duct board will not melt like foam types of insulation, as it is fiberglass. This will help mitigate the risks discussed in section 3.8.5.

3.3 ENGINEERING PRINCIPLES

Computer-aided design: Use of SolidWorks to create hosing for the display. Created engineering drawings to help during fabrication phase for cutting aluminum sheets using the waterjet. Used to determine approximate weight of housing so that proper mounting mechanism cold be designed. Certain mounts we were looking at could not hold the weight of the display and housing without causing wear to the dash over time so knowing the exact weight was important.

Human factors design: Consideration of key human factors principles including vertical and horizontal line of sight, reach, intuitive display design, and designing for extremes. Reach and line of sight principles were used extensively when determining the proper mounting location for the HMI display. When designing the layout of the HMI we used principles of display design such as proper sizing of alphanumeric characters, color, and minimization of informational loading. Using these principles, we were able to design an intuitive display that would be easy for the operator to use and obtain information from without too much strain.

Manufacturing process: Used to determine proper fabrication methods for the HMI housing. Using the design made in SolidWorks different fabrication methods were evaluated such as bending and cutting sheet metal or using the waterjet. We also had to learn the basics of FDM

3D printing to manufacturing the center portion of our display housing. Understanding the different manufacturing methods available allowed us to create a better design. We considered several options for the housing design and for each of these we had to consider the different manufacturing methods that they would entail. This helped us come to our final design and manufacturing method.

Material science: Used to help determine best materials for HMI housing. Used principles of rust and corrosion to decide between steel and aluminum for the housing. We determined that using aluminum would help avoid the problem with rust even though it does have the potential to corrode. The materials of the center of the HMI housing were also an important choice. We decided to use ABS over PLA due to its superior qualities in durability. ABS is more durable and has better heat protection than PLA (*Pla vs ABS, n.d.*). It is also a better material for prototyping and creating functional parts because it is less rigid than PLA (*Pla vs ABS, n.d.*). Aluminum, steel, and plastic, in both billet and sheets for the metal, was evaluated for cost, ease of manufacturing, and weather resistance. The materials needed to be able to withstand the weight of the display and be weatherproof to protect the electronics and last for a long time.

3.4 EHS CONSIDERATIONS

COVID-19: It is important for us to make sure we are following all CDC and university guideline on COVID-19 to ensure the health of all members of the group. It is important to make sure that if team members are sick, they are staying home to avoid contact with other team members. This will require online communication from the members not there in person. We had several team members who had potential exposure. They made sure to test before coming to any meetings to avoid exposing other members. This was very important during detailed design because collaborations between all team members was important and in-person attendance to meetings was preferable.

Safety/Electrical safety: It is important to make sure that all team members are following NCL and Endeavor safety precautions. This is imperative during the fabrication and testing phases of the project. Proper PPE should be considered during each phase of fabrication and testing. Since the HMI will need to be hooked up to a power source electrical safety must also be considered. This will be especially important during the testing phase when energization of the entire system will occur. When hooking up the HMI display to the power source it is important for the team to recognize electrical precautions and make sure all connections are checked before any energization takes place.

Recycling old materials: Since we are using a new HMI display and designing a new housing for the display, we will need to recycle the old materials that are no longer being used. This will include recycling the old user interface display screen and its components. In addition, we will have to determine the proper methods for recycling the steel enclosure from the old design. Once replaced we will recycle the old materials in a way that is environmentally and ethically friendly. The new design does not include any waste, but this should be considered when the design is replaced in the future.

Ethical and professional: As engineering students we have the ethical obligation to uphold the reputation of the Industrial Engineering department as well as the reputation of Oklahoma State University. Having work checked before anything is energized or used is important to not damage any equipment or cause harm to any team members. Consulting teammates and professors during the detailed design phase was very important to make sure we were considering everything that we needed to. This was especially important when designing components that were out of our area of expertise.

3.5 ENGINEERING CODES AND STANDARDS

NIOSH Publication No. 98-126: This publication outlines a standard for noise exposure for workers (National Institute for Occupational Safety and Health, 1998). This standard is more restrictive than OSHA 1910.95 (noise exposure for workers) and reflects best practice. In relation to our project, we measured the sound level of the generator to determine the risk associated with its operation and suggested mitigations.

ISO 9241-112:2017: This standard outlines the principles of presentation of information when designing an interactive visual display. For the purposes of our project, we used this standard to design our visual display and determine the best possible layout of the information. We used this standard to guide us when determining what information was important to display and how that information needed to look. This was especially important since the operator would need to look at the display quickly and be able to understand everything they needed to. This meant making sure visual information was simple and easy to read (International Organization for Standardization 9241-112:2017, 2017).

ISO 6385:2016: This standard provides details on the principle in the design of work systems that we will be using in conjunction with ISO 9241-112:2017. We used this standard to understand the fundamental principles that are used in our design of the display. This standard helps to detail the optimal working conditions that were used when doing our calculations for the mounting location of the display (International Organization for Standardization 6385:2016, 2021). Working conditions were also considered in the display design in determining what background color and text color to use when considering the normal working conditions of the UTV. The health and safety of the operator was considered in our design with neck rotation and flexion. Continual neck flexion and rotation can cause worker fatigue and injury over time so using this standard helped guide our design to consider the safety of the operator.

ISO 1503:2008: This standard outlines the "principles, procedures, requirements and recommendations for the spatial orientation and direction of movement of controls and displays" (International Organization for Standardization 1503:2008, 2018). This standard, much like the one before, focuses on the safety of the operator and decreasing the possibility of making errors. In addition, it discusses improving the effectiveness and efficiency of the operator. It provides specific requirements to be used when designing GUIs and discusses the relationship between the human operator and the electronic display. This standard helped us understand how to design a display that would make the operator more efficient and effective when using it. If the display was not designed and mounted properly this would increase the number of errors the operator could potentially make.

3.6 Knowledge Acquisition

Fabrication Methods: We needed to obtain information on the best way to cut our material into the shapes that we needed for the housing we designed. We attended design Friday sessions to show our design and figure out how we would cut our aluminum sheets. We also received recommendations for materials to use for the housing to replace the current design. They recommended using aluminum over steel to avoid the possibility of rust forming. Printing the center portion in plastic was also recommended due to the size and complexity of it. We will continue to communicate with the NCL staff throughout the fabrication stage to make sure we are using the most efficient methods. Finally, our team also attended necessary trainings for fabrication such as sheet metal bending and welding. Our team will be assisting others where fabrication help is needed so it was important to be prepared.

HMI display design: Although we were familiar with human factors concepts for designing displays, we had to take some time to learn how the HMI software worked. To learn how to use the software we watched tutorials on the Velocio website and practiced using the software to create a mock display design to be used. Practicing with the software and watching the tutorials on the Velocio website helped us figure out how to use the software and create an effective design. We also worked with the controller team to better understand how the Velocio communicated with the HMI to use this when creating our design. We also had to collaborate with the controller team to determine what information the Velocio was capable of presenting. This allowed us to determine how we would present information such as battery level to the operator. Additionally, we consulted ergonomics textbooks used in our courses to make sure we were following proper principles for electronic display.

Noise exposure analysis: When analyzing the noise exposure of the generator our team had to become familiar with the measuring device used to detect sound level. Using the meter provided by an ergonomics professor from our department we were able to determine the noise exposure from the generator. Once we obtained that value, we had to determine how the noise exposure level obtained would affect the operator. This is where we had to do some research on proper noise exposure levels from OSHA and NIOSH. Both organizations present information on how long you can be around a sound of a certain decibel rating. Once we obtained this information, we were able to determine how long an operator of the UTV could be around the sound level obtained from the meter.

3.7 Concept Evaluation

During the preliminary design phase there were several different concepts that we were considering for the HMI mounting location. This is shown in figure 7 below. The first concept was using the old UI system and mounting location and trying to adjust it to get it functioning properly. However, due to the upgrade of the controller this option was not feasible as the old UI was not compatible with the new controller. The second concept we considered was upgrading the HMI to the Velocio compatible HMI but keeping the old mounting location. This concept was more feasible than the first as it provided us with a display that was compatible with the controller. However, it did pose issues with human factors much like the original UI. The final concept we considered was updating the UI to the new HMI display and adjusting the mounting location and mechanism. This improved human factors performance and was simple to use. We were able to create a design that was easy for the operator to access and read. Figure 9 below shows the different concepts we considered and their scores. In this matrix 1 is considered the best and 4 is considered poor. The option with the lowest overall score was used as the final concept.

	Old UI System and mounting location	New HMI system with updated mounting location	New HMI system with old mounting location
Health and Safety	1	1	1
Cost	1	3	2
Usability	3	1	2
Compatibilty with Velocio	4	1	1
Accessibility	3	2	2
UTV Modification	1	3	2
Human Factors Considerations (Line of sight and reach)	4	2	4
Team Opinion	3	1	2
Total	20	14	16

Figure 9: Concept decision matrix for HMI

The next two decision matrices we will discuss are the materials used for the HMI housing and the different concepts considered for the mounting mechanism this is shown in figure 10 below. Regarding the materials used for the housing we considered a sheet metal design, all 3D printed design and a combination of aluminum sheet metal and ABS plastic. The first method we determined would take too much fabrication time and because it was steel, we would need to coat the material to protect from the elements. This method was also going to cost more to purchase more sheet metal than the other options. We decided against using just ABS because although it was cost effective the 3D printing would have taken more time and probably would have required several iterations of printing. ABS is also not very UV resistant so we would have had to make sure every potion was covered in spray paint to make sure it would not break down over time (Giang, n.d.). The final concept we decided on was using a combination of aluminum and ABS here there would be less plastic to paint to avoid UV damage. We spray painted the ABS portion to help with UV resistance and painted the aluminum to give it some protection as well. Figure 5 below shows this decision matrix.

	All steel sheet metal	All ABS	Aluminum and ABS
Cost	3	1	2
Weather resistance	3	3	3
Ease of fabrcation	4	1	2
Time needed to fabricate	4	3	2
UV Resistance	1	3	2
Durability	1	3	2
Strength	1	3	2
Team opinion	3	2	1
Total	20	19	16

Figure 10: Concept decision matrix for housing

The final decision we had to make was the mounting mechanism and is shown in figure 11 below. We were deciding between mounting directly to the dash using a bracket like last semester, mounting using a long ball and socket arm, and finally mounting using a short ball and socket arm. Mounting directly to the dash had issues with line of sight and reach which will be discussed in detailed in the next section. This method also does not provide the operator with much adjustability. The long ball and socket arm had the potential for cracking the dash due to the long moment arm created by its length. The short ball and socket arm was ultimately chosen because of its adjustability and safety of the design. The shorter arm does not create as much of a moment arm and will not have the potential to crack the dash and become dislodged over time. Figure 6 below shows this decision matrix.

	Mount directly to the dash	Using long ball and socket arm	Using short ball and socket arm
Health and Safety	1	4	2
Cost	1	3	2
Usability	3	2	2
Moment created by arm	1	4	2
Accessibility	3	1	1
UTV Modification	1	2	2
Human Factors Considerations	4	1	2
Team Opinion	3	3	1
Total	17	20	14

Figure 11: Concept decision matrix for mount

3.8 Engineering and Other Analysis

3.8.1 Human Factors Design Considerations

The first key human factors concept we utilized in our design was optimum line of sight for the operator. According to Niebel and Freivalds the optimal viewing range is approximately 15 degrees below and above the normal line of sight (2014). Within this range head movement is not required and the chance of eye strain and fatigue for the operator is minimized. Based on the information in figure 12 below it is shown that frequently used displays should be in between 15 and 30 degrees below the horizontal line of sight and infrequently used display can be in between 30 and 45 degrees below the horizontal. This is similar for horizontal line of sight (turning your head side to side) shown in figure 13 below. 15 degrees from the center on either side of the origin is optimal and the maximum is 35 degrees. These concepts were considered when determining the optimal and final mounting location of the display.

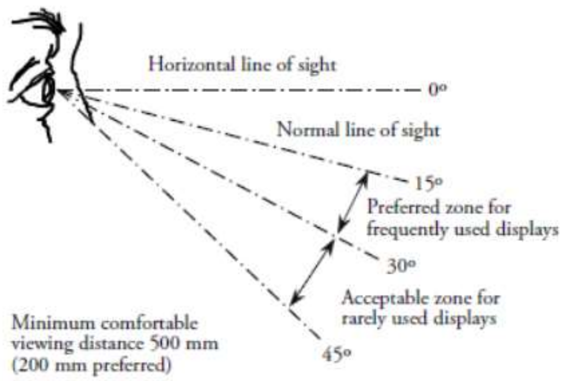


Figure 12: Vertical Field of View (Ross, 2011).

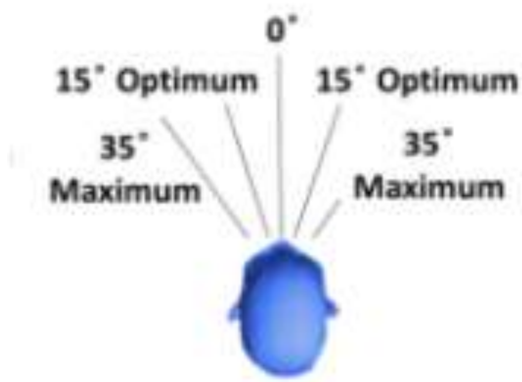


Figure 13: Horizontal Field of View (Ayoub, Hussein, & Elbashar, 2021).

Another key concept that was considered in our design was reach. According to Niebel and Freivalds "the greater the distance, the larger the muscular effort, control, and time" (2014). Therefore, it is important to have a design that minimizes reach and the distance from the operator to the device. The original location of the UI required reaching further than we wanted as reaching that far takes much more effort and can lead to fatigue over time and less control of movements. This factor was considered when determining where the display would be in relation to the operator for our new design. The image shown below taken from Niebel and Freivalds shows the normal and maximum working areas for a woman (2014). These measurements were considered in the calculations shown in the next section for vertical and horizontal line of sight. We used the maximum value of reach for the 5th percentile female to calculate our vertical line of sight as this would give us a measurement that would be able to be reached by most of the population.

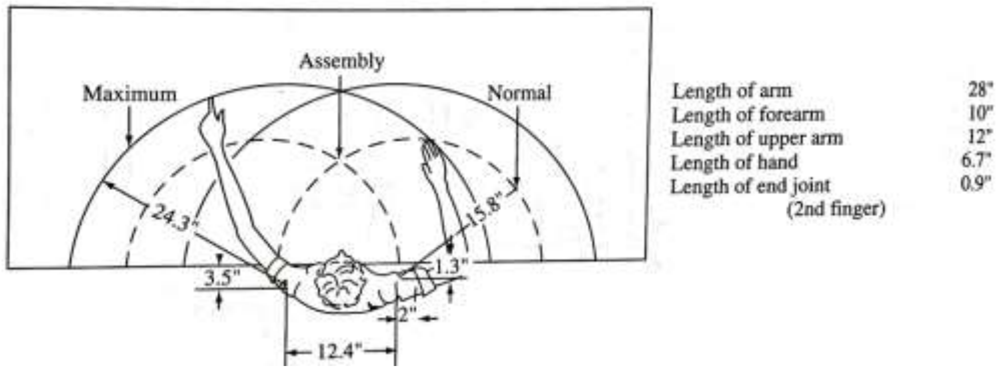


Figure 14: Normal and maximum working areas in the horizontal plan for women (Niebel and Freivalds, 2014).

The third key concept and one that is important for both line of sight and reach is designing for the extremes. For line of sight this means we did our locations for mounting the display based on a male in the 95th percentile. This is because most of the population will be able to see the display in the optimal range as they are shorter than the 95th percentile male. For reach we did the opposite and catered our design to a woman in the 5th percentile. This means that if a woman in the 5th percentile can reach the device than virtually anyone else can as well. This concept was considered in full when doing our calculations in the next section and our calculations for the final mounting location.

The fourth human factors concept that was used in our design is the design of cognitive work and display of visual information. We used these concepts in creating the layout of our visual display. One of the most important concepts to consider here was minimizing the amount of information presented to the user so they do not become overwhelmed (Niebel and Freivalds, 2014). Having a lot of information can increase the chance that the operator will make an error when reading the information. Using color on display and limiting the amount of text can help alleviate this problem (Niebel and Freivalds, 2014). The proper sizing of alphanumeric characters was important for us to consider when designing the layout of our display. According to Niebel and Freivalds in general when viewing from 20 inches away the font size should be at least 10 (2014). Other methods such as bolding and capital letters were included in our design. Simple screen design concepts are also presented by Niebel and Freivalds who explain that a user will first typically look to the top left corner of the screen and continue in a clockwise direction (2014). Simplicity and making it easier on the user are priorities for screen design.

The final human factors concept that was considered is noise exposure. According to Niebel and Freivalds noise is defined as “any unwanted sound” (2014). The measurement that is typically used to measure it is decibels. Being exposed to high intensities for long periods of time can lead to hearing impairment and even loss (Niebel and Freivalds, 2014). Noise can be very annoying and distracting to operators. In a working environment exposure to noise can not only cause injury but can decrease the efficiency of the worker and their ability to detect errors (Niebel and Freivalds, 2014). This concept is being considered for the noise level of the generator. If the noise level is higher than a certain threshold the operator will become less efficient especially when completing tasks such as analyzing the information presented on the display. The details of this test and designing a solution are further discussed in section 3.6.5. We will be using the sound level obtained from the generator to recommend the solution to decrease the decibel level experienced by the operator.

3.8.2 Mounting location and calculations

In this section we will be discussing the original and optimal mounting locations for the HMI display. This information was used to obtain the final mounting location that we discussed at the beginning in section 3.2.1. The original mounting location gave us a starting point for our calculations and then we were able to determine the optimal mounting location as well as the final mounting location. However, as discussed previously we had to mount the HMI in a less optimal position due to the limited space of the dash and potential moment that would be created from using a longer mounting arm. In CDR we had recommended a practical mounting location however, as discussed previously, we had to make some adjustments with the final mounting location that was seen at the beginning of this report. The practical mounting location had a neck flexion and neck rotation angle of 33 degrees and a distance from the display of 28.8 inches. Our new mounting location has a neck flexion angle of about 32 degrees, a neck rotation angle of 37 degrees, and a distance of 30 inches from the display.

Original location:

This layout is what was implemented by the Spring 2021 team. Figures 15 and 16 illustrate the location of the center of the display in relation to the eye position of a 95th percentile male, as defined by Gordon et. al (2014). A 95th percentile male represents the largest person that it would be designed for, as discussed previously in design of extremes. These measurements were developed using Kaiser as a reference model, and then generalized to the 95th percentile male to represent the worst-case scenario.

Figure 15: Original UI mounting location

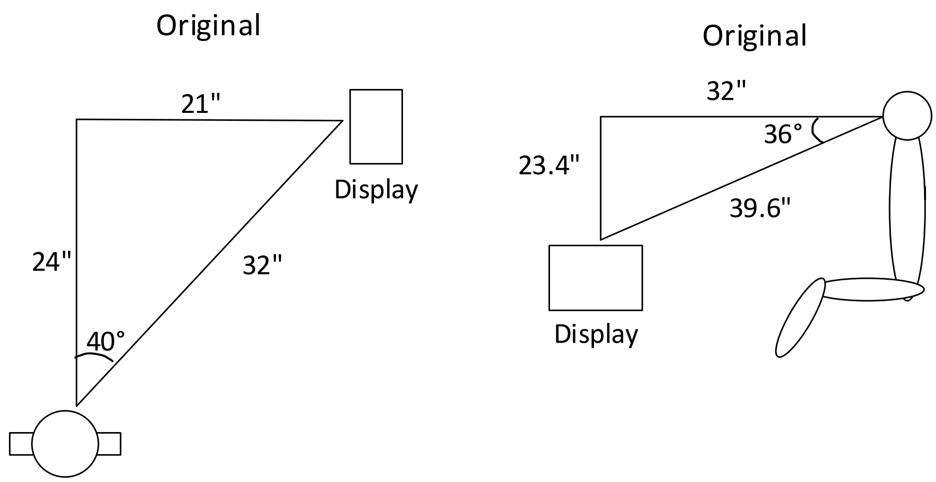


Figure 16: Line of sight calculations for original mounting location

The 95th percentile male has a sitting eye height of 33.86 inches. Based on our calculations, all people must rotate their head 40 degrees from their sagittal plane. For neck flexion (tilting the head down), the worst-case scenario has a flexion of 36 degree. This causes the driver to completely remove the road from their vision while they look at the display. This can also cause a lot of fatigue and potential neck injury if done frequently for long periods of time. Figure 5 above shows the diagrams for the calculations for neck flexion and neck rotation.

Optimal Position:

To improve the position of the display from the original, we first created a design that represents the optimal position of the display. Our goal was to require the driver had no more than 15 degrees of both neck flexion and rotation for the worst-case scenario. We also accounted for the grip reach of a 5th percentile woman; the standard smallest person used for general purpose designs. A 5th percentile woman has a reach of 24.53 inches (Gordon et. al., 2014). This represents the farthest distance the display should be from the driver. The following diagram shows the optimal position relative to the eyes of a 95th percentile male. Figure 17 shows the diagrams for the calculations for neck flexion and neck rotation.

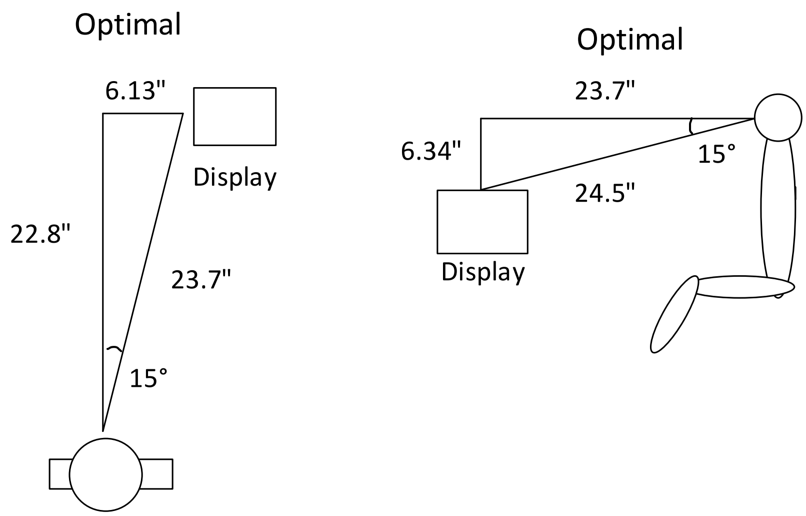


Figure 17: Calculations for optimal mounting location

3.8.3 Screen Housing Design

As we discussed previously in our overall solution section the housing was designed to contain the HMI display. We used aluminum and ABS plastic to construct the housing. Initially at CDR we had considered using PLA but after further analysis we determined that ABS was better suited for our application. As we mentioned in our engineering principles ABS is more durable than PLA and has better heat resistance (*Pla vs ABS, n.d.*). Because the UTV will be used outside we needed a material that would be able to withstand the elements while still being reasonable to manufacture. The aluminum plates were chosen as they will not rust over time as the original steel housing had. We spray painted both the aluminum and 3D printed portion to add an extra layer of protection from the sun as well as weather. Additionally, as we mentioned in our solution section it was important to protect the display from water ingress, so a silicon seal was applied to the areas between the aluminum sheets and the plastic portion. At the time of the critical design review, we had planned on using a gasket maker but after further discussion we determined that using silicon was the best method. The gasket maker would have made the solution permanent, and we wanted the operator to have the ability to take the housing apart if it was needed.

As we discussed in our concept evaluation section determining the mounting mechanism was very important for us. We considered several options but ultimately decided that using a short ball and socket mounting arm was the best solution. This solution gave us the best ergonomic improvement to the original design while maintaining the longevity of the dash of the UTV. A longer mounting arm could have caused cracking and damage to the dash over time. The ball and socket mount that we decided on was shown in our overall solution section. We had originally during the critical design review sourced a ball and socket mount from Ram Mounts but after receiving it we determined that it was too large to be mounted on the dash, so we went with the McMaster-Carr option instead as it was smaller and fit on the dash better.

3.8.4 Interface Layout and Design

The layout and design of the interface considered some of the main human factor's principles used in designing and intuitive user interface. The first important concept that was used in the layout design was font size of alphanumeric characters. This was determined based on the viewing distance from the operator. As mentioned previously, for operators who are sitting 20 inches away a minimum font size of 10 should be used (Niebel and Freivalds, 2014). For our design we made the font size slightly larger to allow for better visibility from a distance greater than 20 inches. Based on the new mounting location calculations section 3.21 the operator will be about 30 inches from the display, so we increased the font sizes proportionally. The fonts we used ranged from 16 to 24-point font. The parts of the display that are more important use the larger font sizes such as the titles and the percentage level on the battery scale. We also utilized bolded letters and a mix of upper and lowercase letters throughout or design and tried to make any text brief and meaningful. This is so the operator does not have to spend much time getting the information they need. Color was used to help draw distinction but was not overused to avoid cluttering the display. We wanted to make each set of information distinct from each other while keeping the display simple and easy to read.

Another important we considered in this design is how much information we are presenting to the user. It is important not to overwhelm the user with too much information on the screen or information that is not useful. Since the display will need to present information that the driver will need to analyze quickly, we had to make the screens as simple as we could and only display the most important information. Working with the controller team allowed us to determine what information we needed to display, and we had to determine how it would be presented to the operator in a meaningful way.

The information chosen was battery charge level, tilt information for roll and pitch, and information on the solar panels. For the battery level we used a simple bar graph with a scale on the side to show percentage. The voltage read by the Velocio controller will be converted into a percentage to be shown on the bar graph. For the tilt information we will be using a slider for both pitch and roll that will show the angle of each. This information will be obtained from the sensors and converted to a degree measurement from the Velocio. When the degree measurement is obtained, the slider will move giving a visual representation of the angle of the vehicle. Since the driver does not need to know the exact values of pitch and roll the visual gives them a representation of the approximate angle. This was adjusted slightly for the final design that we discussed in our overall solution section. The range for tilt was decreased to plus and minus 45 degrees instead of 90 based on the information we obtained from last semester's solar structures team. Finally, for the solar panels we will be using a bit lamp to show when the solar panels are charging. The lamp will be green when the solar panels are charging and red when they are not. This information will be sent to the Velocio from the solar panels and displayed to the operator on the HMI. This much like the battery and tilt sensor information gives the operator a visual representation of their solar panel data rather than providing them with voltage or amperage values.

Initial Display design:

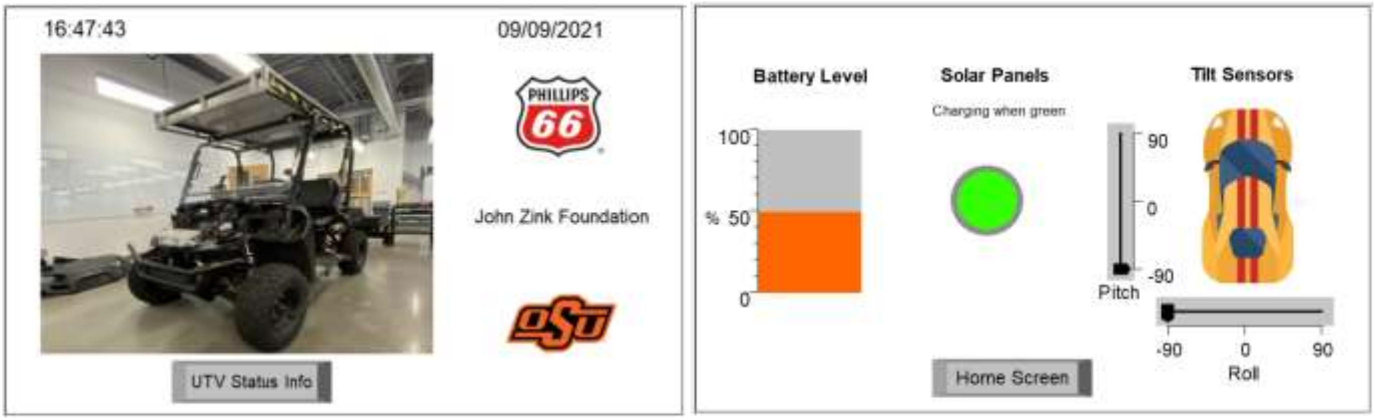


Figure 18: Display design

Since the UTV can navigate rugged terrain the design of the display had to account for this as well. We decided to go with a layout that has little operator input since if driving on rough terrain the driver will be prone to making errors when interacting with the display. Our display layout is catered to this idea and requires little input from the user to reduce potential mistakes. Taking this into account we needed to make the display be mostly visual based and ensure the operator can read the information quickly and efficiently. This also plays into the ability of people to process information. From a human factors perspective visual information is easier for the user to process than text based and is more meaningful in cases like ours.

3.8.5 Noise Exposure

Noise exposure is an important issue in the workplace. Overexposure can lead to hearing loss. NIOSH Publication No. 98-126 *Occupational Noise Exposure* recommends a limit for maximum exposure (1998). A 100% dose is 8 hours at 85 dBA. This is a time weighted average of all the noise levels and corresponding exposure times encountered throughout the day. The daily dose (*D*) is calculated using the following formula:

$$D = [C_1/T_1 + C_2/T_2 + C_n/T_n] \times 100$$

where

C_n = total time of exposure at a specified noise level

T_n = hazardous duration threshold.

The daily dose (*D*) must not exceed 100. The values for T_n can be calculated using the exposure level (*L*) with:

$$T(min) = \frac{480}{2^{(L-85)/3}}$$

Calculated values for T can be found in appendix 11.1.1. These values are used in the analysis later in this section.

The human ear is more sensitive to certain frequencies than others. Frequencies between the range of 2400 to 4800 Hz have a greater potential to cause damage to the ear than lower frequencies. (Niebel Freivalds, 2014). The A-weighted dB scale (dBA) assigns a different sound level (L) to the noise that takes this into account. This scale is used in noise exposure calculations to better capture the effect of noise on hearing. Figure 19 relates sound pressure level in dB and frequency to its corresponding level on the dBA scale.

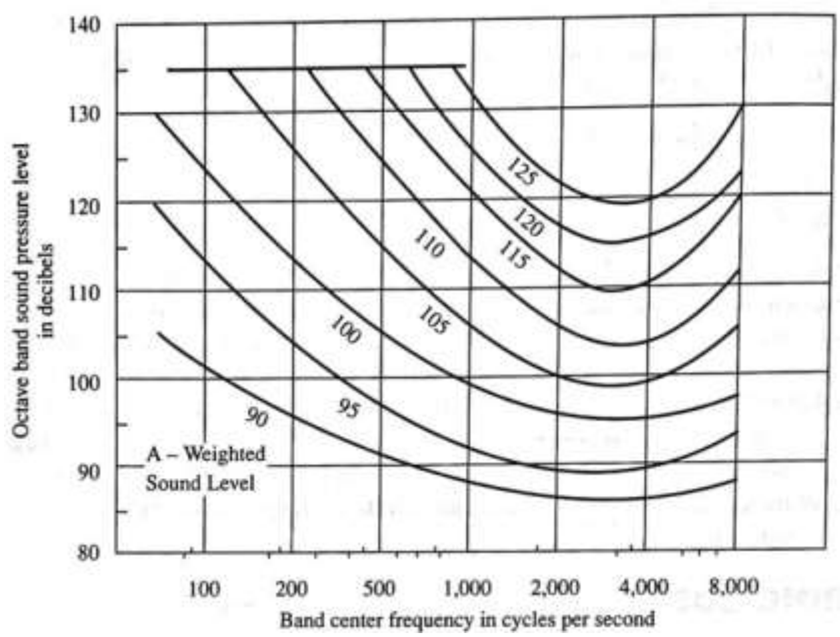


Figure 19: Equivalent sound level contours (Niebel and Freivalds, 2014)

We did a sound exposure analysis on the UTV generator to determine the risk in operating it and to make recommendations on exposure mitigations. Using a sound pressure meter, we measured the sound level outputted by the generator at 3 different areas of the UTV as seen in the table below. Since the noise level at the driver's seat was 86 dBA, we had to implement some sort of mitigation to prevent the operator from being overexposed during a shift. Using the formula above, a 100% dose of noise at 86 dBA occurs at about 6 hours and 20 minutes. Any sort of environmental noise or noise from other tools will compound with the output of the generator and has the potential to significantly shorten this time.

	Location

	Driver's Seat	Passenger's Seat	6 feet from passenger side
Noise level (dBA)	86	83	82

There are a couple of options that we considered to help mitigate the risks to prolonged sound exposure. The first option we considered was to require the operator to wear ear protection while the generator is in use. However, the risk associated with this option is compliance on the operator's behalf. The second option was to try to insulate the compartment that the generator is in to reduce the amount of sound being transmitted into the environment. This would avoid the compliance risk presented by the previous option, as the operator does not need to do anything. There are a few risks that this option presents, however. Since the generator is air cooled, the compartment that it is in has the potential to get very hot. As we mentioned when we discussed our solution of adding the duct board, we had to make sure the generator compartment would not overheat which is why we went with the type of insulation that we did.

3.9 TESTING PERFORMED

3.9.1 HMI Functionality

Testing for the HMI coincided with testing of both the controller and the generator. Because the controller reads information from all of the sensors checking the functionality of the HMI revolved around getting the UTV turned on and making sure the controller was reading proper values. During our testing we ran into several communication errors between the Velocio and the HMI that we will discuss in more detail at the end of this section. The main areas we needed to make sure were displaying properly were,

- Battery percentage level
- Solar panel charging light
- Tilt sensors

For the battery level we added a numerical display box that would show us if our voltage was reading correctly for the battery percentage. The controller team had the program running on the computer and hooked up to the Velocio to make sure the number showing up on the HMI matched what was appearing in the Velocio program. When testing the battery level, we did run into some issues. During testing we noticed that the value being read on the HMI did not match the value showing up in the Velocio program, this was due to mismatched datatypes between the code and what was on the HMI. The bar graph datatype should be set to 32-bit floating point, however, when we had initially begun testing, we had it set to a 16-bit unsigned integer. After this error was fixed the battery level was displaying properly. Additional testing revolved around determining the proper range that needed to be set for the battery level bar graph based on the voltage range of the batteries.

One thing we added to our HMI screen during the testing phase was a light showing the generator coming on. This was used for testing to make sure that the controller was automatically turning the generator on when the battery voltage/percentage dropped below the value specified by the controller team. Having the light come on allowed us to see when the controller had in fact turned the generator on. This was very similar to checking the functionality of the solar panel light. The controller team connected the Velocio to their computer via the USB cord and made sure that the solar panels were charging when they were supposed to and that the light came on for the operator. We also listened to the clicking of the relays to make sure they were switching when they were supposed to and opening the path from the solar panels to the battery.

Our initial tilt sensor testing was like the testing process used for the battery level in which we display number boxes to see if the values for pitch and roll appearing on the HMI were matching those showing up in the Velocio programming window. This confirmed that the data types we had for the tilt sensors on the HMI were correct. We than had to test to make sure they would work properly when the UTV was parked or drove on a slope. We tested the approximate angles while calibrating the tilt sensors and moving them back and forth to see the change in angle measurement. The values on the slider were changing in relation to the orientation of the sensors. Determining the range for the sliders was like the battery level bar graph in which we had to determine the voltage range of each tilt sensor to set the proper range on the sliders.

Throughout the testing process we encountered several errors with communication between the Velocio and the HMI. The table below shows the different errors we encountered during the testing phase. These errors occurred due to several reasons: address mismatch between Velocio code and HMI, data type mismatch, and wrong communication port. As these errors came up, we ran through our code and each component of the HMI to make sure everything was matching to ensure the proper flow of information from the Velocio to the HMI. Once we had determined the cause of each communication error, we conducted a full test to make sure there were no more issues.

Table 1: HMI comm errors

Communication Errors Received	
0x11	Local data-Real-time read-ECC Error
0x41	Local data-Real-time read-No data returned
0x71	Local data-Real-time read-wrong return length

Further testing that could be conducted would be to confirm the ability of the operator to read the information presented on the HMI quickly and efficiently. Most of our testing revolved around making sure the Velocio and HMI were communicating properly. We also wanted to make sure that the values showing up on the HMI screen corresponded to the values being read by the Velocio program. More testing should be conducted to make sure that the operator can accurately read the values being presented on the HMI.

3.9.2 Noise exposure

After installing the insulation in the UTV, we took the same measurements as before to determine the effectiveness of the solution. The results can be seen in the table below.

	Location

Noise Exposure (dBA)	Driver's Seat	Passenger's Seat	6 feet from passenger side
Without insulation	86	83	82
With insulation	82	80	80

These results were obtained using the same noise level meter with operator holding it at head level while in those positions. This is with only one person in the UTV. We found that having multiple people in the UTV further decreased the noise level, as the human body absorbs lots of noise, so we wanted to measure for the worst-case scenario. The max exposure time to the generator for the driver was increased from about 6.3 hours to 16 hours. This is much safer for the driver over an 8-hour workday.

3.10 Work Breakdown Overview

Maggie Goodin – Team Lead
Report:

- Human factors design considerations
- Knowledge acquisition
- EHS Considerations
- Codes and standards
- Interface layout and design
- HMI testing
- Problem description

Analysis:

- Assisted with human factors calculations for line of sight and reach for original, optimal, practical, and new mounting locations.
- Designed HMI layout and assisted controller team with testing of functionality.
- Human factors design considerations for line of sight and reach as well as the proper layout for the HMI.
- Assisted with mounting the HMI to the dash.

Kaiser Cleburn – Team Planner
Report:

- Mounting location and calculations
- Screen mounting box
- Noise exposure
- Noise exposure testing
- Project Plan

Analysis:

- Human factors calculations for line of sight and reach for original, optimal, practical, and new mounting locations.
- Noise exposure analysis, mitigation, and testing. Added insulation to UTV to reduce the noise level experienced by the operator.
- Determined proper mounting solution.
- Designed housing for HMI.

4 BATTERY CART TEAM

4.1 PROBLEM DESCRIPTION

The battery cart that last semester's team designed and fabricated works tremendously as a proof of concept and preliminary model. It allowed the user to transport a battery unit from the charging station to the UTV with relative ease. With this being said, there are some areas of the design that our team saw could be improved upon. Our main goals with the battery cart redesign were to: improve and ensure ease of user operation, ensure safe operation of the battery cart, and to ensure convenience of battery cart usage. Some of the main factors that we have considered with this redesign are weight, amount of UTV downtime, time required for battery interchanges, and overall safety within every aspect of our design. Some of the potential issues with our redesign come from: potential linear actuator failure leading to injuries, failure of rotating table leading to manual interchange of batteries, and failure of new latch system leading to potential battery unit movement while in the UTV.

Ultimate Question:
Will design modifications to the quick-change battery cart enhance safer, faster battery exchanges for charging and decreased UTV downtime?

4.2 OVERALL SOLUTION AND SUBSYSTEMS

Building on a great proof-of-concept, our team has utilized the existing cart design to enable safer, faster battery exchanges that increase UTV operability. The final design features upgrades to the battery cart for more robust terrain accessibility, user-friendly ergonomics with an electrically operated scissor lift, lighter materials, a more secure battery mounting system, and an upgraded tabletop that rotates to facilitate simultaneous battery module exchanges.

4.2.1 Overall Solution

Figure 20: Fall 2021 semester's completed battery cart.

The final product for the battery cart is the result of multiple design concepts, concept evaluations, detailed design and analysis for our chosen concept, and weeks of fabrication and testing to produce the overall solution used to enhance the existing cart in order to enable quick simultaneous battery module exchanges in a safe fashion in varying terrains. The realized product utilizes features that can be offered as solutions for the client's problems when operating the UTV, as improvements identified during the conceptual design phase, or a combination of both, where the cart was modified for more robust terrain accessibility, decreased battery downtime, and increased safety and reliability.

An electrically activated linear actuator was added to the cart to replace the existing hydraulic unit. The circuit was built on a simple series circuit model using a 12-volt direct current power source and operated by a momentary switch. Adding the actuator reduced weight, increased lifting capacity, and made the cart easier to operate for the user during battery module exchanges.

A rotating tabletop was implemented into the existing cart's design by replacing the single-framed battery tray with a circular HDPE and aluminum tabletop supported by a manufactured lockable rotating turntable. This design features rails to support both battery modules on the tabletop simultaneously, allowing for the user to load both battery modules onto the cart instead of having to make multiple trips for battery swapping.

All-terrain wheels were selected to replace the existing four-inch diameter slick plastic wheels in order to increase grip on varying terrains and to increase the cart's loading capacity. Casters were utilized at one end of the cart to enable a short turning radius similar to the original cart design so that maneuverability was maintained even with larger diameter wheels with increased grip on most surfaces.

Our final design utilized a range of materials including 1020 plain carbon steel, 3003 aluminum, and high-density polyethylene (HDPE) in order to decrease weight where possible, increase strength where necessary, or insulate the user from electricity. Rubber and polyethylene wheels were used for increased terrain access and safer grip. Lightweight steel square tubing was used for the modified frame and structural support and allowed for a stronger design with infinite life while also reducing weight from the original cart's plate steel. The rotating tabletop featured a combination of aluminum and HDPE to reduce weight, maintain support of the battery modules, and reduce the potential for electrical conductance.

4.2.2 Linear Actuator Subsystem

Figure 21: An electric linear actuator replaced the original hydraulic lifting system to increase ease of use and reduce weight.

The linear actuator and associated electrical circuit replaced the existing cart's hydraulic lift system that was previously used to operate the scissor lift during battery exchanges. The decision to modify this subsystem was based on concept evaluations during the preliminary design phase of the project where objective evaluations resulted in an electrically operated actuator that would reduce weight and enhance the user's ability to simultaneously exchange battery modules without requiring multiple trips to and from the UTV. This subsystem helped to resolve the larger problem involving multiple trips for UTV exchanges by allowing the user to more efficiently handle larger loads from multiple batteries with much less physical exertion. The modified lifting system reduces the overall cart's weight by an estimated 10 pounds and eliminates the physical requirements for the user to manually pump the lifting system. The updated system also allows loading capacities relevant for simultaneous loading of both battery modules.

The final design for this subsystem uses a Progressive Automations Model PA-17 actuator, a simple circuit using a Dakota LiFePO4 12 volt direct-current battery rated for 10 amp-hours, and a Progressive Automations momentary switch. The actuator features a dynamic loading capacity of 2000 pounds and a static capacity of 4000 pounds. As indicated by the testing phase of this project, the power source allows at least 15 minutes of continuous operation at loads greater than standard operating loads with minimal heat generation throughout the circuit or actuator. The momentary switch allows complete control of the scissor-lift operation by forcing the user to physically maintain force on the switch to close the circuit and power the actuator so that raising and lifting requires conscious effort and movement is fully deactivated whenever the switch is released. Wiring is rated at 10 gauge to handle the basic circuit configuration and wiring for the final design is completely insulated to avoid electrical hazards for the user. Wiring is routed conveniently to allow complete range of motion for the scissor-lift, and the switch is located on a modified platform on the cart's handle for ergonomic ease-of-use.

Using these designed systems for the cart's scissor-lift allows the user a convenient method to operate the cart for UTV battery module exchanges. The modified design enhances the previous cart's ability to handle the load of two battery modules, reduces physical exertion by the user, decreases the number of trips required to swap batteries, and reduces weight from the original design.

4.2.3 Rotating Tabletop Subsystem

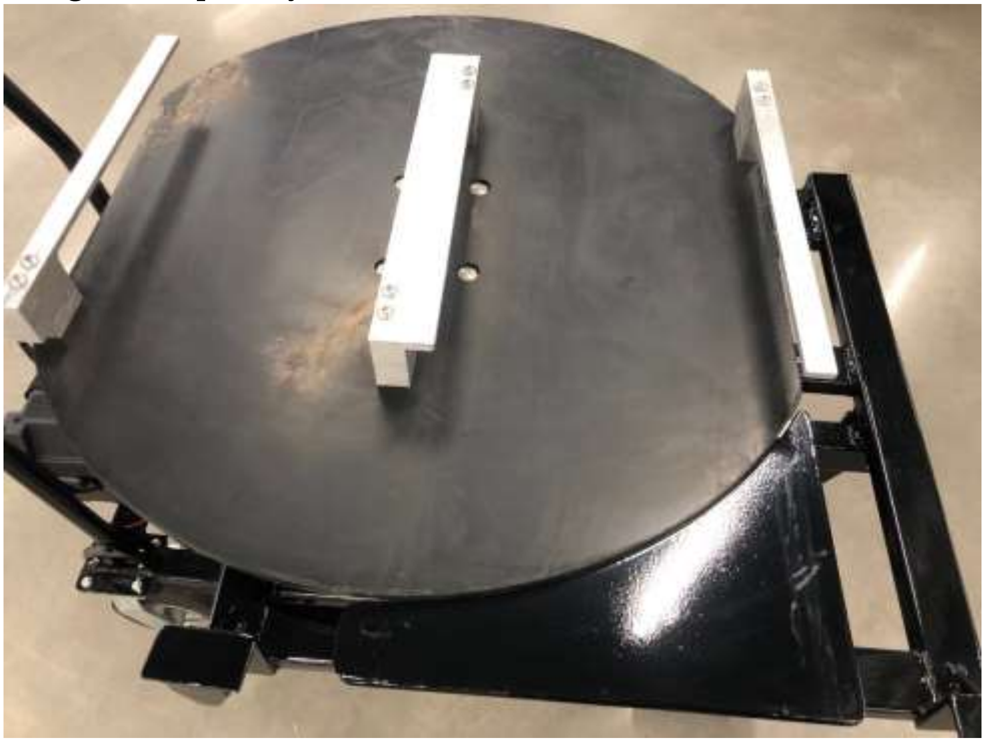


Figure 22: A rotating tabletop was added to the cart to enable simultaneous battery module exchanges.

The rotating tabletop system was modified from the stationary tabletop from the previous semester's design to allow for the transportation of two battery modules during a single trip for UTV battery exchanges. The decision to modify this subsystem was based on concept evaluations during the preliminary design phase of the project where objective evaluations resulted in a tabletop that allows transportation of two battery modules to avoid multiple trips for a battery module exchange. Additionally, safety and ease-of-use requirements resulted in the use of lighter materials, including updates from heavier steel to an aluminum base, and HDPE as the table's primary surface in order to reduce the potential for unwanted electrical conductance. The original docking system was used with modifications from the previous semester's design to allow for the rotating tabletop system to effectively align to the UTV to add and remove battery modules. In order to reduce weight and support the complete redesign of the tabletop, the existing cart's structural support system was completely redesigned with custom fabrication. Structural modifications include a design utilized lighter steel with square tubing to replace the previous design's plate-steel structural system, where the new design reduced weight by an estimated 20 pounds while maintaining infinite fatigue life. Due to the tabletop's complete redesign, a new rail system was also developed to support two battery modules. 3003 series aluminum was used to decrease weight while maintaining lateral stiffness in order to support battery modules and associated latches, and the rails were milled using university mills. The addition of the rotating turntable subsystem is crucial to resolve the client's issue demanding battery swaps for discharged UTV batteries by reducing the cart's weight, increasing battery module security, decreasing the potential for electrical conductance, and providing a robust platform to load two battery modules simultaneously for more efficient battery swaps.

The final design for this subsystem features a McMaster-Carr rotating turntable, a 3003 series aluminum base for the table's platform, a high-density polyethylene tabletop, 3003 series aluminum rails, and rubber latches to hold the battery modules during transport. The rotating turntable features zinc-plated steel for corrosion mitigation, a weight limit of 1500 pounds, and a locking mechanism that prevents rotation at 90-degree intervals. The table's aluminum and HDPE platforms were designed to deflection limits of 0.1" with complete operation within the elastic region of each material to allow for smooth transitions during battery module swaps to and from the UTV. CAD modeling with finite element analysis was used to develop these components, and university water jet cutting machines were used to cut the components from selected stock material. 3003 series aluminum rails were also developed using CAD and university mills were used to fabricate the final design from selected stock material. Rubber latches were selected based on the previous semester's design due to successful function.

Finally, designing and developing these components for the rotating tabletop was integral to the modification of the overall cart based on client expectations and the previous semester's design. The new rotating tabletop subsystem reduces weight, avoids electrical conductance, provides a stable and robust platform for dual battery module transport, and ultimately allows the user to safely transport two battery modules for UTV battery exchanges within a single trip.

4.2.4 All-terrain Wheels Subsystem

Figure 23: Larger diameter wheels with all-terrain tread patterns were added to increase terrain access during UTV battery exchanges.

The all-terrain wheels subsystem was modified from the cart's previous design of 4-inch diameter untreaded plastic wheels in order to enhance the user's ability to complete battery module exchanges on uneven and less-than-ideal terrains that are likely to be encountered during typical UTV operating conditions. The decision to modify this subsystem was based on concept evaluations during the preliminary design phase of the project where objective evaluations resulted in modifications to the existing cart's wheels to increase safety during adverse operating environments and to provide a stable, more robust platform for simultaneously loading two battery modules for battery exchanges. A similar design to the previous semester's cart was chosen for the front and rear axle systems, including a solid front axle and rotating casters for the rear wheels to allow the user to maintain control over the cart during UTV docking and general transportation. Structural modifications were required to support the larger diameter all-terrain wheels while maintaining an adequate range of motion for the cart's scissor-lift system and maintaining an appropriate turning radius.

For the wheel-axle-caster subsystem, the final design includes Rock N Roller Multi-Cart Stealth R-Trac wheels for the front of the cart, McMaster-Carr caster wheels for the rear, a solid steel front axle, and a modified steel square tubing structural system to support the casters at the rear of the cart. The front wheels are 8 inches in diameter with a 2-inch width and feature rubber tread with a solid cross section to prevent flats. The front wheels are capable of supporting a 300-pound load. The rear caster wheels feature plated steel casters capable of 360 degrees of rotation in order to maintain a user-friendly turning radius and adequate control for heavy loading conditions. The rear caster assemblies feature rubber tread with a solid cross section to prevent flats and are capable of supporting a 300-pound load. The existing cart's frame was modified to fit the solid steel front axle that supports the symmetrical wheel hubs and maintains the cart's original range of motion with increased wheel diameter. Square steel tubing rails were used to extend the rear of the cart in order to support the modified all-terrain caster wheels and to maintain complete rotation of the casters. The support system was also thoughtfully developed to maintain the cart's original range of motion with the added caster height and increase in wheel diameter.

Selecting these components and designing the modified structure for the all-terrain wheels subsystem allows the user to effectively operate the cart in a variety of terrain conditions with increased safety and stability. Designing the cart to feature all-terrain capability to match the typical operating environments for the UTV was necessary to complete efficient battery module exchanges, and the modified design allows the user the advantage of increased diameter wheels with more aggressive flat-free tread patterns to enhance the cart's capabilities. Finally, even with modifying the wheels to feature larger diameters and all-terrain treads, the structural modifications maintain the cart's original turning radius and range of motion in order to successfully complete UTV docking and battery exchanges.

4.2.5 Scissor Lift, Frame, and Updated Materials Subsystems

Figure 24: The existing cart's frame and structural support system was modified as necessary to increase strength and reduce weight.

The cart's frame, scissor-lift system, and materials were modified to support user requirements, added or modified components and subsystems, and to optimize the strength and weight of the cart to support simultaneous battery module loads. The decision to modify these subsystems was based on concept evaluations during the preliminary design phase of the project where objective evaluations resulted in structural modifications to reduce weight and increase strength. Modifications to these subsystems were also often necessitated by modifications to other subsystems, such as adding the linear actuator that also forced basic modifications to the scissor-lift to adopt the actuator's mounting system. Frame modifications include modifications to the existing cart's frame to support the rear caster wheels and front axle and complete design and development of a structural system to support the rotating tabletop design. Modifications to the scissor-lift include redesign of the guiderails used to support scissor-lift movements and redesigning mounting systems and locations to attach the linear actuator. Material modifications include optimizing steel systems to reduce weight and add strength, considering aluminum and

HDPE materials where necessary to reduce weight or avoid electrical conductance, and coating systems to prevent corrosion and insulate metals present in the cart.

The final design for the cart's structural support system utilizes square steel tubing to reduce weight and increase strength relative to the original cart's thick plate steel. Square steel tubing was used for the redesigned structure used to hold and support the rotating tabletop and fabrication was completed using university equipment. Square steel tubing was also used for modifications to the cart's rear subframe used to support the selected caster wheel assemblies. 1020 plain carbon square steel tubing was chosen for these structural systems based on the material's mechanical properties that allowed weight reduction while also maintaining strength relative to lighter aluminum alloys. This material was also readily available commercially and was relatively inexpensive compared to other steel alloys with similar mechanical properties. 3003 series aluminum was used for the rotating turntable's base platform and this material was chosen to reduce weight compared to steel while maintaining adequate deflection and stress limits required to support battery module loads. High-density polyethylene was also selected for the rotating turntable's primary platform and this material was selected based on mechanical properties that met reasonable deflection limits while also reducing weight substantially compared to metal alternatives and providing electrical insulation. Frame and scissor-lift attachment points for the linear actuator were modified using plates designed in CAD and cut using the university's water jet machine. 1020 plain carbon steel was also used for these modified attachments, including modified pins. Materials for these modifications were chosen based on weldability and mechanical properties that allowed the attachments to maintain adequate structural integrity under stress from large actuator loads throughout the scissor-lift's range of motion. Finally, powder coating was used after the completion of cart fabrication and assembly to protect steel components from corrosion.

Generally, design considerations and modifications to the cart's scissor-lift, frame, and materials were chosen based on early concept evaluations, modifications required by other subsystems, and practical fabrication limits. The modifications enhance the cart's ability to perform UTV battery exchanges by increasing structural integrity and strength, reducing weight, and providing electrical insulation.

4.2.6 Final CAD Drawings

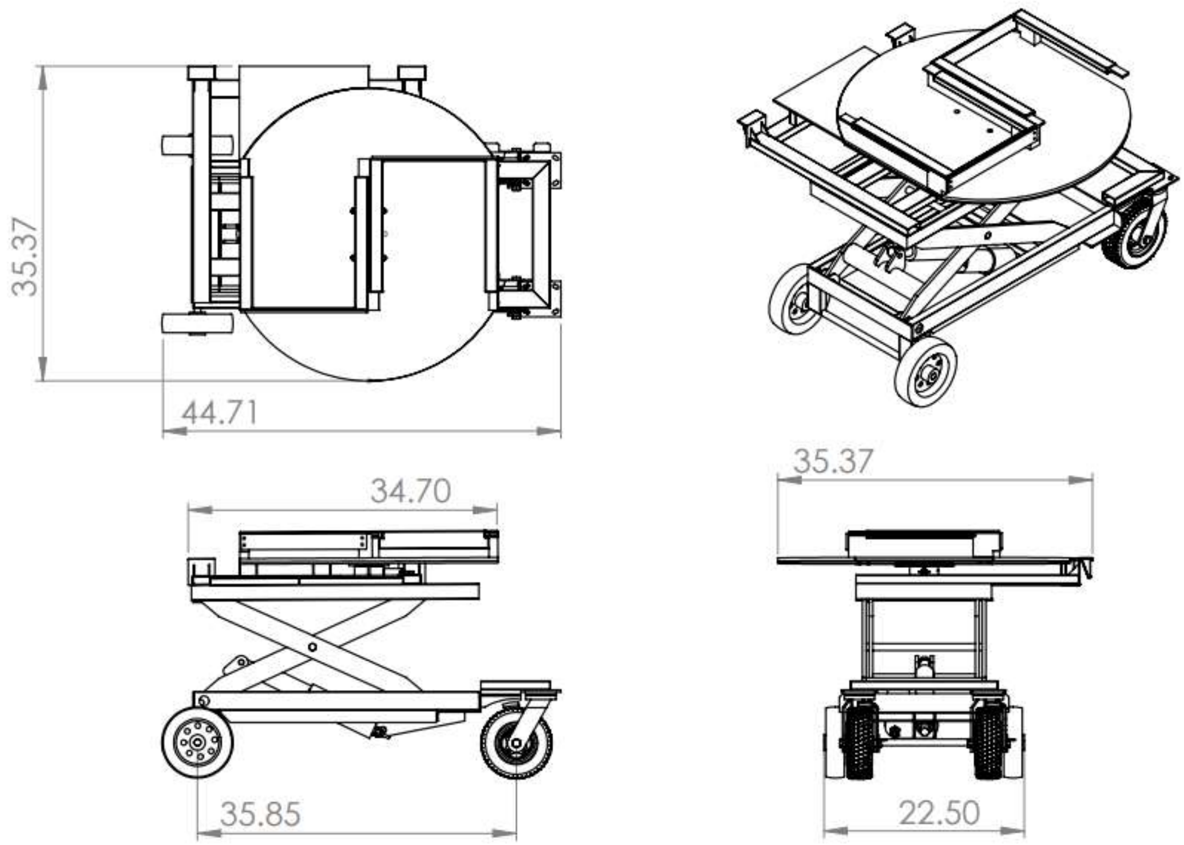


Figure 25: General dimensions for the final cart design after Fall 2021 modifications.

Final CAD drawings were developed during the detailed design phase of the project for use in analysis, material and component selection, and the development of detailed drawings for fabrication. Figure 25 shows the general dimensions for the cart's final design realized during fabrication. Appendix 11.2 includes detailed drawings and CAD models for the final design including general dimensions and detailed drawings and CAD models for specific subsystems.

4.3 ENGINEERING PRINCIPLES

Static and Dynamic Loading: Determining the load forces applied to the cart as well as their exact locations. This helped us determine the loads that our linear actuator, casters, and tabletop will need to withstand and/or support.

Fatigue and Stress Analysis: Determining the stresses at critical locations on the battery cart such as the pins, as well as the estimated life of critical components of our design such as the casters. This made sure that pins we have selected to use have adequate material properties and sizing to support certain shear stress. Also, it has helped us ensure that our frame will be able to support the max stress that it will ever be subjected to.

Factor of Safety: Ensuring the safety of every subcomponent of our proposed design as well as our overall design, as well as ensuring that they will be able to withstand all terrains. A specific example of how this has been utilized in our design phase is shown in how we made sure to abide by certain codes and standards. As discussed later, one of the codes that our design needed to abide by is ANSI MH29.1. This code has certain factors of safety that different classes of materials need to abide by. With this being said, we calculated factors of safety for different components in our design that utilize different materials and ensured that they are well above any of the factors of safety set by ANSI MH29.1.

Materials Science: Determining the effectiveness, advantages, and viability of HDPE and/or aluminum alloys. Allowed us to use the knowledge of material properties in various calculations such as deformation, fatigue stress, and weldment analysis. More specifically, this allowed us to figure out different areas that we can sacrifice material strength properties of steel to save weight for the design by using aluminum or HDPE. This will make the design more operator friendly overall.

Manufacturing Processes: Determining what fabrication methods need to be utilized to complete our design safely and efficiently. Understanding the complexities of milling, welding, and grinding to better define our achievable scope of work within our timeframe. A better understanding of manufacturing processes also allowed us to select materials that will be easier to work with. This includes choosing to work with steel instead of HDPE or aluminum because of the challenges of fabricating HDPE, or welding with aluminum. With that being said, we have investigated outsourcing fabrication of HDPE/aluminum because the price is justified with the material advantage.

Electrical Circuits: Determining the wiring and layout of our linear actuator lift system, as well as the battery connections while in the UTV. This has helped us ensure that our linear actuator lift system will not be too complicated to wire, which will lead to quick and seamless maintenance by the operator. It has also helped us determine the configuration of charging for the battery that will power the linear actuator.

Bolt and Pin Analysis: Determining the correct sizes and materials for our bolts and pins to ensure that they will be able to handle our loading conditions. This has allowed us to ensure that we have determined and located the correct number of bolts for our entire proposed design. Using this in conjunction with stress analyses has also allowed us to determine the correct size and material for the bolts and pins used in our linear actuator.

Deformation and Deflection: Determining if HDPE and/or aluminum will be a viable material to use in our design by determining if it will deform and deflect excessive amounts under certain loading conditions. Using this in conjunction with finite element analysis, we were able to identify the location on the rotating table that would deflect the most, and to see if any would deflect more than the max of 0.1”.

Weldment Analysis: Determining the configurations that we will need for weldments to ensure adequate torsional strength for our loading conditions. This also allowed us to determine the number of welds we will need for different components of our design. Most importantly, this allowed us to determine the amount of shear and axial stress that our structural support frame and linear actuator frame would be subjected to. This allowed us to ensure that we abided by the AWS/AISC weldment codes and standards.

Computer-Aided Design: Utilizing SolidWorks for visual representations of our proposed design to ensure proper sizing and assembly. This allowed us to display our final design proposal to our stakeholders, as well as determine clearances and mating locations for different components within our design.

4.4 EHS Considerations

Lithium-Ion Batteries: The lithium-ion batteries that we are using for our proposed design will require to be recycled back into the environment at the end of their life cycle (3-6 years). These will need to be taken to a certified battery electronic recycler, such as the Oklahoma State University EHS Department, to ensure that they are disposed of properly and safely. Additionally, if they are chosen to be recycled through OSU, they will need to follow the Oklahoma State University battery disposal guide (link found in reference list). With the difficulty of extinguishing a lithium-ion fire, we have designed the box that they are contained in to contain the fire to prevent it spreading to the rest of the vehicle, or the surrounding environment.

Toxic Vapors: With potential coating of certain elements to reduce the risk of electric discharge, the people in charge of the application will need to employ the use of respirators to ensure they do not inhale toxic chemicals. With this in mind, we have composed a design that limits the number of areas that will need to have protective coating applied. The only component in our design that will need to be coated will be the battery box.

Welding and Fabrication Safety: Since our design will require significant amounts of fabrication, we need to ensure that we are following correct safety protocols. These include things such as making sure you have the right welding helmet, gloves, and are wearing cotton clothing. With this danger, we have ensured (with NCL staff) that our design will be safe and straightforward to fabricate and weld. We have also ensured that our team members have obtained training and certifications to safely operate the fabrication machinery.

Old Materials: With the new design, a lot of material used in the old design will need to be disposed of. This will require proper recycling methods for steel, rubber, hydraulic fluid, etc. With this being said, we will ensure that we properly dispose of the scrap metal from the fabrication phase at scrap metal yards where they will be composed into new pieces of metal. We will also check with the NCL staff to see if there is potential for use of this scrap material for future/current projects going on at the university.

COVID-19: Ensure that every team member is practicing safe health practices to avoid COVID cases within the team. These practices include things such as: working from home, communicating with the team, and informing the university when you are feeling sick.

4.5 Engineering Codes and Standards

OSHA 1910.136: Relates to the use of proper footwear when working in areas where there is a danger for foot injuries related to rolling objects, sharp objects, etc (Occupational Safety and Health Administration 1910.136, n.d.). In regard to our project this will factor in when working anywhere near the battery cart, since it has the capacity to roll. We have abided by this standard by ensuring that we require proper footwear in the SOP for the battery cart. We also tried to reduce the weight in certain areas of the cart to mitigate the damage that could be caused due to someone having their foot rolled over by the cart.

OSHA 1910.138: Relates to the use of proper hand protection equipment when in the presence of environments that can lead to hand absorption of chemicals, severe cuts or lacerations, severe compression, etc (Occupational Safety and Health Administration 1910.138, n.d.). This factors into our design for anyone working near the battery cart since it has various pinch areas that can severely injure hands. To abide by this standard, we have also included proper hand protection usage in the SOP. We also plan to implement a rubber stop system on the rails of the scissor lift to ensure that it cannot fully retract, which will ensure that no one’s appendages can be pinched. Finally, we have also made sure to properly label no hand zones on the cart to ensure that people do not put their hands in areas prone to pinching hazards.

OSHA 1926.441: Relates to the use of batteries and battery equipment (Occupational Safety and Health Administration 1926.441, n.d.). Details the proper storage methods for batteries as well as how surfaces that the batteries traverse will need to be equipped. Ensures that anyone moving the battery cart while batteries are loaded onto it has surveyed the area and removed any impedances. This makes sure that there is no chance for batteries to experience electrical discharge onto surfaces that will come into contact with operators. We abided by this standard by making sure to include proper battery storage and handling methods in our SOP. This includes things such as making sure to keep the batteries in a dry environment and making sure that everything is disconnected before touching and batteries.

ISO 11228-2:2007: Relates to the ergonomics and factors that go into the adequate pushing and pulling methods for the whole body (ISO, n.d.). Ensures that operators of the battery cart are not straining their bodies while moving the battery cart to and from the UTV. To abide by this standard, our team strived to reduce the weight of the cart in any areas possible by using lighter materials. This will make operating the battery cart easier and reduce the risk of an operator straining themselves.

NFPA 70B: Relates to the proper maintenance techniques for electrical equipment (NFPA 70B, n.d.). Ensures that the batteries themselves will have an adequate life cycle and will not become a potential hazard from improper storage procedures. Again, to abide by this standard, our team made sure to include in the SOP how to properly store the batteries when they are not in use. This will ensure that they will not deteriorate and potentially become a fire hazard.

NFPA 70E: Relates to the proper and safe work practices when handling or working with electrical energy (NFPA 70E, n.d.). This will ensure that anyone working with the batteries themselves will not be exposed to electrical shock and/or harmful chemicals. To abide by this standard, our team has selected to use non-conducting materials in the areas that have direct contact with batteries, as well as using insulated wire and contacts.

ANSI MH29.1: Relates to the safe use and practices revolving around handling or working around scissor lifts (ANSI MH29,1, 2021). The standard provides a minimum design and performance criteria to ensure the safe application and utilization of industrial scissor lifts. The first way that we are following this standard, is with the Section 4.5, which covers stability. To abide by this, we have ensured that our design is safe from tipping hazards for use on any slope up to 35 degrees if operated by the recommendations of the established SOP. The next way we are following this standard is with Section 4.9, which covers control systems. The more detailed section that we will follow is Section 4.9.1, which says that the lifting control must: make the scissor lift operate when pressed, make the scissor lift stop when released, have clear direction and function distinction, be protected from inadvertent operation, and be readily accessible to the operator when released. Our design conforms to this section by having an up and down switch attached to the handlebar of the cart. This switch will move the cart based upon which arrow you press and hold. It will also not keep moving after you release the switch. Finally, the engaging method that our cart uses with the UTV/charging station will ensure that there is no chance for inadvertent operation. Lastly, our design conforms to this code through Section 4.10.1.1, which relates to mechanical system overload protection. This section says that any mechanical lifting system must be rated for the max forces encountered during lifting and have a safety factor of at least 3:1. Through careful calculations, we have determined that our linear actuator system has a safety factor of 4.51, which is above that set by this section.

AWS/AISC: Relates to the proper welding standards for measurements and mechanical properties (AWS 5.1, n.d. and Specifications for structural steel, 2016). These codes ensured the design strength for critical weldments in the cart's structure and linear actuator attachment points. This standard also sets out regulations for criteria regarding the welding equipment itself. To abide by this, we have ensured that the welding materials provided by the NCL satisfy these criteria. To satisfy the weldment length requirements, we have calculated that our nominal allowable shear and axial stresses are below the actual stresses our welds will experience when using the limited weld lengths given. Using Section 2.2b in the standard, we found the limitations for these allowable stresses to be that the size of our weldments must not be greater than the thickness of our material. When using these criteria to determine our weldment dimensions, we found that the actual shear and axial stresses out weldments would experience will be 3.5 and 17.3% of our allowable stresses respectively.

4.6 KNOWLEDGE ACQUISITION

Fabrication Methods: Our new proposed design will require a great deal of fabrication such as welding of different members and grinding of the current tabletop. This means that our team needed to make sure that we take all the trainings provided by the NCL to not run into issues once the fabrication phase begins. With the amount and variation of fabrication we require, it is vital that we run smoothly and efficiently. Our team has successfully completed all the trainings that we have set forth to complete the fabrication of our design. These trainings include welding, sheet metal, and green badge (lathe and mill training). We have also learned of methods to utilize the waterjet machinery provided by the NCL. Design Friday meetings with DML/NCL staff have guided manufacturing-related design decisions and provided the team with the knowledge and methods appropriate for utilizing campus facilities where practical. We have also received quotes about outsourcing some fabrication of more complicated components of our design.

Welding Techniques: The fabrication of our design requires weldments for many of the structures. Therefore, members of our team attended the NCL Welding training to learn about MIG welding, as well as ensured that the NCL was equipped for all forms of welding such as TIG and stick welding in the event that one technique was more suitable than another. The NCL staff assured our team that they would be available for advisement on fabrication methods to ensure safe and secure construction.

Project Planning: Project planning utilized Microsoft Project to create detailed Gantt charts with sub team-specific tasks and project goals and milestone. MS Project also allowed the team to track weekly progress and update goals and plans for project meetings. Required knowledge gaps include the ability to learn and utilize the Project software as the semester progressed which involved self-learning, online tutorials, and practice.

Linear Actuator and Wiring Setup: Linear actuator research was required to fulfill knowledge gaps surrounding loading conditions, circuit design, and power sources appropriate for the cart's design. Research was conducted with considerations to the static and dynamic loading capacities for various linear actuators and knowledge was obtained through discussions with manufacturers when necessary. Design specific questions such as actuator and motor orientations, appropriate stroke and body lengths for the multiple actuators considered for our final design, power sources, and switching mechanisms were also researched through technical discussions with manufacturers, researching data sheets, and verifying product specifications.

Weldment and Bolt Shear Calculations: Our proposed design requires the use of weldments, bolts, and pins in critical design locations so that it was necessary to understand the strengths, stresses, loading conditions, and material specifications for these design components. To accomplish this, we have referenced *Shigley's Mechanical Engineering Design, Eleventh Edition* (Budynas, 2021) textbook to check the calculations for different configurations of weldments, bolts, and pins that we have included in our design.

4.7 CONCEPT EVALUATION

At the beginning of the design phase, the team constructed different concepts that could potentially benefit the functionality of the battery cart. Each concept differed from each other in certain ways, which brought about advantages and disadvantages for each concept. These advantages and disadvantages were weighted and compared against each other to determine which concept would provide the best improvement in functionality of the battery cart, while still keeping EHS considerations at the forefront. These comparisons were carried out through the use of different evaluation matrices that are shown below.

Concept 1: The first concept that the team considered was using the cart as previously designed last semester. This was a considered design concept due to the fact that the previous battery cart worked fundamentally for what it was designed for originally.

Concept 2: The second concept that the team proposed involved redesigning some of the key aspects of the current cart. Some of those redesigns were replacing the flat caster wheels with all terrain wheels, coating the cart for electrical insulation considerations, and converting the cart from a steel construction to an aluminum composition. This design also would still utilize the previous hydraulic lift system in the cart.

Concept 3: The third concept considered by the team involved much of the same redesigns as in concept 2. The main difference of this concept is that the cart would still be composed of steel. This concept would also still utilize the previous hydraulic lift system in the cart.

Concept 4: The final concept that was proposed by the team was to add all of the previous redesigns mentioned in the previous two proposed concepts, but with some key additions. First, the cart would be extended to be able to transport two battery units instead of one. Second, the tabletop that the battery boxes would sit on would have the ability to rotate 180° in both directions. The tabletop would be composed of an upper layer made of HDPE with a supporting bottom layer composed of aluminum. Finally, this concept involved replacing the previous hydraulic lift system used with a 12V Li-Ion powered linear actuator.

Scale 1-4; 1 => greatest usability		Alternative #1	Alternative #2	Alternative #3	Alternative #4
Movement	Stability of cart loaded	3	2	2	1
	Stability of cart with battery module	3	2	2	1
	Cart weight	3	2	3	2
	Rolling over bumps/cracks	4	2	2	1
	Visibility while loaded	2	2	2	1
	Visibility while unloaded	2	2	2	1
Extracting Battery Module	Positioning cart at UTV	3	2	2	2
	Ease of raising cart to battery bay	3	3	3	1
	Speed of raising cart to battery bay unloaded	3	3	3	2
	Fine adjusting battery cart height	3	3	3	2
	Keeping cart in position	1	1	1	1
	Sliding battery module onto cart	3	2	2	1
	Speed of lowering cart loaded	1	1	1	1
	Speed of entire process	2.428571429	2.142857143	2.142857143	1.428571429
Ergonomics	Handle positioning	2	2	2	2
	Raising cart	3	3	3	1
	Lowering cart	2	2	2	2
	Locking battery module on cart	3	1	1	1
	Cart balance	3	3	3	2
Ease of Ownership	Portability (i.e., transporting to jobsite)	2	2	2	3
	Storage footprint	3	3	3	3
	Maintenance frequency	1	1	1	3
	Ease of maintenance	1	1	1	3
	Positioning cart with battery module onboard	3	2	2	1
Replacing Battery Module	Speed of raising cart to battery bay loaded	3	3	3	2
	Speed of lowering cart unloaded	2	2	2	3
	Sliding battery module off of cart	3	3	3	2
	Speed of entire process	2.666666667	2.666666667	2.666666667	2.333333333
	Total	**70.0952381**	**59.80952381**	**60.80952381**	**48.76190476**

Figure 26: Usefulness index for battery cart concept evaluations.

The first method of comparison for the team's proposed concepts was a usefulness index that would take each concept and evaluate them based on some of the key factors that contribute to the overall functionality of the battery cart. The table starts with concept 1 on the left and goes to concept 4 on the right. The first subcategory that the team deemed vital was the process of extracting a battery module. Across the board, concept 4 was deemed as the most useful in this subcategory, but most importantly in the category of keeping the cart in place during the extraction. The other three concepts would all require the user to unhook the cart and go back and forth to the charging station, while concept 4 allows the user to extract a battery module in one motion. The next subcategory evaluated was the ergonomics of the battery cart. This category was a lot closer between the four concepts, but the action of raising and lowering the cart was where concept 4 shined. With the new linear actuator lifting system, it took all factors of human exertion out of the equation, which will lead to a much more functional cart since more people can operate it. Next, the team evaluated the concepts for ease of ownership of the battery cart. This category involved things such as ease of storing the cart, portability, and maintenance. With the extension and addition of a rotating feature to the tabletop, it made concept 4 more difficult to transport due to it being heavier, and it also involved more components that could possibly require maintenance. Finally, the last subcategory evaluated was the process of replacing the battery module. This category was very uniform across all four concepts, but the speed of raising and lowering the cart while loaded was where concept 4 outperformed the other concepts. The linear actuator being able to raise and lower at relatively the same speed under heavy loads was what the team deemed as a factor that made concept 4 stand above.

Design 1 - No Cart Modifications					
Topic	**Benefit**	**(+)**	**Cost**	**(-)**	**Net**
Economic	No cost for Fall '21 project	1			1
Health			Bending, reaching for heavy loads	1	-1
			Hydralic fluid is a potential irritant	1	-1
Safety			Potential for electrical hazards and corrosion (no coating)	1	-1
Global					
Cultural					
Social					
Environmental	No new materials required	1	Potential for hydraulic fluid spills	1	0
			Total EHS score		-2

Design 2 - Aluminum Materials & Hydraulic Lift w/ Design Modifications					
Topic	**Benefit**	**(+)**	**Cost**	**(-)**	**Net**
Economic			Fall '21 project incurs additional cost	1	-1
Health	Lighter materials	1	Hydralic fluid is a potential irritant	1	0
Safety	Coating to provide electrical insulation	1			1
	Design for no pinch points	1			1
	All-terrain tires and wheels	1			1
Global					
Cultural					
Social					
Environmental			New materials required and old materials recycled	1	-1
			Potential for hydraulic fluid spills	1	-1
			Total EHS score		0

Design 3 - Current Steel & Hydraulic Lift w/ Design Modifications					
Topic	**Benefit**	**(+)**	**Cost**	**(-)**	**Net**
Economic			Fall '21 project incurs additional cost	1	-1
Health			Hydralic fluid is a potential irritant	1	-1
Safety	Coating to provide electrical insulation	1			1
	Reduce pinch points	1			1
	All-terrain tires and wheels	1			1
Global					
Cultural					
Social					
Environmental			Some new materials required and old materials recycled	1	-1
			Potential for hydraulic fluid spills	1	-1
			Total EHS score		-1

Design 4 - Linear Actuator (Electric) Lift w/ Rotating Battery Tray					
Topic	**Benefit**	**(+)**	**Cost**	**(-)**	**Net**
Economic			Fall '21 project incurs additional cost	1	-1
Health	Potential for lighter materials	1			1
	Better ergonomics for heavy loads/lifting	1			1
	No hydraulic fluid as a potential irritant	1			1
Safety	Coating for electrical insulation	1			1
	Reduce pinch points	1			1
	All-terrain tires and wheels	1			1
Global					
Cultural					
Social					
Environmental	No hydraulic fluid	1	New materials required and old materials recycled	1	0
			Additional battery for linear actuator must be recycled in the future	1	-1
			Total EHS score		4

Figure 27: Environmental, health, and safety ranking matrix for battery cart concept evaluations.

The next method of comparison between the concepts utilized an EHS ranking matrix that would evaluate each concept for how they affect the environment as well as health and safety of the operator. When looking at design concept 1, the only benefit that the team could see was the amount of money that would be saved from not modifying the previous cart. With that being said, there were numerous health and safety hazards associated with it keeping the previous team's design. The main hazard being the risk of electrical discharge due to the cart not having any protective coating applied to it. Design concept 2 was a lot more beneficial regarding health and safety due to the design upgrades such as the all-terrain wheels that make the cart easier to operate. The drawback with this concept was the fact that all the materials from the old cart would need to be disposed of, which would be harmful to the environment if not done correctly. Much like design concept 2, concept 3 would have been drastically safer to operate than the previous design. The drawback from this concept was the fact that the use of steel would involve the cart being a lot heavier which could lead to health and safety hazards when operating the cart. Finally, concept 4 has no health and safety hazards that the team could imagine due to the composition of materials and lifting system. The only drawbacks that this concept had were the additional cost that this design would require to be built and the fact that an additional 12V battery would need to be recycled at the end of its life cycle.

Potential Effects of Failure	Severity (out of 5)	Potential Causes / Mechanisms of Failure	Occurance (out of 5)	Current Design Controls Prevention	Detection (out of 5)	Risk Priority Number (out of 125)
Rails and/or batteries are slowly lowered	3	Weight capacity exceeded, fatigue / wear	1	Deflection analysis, fastener shear analysis, finite element analysis	5	15
Cart won't raise up	3		1		5	15
Arm gets stuck	4		1		5	20
Actuator won't engage to move cart up/down	4	Corroding wires, poor insulation, poor electrical contact	2	Ensure appropriate selection of actuator and motor, robust insulation, circuit inspections and maintenance for SOPs	3	24
Arm gets stuck	4		2		3	24
Electrical hazard	5		2		3	30
Cart rapidly falls	5	Fatigue / wear, wrong / faulty material	1	Deflection analysis, fastener shear analysis, finite element analysis	5	25
Pin impacts user	5		1		5	25
Can't load/unload batteries for removal/replacement	3	Fatigue, wear, overloading, faulty circuit/motor	1	Deflection analysis, fastener shear analysis, finite element analysis, circuit inspections and maintenance	2	6
Cart tips, batteries damaged, user injured, user inconvienced	5	Shear, fatigue, fastener holes shear, wrong material	1	Deflection analysis, fastener shear analysis, finite element analysis	3	15
	5	Heavy cart that is difficult to move and control	3	Utilize efficient design and lightweight materials where possible	2	30
Cart tips, batteries damaged, user injured, user inconvienced	5	Shear, fatigue, fastener holes shear, wrong material	2	Deflection analysis, fastener shear analysis, finite element analysis	3	30
User inconvenienced, entire assembly unusable	3	Bearings fail	2	Provide lubrication instructions in user manual	1	6
Bottle jack or scissor lift mechanism is damaged	5	User misuse (potentially messing with overload valve) or overloading cart	1	Deflection analysis, fastener shear analysis, finite element analysis, alignment hook update	3	15
Battery module gets jambed or falls or rails get damaged	5	User doesn't pay attention, one side hooks in and the other jambs, uneven surface	3		2	30
User inconvenienced, user injured	5	Shear, fatigue, fastener holes shear, wrong material	2	Deflection analysis, fastener shear analysis, finite element analysis	2	20
Battery module falls	5	User abuse, pin shears	2	User can notice it before it gets too bad	3	30
Battery module falls if not fixed	5	User misuse, forklift arms bent	5	User can see problem easily	1	25
Battery module falls if not fixed	5	Something is stuck in closing mechanism	3	User can see problem easily	1	15
Damaged components, total battery failure, personal hazard (injury)	5	Overcurrent, battery damage, uninsulated frame, etc.	1	Protective battery box and insulating coating	2	10
User inconvenienced, entire assembly unusable	2	Bearings fail	3	User can notice it before it gets too bad	1	6
Slipping, sliding, cart won't move	3	Overuse, overloading, rough terrain	3	Foam filled tires to prevent flats, all terrain treads for long life, appropriate wheel/tire sizing	1	9
Cart can't move	4	Bearings are old/worn/dirty	3	User only notices when wheel isn't working	5	60
Cart jerks and batteries fall	5		3		5	75
Cart can't move	4	Bearings are old/worn/dirty	3	User only notices when wheel isn't working	5	60
Movement is unstable	3	Wheels are old, ran over something sharp	4	User only notices when wheel isn't working	5	60
					Total RPN	680
					Average RPN	26.15384615
					Median RPN	24

Figure 28: Failure mode and effects (FMEA) analysis and ranking for battery cart concept evaluation. This table shows the final ranking for our chosen concept and similar analyses were conducted to rank alternatives appropriately.

Next, the team evaluated each concept considering the different ways that they could fail using an FMEA chart. This table shows the potential method of failure, what could possibly cause this, as well as what the team did to account and prevent this failure. The table also shows the severity of the failure, the chance of occurrence, and the effectiveness of the method of detection. The figure above shows the FMEA chart used for design concept 4. Some of the most important failure modes that the team recognized for this concept start with if the cart tips due to heavy loading conditions. Some of the ways that this failure mode could be caused are the fastener holes shearing or the cart being too heavy. To mitigate this in concept 4, the team has utilized lighter materials where possible, as well as carried out deflection and tipping analyses to ensure that the cart will not buckle under heavy loading as well as to allow the operator to know what degree slopes to avoid. Another failure mode the team identified was if the cart gets jammed or stuck when traversing different terrains. To address this, the team has redesigned the wheel system to incorporate an all-terrain set of wheels that will allow for easy movement of the cart on any terrain. The wheels have also been sized correctly to ensure that they will be able to withstand the loading conditions that the cart will be experiencing. After evaluating all identified failure modes of each concept, the team developed a risk priority number, which is calculated by multiplying severity, occurrence, and detection.

	Alternative #1	Alternative #2	Alternative #3	Alternative #4
FMEA (total RPN)	4	1	3	2
Environmental	1	3	4	2
Health and Safety	4	2	3	1
Ethical	1	1	1	1
Usefulness	4	2	3	1
Cost	1	3	2	4
Ease of modification	1	3	2	4
Battery Team Opinion	4	2	3	1
UTV Modification	1	2	2	2
Team Opinion	4	2	3	1
Total	25	21	26	**19**

Legend	
1: Best	Lowest total score is the final decision.
2: Better	
3: Good	
4: Poor	

Figure 29: Decision matrix used for final concept evaluations for battery cart modifications.

Finally, the team compiled all the different evaluation methods mentioned previously and assigned scores to each concept regarding these methods. After doing so, the team identified that design concept 4 would be the design that would be further explored and fabricated. The major deciding factor that led to this decision was the safety aspect of design concept 4. With the new wheels, new lifting system, and new lightweight materials, the design would be far safer to operate than the three other concepts. Another deciding factor was the ease of use of concept 4. With the new modifications to the cart, it takes out nearly all human exertion needed to operate the cart, while also ensuring that the cart can be easily maneuvered through any terrain that the UTV might encounter.

4.8 ENGINEERING AND OTHER ANALYSIS

Preliminary Design Concept

Figure 30: PDR Concept Design

The preliminary design concept revolved around all the improvements mentioned in the Detailed Design section. Envisioned, was a battery system that was able to rotate on top of the cart which would allow batteries to be exchanged quickly and without multiple trips. Also, one design requirement was to be able to navigate through more rugged terrain so larger wheels and tires on the battery cart were included. These ideas were packaged into a concept and analyzation started to determine what materials to utilize in the final design.

Final Design CAD Model and Drawings

Figure 31: Final Concept Front

- The final design utilizes the factory scissor lift design, while modifying the base to allow the use of an electric linear actuator. This is topped off with a redesigned, simple steel frame that supports a turntable and tabletop that can rotate and hold two batteries.
- The decision was made to use HDPE for the top of the table to lower weight versus an all-metal construction and limit the chances of an electrical short between the battery boxes and the tabletop. During analysis of the HDPE table, it was found to deflect too much and needed a small amount of structural support underneath from an aluminum sheet. This decision kept weight down, while adding the support needed to meet the design standards.
- The frame was designed using thin wall rectangular tubing 1” by 2” with a wall thickness of 0.08”. The different members will be welded during assembly while keeping the

turntable system secure with bolts for ease of maintenance, future improvements, and repair potential.

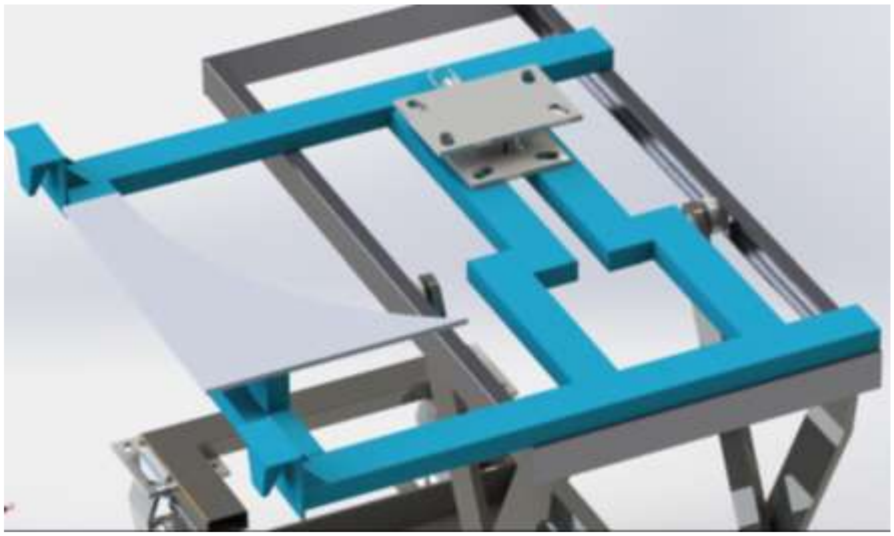


Figure 32: Top Frame

Figure 33: Final Concept Rear

Frame Deflection and Fatigue

Using properties of the steel selected for the project, the frame components of our design have a fatigue strength of 26,000 psi. This property, along with the yield strength of 38,000 psi, will be used to determine how safe the design is.

Sy	38000	psi	a	84240	
Sut	52000	psi	b	-0.085090835	
Se	26000	psi	N	1000000	
f	0.9		Sf	26000	psi
Max Stresses					
Turn Table					
Frame	**2800**	psi			
C Channel					
Frame	**7470**	psi			
Rear Caster					
Frame	**5750**	psi			

$$S_f = aN^b$$

$$a = \frac{(fS_{ut})^2}{S_e}$$

$$b = -\frac{1}{3}\log\left(\frac{fS_{ut}}{S_e}\right)$$

Figure 34: Fatigue calculations.

<u>C-Channel Section</u> :

Utilizing conservative measurements of c-channel shaped steel 1 inch wide by 2 inches tall with a universal web thickness of 0.08 inches, the worst-case scenario was found when the scissor lift was raised all the way up and the forces distributed in the manner shown in Figure 17. Simulating a load twice what is expected during normal use, the maximum stress found in the c-channel frame was 7470 psi which is below our fatigue strength for infinite life and below the yield strength as well. The resulting fatigue and yielding safety factors are 3.5 and 5.1 respectively.

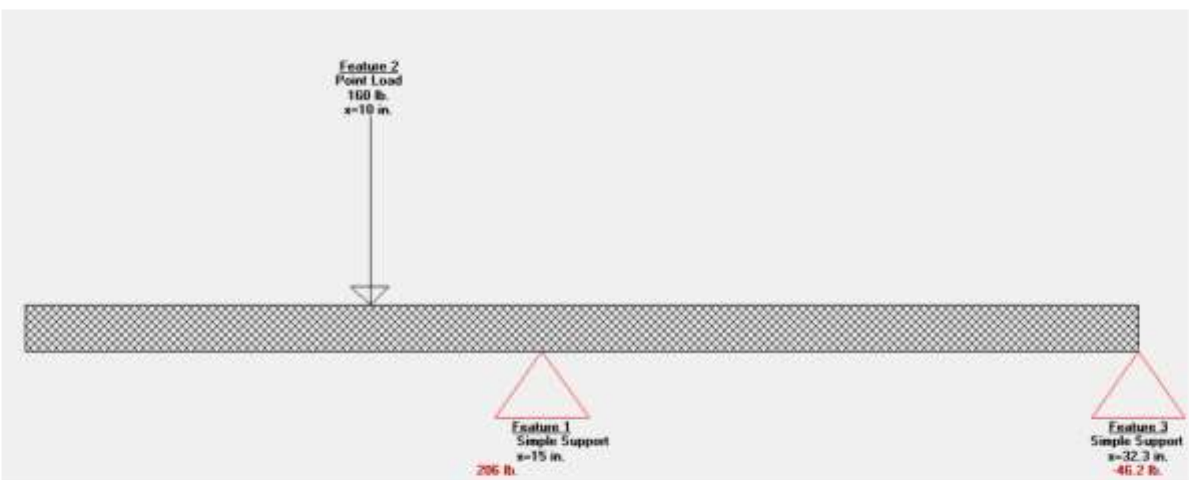


Figure 35: Beam Load Locations

Maximum Values

	Maximum Value	Location
Bending Moment	-800 lb.-in.	15 in.
Bending Stress	7470 psi	15 in.
Deflection	-0.107 in.	0 in.
Slope	0.421 degrees	10 in.

Close

Figure 36: C-Channel Max Stress

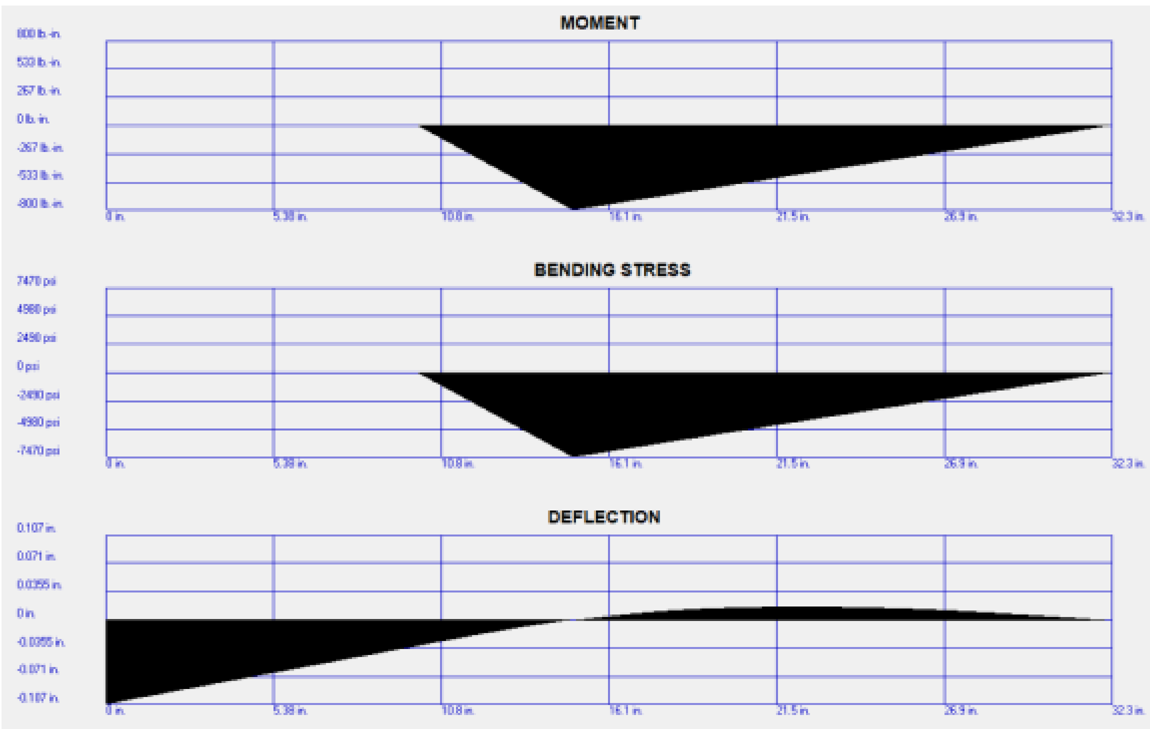


Figure 37: Moment, bending stress, and deflection diagrams for worst-case loading on the battery cart's frame.

Turn-Table Frame:

The maximum stresses found in the turntable supporting frame members was found to be 2800 psi at the loaded positions shown in the Figure 38 below. This gives the design a fatigue safety factor of 9.25 and a yielding safety factor of 13.6. This confirms a very conservative design while remaining lightweight and easily fabricated.

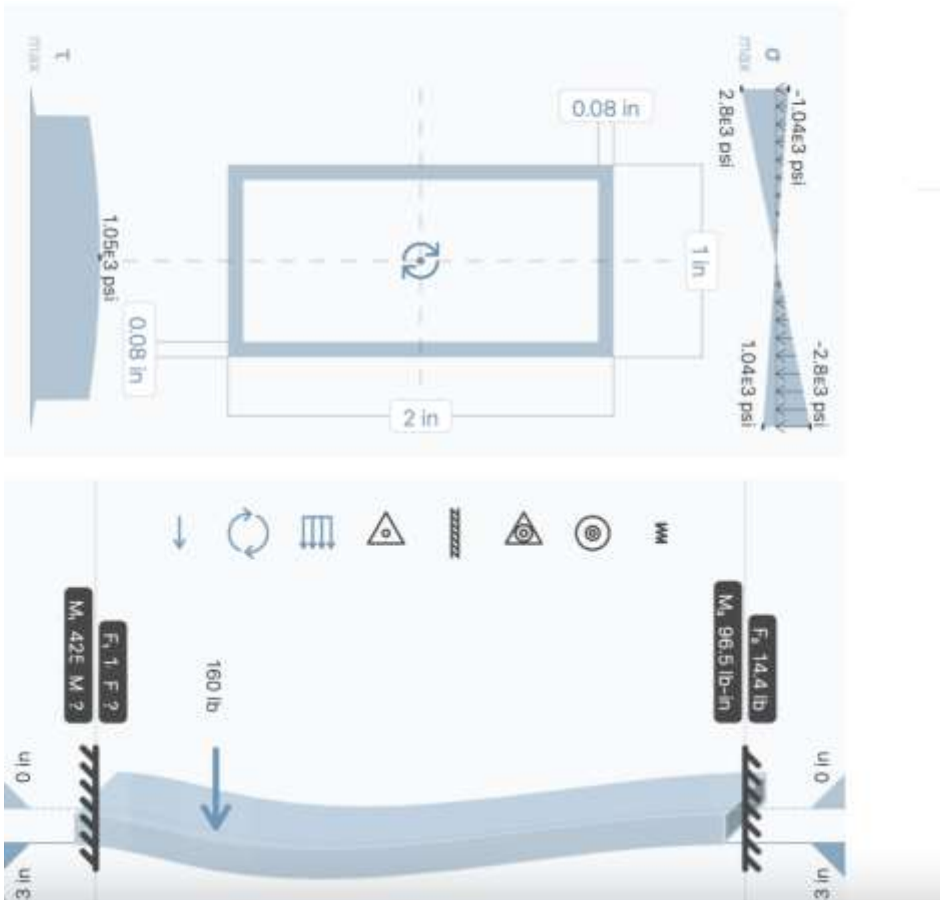


Figure 38: Turn Table Frame

Materials Selection

For our material selection, we wanted to utilize materials that were lightweight, economical to access, and for parts that would be near or in contact with energized power supplies we wanted materials that would act as insulators to prevent shorting or electrical discharge. For our construction we decided to utilize three main materials listed below and in Table 1 with relevant mechanical properties.

- **High Density Polyethylene (HDPE):** HDPE was chosen as it is a stiff and strong plastic, is accessible for purchasing, is easy to fabricate with, and acts well as an insulation material. HDPE is used in our rotating tabletop design and our rails as both structures will be in direct contact with the battery boxes and have the highest chance of causing shorting or discharging in the current cart design.
- **3003 Aluminum:** We wanted to incorporate aluminum into our structure wherever possible as aluminum is a strong and lightweight material as an alternative to steel. However, aluminum is harder to fabricate than steel as we are limited to mechanical joinery. Aluminum welding while possible, is expensive, requires special tools, and requires extensive training that we do not have time to undertake. Therefore, we limited our aluminum components to be supporting pieces underneath the HDPE to keep the

rotating table lightweight, but limit the deflection experienced from the loading of batteries.

- **1020 Plain Carbon Steel:** For the bulk of our structure, we will use plain carbon steel tubing as this material is strong, easily accessible for purchasing, easy for fabrication methods such as welding, and tubing is a lightweight alternative to solid bar stock while still maintaining mechanical properties necessary for loading.

Table 2: Mechanical properties for primary materials used in battery cart design (SolidWorks, 2021).

Battery Cart Material Properties			
	Elastic Modulus (psi)	Yield Strength (psi)	Tensile Strength (psi)
HDPE	155190.38	4351.13	4886
3003 Aluminum	10007603.9	40,003	60190.66
1020 Steel	29007547.53	50991.06	60989.38

Static Loading for Variable Cart Positions

Static loading analysis was used to determine the forces experienced by specific structural members of the cart, forces experienced by the linear actuator, and reaction forces at wheel and axle locations. General equations for forces experienced by the linear actuator were developed using the method of joints applied at points of interest on the cart's structural system. Reaction forces at each wheel were determined by force balances applied to the free body diagram of the cart's overall structure. Figure 39 shows a diagram of the cart with the variables defining forces, structural points, reactions, and loading conditions used to develop general equations.

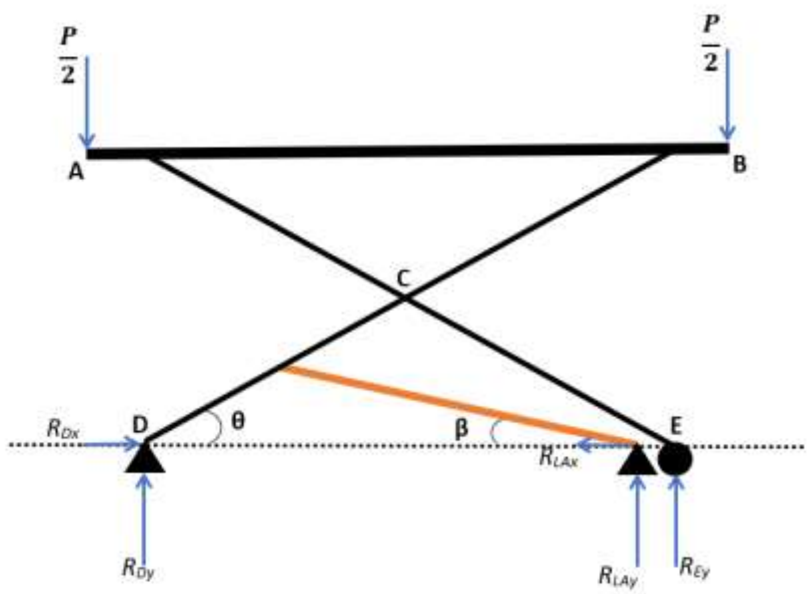


Figure 39: General loading conditions, reaction forces, and angles for the battery cart (the orange member represents the linear actuator).

To build a conservative estimate for the reaction forces occurring at each wheel-axle configuration, the orange member in Figure 39 representing the linear actuator was removed from analysis so that reaction forces were determined at points D and E. The wheel-axle configurations will be constructed where loadings will not apply forces or affect reactions in the x-plane so that only loadings and reactions acting vertically were considered for wheel-axle reactions. The general relationship between an applied load P and vertical reaction forces is given by the equation

$$\sum F_y = 0 = -P + R_{Dy} + R_{Ey}$$

and considering the symmetry of the scissor lift it can be determined by inspection that

$$\frac{P}{2} = R_{Dy} = R_{Ey} \; .$$

Since this analysis occurs in two dimensions and the cart has four wheel-axle configurations it can be determined that each wheel experiences one-quarter of the load applied to the cart's tabletop. The three-dimensional aspect of the cart's loading conditions can be related to the previous equation by

$$\frac{P}{2} = 2R_{Dy} = 2R_{Ey} => R_{Wheel} = \frac{P}{4} \; .$$

For the loading conditions expected by simultaneously loading both battery modules on our cart, expected loads of 40 lbf will be applied at the interface of each wheel, caster, and axle configuration.

Estimating the forces carried by the linear actuator involved removing member CE from the structure shown in Figure 39 and considering the orange member representing the linear actuator and member CD to share half of the load P. This assumption was made to build a conservative relationship between the applied load P and the load carried by the actuator during static and lifting conditions.

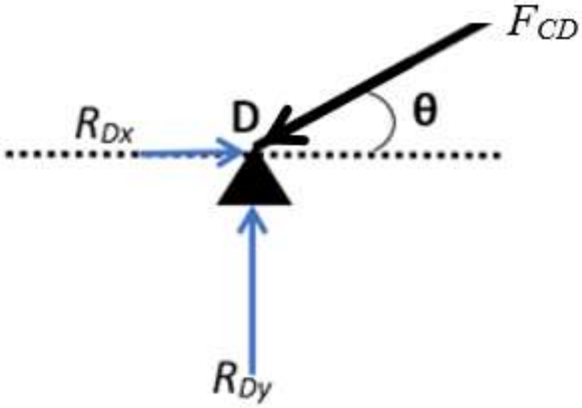


Figure 40: Method of joints applied at Figure 14's point D.

By using the method of joints and beginning at point D it can be shown that

$$\sum F_x = 0 = R_{Dx} - F_{CD}\cos(\theta) ,$$

$$\sum F_y = 0 = R_{Dy} - F_{CD}\sin(\theta) = \frac{P}{2} - F_{CD}\sin(\theta) \Rightarrow F_{CD} = \frac{P}{2\sin(\theta)},$$

and

$$R_{Dx} = F_{CD}\cos(\theta) = \frac{P}{2\tan(\theta)}.$$

Summing the x-plane forces for Figure 14 show that

$$\sum F_x = 0 = R_{Dx} - R_{LAx} \Rightarrow R_{Dx} = R_{LAx} = \frac{P}{2\tan(\theta)} .$$

To determine the direct force experienced by the linear actuator, forces can be resolved by making the assumption that $R_{LAy} = \frac{P}{2}$ and by using the equation

$$F_{LA} = \sqrt{(R_{LAx}\cos(\beta))^2 + \left(R_{LAy}\sin(\beta)\right)^2} = \sqrt{\left(\frac{Pcos(\beta)}{2\tan(\theta)}\right)^2 + \left(\frac{Psin(\beta)}{2}\right)^2}$$

where F_{LA} is the force occurring in the linear actuator at any given configuration of the battery cart.

For project considerations, the battery modules weigh 80 pounds each for a total of 160 pounds applied to the cart when the battery modules are loaded simultaneously. Due to the extension of the linear actuator's arm when lifting any load, the angle β remains relatively constant at 22°. By fixing the load P at 160 pounds and the actuator arm's angle β at 22°, the latter equation can be used to determine the direct force acting on the linear actuator by the applied weight from simultaneous battery module loading. The actuator features a static load rating of 4000 lbf. capacity so that the safety factor can also be calculated by the equation

$$Safety\ Factor = \frac{4000}{F_{LA}} .$$

Results from this analysis are shown in Table 2 where trends indicate that the direct force on the linear actuator from an applied load of 160 pounds decreases and the factor of safety increases as the cart is raised and the angle θ increases.

Table 3: Direct actuator forces and safety factors experienced by varying θ angles. Results assume an applied load of 160 lbf. and a constant β angle of 22°.

Linear Actuator Forces for Variable Loading Configurations		
ϑ (degrees)	***F_{LA} (lbf.)***	***Safety Factor***
5	848	5
15	278	14
25	162	25
35	110	36
45	80	50
55	60	67
65	46	87
75	36	111
85	31	130

These general relationships developed by analysis of the cart's static loading conditions are used to determine forces for subsequent analyses, optimal operating conditions, and material and component selections for the final design of the cart.

Finite Element Analysis for Battery Cart's Rotating Table

Due to the complexity of the geometry and loading conditions for the cart's rotating tabletop, a finite element analysis was completed by performing a study in SolidWorks. This study was performed assuming known final design conditions for the tabletop, including: 1.) a CAD model of our actual locking turntable from the manufacturer with alloy steel material properties, 2.) ¼" thick 3003 aluminum with a 32.75 in. diameter, and 3.) 3/8" thick high-density polyethylene material with a 32.9-inch diameter. Model parameters include four 9/16" bolts at the tabletop's connection points modeled as fixed connections, fixed x, y, and z plane boundary conditions at the model's base, and two 120 lbf distributed loads applied at the top layer of the HDPE to model the loading from the battery boxes. Analyses were performed for displacement and stress and results were used to confirm realistic performance of final design conditions.

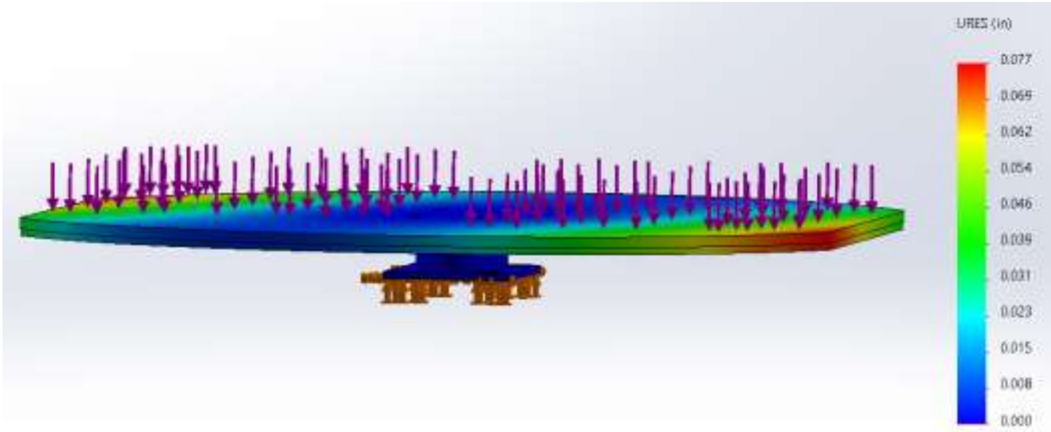


Figure 41: Finite element analysis results showing the deflection of the cart's rotating tabletop. Loads represent forces from the weight of the battery boxes.

Figure 41 shows the results from the deflection study completed in SolidWorks, with deflections from 240 lbf total applied loads ranging from 0.00" to a maximum deflection of 0.077" at the outer edge of the HDPE and aluminum plates. Desired deflection limits for design were decided to be less than 0.1" for the rotating tabletop and battery module system to function well and properly interface with the UTV during battery exchanges. For this study using a conservative 240 lbf load condition, the actual operating conditions will not exceed the desired deflection limit.

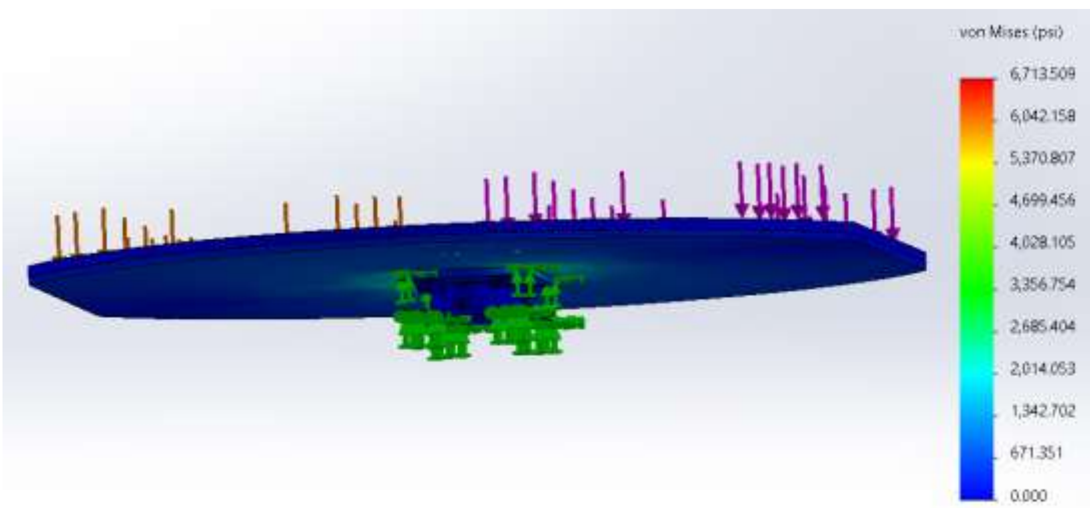


Figure 42: Finite element analysis results showing stresses acting on the cart's rotating tabletop under loads representing the weight of each battery box.

Figure 42 shows the results from the stress study completed in SolidWorks, with stresses from 240 lbf total applied loads ranging from 0.00 psi to a maximum range of just under 4800 psi. The maximum stresses occur within the aluminum support plate near the bolted connections and the base of the rotating turntable. For 3003 aluminum, the yield strength is about 40.0 ksi so that the design's maximum stress is 12% of the yield stress for this material. Maximum stresses occurring within the HDPE tabletop are less than about 450 psi so that for HDPE, with a yield strength of around 4.30 psi, the design's maximum stress is about 10.5% of the yield stress for this material. Maximum stresses occurring within the alloy steel turntable are less than about 700 psi so that our design maximum stress for the turntable is about 1.37% of alloy steel's yield strength of about 51.0 ksi.

Design geometries have been chosen to suit material properties so that all selected materials will operate within their range of elastic deformation well below yielding points. With a maximum deflection of 0.077", which is less than the desired design deflection, and a maximum stress from conservative loading conditions of 4.80 ksi, the rotating tabletop utilizes materials that are relatively lightweight, electrically insulating, aesthetically pleasing, and desirable for the cart's functionality.

<u>Tipping Hazard and Range of Stability</u>

Due to the potential for the UTV to be used for utility and recreational purposes in outdoor settings it is likely that less-than-pristine operating conditions will be encountered including unevenly sloped terrain and steep grades. Considering the operating environment, analyses were conducted to determine the battery cart's tipping stability to find an appropriate range of use of the cart for battery exchanges. Tipping conditions were determined by comparing static loading conditions for two scenarios: 1.) worst-case (conservative) and 2.) design conditions (actual).

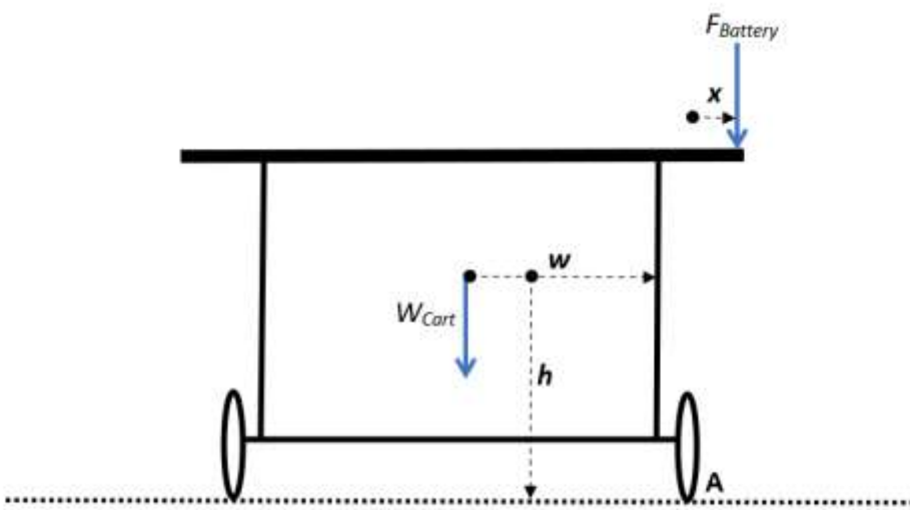


Figure 43: Loading diagram of the cart to determine tipping stability and range of use.

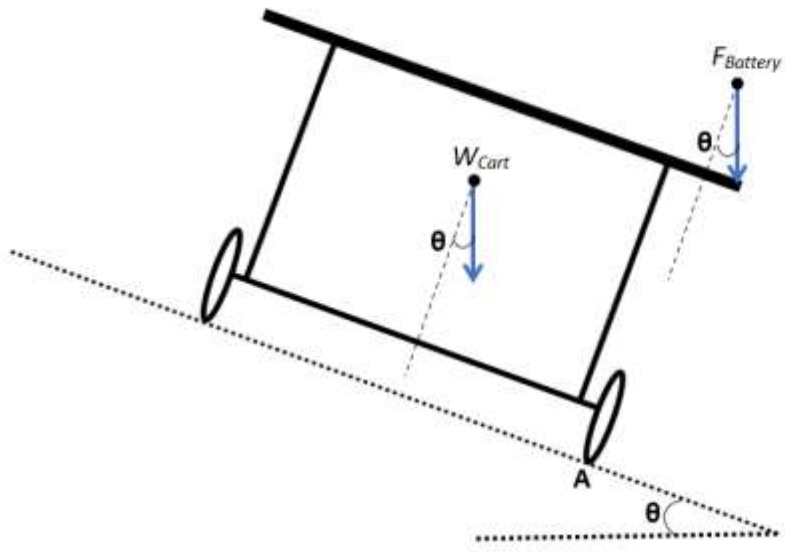


Figure 44: Loading diagram of the cart to determine tipping stability and range of use. Shows the relationships between basic forces and the cart's inclination angle.

The general equation used for tipping analysis was developed from the loading conditions indicated in Figure 44 where W_{cart} is the center of gravity of the battery cart, $F_{Battery}$ is the applied load of the battery module, θ is the inclination angle of interest, and A is the cart's tipping point. By using conditions shown in Figure 26 and summing the moments about point A the general equation relating the cart's dimensions to the tipping point at a particular angle of inclination can be shown by

$$\sum M_A = 0 = wW_{Cart}\cos(\theta) - hW_{Cart}\sin(\theta) - xF_{Battery}\cos(\theta)$$

where solving for x gives

$$x = \frac{wW_{Cart}\cos(\theta) - hW_{Cart}\sin(\theta)}{F_{Battery}\cos(\theta)}.$$

With a constant width w to the center of gravity of 9 inches, a battery force $F_{Battery}$ of 160 pounds, heights h to the center of gravity varying from 11 inches to 30 inches, and reasonable assumptions based on design geometry for x, the distance between the applied load and the tipping point, this equation can be used to study valid ranges of use for the cart on a variety of slopes.

The conservative analysis for the theoretical worst-case scenario was conducted by assuming an applied point load with the weight of 160 lbs. to approximate the loading from both battery box modules placed at the outermost edge of the cart's frame at a distance x of two inches to produce the maximum theoretical moment acting about the tipping point against the cart's center of gravity. Additionally, the cart's center of gravity was assumed to be at its maximum possible height of 30 inches. Using these values and solving for the inclination angle θ, the tipping point occurs at an angle of 14°.

The analysis based on design conditions and actual operating conditions followed guidelines for battery cart use outlined by the standard operating procedures where the cart is moved for loading at its lowest maximum height with battery modules loaded centrally on the tabletop. This model utilized an applied point load with the weight of 160 pounds to approximate the loading from both battery box modules placed at actual operating locations at a distance x of 1 inch and a height h to the center of gravity of 11 inches. Using these values and solving for the inclination angle θ, the tipping point occurs at an angle of about 35°.

Based on these analyses, the recommended range of use for the cart is to operate battery module exchanges at the cart's lowest possible height on slopes from 15° to 35°. With the UTV's recommended operating range of 15° maximum slope, the cart features the ability to traverse potentially difficult terrain to facilitate battery module exchanges.

Bolt and Pin Analysis

Bolts and pins for critical components and connections were analyzed for strength under axial and shear loading conditions. Critical areas analyzed include fasteners or connections at three major cart components: 1.) bolts fastening the turntable system under tensile and compressive axial loading due to weight from battery modules, 2.) pins connecting each end of the linear actuator to the battery cart's frame under shear stresses, and 3.) bolts and pins connecting wheels, axles, and casters at the bottom of the battery cart. Where bolting patterns occur in three dimensions, only two-dimensional analyses were conducted for simplicity.

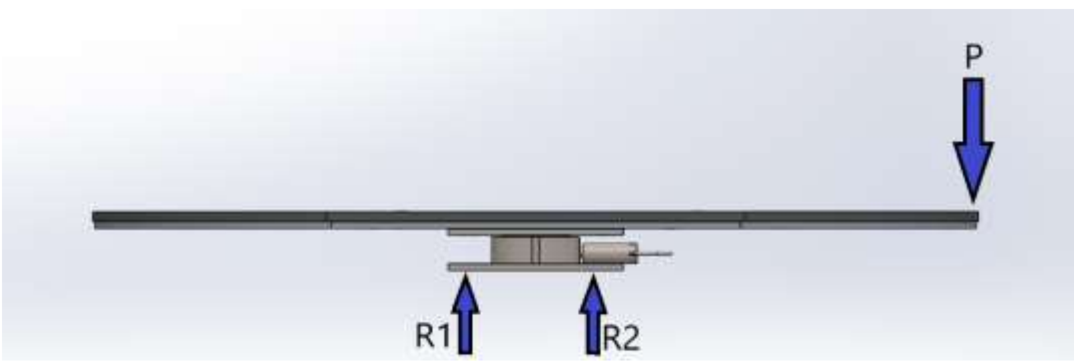


Figure 45: Loading diagram for forces and reactions acting on the cart's rotating tabletop.

Bolts connecting the rotating tabletop to the cart's frame have the potential to be loaded with significant stresses from battery modules placed on the tabletop during exchanges. For a conservative approximation of the bolts experiencing the most substantial stresses, loading configurations show by Figure 45 were used where P is a point load applied at the outermost edge of the tabletop, R_1 is the reaction force for the first bolt in the base's connection pattern, and R_2 is the reaction force for the second bolt. The design dimensions for the tabletop system include a three-inch distance between bolts and a distance of 15 inches from the applied load to the second bolt. Stresses were assumed to be axial and were evaluated by summations of static loading conditions where

$$\sum F_y = 0 = -P + R_1 + R_2$$

and

$$\sum M_{R2} = 0 = (3\ in.)R_1 - (15\ in.)P.$$

By assuming the applied load P to be the weight of a single battery module at 80 pounds and solving for the reaction forces, R_1 is 400 lbf in tension and R_2 is 240 lbf in compression. Using the greater force of 400 lbf and the bolts' design diameter of 9/16", the axial stress acting upon these critical bolts can be determined by

$$\sigma = \frac{F}{A} = \frac{400\ lbf}{\frac{\pi}{4}\left(\frac{9}{16}in.\right)^2} = 1610\ psi.$$

For 1020 steel bolts with a yield strength of about 51,000 psi, the conservative stress acting on these critical bolts is 3.16% of the material's yield strength.

Pins connecting the linear actuator to the cart's frame experience shear stress from two planes resulting from axially loading the actuator. Assuming the linear actuator's highest loading condition of 848 pounds and using the pin's design diameter of ½", shear stresses can be determined by

$$\tau_{pin} = \frac{2P}{\pi d^2} = \frac{2(848\ lbf)}{\pi\left(\frac{1}{2}in.\right)^2} = 2160\ psi\ .$$

For 1020 steel pins with a yield strength of about 51,000 psi, the conservative stress acting on these critical pins is 4.24% of the material's yield strength.

Axles and axle pins within the cart's wheel-caster configurations experience loads at 25% of the cart's overall loading condition. Assuming a conservative weight of 300 pounds loaded on the cart's rotating tabletop and a cart weight of 200 pounds, the total load experienced by a single wheel is 125 pounds. For standard operating conditions, shear stresses act on the cart's axles and axle pins. For the cart's front axle diameter of ¾", shear stress at a single wheel can be determined by

$$\tau_{wheel} = \frac{4P}{\pi d^2} = \frac{4(500\ lbf)}{\pi\left(\frac{3}{4}in.\right)^2} = 1130\ psi\ .$$

For a front axle of 1020 steel with a yield strength of about 51,000 psi, the conservative stress acting on the axle at a single wheel is 2.22% of the material's yield strength. For pins on the rear casters with a diameter of 3/8", shear stress at a single wheel can be determined by

$$\tau_{wheel} = \frac{4P}{\pi d^2} = \frac{4(500\ lbf)}{\pi\left(\frac{3}{8}in.\right)^2} = 4530\ psi\ .$$

For 3003 aluminum pins with a yield strength of about 40.0 ksi, the stress acting on the axle at a single wheel is 11.3% of the material's yield strength.

Based on these analyses, bolts and pins at critical fastening locations and axles and axle pins will experience stresses entirely within the range of elastic deformation. As determined by conservative approximations, material yielding and risk of failure for critical connection points has been mitigated by appropriate design considerations.

Weldment Analysis

Modifications to the battery cart require substantial welding in critical areas including the cart's structural frame to support the scissor lift rails and rotating turntable and brackets to support linear actuator's pinned connections. Fillet welds will be utilized due to the geometry of the surrounding materials and analyses were conducted for these connections. MIG welding will be the primary attachment method and ER70S6 specification electrodes will be used to bond parts.

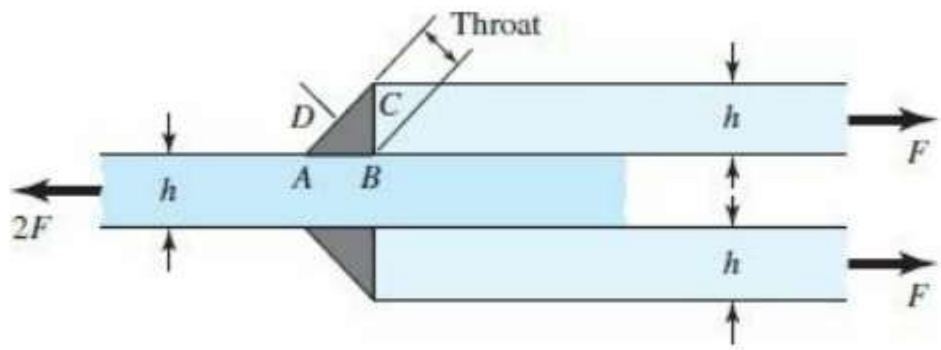


Figure 46: Fillet weld diagram with dimensions used for stress calculations (Budynas, 2021).

Weldments at the cart's structural frame supporting the rotating tabletop are oriented along a rectangular cross section where design conditions feature a ¼" height, a 0.707-inch throat, a separation distance d of two inches, and a separation base b of two inches. Stresses for critical welds in the frame's supporting structure are under both shear and bending stresses simultaneously and the bending stress is determined by

$$\tau = \sqrt{\tau'^2 + \tau''^2}.$$

The primary shear acting on the weld is given by

$$\tau' = \frac{V}{A},$$

Where V is the shear force and A is the total throat area. The secondary shear acting on the weld is determined by

$$\tau'' = \frac{Mc}{I} = \frac{1.414M}{bdh},$$

Where M is the moment, b is the separation base between welds, d is the separation distance between welds, and h is the weld height. The expression on the right of the latter equation is a conservative, simplified model from American Welding Society codes (AWS A5.1, 2021) used for this analysis. For a 142-pound shear force based on a 160-pound load determined by previously discussed analyses and applying the design dimensions discussed above for the structural welds gives a primary shear stress determined by

$$\tau' = \frac{V}{A} = \frac{142\ lbf}{0.707\ in.^2} = 201\ psi.$$

For a moment of 425 lb.-in. based on a 160-pound load determined by previously discussed analyses and applying the design dimensions discussed above for the structural welds give a secondary shear stress determined by

$$\tau'' = \frac{Mc}{I} = \frac{1.414M}{bdh} = \frac{1.414(425\ lb.-in.)}{(2\ in.)(2\ in.)(\frac{1}{4}\ in.)} = 601\ psi,$$

So that the total bending stress is given by

$$\tau = \sqrt{\tau'^2 + \tau''^2} = \sqrt{(201\ psi)^2 + (601\ psi)^2} = 634\ psi.$$

American Welding Society and American Institute of Steel Construction (AWS A5.1, 2021 and ANSI/AISC, 2016) apply conservative mechanical properties and safety factors to 70-series electrodes, where the tensile strength is 62.0 ksi and the allowable stress for fillet welds under shear loads as 0.30 times the tensile strength for an allowable shear stress of 18.6 ksi. With a total bending stress of 634 psi, the structural frame's welds are 3.41% of the material's yield strength.

Weldments occurring at the connection supports for the linear actuator's pins experience compressive loading resulting from axially loading the actuator. Fillet weld dimensions for these connections have a height h of ¼" and a length l of 2 inches. Assuming a force F of 1,000 pounds from the linear actuator's load condition, and the maximum stress at any point within the weld can be determined by

$$\sigma' = \frac{2.16F}{hl} = \frac{2.16(1000\ lbf)}{\left(\frac{1}{4}\ in.\right)(2\ in.)} = 4320\ psi.$$

Using mechanical properties for 70-series electrodes of 50.0 ksi for the material's yield strength and AISC (ANSI/AISC, 2016) safety factor of 0.5 times the yield strength, the welds for the actuator's support brackets are 17.3% of the material's yield strength.

<u>Wheels, Casters, and Axles</u>

The design from last semester uses four casters to allow the cart to move. The design has two rotating casters in the back to allow for zero-point turning, as well as two rigid casters in the front. As a proof of concept, this design works, but when applied to the terrain that the UTV and battery cart will be traversing this system will make the battery cart nearly impossible to move. Also, with the new proposed design of our battery cart to house two battery units, that increases our potential load from roughly 80 pounds to nearly 160 pounds. This, along with the fact that it is already difficult to move, has forced the team to redesign the caster system.

In our new caster system, we are keeping the same idea of having two rotating casters in the back, while keeping two rigid casters in the front. The reason for this is because we believe that it is still the best system for movement of the battery cart. The modifications that we are making are based around methods of attachment, size, materials, and wheel design.

First, our new rotating casters mounted onto the back of the battery cart will still be bolted. With that being said, we are replacing the existing 5-inch diameter casters with an 8-inch diameter polyurethane wheel. Along with the new material, the casters will also have a tread pattern that will allow for much better traction on any surface. The new caster material, size, and tread pattern will allow the cart to be much more agile and dexterous when traversing unideal terrains such as a farm or oil field, which are all terrains that the UTV could find itself in. For our new method of attachment of the back casters, we are also slightly modifying the existing design to accommodate for the increase in caster diameter.

Next, we are replacing the rigid casters that are mounted on the front of the cart. Along with this replacement, we are also introducing an axle on the front end of the cart that will allow for a wider wheelbase for the cart. The existing rigid casters have a 5-inch diameter, while the new casters will have an 8-inch diameter. The new casters also include a 2-inch diameter hub composed of a high strength polymer that will ensure that they can withstand the desired load. Another advantage of the wider wheelbase is the fact that it allows us to accommodate the increase in caster diameter by allowing the casters to be located outside the main scissor frame. The newly introduced axle will have a length of 21.5 inches, which is longer than the scissor frame width of 16.25 inches. The axle will be attached to the scissor lift frame through weldments and is made from 1020 steel.

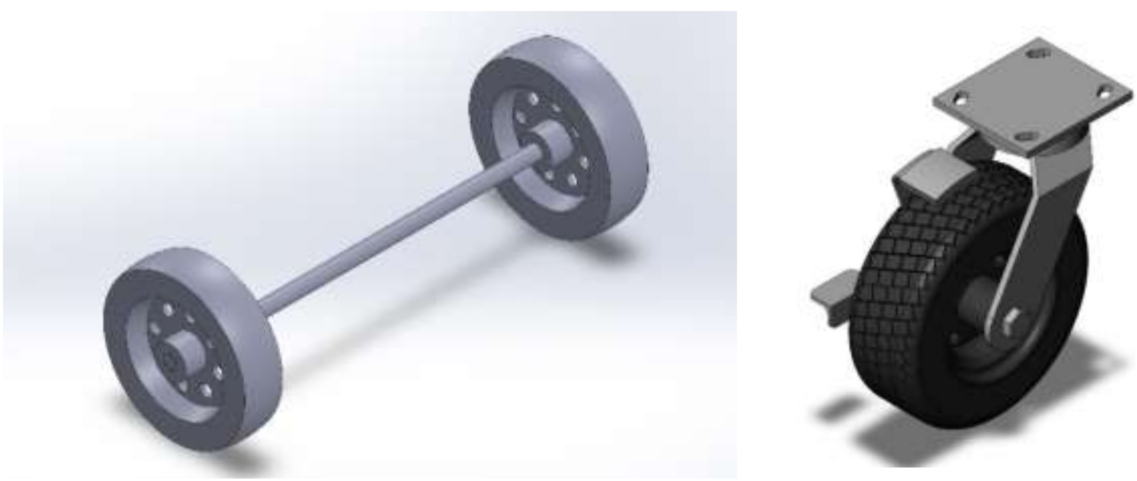


Figure 47: Front caster and axle assembly and rear rotating caster.

<u>Component and Material Selection</u>

For our component and material selection we utilized our various analyses to find and select parts that would well exceed the critical forces that would be acting on our cart.

- **Rigid Wheels:** For our rigid wheels, we decided to use the stealth 8” x 2” caster wheels from R-Trac. These wheels are no-flat all-terrain wheels that are rated for 300 lbs., exceeding the 250 lb. requirement for our cart’s 1000 lb. maximum load rating.
- **Rotating Casters:** For our rotating wheels, we chose to use McMaster-Carr Flat-Free casters with 8” polyurethane wheels and brakes. This fulfilled all our functional requirements such as including a braking system, having a flat mounting plate for ease of fabrication, and are rated to carry 270 lbs. per caster, which exceeds our 250 lb. requirement.
- **Linear Actuator:** We decided on a linear actuator from Progressive Automations that fit the necessary requirements in stroke, dimension, and force to operate our cart. The linear actuator has a 4” stroke, a dynamic force rating of 2000 lbs., and takes a power input of 12 VDC.
- **Power Supply:** To power the linear actuator, we required a 12V power supply which we sourced from Dakota Lithium. The unit supplies 12V and is rated for 10AH which should suffice for normal operation of our cart.
- **Turntable:** We rated our turntable for the full maximum load of our cart, which is 1000 lbs. Therefore, we decided to utilize the McMaster-Carr lockable turntable, which has a 1500 lb. capacity, has bolt holes pre-drilled, and is constructed from zinc-plated steel. The bolt holes and steel construction give our team flexibility in the fabrication of our cart, allowing us to optimally use bolts to mount the turntable, but in worst case still allows us to weld the turntable if needed.
- **Bolts:** For the construction of our cart, we will require bolts in many places, especially to fasten structures of differing materials together. We chose to use Stainless ANSI 304 and 316 bolts because the minimum tensile strength of ¼ in bolts in this material is 4600 lbs. which well exceeds our estimated loading of 160 lbs., are small and easy to place in access points for our cart and will be economical to purchase in large quantities for our construction.

4.9 TESTING PERFORMED

We tested our finished prototype in four areas that were critical to the satisfactory performance of the cart: load, battery life, module exchange time, and tabletop deflection.

Load testing was performed by adding weight to the cart and lifting to its maximum height to ensure that the cart’s lift mechanisms would function under operational conditions. For minimum performance we desired operation at 160 lbs. which would be the load of two battery units. For optimal performance we desired 150% operational capacity, which would be 240 lbs. of load. As Table 4 shows, we were able to reach our desired optimal performance, and failed to lift at 270 lbs.

Battery life testing was performed by constantly running the lift mechanism up and down under suboptimal loading conditions (200 lbs) to test how long the battery would last. Our desired minimum performance would be 5 minutes which would be about the continuous lift time of 5 battery changes. Table 5 shows the results of the battery life test, which shows we reached triple our minimum performance before stopping the test due to the understanding that the battery life well exceeds what the normal use of the device would require in normal operation.

Battery module exchange time testing was one of our most critical testing metrics, as we were looking to create a design that would take less than half the time required to change batteries of the previous design. We tested exchange time by beginning with one battery module in the UTV, and one battery module on the charging station which was located on the opposite side of the UTV battery module. The battery cart began aligned on the charging station, timing began, the first battery unit was moved from the charging station to the cart, the battery cart was disengaged from the charging unit, lowered to the ground, the cart was moved to and engaged to the battery storage of the UTV, the UTV battery was moved to the battery cart, the "new" battery was moved from the cart to the UTV, the cart was disengaged from the UTV, and then timing was stopped. The previous design metric was a 10-minute maximum battery exchange time. Table 6 shows that our average exchange time was 3 minutes and 15 seconds. However, the first testing was performed before we were able to adequately secure the turntable pin to the handle of the battery cart, and manual engagement of said pin resulted in much longer exchange times than what would be expected with the mechanism rightly fixed. Once we made the correct alterations to the pin activation mechanism, our times for exchange were significantly reduced. Table 7 shows our final design results in which we averaged 56 second exchange times, which reaches below $1/10^{th}$ of the previous semester's evaluation metric.

Our final testing parameter was the tabletop deflection testing. Our critical design review metric was a maximum deflection of 0.1 inches. We loaded the cart with even loading in the positions that the battery modules would be located, and as shown in Table 8, our maximum deflection of 0.1 inches was reached only when a load of 200 lbs. was applied to the tabletop.

Table 4: Testing results from controlled load testing under increasing loads for the updated battery car

Battery Cart Controlled Load Testing		
Load (lb)	*Pass/Fail*	*Notes*
0	Pass	Clean lift
50	Pass	Clean lift
100	Pass	Clean lift
150	Pass	Clean lift
200	Pass	First sign of struggle under load
230	Pass	Difficult initially
245	Pass	Clutch engagement at low cart height
270	Fail	Clutch engagement at at start, no lifting

Table 5: Testing results from controlled actuator testing under a constant 200-pound load with continuous motion.

Battery Cart Linear Actuator Battery Discharge		
Time (mins)	*Lift/Stall*	*Notes*
0	Lift	
2.5	Lift	
5	Lift	Tested under constant load at 200 lb load
7.5	Lift	
10	Lift	
12.5	Lift	
15	Lift	

Table 6: Testing results from battery module exchanges in a controlled environment.

Battery Cart Battery Module Exchange Testing	
Trial	*Time (mins)*
1	3' 30"
2	3' 09"
3	2' 00"
4	3' 15"
Average	3' 15"

Table 7: Testing results after making an improvement on the operating mechanism for the turntable pin.

Battery Cart Battery Module Exchange Testing V2	
Trial	*Time (mins)*
1	1' 08"
2	0' 49"
3	1' 02"
4	0' 44"
Average	0' 56"

Table 8: Testing results from deflection measurements under varying loads on the rotating tabletop.

Battery Cart Tabletop Deflection Testing	
Load (lb)	*Deflection (in)*
0	0
42	0.04
78 (Single Module)	0.05
156 (Double Module)	0.07
200	0.1

4.10 WORK BREAKDOWN OVERVIEW

Justin LaNoue:

- Fabrication Method Viability
- Detailed Drawings
- Testing Performed
- CAD Modeling
- Concept Ideation and Evaluation
- Materials Selection
- Frame Fatigue and Strength Analysis
- Component Selection

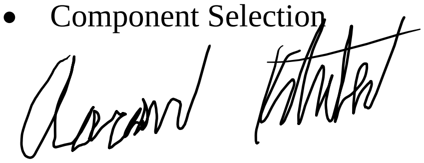
Braydon Leger:

- Overall costs/BOM
- Last semester’s UTV overview
- Engineering principles
- Knowledge acquisition
- Codes and standards
- General proofreading
- Risk management
- Project video

Aaron Katada:

- Fabrication Method Viability
- Detailed Drawings
- Testing Performed
- CAD Modeling
- Concept Ideation and Evaluation

- Materials Selection
- Welding Techniques
- Fastener and Weldment Strength
- Tipping, Stability, and Range of Use
- Component Selection



<u>Michael Willhoite:</u>

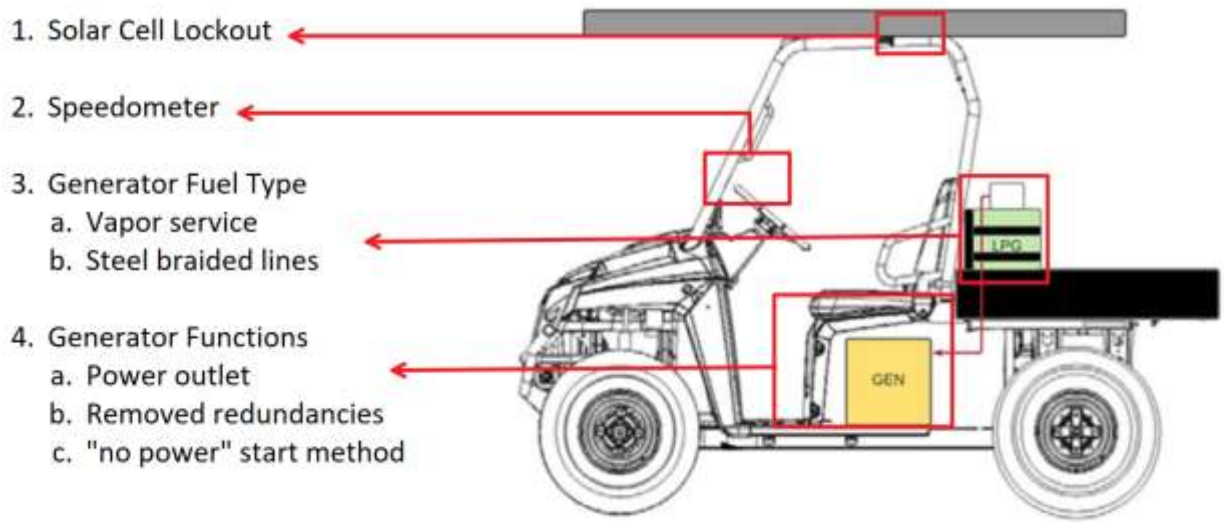
- Concept evaluations including Usefulness Index, EHS Chart, FMEA, and final Decision Matrix
- Secondary CAD modeling contributions (primary Justin LaNoue and Aaron Katada)
- Analysis contributions including materials, static loading for variable conditions, finite element analysis, tipping and stability, material stress/strength for pins, bolts, welds, etc.
- Fabrication contributions including general assembly, machining and milling rails and small components, waterjet cutting
- Testing contributions include developing test plans, forming spreadsheets for data, and data collection
- Report contributions include engineering analysis and detailed design sections, overall solution, figures and tables for multiple sections, and general proofreading
- Presentation contributions include engineering analysis and detailed design, overall solution, codes and standards, testing, and general proofreading

5 SOLAR, GENERATOR, SPEED TEAM

5.1 PROBLEM DESCRIPTION

In this design project, our sub team landed three different areas in which to design improvements to the overall UTV safety, function, or utility. The first area consisted of solar cells and the conclusion came to implementing an ignition interrupter to be utilized as prevention of UTV driving operations when the lower solar panel is not locked in the closed position. Secondly, in the area of performance data improvements, it was decided that the UTV's ground speed should be clearly displayed. Lastly, the propane generator was virtually inoperable at the conclusion of the previous design semester and this unknown issue clearly needed to be addressed. Additional changes to the propane generator system were agreed upon to improve utility and remove redundancy.

5.2 OVERALL SOLUTION AND SUBSYSTEMS



Pictures of the actual system can be found below in section 5.8 engineering and other analysis.

5.3 ENGINEERING PRINCIPLES

Data Acquisition: By sampling the signal from the hall effect sensor located beneath the driveshaft, we can use the collected data in the dynamics equations to calculate the ground speed of the UTV.

Computer Programming/ Coding: Writing code that will receive, process, and manipulate the hall effect signal into useful information and be able to display this performance data for the operator. A sample of this code is discussed and shown in the detailed design section.

Computer Aided Drafting: Using software (SolidWorks) to design and produce precision designs to be manufactured and used in the fabrication process. In relation to our design, we used SolidWorks to create a housing and mounting solution for the new speedometer. This will then be 3D printed during fabrication.

Thermodynamics: To understand the generator operation and resolve its issues, we had to analyze the propane phase desired by the generator versus the phase previously provided.

Circuits: Implemented changes to electrical system functionality by using loop analysis as well as understanding power consumption versus supply. Circuits was important when designing our speed measurement system. Since we are using an Arduino for the speedometer, we needed to understand the circuitry components.

Failure Analysis: Determining the causation of generator performance issues through an investigation of previous alterations to the manufacturer design. This was important at the beginning of the detailed design phase. We spent time determining why the generator was not functioning properly.

Energy: Analysis of generator capacity to prevent over-drawing the power supply provided by the generator.

Dynamics: To convert the measured driveshaft revolutions into meaningful ground speed information the UTV dynamics were analyzed. This calculation was very important for our design and is discussed and shown in our detailed design section.

5.4 EHS Considerations

COVID-19: With Covid-19 happening we are as a team responsible to make sure that everyone be aware of CDC and university guidelines. Also, we ask every team member to stay home when feeling sick, and we encourage the use of face masks.

Environmental: Our system prefers the use of solar panels over the generator. The system has no waste to minimize the environmental pollution effects. Also, the source we have chosen to fuel the generator is propane gas. Propane is considered to produce less pollution and burns clear, compared to all other petrol fuels.

Safety/Electrical safety: Our team is taking safety measures very seriously for this project. For safety concerns, we are following all codes and standards that have been chosen for the system. Also, we make sure that each one of us has taken the safety quizzes for the desired system. For electrical safety concerns, it is important to know how much current and voltage is allowed to be driven through each part of the system to avoid any electrical sparks and fire hazards. The system we are developing must be waterproof to avoid any disconnections.

Propane tank safety: It is important to follow all the manufacturing guidelines and the manuals for the propane tank and the generator. The propane tank placement, lines, and regulators are chosen after following the manual. Lifting and placing the propane tank is done carefully and securely. For line leaks concern, a water spray leakages test will be applied to make sure there is no leakage that could cause fire hazard.

Speedometer Screen safety: For the placement of the speed screen, human factors are considered so the driver could not be distracted while driving the car. The speed screen information accuracy must be achieved with the proper code and proper waterproof wiring system, to avoid any disconnection.

Ethical and professional: For this project we are all required to work professionally and seriously. As engineering students, we must follow the engineering codes of ethics, be honest about our work, work within our area of knowledge, and report any problem in a truthful manner.

5.5 CODES AND STANDARDS

American Wire Gauge: The American wire gauge table must be followed to choose the right electrical wires size traveling current in the system (AWG wire gauges current rating, n.d.). AWG will be followed for all wires in this project. This was important for our design when determining the proper electrical components and how they would be integrated.

NFPA 70B: Standard use for electrical and electronics equipment maintenance in industry (NFPA 70B, n.d.). To make sure everyone is aware of electrical equipment fundamental, and how testing methods are applied when dealing with electrical systems. This was used when working with the generator as well as determining procedures that would be used for maintenance and future testing.

NFPA 70E: Standard for electrical safety in the workplace and information on how employees should avoid workplace injuries and fatalities due to shock (NFPA 70E, n.d.). This should be followed when dealing with electrical wires, voltage sources, and each electrical equipment in our system to achieve safe work practices. Since our team is working with multiple sources of electricity with our design it is important that all members are aware of proper protocol to avoid potential injuries. This will be especially important during the fabrication and testing phases when energization of the system occurs.

NFPA 70: National Electrical Code for safe installations and design for electrical systems (NFPA 70, n.d.). When designing the system, it will help us to ensure safe electrical installation to avoid any violations and know all the electrical needs. This is the main NFPA standard that was adhered to during the design phase. The information presented for NFPA 70E and 70B also applies here.

OSHA 1910.176: Use of mechanical equipment and how to handle and store them in the proper way to avoid creating any hazard (Occupational Safety and Health Administration 1910.176, n.d.). For our system we need to follow the safe method of handling and storing the generator and the propane tank.

OSHA 1910.136: Use of protective footwear for employee's protection from an electrical hazard, like static-discharge or electric-shock hazard and falling hazard (Occupational Safety and Health Administration 1910.136, n.d.). This standard will be followed by our team when dealing with wiring any electrical wires. Also, when placing the propane tank to avoid any falling or rolling hazard that could cause foot injuries. This also applies to dealing with the generator, especially if the generator will be removed from the vehicle.

OSHA 1910.138: Standard for the use of appropriate hand protection when working with hazardous materials like harmful substances, severe cuts, chemical burns, and thermal burns (Occupational Safety and Health Administration 1910.138, n.d.). Appropriate hand protection when testing the propane tank leakage to make sure no left substances on hand. Also, this standard will be followed when crimping or stripping any electrical wire for the system, to avoid hand injuries.

5.6 KNOWLEDGE ACQUISITION

DAQ/Coding: Comparative analysis of code examples was utilized to understand the new language. Through the testing of different program examples, we were able to acquire the tools necessary to sample the data from the hall effect sensor, logically sample that data in a timely manner to use it effectively, make calculations based on data stored and discovered, and effectively display speed data on the speedometer display screen. Logic and sampling processes were taught in a previous course and were utilized here.

Circuits: To ensure the proper electrical circuits required for several of our designs were produced, we first revisited any useful prior knowledge of circuits from our physics and circuits classes. We then consulted those within the EE discipline and were able to then get advice and re-affirm some of our designs. We then referenced standards such as AWG to ensure designs were made to specifications.

Generator and Propane Source: To troubleshoot the generator not running properly, we first referenced the manufacturer information provided in the owner's manual to fully understand the expectations of the generator. We then combined these insights with observational component analysis of the system modifications done by previous design teams. This process was aided by prior knowledge of engine cycle performance given in thermodynamics class.

Design and Fabrication: Fabrication training was attended at the NCL to gain expertise (or apprenticeship) in several manufacturing methods to be used when making the mounts for several pieces of the design. In addition to these trainings, knowledge of modeling with SolidWorks was refreshed from the courses we took years ago and used to design parts for this project. The additive manufacturing one course was taken at the Endeavor to be able to 3D print these computer models and use them.

5.7 CONCEPT EVALUATION

There were three options considered for methods of speed measurement for display. The independent digital display, which we decided upon, included a processor, sensor and screen implemented to measure the speed. This system works independently of all other systems and only requires a power input to function. The integrated digital option was to send sensor information the controller team's processor and having it displayed on the user interface. The independent mechanical would be a gear measure and needle reading. Below you can see the considerations which led to this decision.

	Independent Digital	Integrated Digital	Independent Mechanical
FMEA (total RPN)	1	1	3
Cost	3	1	3
Utility	1	2	2
Power Draw	3	2	1
Readability	1	2	3
Location	1	3	1
Team Opinion	1	2	3
Total	11	13	16

Figure 48: Speedometer decision

With the decision to have an independent digital speedometer system, the speedometer required housing to be 3d printed due to specific sizing of the Arduino board and display. The housing was decided to be 3d printed as the speedometer is small and lightweight so that it would not require a strong material such as sheet metal for housing. Using the resources made available to us, we had two materials for 3d printing filament: ABS and PLA plastic. Both materials cost relatively the same so other properties needed to be considered on deciding the material as shown in figure 49. Strength was not a large factor in deciding which material to use as the speedometer is light weight and unlikely to be struck by large force during regular use. Factors we considered more important were performance properties where ABS rose to the top with higher heat resistance, UV resistance, water resistance and durability than PLA. An acrylic screen cover was used to seal and protect the screen inside the case.

	ABS	PLA
Cost	1	1
Heat resistance	2	3
Strength	3	2
UV resistance	1	2
Water resistance	2	3
Durability	2	3
Total	11	14

Figure 49: Screen case decision

The mounting method for the speedometer was decided after the location of the HMI mount location was confirmed. The speedometer was to be mounted on the roll bar of the driver side for ease of visibility. When deciding how the housing will be mounted, it was universal in each of the concepts to have a clamp with a ball in socket. The first option was with no arm between the cases socket and the bar clamps ball. The second option included a long socket-arm between the bar clamp's ball and the case's ball so that it would extend further into the view of the driver. The third option is like the second but with a short arm. The arm was chosen to increase the degrees of freedom for people of varying heights.

	Ball in socket mount (no arm)	Ball in socket mount with long arm	Ball in socket mount with short arm
Degrees of freedom	4	1	1
Human Factor consideration (Line of sight)	3	3	1
Grip	1	2	2
Cost	1	2	2
Team Opinion	3	2	1
Total	12	10	7

Figure 50: Arm mount decision

5.8 Engineering and Other Analysis

Solar Cell Lockout

The 'normally open' limit switch is placed so that the lower solar cell will actuate it and complete the ignition circuit only when the lower panel is securely in the closed and locked position. The leads of this limit switch were used to interrupt the ignition circuit as shown in Figure 51 below.

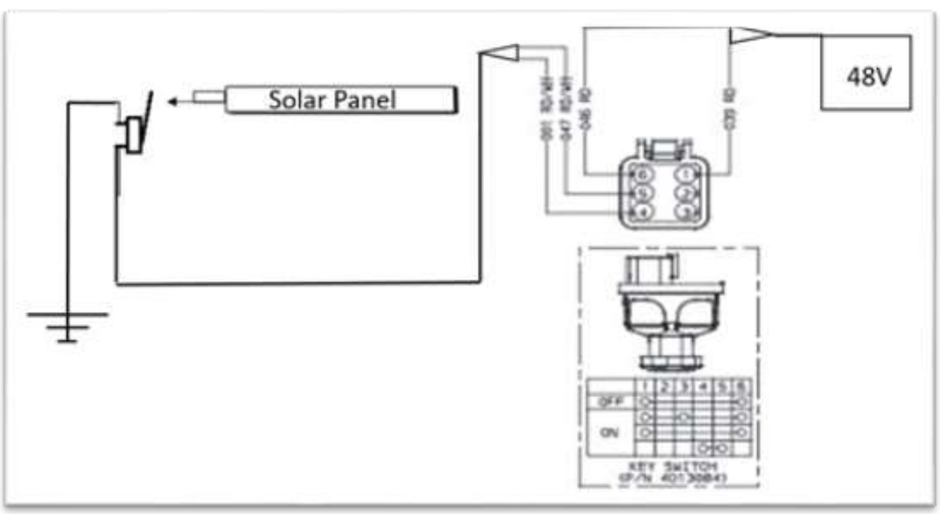


Figure 51: Solar Cell Lockout Diagram

By interrupting the ignition at this location, the operation of the vehicle is prevented when the solar cell panel is out of the locked position. This is a safety enhancing feature that will prevent damage to the UTV. The lower panels sliding rail support structure was designed for stationary use. The added and irregular forces associated with operating this UTV in its intended environment could lead to a structure failure and potential harm to the operator. This design has been completed and implemented.

Propane Service

After being tasked with figuring out why the generator was "running lean," our preliminary investigation concluded that the generator was receiving propane in the wrong phase. The previous team had installed a forklift propane tank. The forklift tank installed provides liquid propane. It was evident from the capped gasoline intake line, which terminates into the carburetor, that the liquid fuel needed vaporized for injection. It was observed that the propane service line terminated just after the carburetor, meaning that no mechanical vaporization would be allowed for. Upon installation of a standard 20-pound propane tank with a vapor service line, the generator was tested for operation and ran effortlessly. The propane tank mounts were relocated on the UTV bed as shown in Figure 52.

Figure 52: LPG Location

This location allows for easy removal and replacement of propane tanks. It was also noted that this design increases the ease of operation by allowing for "over the counter" propane tank usage. The need for special propane tank refill equipment is now gone. The new fuel line system will utilize 6AN lines to ensure longevity and durability of the fuel lines. This configuration incorporates an actuator bypass valve as seen in Figure 53. This valve will be manually operated by removing the seat when there is no power available to the controller and thus no way of actuating the propane service to supply the generator.

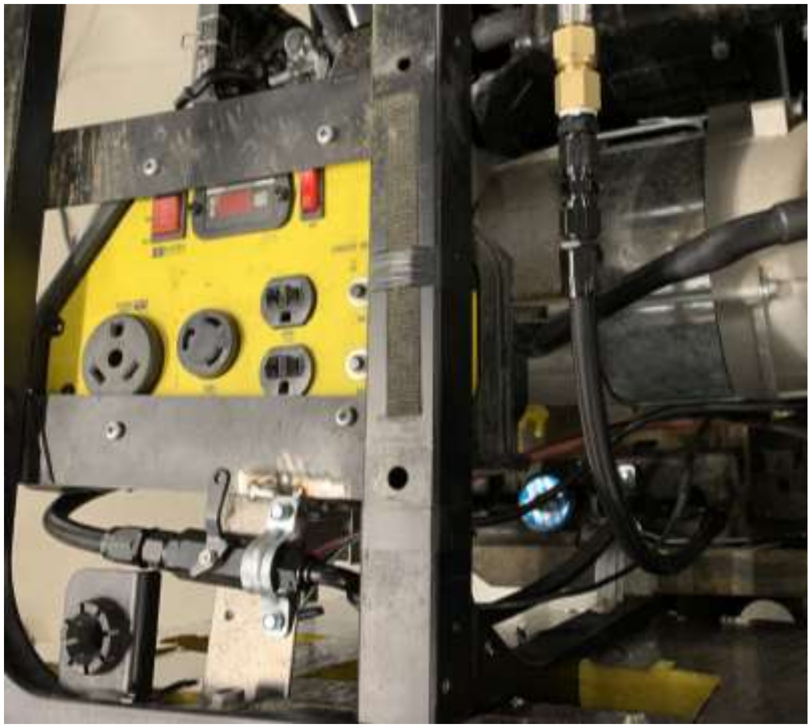


Figure 53: New Lines

Upon opening this bypass valve the operator can then pull start the generator utilizing the door installed in the side panel. This can provide charging to the battery box in situations where the solar cells are un-usable. To charge the batteries using this manual start, the UTV's wall charging cable will have to be plugged into the outlet located on the side of the UTV and the wall charge switch located on the dash must be activated. This switch changes the no power relay positions from solar charging to wall charging. It will be noted that if the bypass is utilized, the valve must then be closed to turn the generator off and return to normal operation controlled by the actuator.

Figure 54: LPG Line Diagram

Propane Generator

The starter battery had been maintained using a battery charge controller which was plugged directly into the generators available 120V outlet. The generator, unsurprisingly, can maintain its own starter battery and thus the maintainer is unnecessary. Removing this redundant system freed up the outlet which was relocated and installed on the side of the UTV for normal utilization. Necessary GFIC and weatherproofing was applied as shown below.

Figure 55: Exterior Outlet

Speed Measurement

The addition of the speedometer was included as a potentially necessary device depending on the location of UTV as well as a general safety consideration. Having accurate speed information will increase the level of safety and allow speed limits to be followed. This speedometer relies on an Arduino Mega2560 to sample and process the information from the Hall Effect sensor located under the driveshaft and display the information on a thin film transistor (TFT) screen. The screen has been mounted to the roll cage bar according to ergonomic guidance from the project management team. The mount utilizes an arm on ball and socket joints to allow the orientation to be set according to driver preference. ABS was chosen to 3D print the case due to its comparative strength and weatherability the CAD drawing of the case can be found in the appendix 11.3.

Figure 56: Speedometer System

The logic for measuring the speed of the UTV is depicted in Figure 57. This code will record the time between readings until a set number of readings is met at which point the average time between readings will be used to calculate the speed of the UTV by the calculations shown below. It includes several proofing features including a timeout to reset the speed value to zero when UTV is stopped and a mapping function to evaluate and adjust the reading threshold for higher accuracy at various speeds. The full code is available in figure 58.

$$distance\ treveled(ft) = \frac{circumference\ of\ wheel(ft)}{3(drive\ shaft\ revolutions\ per\ wheel\ revolution)}$$

$$Vehicle\ Speed(MPH) = \frac{distance\ traveled(ft)}{time\ between\ sensor\ reading(s)}\left[\frac{mile}{5280ft}\right]\left[\frac{3600s}{hr}\right]$$

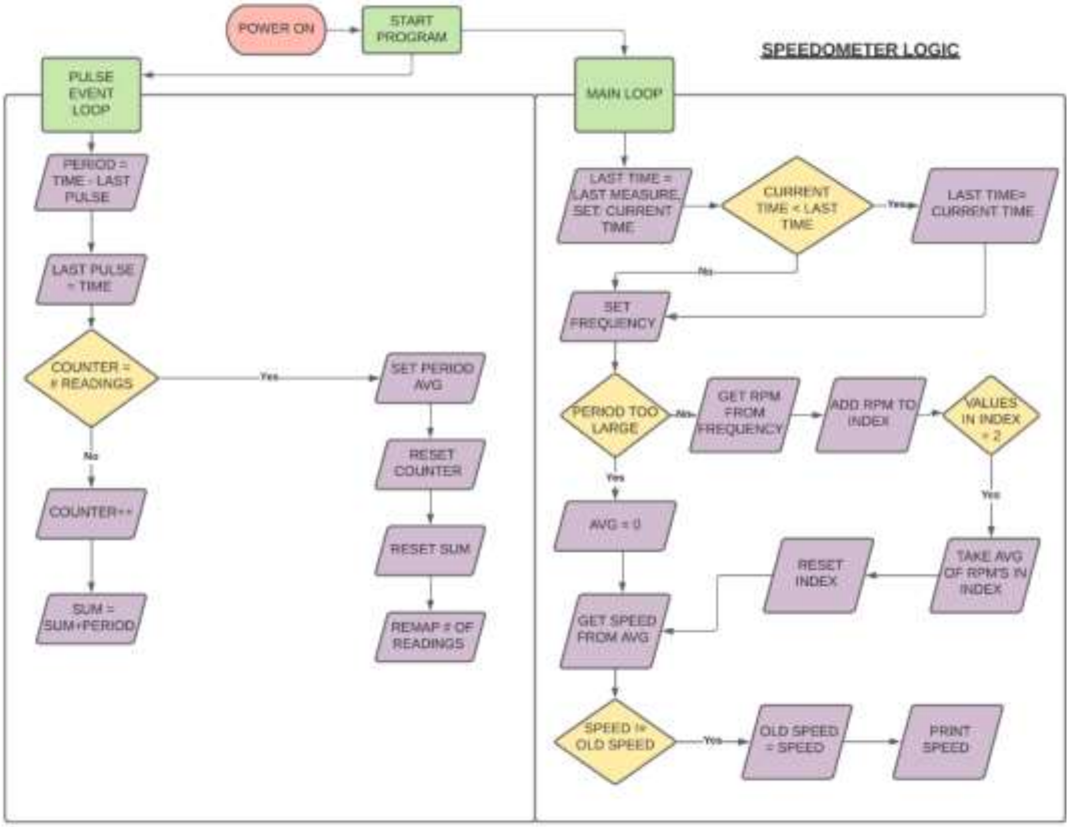


Figure 57: Speed Measurement Logic

```
#include <TFT_HX8357.h> // Hardware-specific library

TFT_HX8357 tft = TFT_HX8357();       // Invoke custom library

#define TFT_GREY 0x5AEB

const byte PulsesPerRevolution = 1;  // Set how many pulses there are on each revolution. Default: 2.
const unsigned long ZeroTimeout = 500000;  // For high response time, a good value would be 100000.
const byte numReadings = 2;  // Number of samples for smoothing.
volatile unsigned long LastTimeWeMeasured;  // Stores the last time we measured a pulse so we can calculate the period.
volatile unsigned long PeriodBetweenPulses = ZeroTimeout+1000;  // Stores the period between pulses in microseconds.
volatile unsigned long PeriodAverage = ZeroTimeout+1000;  // Stores the period between pulses in microseconds in total, if we are taking multiple pulses.
unsigned long FrequencyRaw;  // Calculated frequency, based on the period. This has a lot of extra decimals without the decimal point.
unsigned long FrequencyReal;  // Frequency without decimals.
unsigned long RPM;  // Raw RPM without any processing.
unsigned int PulseCounter = 1;  // Counts the amount of pulse readings we took so we can average multiple pulses before calculating the period.
unsigned long PeriodSum; // Stores the summation of all the periods to do the average.
unsigned long LastTimeCycleMeasure = LastTimeWeMeasured;  // Stores the last time we measure a pulse
unsigned long CurrentMicros = micros();  // Stores the micros in that cycle.
unsigned int AmountOfReadings = 1;
unsigned int SeroDebouncingExtra;
unsigned long readings[numReadings];  // The input.
unsigned long readIndex;  // The index of the current reading.
unsigned long total;  // The running total.
unsigned long average;  // The RPM value after applying the smoothing.
unsigned long speed_val;
unsigned int lastVal;

void setup(){
  Serial.begin(9600);  // Begin serial communication.
  attachInterrupt(digitalPinToInterrupt(2), Pulse_Event, RISING);  // Enable interruption pin 2 when going from LOW to HIGH.
  tft.init();
  tft.setRotation(3);
  tft.fillScreen(TFT_BLACK);
  // set speed to zero and print RPM
  int numxpos = 30;
  int numypos = 80;
  tft.setTextSize(2.25);
  tft.setTextColor(TFT_WHITE,TFT_BLACK);
  tft.drawNumber(speed_val,numxpos, numypos, 8);
  tft.setCursor(265, 100);
  tft.setTextSize(3);
  tft.setTextColor(TFT_WHITE, TFT_BLACK);
  tft.print("RPM");
  lastVal = 0;
  delay(1000);
}

void loop(){
  LastTimoCycleMeasuro = LastTimeWeMeasured;  // Store the LastTimeWeMeasured in a variable.
  CurrentMicros = micros();  // Store the micros() in a variable.

  if(CurrentMicros < LastTimeCycleMeasure)
  {
    LastTimeCycleMeasure = CurrentMicros;
  }
  FrequencyRaw = 10000000000 / PeriodAverage;  // Calculate the frequency using the period between pulses.

  if(PeriodBetweenPulses > ZeroTimeout - ZeroDebouncingExtra || CurrentMicros - LastTimeCycleMeasure > ZeroTimeout - ZeroDebouncingExtra)
  {  // If the pulses are too far apart that we reached the timeout for zero:
    FrequencyRaw = 0;  // Set frequency as 0.
    ZeroDebouncingExtra = 2000;  // Change the threshold a little so it doesn't bounce.
  }
  else
  {
    ZeroDebouncingExtra = 0;  // Reset the threshold to the normal value so it doesn't bounce.
  }
  FrequencyReal = FrequencyRaw / 10000;
  RPM = FrequencyRaw / PulsesPerRevolution * 60;
  RPM = RPM / 10000;  // Remove the decimals.
  total = total - readings[readIndex];  // Advance to the next position in the array.
  readings[readIndex] = RPM;  // Takes the value that we are going to smooth.
  total = total + readings[readIndex];  // Add the reading to the total.
  readIndex = readIndex + 1;  // Advance to the next position in the array.
```

```
  if (readIndex >= numReadings)  // If we're at the end of the array:
  {
    readIndex = 0;  // Reset array index.
  }
  average = total / numReadings;  // The average value it's the smoothed result.

  speed_val = average *(60 * 2.08 / 5280);

  if(speed_val != lastVal){
    lastVal=speed_val;
    if(speed_val >=10){
      //lastVal=speed_val;
      int numxpos = 30;
      int numypos = 80;
      tft.setTextSize(2.25);
      tft.setTextColor(TFT_WHITE, TFT_BLACK);
      tft.drawNumber(speed_val, numxpos, numypos, 8);
      } else{
        tft.fillScreen(TFT_BLACK); // needed to remove second digit when speed less than 10 mph
        tft.setCursor(285, 100);
        tft.setTextSize(8);
        tft.setTextColor(TFT_WHITE, TFT_BLACK);
        tft.print("MPH");
        int numxpos = 30;
        int numypos = 80;
        tft.setTextSize(2.25);
        tft.setTextColor(TFT_WHITE,TFT_BLACK);
        tft.drawNumber(speed_val,numxpos, numypos, 8);
        }
  }
}

void Pulse_Event(){
  PeriodBetweenPulses = micros() - LastTimeWeMeasured;
  LastTimeWeMeasured = micros();  // Stores the current micros so the next time we have a pulse we would have something to compare with.

  if(PulseCounter >= AmountOfReadings)  // If counter for amount of readings reach the set limit:
  {
    PeriodAverage = PeriodSum / AmountOfReadings;
    PulseCounter = 1;  // Reset the counter to start over. The reset value is 1 because its the minimum setting allowed (1 reading).
    PeriodSum = PeriodBetweenPulses;  // Reset PeriodSum to start a new averaging operation.

    int RemapedAmountOfReadings = map(PeriodBetweenPulses, 40000, 5000, 1, 10);  // Remap the period range to the reading range.
    // 1st value is what are we going to remap. In this case is the PeriodBetweenPulses.
    // 2nd value is the period value when we are going to have only 1 reading. The higher it is, the lower RPM has to be to reach 1 reading.
    // 3rd value is the period value when we are going to have 10 readings. The higher it is, the lower RPM has to be to reach 10 readings.
    // 4th and 5th values are the amount of readings range.
    RemapedAmountOfReadings = constrain(RemapedAmountOfReadings, 1, 10);  // Constrain the value so it doesn't go below or above the limits.
    AmountOfReadings = RemapedAmountOfReadings;  // Set amount of readings as the remaped value.
  }
  else
  {
    PulseCounter++;  // Increase the counter for amount of readings by 1.
    PeriodSum = PeriodSum + PeriodBetweenPulses;  // Add the periods so later we can average.
  }

}  // End of Pulse_Event.
```

Figure 58: Arduino Code

5.9 TESTING PERFORMED

To ensure our project met the goals as well as operated safely, we performed testing on the functionality of the solar cell lock out, manual generation starting, generator operation by controller input, outlet power, speedometer logic performance, and a propane line leak test. The solar cell lockout was tested with the oversight of Dr. Taylor. It was verified that the lockout prevented ignition when unlocked, cut power when opened during operation, and allowed normal operation when closed. For the “no power” start-up, the vehicle was taken to a well-ventilated area outside and the battery box was disconnected, meaning the actuator was stuck in the closed position. The bypass valve was opened beneath the seat and the pull start was utilized. Operation was verified and power was available as shown below.

Figure 59: Outlet operation

The generator operation by controller input was tested here as well, with the help of the controller team. The controller team used test code to simulate the starter function from the controller. All operations of generator performed as planned. The speedometer logic and functionality were tested with tools that we already had. Preliminary testing of the rpm reading was done using a fidget spinner with a magnet attached. The fidget spinner was spun at various speeds and the reading was assessed. After completing the code and installing the speedometer, the speed reading was verified by comparison with GPS speed data from a cellular application.

5.10 WORK BREAKDOWN OVERVIEW

Evan Brinegar

- Design management and overview, welding and fabrication, speedometer coding

Heba Alamri

- Electrical systems design, Mega2560 system fabrication

Cullin Snell

- Generator system design and implementation, team planning

Brandon Seodara

- CAD design, part procurement

6 CONTROLLER TEAM

6.1 PROBLEM DESCRIPTION

The controller team is tasked with combining the work of the DAQ, Controller, and UI team from the previous semester to seamlessly control which sub-energy system is charging the main battery and update a UI touch screen with pertinent battery and vehicle information. The control of the charging systems is to be controlled automatically through an electronic controller, not manually by the user. Solar panels and a propane generator have been installed and wired to function independently. The controller switches between these two charging systems depending on the voltage level of the battery, while the UTV is in use. There is also access to a wall plug to battery charging alternative for when the UTV is parked and not being used.

Along with the controller logic and programming, we overhauled the current wiring scheme and physical wiring. Previously, the layout was a combination of three different teams wiring all their respective components to each other. It was incredibly difficult to follow what was going where, and there were some safety concerns and general wiring practice deficiencies. Adding terminal blocks, reorganizing the controller box, and re-running the wiring from the back to the front, we will have a scheme that is much easier figure out where issues are in the event something isn't working properly. As well as ensuring all systems are safe and terminated properly.

The previous control – processor – UI display was composed of an Arduino to Raspberry pi ComfilePi system. The Raspberry pi was the decision maker and would tell the Arduino what to control after interpreting sensor data that the Arduino was collecting and sending to the Raspberry pi. It was incredibly inefficient and complicated. This system was developed as a proof of concept, and the resulting complexity was because three different teams of students were, essentially, working on the same system. On top of the logic complexity of having two controllers passing data and controlling one another, the Arduino was programmed in the C++ language, while the Raspberry pi was operating in python. Which meant that another program had to convert the C++ to python. When we began looking through the final reports and work done by the previous semester, it became very apparent that we would be starting over as far as the logic and controller scheme was concerned. The python code generated by the last teams totaled 10s of thousands. None of the current controller team members are expert programmers, so interpreting and understanding that amount of code in a semester is impossible. Let alone the fact that it didn't function properly in the first place.

We elected to change the controller from an Arduino to Raspberry Pi controller and UI setup, to a Velocio industrial PLC and Velocio HMI display. Because of the change, we designed a new mounting system for the controller itself. The design is as sturdy and secure as possible while still being removable for ease of reprogramming and future modifications.

6.2 OVERALL SOLUTION AND SUBSYSTEMS

6.2.1 Overall Solution:

Conceptually, our solution to the problems stated above are simple. We redesigned the energy sub-system control schemes and sensor input to a system that is controlled by the Velocio brand PLC and then uses the Velocio brand HMI to display sensor data. Implementing this solution was much more complicated. The basis of the implementation started with understanding what the previous semester had accomplished, and how they accomplished it. Analyzing the circuit and programming code was a necessary step to knowing what we actually had on our hands. Once we were familiar with the starting systems, we were able to come up with and implement a solution. The Velocio is responsible for switching a series of relays that connect different power sources (Solar or generator) to the battery, allowing the battery to charge. For the solar side of things, the only thing we are doing is opening or closing the path from the panels to the charge controller. For the generator, we use the Velocio to open the fuel line, allowing propane to reach the generator, and then activate the electric starter to start the generator. The Velocio also shuts off the fuel line and switches the solar relay back when appropriate. For HMI sensor display, the Velocio reads its analog in ports and updates variables within the code that the HMI reads and copies to the display. We use analog tilt sensors, and two voltage dividers to gain information on the pitch and roll of the UTV, as well as solar panel output and battery voltage level. Finally, we installed 2 safety switches. One that allows the UTV batteries to be charged via a 120v wall outlet, and one that is a master power switch for all the aftermarket screens and controller.

6.2.2 Subsystems:

Controller: The chosen model is the Velocio ACE5150c10. Below are relevant data points of the model (Ace PLCs, n.d.):

- 12x Digital Out- 3 to 30 VDC sinking transistor. 300 mA max.
- 12x Digital In- 3 to 30 VDC
- 3x Analog In- 12 Bit
- 1x RS232 Serial Comm Port
- 4.7 to 5.5 VDC Power Input

More data can be found in the ACE data sheet provided in the controller upgrade reference list. The 3 to 30 VDC digital output power is significant as the previous team were unable to output this much current. The overall theme with the Velocio components is simplification.

HMI Display: The model of HMI (human machine interface) we used is the HM-070BE. This model sports a 7” full color touchscreen. They feature a battery backed real time clock and some memory capabilities. The screen itself is IP65 waterproof protected, which just means the LEDs are water resistant (*Command HMIs, n.d.)*. There is a gasket that outlines the “rim” of the screen, allowing a housing to secure and waterproof the back of the screen which is where access to the comm ports and electrical internals are located (*Command HMIs, n.d.)*. This and more data can be found on the data sheet located in the controller upgrade reference list.

Velocio to HMI communication: Conceptually very simple, but confusing to understand in the program. Essentially the controller creates variables called “tags”. These tags can be assigned directly to a port on the controller or created and manipulated with assigned values in the programming itself. The tags assigned to the ports will directly relay whatever info that port is receiving and update in real time. Analog ports will read 0-4010, and digital parts will read 0-1 for LOW and HIGH. There’s a button at the top of the software called modbus. There you can generate modbus addresses for each tag individually. The HMI will read these addresses, in real time, and copy whatever value that tag is and update the display screen with it. That is the only programming necessary is auto generating addresses and telling the HMI which address goes where on the screen. YouTube is your friend for understanding this as you can see what’s actually happening. It’s very unique to the Velocio from what we can tell.

Generator Control: Generator fuel line and electric started are controlled by the Velocio.

Charging Source Control: The Velocio controls a relay that switches the solar panels off anytime the generator is the power source charging the battery. A safety switch allows you charge the battery with a standard wall plug by turning the solar panels off and switching from the generator to the wall plug.

Battery Voltage Sensor Input: The Velocio reads the Battery voltage through its analog port, The analog ports can only handle 0-10V so a Voltage divider circuit was designed to put out 10V when the batteries are at full charge.

Tilt Sensor Input: Two 5v analog tilt angle sensors taped to the side of the control box provide a signal to the Velocio which is interpreted into an angle

Solar Charging Sensor Input: To show when the solar panels are the charging source a digital high and low signal to the Velocio was used. Because the voltage from the solar panels changes from 32V to 64V depending on if the second solar panel was being used a voltage divider was used to lower the voltage.

6.3 ENGINEERING PRINCIPLES

Data Acquisition: We collected the data that was created by the previous team, and we made changes to it. The main thing we did was to get rid of the Arduino and Raspberry Pi and introduce the Velocio controller.

Computer Programming/ Coding: The Velocio controller had to be programmed and Velocio already created a playlist that described how to program the controller. All we had to do was follow the steps on YouTube to create the program. Our design is very code heavy and required a lot of research and testing.

Computer Aided Drafting: Using software (SolidWorks) to design and produce precision designs to be manufactured and used in the fabrication process. This was used when creating our box to hold all the different components. The design of this box will be discussed further in later sections.

Circuits: Implemented changes to electrical system functionality by using loop analysis as well as understanding power consumption versus supply. An updated wiring diagram was created for our design. The new wiring diagram was based on the previous semester's design, but we added and removed certain components such as relays.

Failure Analysis: To do this, we didn't have many calculations to do or consider. One of the possible failures we considered was how the devices/components would fit into the box properly while also creating space for the wiring. We managed to create enough space in the box to mitigate any failure possibilities. An additional mitigation includes having the terminal block and Velocio on the DIN rail.

6.4 EHS Considerations

COVID-19: With Covid-19 happening we are as a team responsible to make sure that everyone be aware of CDC and university guidelines. Also, we ask every team member to stay home when feeling sick, and we encourage the use of face masks.

Safety/Electrical safety: Our team is taking safety measures very seriously for this project. For safety concerns, we are following all codes and standards that have been chosen for the system. Also, we make sure that each one of us has taken the safety quizzes for the desired system. For electrical safety concerns, it is important to know how much current and voltage is allowed to be driven through each part of the system to avoid any electrical sparks and fire hazards. The system we are developing must be waterproof to avoid any disconnections.

Ethical and professional: For this project we are all required to work professionally and seriously. As engineering students, we must follow the engineering codes of ethics, be honest about our work, work within our area of knowledge, and report any problem in a truthful manner.

6.5 Engineering Codes and Standards

American Wire Gauge: The American wire gauge table must be followed to choose the right electrical wires size traveling current in the system (AWG wire gauges current ratings, n.d.). AWG will be followed for all wires in this project. This was used extensively when designing the new wiring system.

NFPA 70: National Electrical Code for safe installations and design for electrical systems (NFPA 70, n.d.). When designing the system, it will help us to ensure safe electrical installation to avoid any violations and know all the electrical needs. This is especially important for our design as we are working with mainly electrical components. When installing the new system, we need to be aware of proper safety protocol to be used when handling our electrical equipment. This is very similar to the issues presented by the generator team.

6.6 Knowledge Acquisition

Wiring Schematic and Prior Work Done: The final reports from the DAQ, Controller, and UI teams from last semester provided us with a solid base level to start from. Their pictures and calculations and logic diagrams were paramount in getting us up to speed rapidly, as we needed to consolidate information as much as possible. The first week and a half we dug in to as much information as we could find.

Meetings and Communication with Mentors: Our mentor, Dr. Taylor, started us down the right path by suggesting the Velocio controller. We have also leaned on Dr. Taylor and other faculty members for advice on how best to implement logic and gain a better understanding of what work was already done to the UTV.

Velocio PLC programming: Fortunately for us, Velocio has an official YouTube channel with video tutorials for many different programming scenarios. The videos dedicated to general programming, subroutines, and HMI utilization have been crucial to quickly and efficiently understanding how to program the controller. Velocio also provides a free ACE controller programming user manual as a text-based reference for how to use their controller.

Controller box design: Made use of SolidWorks instruction while creating the box and some of the components and devices in the box. Watched a couple of videos on YouTube that described how to use certain functions on SolidWorks while designing the box. I also talked to Dr Taylor with regards to how we can avoid the possibility of vibrations and we came up with the idea of using an anti-vibration pad inside the box.

6.7 Concept Evaluation

For the concept evaluation, the first thing we did was to compile the previous work done by the spring 2021 controller team. We then made the decision to switch from Arduino to Velocio for different reasons. Some of the few reasons we went for the Velocio controller in comparison to other controllers was because it is easy to program and debug the Velocio controller, it was also a cheaper, and is industry grade standard.

We also built a new base plate for the circuit box to accommodate enough wiring while having enough space and clarity for the wiring. It is important we account for the wiring so that if any other team wants to go through it, they can easily go through the process without much difficulty.

Below is a table showing a breakdown of how we made our decision when selecting what controller to use, 1 is the best 3 is the worst.

Concept Evaluation

Modifications needed/choice made

- Replace Arduino with Velocio
- Replace ComfilePi with Velocio Command HMI
- Make a bracket for the new display, and build a new mount
- With the upgraded power of the Velocio, we might be able to eliminate some relays and simplify the wiring.

- Choice: Total Velocio System
- Cheap to Install
- Simple Programming (Abundant Resources)
- Co-Developed UI Display
- Industrial grade quality and functionality

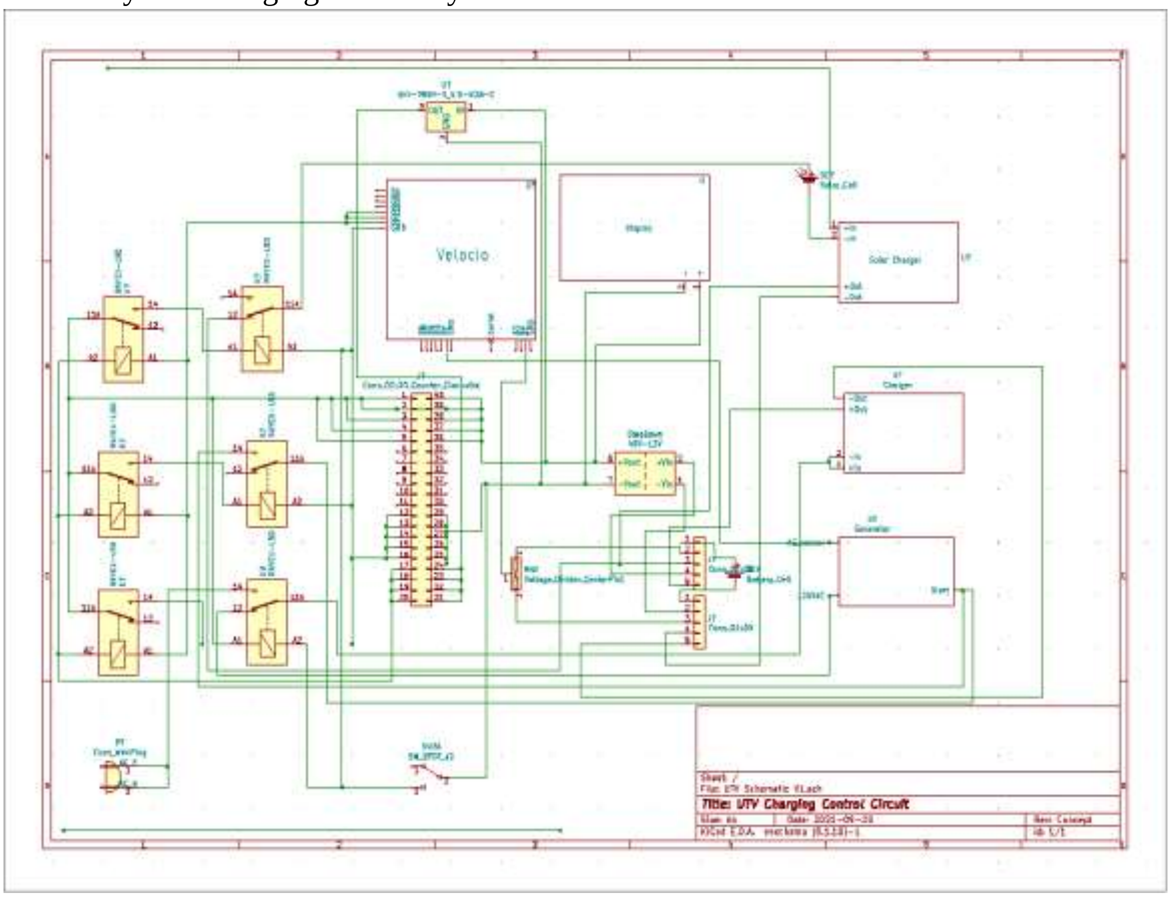
	Arduino + Raspberry Pi	Velacio + Raspberry Pi	Velaco controller and Display
FMEA (total RPN)	2	3	1
Environmental	1	1	1
Health and Safety	1	1	1
Ethical	1	1	1
Usefulness	3	1	1
Cost	1	2	3
Ease of Modification	1	3	2
Estimated Time Requirment	3	2	1
UTV Modification	1	2	3
Team Opinion	3	2	1
Decision	17	18	15

Legend	Rating
Worst	3
Average	2
Best	1

6.8 ENGINEERING AND OTHER ANALYSIS

6.8.1 Circuit Design:

Improving on last semesters design it was decided many of the relays needed to control the circuit could be eliminated. To do this the circuit was designed to default charging through the solar panels by using the normally closed path of the relay connected to the positive output of the solar panel. The whole system uses two battery charging devices the solar charge controller and the standard charger powered by 120VAC, the Standard charger is then powered by either the generator or the wall outlet. The generator is the default path for the AC charger and the way the program works the solar charger is turned off before starting the generator, so you never have more than one system charging the battery at once.



6.8.2 Sensor Reading

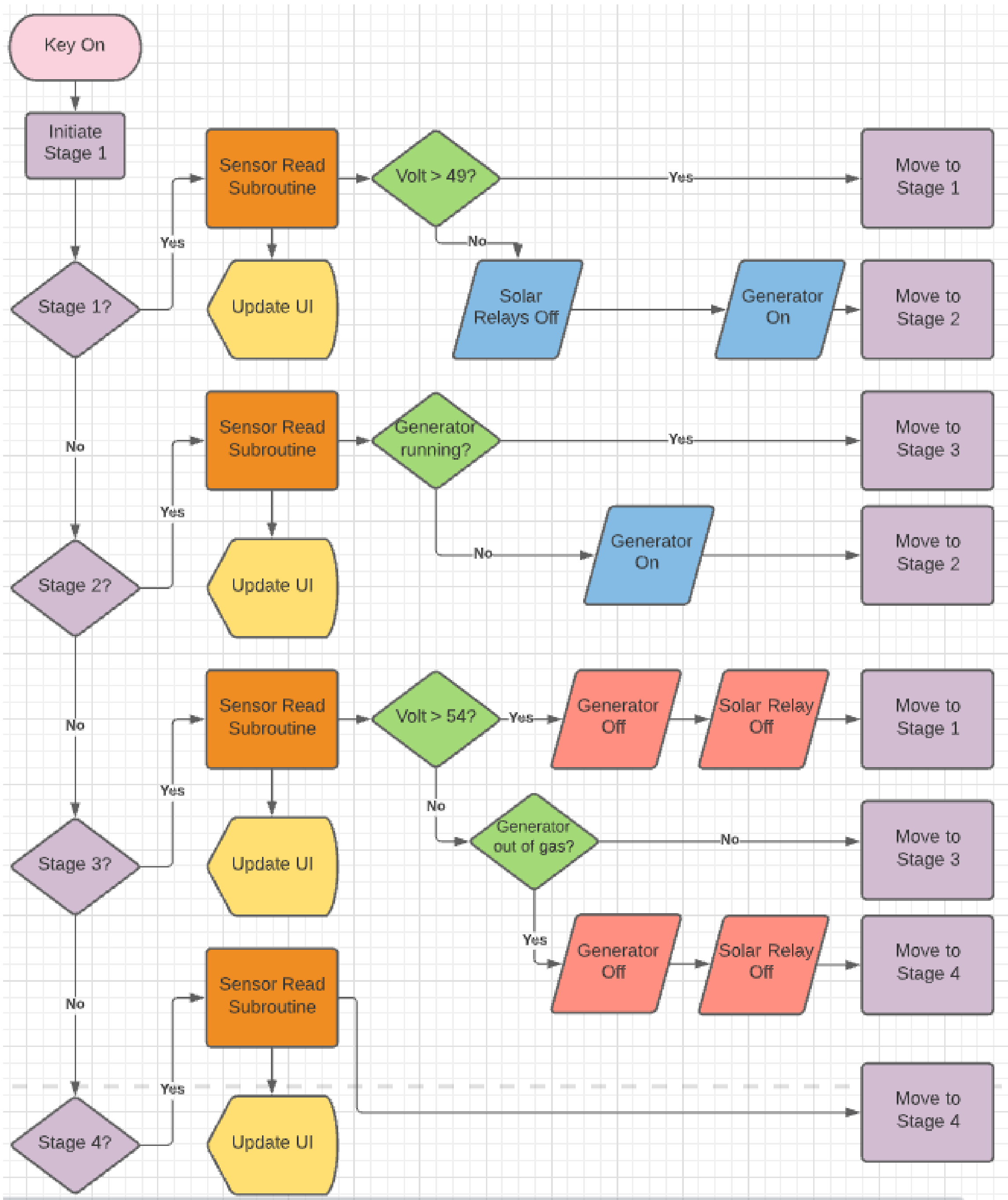
We have two different types of "sensors" we are reading. The generator and solar checks are both digital inputs. These ports are purely just reading if the respective port is receiving power or not. Voltage dividers are used to scale down the voltage to appropriate levels for the Velocio.

The other kind are analog sensors. There are 2 analog tilt angle sensors. These output a voltage that's dependent on the angle the sensors are sitting at. These sensors we have are very cheap don't seem to actually work. They both generate totally different voltages and have two different ranges they operate in. We would advise purchasing better sensors to accurately and consistently output appropriate voltages. The battery voltage is also read through an analog read port on the Velocio. A voltage divider scales down the voltage and then the signal is converted to a scaled and usable voltage value to be used in the program.

6.8.3 Controller Programming

<u>Logic:</u>

The Velocio dramatically simplified the amount of logic required to control the switching of the charging systems, control the functionality of the generator, and upload and display information on the UI display. As stated in the problem statement, the previous semester's programming posed a serious problem to our ability to pick up where they left off. The volume of code was far too expansive for novice programmers to attempt to understand and debug. The programming for the Velocio is incredibly simple in comparison, and much faster to "code" as there isn't much coding to be done. The code itself will be detailed in a later section. As for the logic, the program for the system switching was developed as a state machine of sorts. The system can be in 1 of 4 different states. Each state references a battery level and which energy source is charging the battery. At the same time, each time the controller starts a state, it collects battery voltage level information and allows the display to update with the collected data. Below is a flowchart diagram of the logic:



The diagram has been color coded for ease of reference; light Pink is the start of the logic, Purple refers to the states/stages of the system, Orange is the DAQ subroutine, Yellow refers to the HMI pulling data from the controller and updating the screen (has almost 0 impact on the controller logic, explained later), Green are decisions the controller makes, Blue is switching from the default start of the system, dark Pink switches back to the default state. Below describes what each stage is and does:

- Stage 1: the first state of the system. The stage starts by determining if the battery level is below our "low" threshold. If the battery has plenty of power left, the program loops through this stage. If the battery falls below the threshold, the controller flips the solar relay and runs through a generator start sequence that carries over into state 2, then progresses to stage 2.
- Stage 2: Since turning the generator on isn't as simple as flipping a switch, this stage is for checking the status of the generator, and restarting the generator start sequence if the previous iteration was unsuccessful. After confirmation the generator is running, the program moves to stage 3.
- Stage 3: This stage will loop until one of two things happens; either the battery charges to just shy of full power, or the generator stops producing power to the battery (most likely means out of propane). If the battery sufficiently charges before the generator runs out of fuel, the controller will flip the relays back to the default position, turn off the generator, and advance the program back to stage 1. If the generator runs out of fuel before the battery is charged all the way, the controller will recognize that, flip relays back to default positions, shut off generator, and advance the program to stage 4.
- Stage 4: The point of this stage is to ensure that the display remains updated with current information and ensures that the program will continue to run with the solar panels being able to charge the battery.

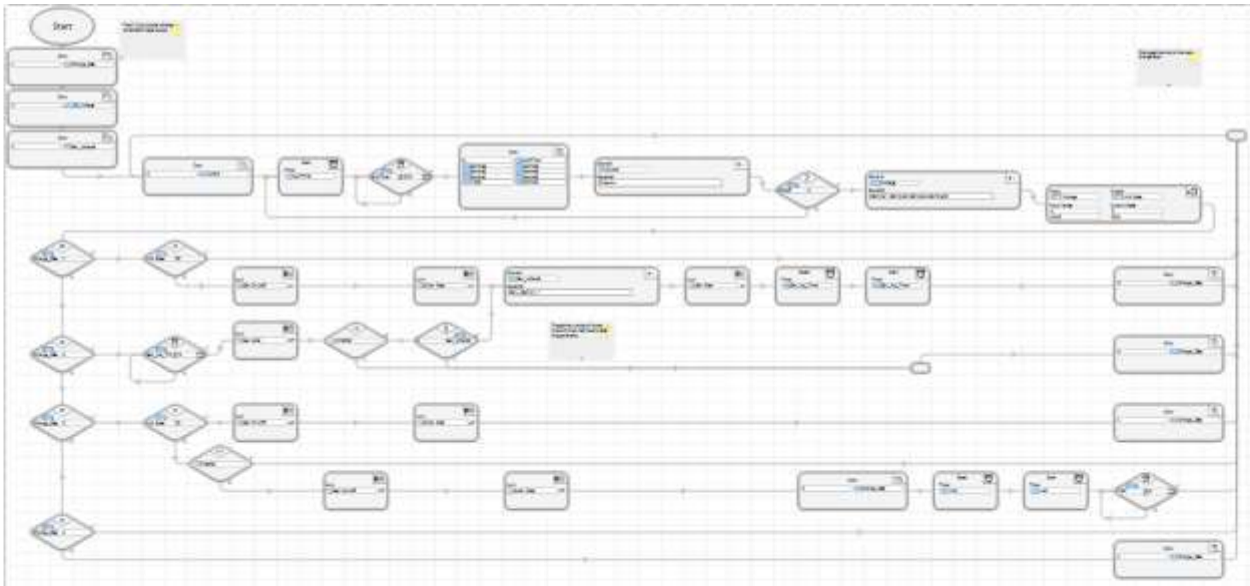
The logic and the wiring scheme are co-developed for ease of programming, as that is the area of work the team lacks the most experience in. At the same time, we made the wiring much simpler by discussing what the controller would be doing.

Programming:

Velocio created their own free programming software for their controllers called vBuilder. This software utilizes graphical depictions of what the controller will be doing/checking which makes programming the controller incredibly simple. Essentially, the flow chart above is imported into the software and wired for the controller to use. Once all the usable blocks' purposes are understood, it really is as simple as giving the controller the logic you want to run. Even variable assignment and manipulation is easy and intuitive. To really understand what is happening in the program, there are a few things that must be considered:

- The path from the solar panels to the battery is default CLOSED
- The path from the 120vAC charging outlet is default OPEN
- The path from the generator to the 120vAC charge controller is default CLOSED
- The propane gas line regulator is default in the closed position (blocking fuel flow) which is default OPEN to the controller
- The generator starter actuator is default OPEN

These concepts are the only thing that gets confusing with the programming. Understanding that we are, mostly, energizing relays at certain points to change the active path of electricity is key to reading the flow chart. Below is a Picture of the program. (I tried a few ways to present the information, but it being a large flow chart, doesn't scale very well in a word document.)



We would advise zooming in on the document itself or saving it as an image and opening it with different software. Below is a chart for pin assignments:

Digital out:		Digital In:		Analog In:	
Gen.Start	D1	InBitB1	B1	Vread	A1
Gen.Shutoff	D4	InBitB2	B2	Ini16A2	A2
Solar.Relay	D5			Roll	A3

How the program works. The first two blocks initiate three variables. Charge_Step =1, B_voltage = 0, Gen_attempt =0. Then the battery voltage read is executed. The velocio collects 4 readings a second and then averages that number. The average is then converted to a voltage which is used to control when the generator turns on and off. The voltage level on the HMI is referencing the 12 bit signal at the analog port itself.

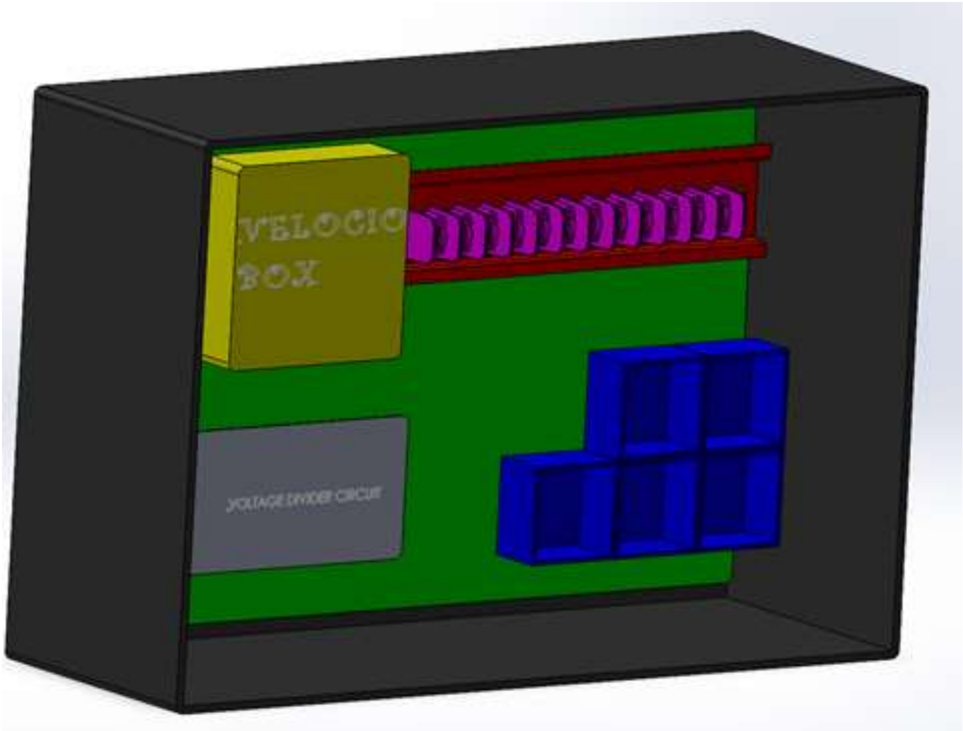
Then the program moves to stage 1. Stage 1 compares voltage to 49. A voltage of 49 signifies that the battery is approximately 60%. If voltage is above 49v, then the program loops through the DAQ subroutine and through the top part of stage 1. If the voltage falls below 49v, then pins D4, D5 are energized first. This switches the flow of electricity from the solar panels and 120v wall power to solely the generator. D1 is energized, which is the actuator for starting the generator. A Reset Timer block sets the Gen_Acc_Timer to 0s and then a Start Timer block begins the timer. Finally Charge_Step is set to 2.

Stage 2 starts by comparing the Gen_Acc_Timer to 3s. If the timer is not at 3s yet, the program loops back through stage 2. Once the timer is at 3s or longer, the actuator is turned off and B2 is checked for HIGH or LOW. Generators don't always start on the first try, so this check will send the program back through the bottom path of Stage 1 to re-energize the actuator and restart the timer if the controller reads LOW at pin B2. If B2 is HIGH, Charge_Step is changed to 3, and the program moves to stage 3.

Stage 3 starts by comparing voltage to 54. 54v was selected as a voltage that is 1-2% shy of 100% of a 48v battery. If the voltage is above 54v, the controller turns off D4 and flips the solar relays back to default positions and resets the program back to stage 1. If the voltage is not high enough, the program moves down and checks B2 again. *This step is in there to make sure the generator is still running, as this stage will be looped many times before the battery can be sufficiently charged (if ever) by the generator. More than likely, the generator will run out of propane before the battery reaches 98-99%. So, this check is necessary to make sure that the generator is still being utilized. If the generator is still running, the program will keep looping through stage 3. If the generator is not running anymore, the controller turns off D4 and flips the solar relays back to default positions. At this point, we only want to stay in solar mode, so we move the program to stage 4.

Stage 4 loops through reading the battery voltage and back through stage 4, effectively acting as a display updater. The generator is inoperable, so we don't want to attempt to start it anymore. This means we no longer need the other steps.

6.8.4 Box and Mounting Design



The components/devices in the box are Velocio controller, voltage circuit divider, DIN rail, terminal block, and relays.

The first thing we did was create a prototype of what the inside of the box would look like. While doing this we took into consideration the measurements of everything that would be going into the box, so we made sure each item was properly measured. The purpose of doing this is to make sure we are not trying to put in devices that can't work or may be too big to fit. To create the model above the first thing we created was the box, then we created a base plate which has five box spaces that would hold the five relays we plan to use. We also created a lookalike of the Velocio controller, DIN rail and the terminal block. Everything with regards to the box and its component has been color-coded to easily identify them.

When installing these components, we must account for different things to make sure everything fits in perfectly. One of the main things is vibration. It is important to make sure that everything in the box is properly installed and rigid while also being easy to remove. Installing a slightly thick anti-vibration pad will help this as it would prevent the devices in the box from moving and creeping. An example of how this is will work entails us gluing the pad onto the base plate and screwing the DIN rail which will hold the Velocio and terminal block onto it. For the DIN rail we could either 3D-print it or purchase it and that is a decision that would be made with the group because buying or printing has its advantages and disadvantages. If we were to purchase the rail it would come with its own screw which makes installing very easy in comparison to 3D printing. Our idea is to 3D-print a prototype to see how it would work and fit into the box, that way we would get a physical idea/view of what we are working with. From this we could decide if the 3D printed prototype will work or if we need to purchase the DIN rail. The tables below show the color coding used in the box as well as the dimensions of components in the box.

After simulating the box with the prototype and SolidWorks drawing we created, we finally got our hands on the physical devices. We mounted everything into the box, and all the components fit in properly. There was enough space to still add other components if we needed to. This means that we were able to meet our goal of creating space in the box and making sure it is tidy enough for anyone to trace the connections and the wiring throughout the box.

Color-coding for Box:

Color	Device/component
Black	Box
Blue	Relay space
Grey	Voltage divider circuit
Red	DIN rail
Purple	Terminal block
Gold	Velocio controller
Green	Base plate

Dimensions table

Device/Component	Dimensions (L x W x H)
Circuit box	12” x 7” x 3.63”
Velocio	2.5” x 2.5” x 0.25”
Velocio DIN rail	10” x 1.37” x 0.29”
Anti-vibration pad	12” x 8” x 0.125”
Relay	1” x 1” x 1.4”
Terminal block	6.46” x 1.18” x 0.75”
Tilt sensor voltage divider	3.5” x 2” x 0.04

6.8.5 Trouble Shooting

-Velocio turning on when not supposed too. *design change

Determined the power source for controller is not ran through key switch

A master power switch was installed to control when the UTV uses Velocio controlled systems.

-Arduino not turning on *fixed

The + and – wires didn’t follow the color standard we have and the wires were connected incorrectly.

-Generator shut off Velocio, HMI, and Arduino *fixed

Blew a fuse near the battery (replaced fuse)

-Why did fuse blow? *fixed

Bad/ confusing wiring from previous semester

-Vel, HMI, Arduino not turning on again *fixed

We blew the 48v – 12v DC-DC converter when the new battery connectors got incorrectly installed and caused the batteries to be connected backwards.

-Fried Velocio controller *fixed

When trying to measure Voltage an accidental short from the probe caused a 120V surge that fried a 12V power supply and damaged the Velocio.

Replaced with new controller and found safter points to measure voltage.

-Various programming changes *design change/fix

Removed analog read subroutine, fixed data type issues, fixed timing issues, fixed voltage level issues, calibrated analog sensors

-12v step down not powerful enough to fully activate starter *fixed

Switched power source for starter back to separate 12v battery

-Burnt up Velocio *fixed

Valve actuator caused to much current to flow through the Velocio digital out ports Causing it to melt and burn.

Moved actuator energization to a double relay system using smaller relay the Velocio can handle.

-Generator check stepdown/convertor created to change AC to DC for Velocio read *fixed

-Velocio digital out ports stuck on high *fixed

Large relays drew too much current when more than one was energized at once.

Now use Velocio to energize smaller relays which control the larger relays

6.9 Testing Performed

<u>Programming:</u>

Each piece of the program was broken out into a separate program and tested independently (generator functionality, analog reading, all version of display updating, even testing how timers work.). The programming software has a debugging mode which will allow you to reference variables and check port status mid program. As well as start and start the program at any point. The testing programs will be provided.

System Testing:

The entire system can be divided into smaller circuits the ones that could, were tested in the lab using a variable power supply and voltmeter. The voltage divider chips were tested for accuracy, the tilt sensors were tested and calibrated for correct measurements, the Velocio was tested for relay control and power output, The AC sensor was tested for current output and speed of output. Once assembled the solar panels were tested for continuous charging next the generator was started after lifting and taping some wires the charging voltage was checked and the power indicator on the charger was observed. Lifting more wires to simulate the safety/wall charging switch the plug was plugged into the generator outlet to test the wall charging capability. Once everything passed a full system test was ran to make sure everything operated when and how it was designed.

6.10 WORK BREAKDOWN OVERVIEW

Cody Vinyard

- Lead Programmer
- Team Leader
- Problem description
- Overall solution and analysis
- 6.8.3, 6.8.4
- Testing performed
- File consolidation

Levi Weaver

- Electrical Lead
- Wiring Lead
- Circuit Design
- Chip design
- Soldering
- Overall Solution and Subsystems
- Troubleshooting
- Testing Performed
- Installation of all electrical components

Temidayo Folarin

- Solid works creation of box
- 3D printed base plate for components
- Team knowledge acquisition
- Engineering codes and standards
- Helped with installation of components into circuit box

7 Costs

Cost Breakdown	
Subteam	**Amount Spent**
Human Factors	$281.03
Battery Cart	$6,098.61
Solar, Generator, and Speed Measurement	$347.85
Controller	$597.69
Miscellaneous	$1,097.75
Total	$8,422.93
Budget Given	$10,000
Amount Left	**$1,577.07**

Table 8: Cost breakdown for each sub team

Our team was given a $10,000 budget from our project sponsors and mentors, which allowed us to pursue expansive projects. With this budget in mind, the team wanted to ensure that we were using the budget wisely and efficiently. As seen in the table above, a greater deal of the budget was sent to sub teams that required a greater deal of mechanical and fabrication work, which was mostly due to the cost of materials in today's world. The teams dealing with more electrical and piping work did not need a substantial amount of the budget due to the fact that a lot of the wiring and piping was already in the UTV, but just needed adjustments and/or improvements.

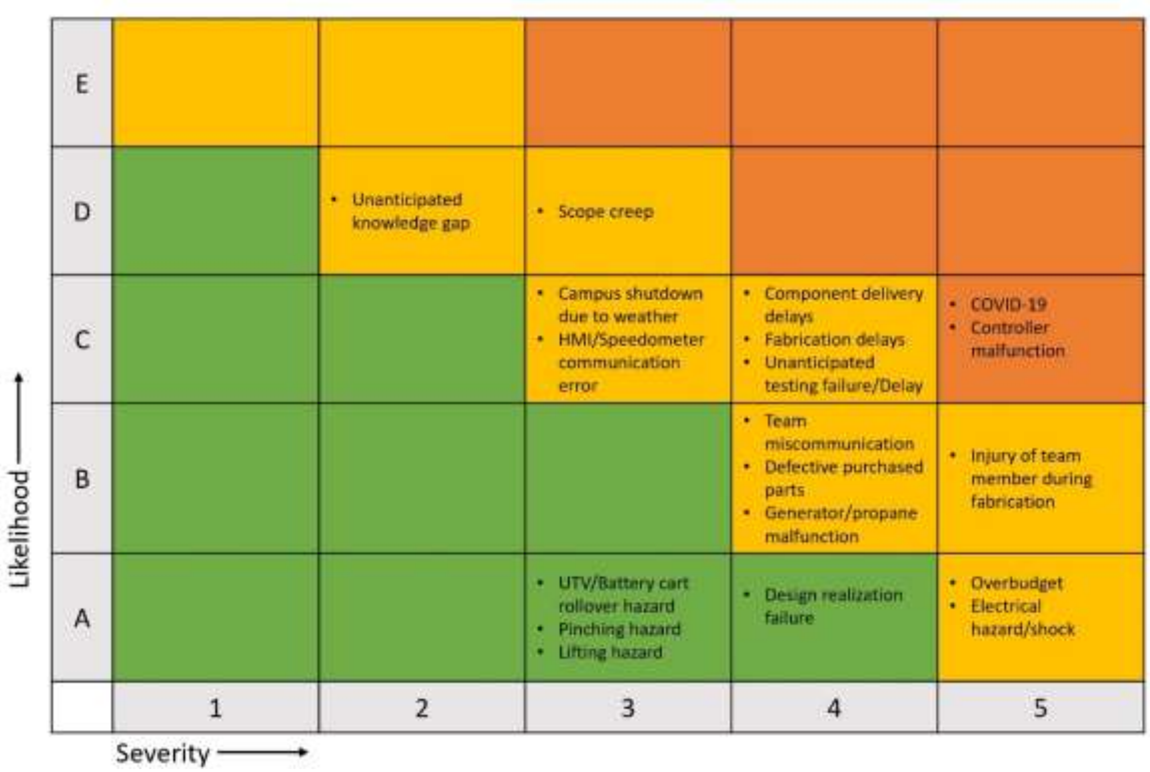
Going into the critical design report presentation, our team had estimated that we would need to spend $5,435.00 (Appendix 11.5) to complete all base designs. But as with any project, further expenses presented themselves during the fabrication phase. These additional expenses included things such as additional nuts and bolts, raw materials, electrical equipment, etc. Some of the ways we could have avoided these additional expenses during fabrication revolve mostly around double checking our work before doing certain things. For instance, our team had to reorder certain items multiple times due to incorrect sizing. This could have been avoided by ensuring that the sizing and measurements were correct before ordering originally. Secondly, our team ran into a few issues with electrical and piping equipment malfunctioning during testing. These issues mostly stemmed from not ensuring proper connections of piping and wiring before energizing the UTV. Lastly, our team could have saved money by taking advantage of local vendors for items to avoid shipping. A lot of our team's items could have been sourced from Lowe's which would have erased a great deal of shipping costs.

Also, a copy of our complete ordering sheet is provided at the end of this document in Appendix 11.6.

8 RISK MANAGEMENT

Our team has created a detailed risk management plan that addresses potential cost, scheduling, and testing risks that have or can affect the success and safety of the overall project. Some of the key risks that have been identified and addressed are being overbudget, injury while operating the battery cart/UTV system, component delivery delays, and unanticipated testing failures or delays. Our team addressed the risk of being overbudget by ensuring that all costs regarding the project were reported to the procurement liaison to keep an accurate record of what has been spent in total. The risk of injury while operating the battery cart/UTV system has been addressed by ensuring that proper operating procedures and equipment are outlined in the SOP and are acknowledged by the operator before use of the UTV. The potential risk of having delivery delays when ordering certain components was mitigated by ensuring that the team allotted sufficient time for bigger orders while also ordering from reputable vendors such as Amazon, Grainger, or McMaster-Carr. The team has also utilized local vendors such as Lowe's and Stillwater Steel to eliminate shipping risks when available. The last key risk the team has identified and mitigated was unanticipated testing failures/delays. This risk was mitigated by ensuring that enough time has been allotted for the testing of more complex aspects of our design such as the controller, but also ensuring to consult faculty and mentors when needed. Provided below is our risk management matrix and table with mitigations.

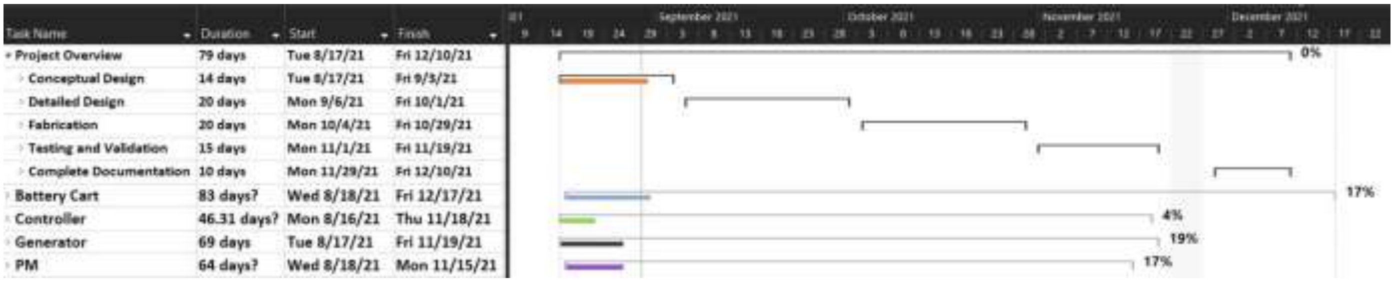
Additionally, some EHS risks that we needed to address are recycling used batteries, upholding the standards set forth by the university, and following codes and standards set out for fabrication and operation of the UTV. To address the danger of recycling used batteries, the team has set forth recycling instructions in our SOP that follow the OSU guidelines. In order to ensure that the team and project upheld the standards set forth by the university, we made sure that we followed all ethical and moral guidelines. Finally, our team followed all codes and standards that related to our project ranging from OSHA to NIOSH.



Risk	Risk Ranking	Mitigation
COVID-19	5C	Follow campus and CDC guidelines for COVID-19.
Controller Malfunction	5C	Ensure proper wiring before start up
Unanticipated knowledge gap	2D	Ensure all teams complete necessary research beforehand. Consider all engineering principles.
Scope creep	3D	Have discrete deadlines for research and design phases. Made sure each team had defined problems and chosen designs after PDR that were not modified.
Campus shutdown due to weather	3C	Ensure proper communication channels on Microsoft Teams.
HMI/Speedometer communication errors	3C	Ensure proper connections to Velocio and Arduino and check code for any potential errors
Component delivery delays	4C	Have backup plan for obtaining different components. Use reputable vendors and purchase parts as soon as possible.
Fabrication delays	4C	Make sure we have sufficient team members trained. Ensure NCL is made aware of fabrication requirements.
Unanticipated testing failure/Delay	4C	Ensure sufficient time is set aside for testing complex components. Consulting proper experts if help is needed.
Team miscommunication	4B	Have set procedures for handling disputes. Ensure all team members are consistently checking email and Teams.
Generator/Propane tank malfunction or fire	4B	Fire extinguisher added to UTV to protect against potential fire. Make sure propane tank is properly attached to ensure longevity of generator.
Defective purchased parts	4B	Make sure a backup plan is in place in the event that parts are defective.
Overbudget	5A	Ensure all costs are being reported to procurement liaison.
Electrical fire/Shock hazard	5A	Make sure the system is deenergized before checking any connections. Fire extinguisher added to UTV to protect against potential fire.
Injury of team member during fabrication	5B	Ensure no one is ever working alone and that property safety protocol is followed at all times.
UTV/Battery rollover/pinching/lifting hazard	3A	Ensure procedures outlined in SOP are adequately followed to avoid pinch points and lifting of heavy objects (e.g. batteries)
Design realization failure	4A	Have multiple design options for all design upgrades.

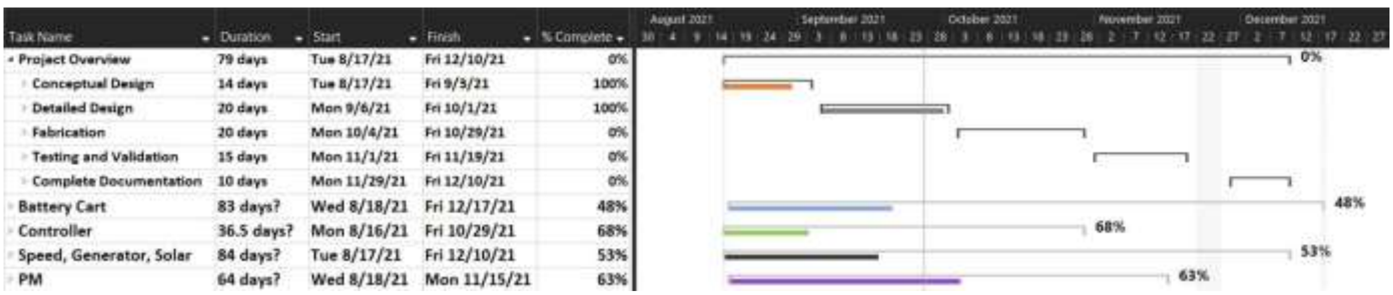
9 PROJECT PLAN

The project plan changed significantly throughout the semester. Before PDR our Gantt chart was very simple and included approximate deadlines and task for each phase of the project. We did not have specific tasks set for the testing phase or the fabrication phase as we were still determining what our designs would be. Once we entered the detailed design phase project tasks became much more specific and task dependencies became more significant. Additionally, our time frames changed frequently during this phase. By the time we got to the end of the detailed design phase we did not have many deadlines changing as we were approaching the end of the project. This was where task dependencies played a big role and overlap of sub team fabrication and testing became very important. Additionally, project percent completion was one of the biggest deviations between each project plan. During PDR the focus of the project plan was on the conceptual design phase and little detail was put in the detailed design and testing phases of the project. This was different for CDR where most of our detail was in the plan for the rest of the semester and tasks and time frames for fabrication and testing became much more detailed. Below is an image of our Gantt chart overview from the PDR phase.



Task Name	Duration	Start	Finish
Project Overview	79 days	Tue 8/17/21	Fri 12/10/21
Conceptual Design	14 days	Tue 8/17/21	Fri 9/3/21
Detailed Design	20 days	Mon 9/6/21	Fri 10/1/21
Fabrication	20 days	Mon 10/4/21	Fri 10/29/21
Testing and Validation	15 days	Mon 11/1/21	Fri 11/19/21
Complete Documentation	10 days	Mon 11/29/21	Fri 12/10/21
Battery Cart	83 days?	Wed 8/18/21	Fri 12/17/21
Controller	46.31 days?	Mon 8/16/21	Thu 11/18/21
Generator	69 days	Tue 8/17/21	Fri 11/19/21
PM	64 days?	Wed 8/18/21	Mon 11/15/21

As mentioned above or CDR plan changed significantly from PDR in the sense that most of our detail was focused more on the fabrication and testing phases of the project. This was the phase where deadlines in our Gantt chart became set and did not change significantly when compared to the final Gantt chart. The project completion percentages changed as we had completed the detailed design phase of the project. Below is a snapshot of our CDR project plan overview.



Task Name	Duration	Start	Finish	% Complete
Project Overview	79 days	Tue 8/17/21	Fri 12/10/21	0%
Conceptual Design	14 days	Tue 8/17/21	Fri 9/3/21	100%
Detailed Design	20 days	Mon 9/6/21	Fri 10/1/21	100%
Fabrication	20 days	Mon 10/4/21	Fri 10/29/21	0%
Testing and Validation	15 days	Mon 11/1/21	Fri 11/19/21	0%
Complete Documentation	10 days	Mon 11/29/21	Fri 12/10/21	0%
Battery Cart	83 days?	Wed 8/18/21	Fri 12/17/21	48%
Controller	36.5 days?	Mon 8/16/21	Fri 10/29/21	68%
Speed, Generator, Solar	84 days?	Tue 8/17/21	Fri 12/10/21	53%
PM	64 days?	Wed 8/18/21	Mon 11/15/21	63%

Some of the main things that we learned were allocating more time than we thought we initially needed. As tasks become more detailed it was apparent that more time would be needed to complete them. We also learned the importance of task dependencies and making sure they were accurate. During the fabrication and testing phases this became very important as certain components had to be tested for functionality before others could be tested. For example, the controller and the communication from the HMI. Without proper functionality of the controller, we could not test the information being displayed on our HMI. This was like testing the automatic turning on of the generator. We had to make sure the generator testing was complete before this could happen. Another important lesson learned was to frequently review the project plan to make sure remaining were on track to be completed. This required frequent review from each sub team and coordination among all team members. During the testing phase this was important as lot of testing overlapped for the sub teams. The project plans for PDR and CDR can found in appendices 11.1.3 and 11.1.4. The final Gantt chart has been submitted as a separate pdf along with this document and pictures of it can be found in Appendix 11.1.5.

10 REFERENCES

10.1 PROJECT MANAGEMENT/HUMAN FACTORS

Ayoub, H. S., Hussein, W. M., & Elbashar, Y. H. (2021). Investigation of automotive digital mirrors ergonomics through laser shadowgraphy and driver's real-road test questionnaire. *Journal of Optics, 50*(1), 95–108. https://doi.org/10.1007/s12596-021-00677-z

Download Softwares & Manuals. Support of ACE AUTOMATION Europe. (n.d.). Retrieved November 14, 2021, from https://www.support.aceautomation.eu/knowledge-base/softwares-manual/.

Giang, K. (n.d.). *Pla vs. ABS: What's the difference?* Hubs. Retrieved November 14, 2021, from https://www.hubs.com/knowledge-base/pla-vs-abs-whats-difference.

Gordon, Claire C. et. Al (2014). *2012 Anthropometric Survey of U.S. Army Personnel: Methods and Summary Statistics.* Defense Technical Innovation Center.

International Organization for Standardization. (2017, March 2). *ISO 9241-112:2017*. ISO. Retrieved September 22, 2021, from https://www.iso.org/standard/64840.html.

International Organization for Standardization. (2021, July 15). *ISO 6385:2016*. ISO. Retrieved September 22, 2021, from https://www.iso.org/standard/63785.html.

International Organization for Standardization. (2018, December 8). *ISO 1503:2008*. ISO. Retrieved September 22, 2021, from https://www.iso.org/standard/40302.html.

5-5/8" Long Rigid Connector for Ball-Grip Positioning Arm. McMaster-Carr. (n.d.). Retrieved November 14, 2021, from https://www.mcmaster.com/5031T68/.

Magnetic Base for Ball-Grip Positioning Arm. McMaster-Carr. (n.d.). Retrieved November 14, 2021, from https://www.mcmaster.com/5031T56/.

Niebel, B. W., & Freivalds, A. (2014). *Niebel's methods, standards, and work design*. McGraw-Hill.

National Institute for Occupational Safety and Health. (1998). *DHHS (NIOSH) Publication No. 98–126: Occupational Noise Exposure*. U.S. Department of Health and Human Services.

Pla vs ABS: The differences – simply explained. All3DP. (2021, September 16). Retrieved September 30, 2021, from https://all3dp.com/2/pla-vs-abs-filament-3d-printing/#:~:text=PLA%20is%20usually%20printed%20with,trap%20heat%20and%20block%20airflow.

Ross, J. M. (2011). Using anthropometrics in designing for enhanced crew performance. *Ciencia y Tecnología De Buques*, *5*(9), 41. https://doi.org/10.25043/19098642.50

10.2 BATTERY CART

AWS 5.1 Standard Meaning. What is the meaning of AWS A5 1. (n.d.). Retrieved September 26, 2021, from http://www.sino-welding.com/news/17363.html.

Battery Disposal - Oklahoma State University. Environmental Health and Safety | Oklahoma State University. (n.d.). Retrieved September 26, 2021, from https://ehs.okstate.edu/batter_disposal_pcf.html.

Budynas, R. G., Nisbett, J. K., Tangchaichit, K., & Shigley, J. E. (2021). *Shigley's Mechanical Engineering Design* (11th ed.). McGraw-Hill.

Department of Labor Logo United Statesdepartment of Labor. 1910.136 - Foot protection. | Occupational Safety and Health Administration. (n.d.). Retrieved September 19, 2021, from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.136.

Department of Labor Logo United Statesdepartment of Labor. 1910.138 - Hand Protection. | Occupational Safety and Health Administration. (n.d.). Retrieved September 19, 2021, from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.138.

Department of Labor Logo United Statesdepartment of Labor. 1910.176 - Handling materials - general. | Occupational Safety and Health Administration. (n.d.). Retrieved September 19, 2021, from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.176.

Department of Labor Logo United Statesdepartment of Labor. 1926.441 - Batteries and battery charging. | Occupational Safety and Health Administration. (n.d.). Retrieved September 19, 2021, from https://www.osha.gov/laws-regs/regulations/standardnumber/1926/1926.441.

Ergonomics — Manual handling — Part 2: Pushing and Pulling. ISO. (n.d.). Retrieved September 19, 2021, from https://www.iso.org/obp/ui/#iso:std:iso:11228:-2:ed-1:v1:en.

Lift manufacturers announce the release of ANSI MH29.1:2012-industrial scissor lifts safety requirements. Leading trade association for the material handling, logistics and supply chain industry - The Industry That Makes Supply Chains Work. (n.d.). Retrieved September 22, 2021, from https://www.mhi.org/media/news/12215#:~:text=1%3A2012%2DIndustrial%20Scissor%20Lifts%20Safety%20Requirements.,ANSI%20MH29.

NFPA 70B. NFPA 70B: Recommended Practice for Electrical Equipment Maintenance. (n.d.). Retrieved September 19, 2021, from https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70B.

NFPA 70E®. NFPA 70E®: Standard for Electrical Safety in the Workplace®. (n.d.). Retrieved September 19, 2021, from https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70E.

Specification for structural steel with low yield to tensile ratio for use in buildings. (2016). *ANSI/AISC 360-16 : An American National Standard*. https://doi.org/10.1520/a1043_a1043m-18

SolidWorks: 2021/2022, SOLIDWORKS Corp., 2021.

10.3 SOLAR CELL LOCKOUT, SPEED MEASUREMENT, GENERATOR

AWG wire gauges current ratings. Engineering ToolBox. (n.d.). Retrieved September 30, 2021, from https://www.engineeringtoolbox.com/wire-gauges-d_419.html.

Department of Labor Logo United Statesdepartment of Labor. 1910.136 - Foot protection. | Occupational Safety and Health Administration. (n.d.). Retrieved September 19, 2021, from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.136.

Department of Labor Logo United Statesdepartment of Labor. 1910.138 - Hand Protection. | Occupational Safety and Health Administration. (n.d.). Retrieved September 19, 2021, from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.138.

Department of Labor Logo United Statesdepartment of Labor. 1910.176 - Handling materials - general. | Occupational Safety and Health Administration. (n.d.). Retrieved September 19, 2021, from https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.176.

NFPA 70B. NFPA 70B: Recommended Practice for Electrical Equipment Maintenance. (n.d.). Retrieved September 19, 2021, from https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70B.

NFPA 70E®. NFPA 70E®: Standard for Electrical Safety in the Workplace®. (n.d.). Retrieved September 19, 2021, from https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70E.

National Fire Protection Association. (n.d.). *NFPA 70®*. NFPA 70®: National Electrical Code®. Retrieved September 30, 2021, from https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70.

Pla vs ABS vs nylon. Markforged. (2021). Retrieved September 30, 2021, from https://markforged.com/resources/blog/pla-abs-nylon.

Pla vs ABS: The differences – simply explained. All3DP. (2021, September 16). Retrieved September 30, 2021, from https://all3dp.com/2/pla-vs-abs-filament-3d-printing/#:~:text=PLA%20is%20usually%20printed%20with,trap%20heat%20and%20block%20airflow

10.4 CONTROLLER UPGRADE

Ace PLCs - velocio.net. Velocio. (n.d.). Retrieved September 30, 2021, from https://velocio.net/AceDatasheet.pdf.

AWG wire gauges current ratings. Engineering ToolBox. (n.d.). Retrieved September 30, 2021, from https://www.engineeringtoolbox.com/wire-gauges-d_419.html.

Command HMIs - velocio.net. Velocio.net. (n.d.). Retrieved September 30, 2021, from https://velocio.net/CommandHMI_DataSheet.pdf.

National Fire Protection Association. (n.d.). *NFPA 70*®. NFPA 70®: National Electrical Code®. Retrieved September 30, 2021, from https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70.

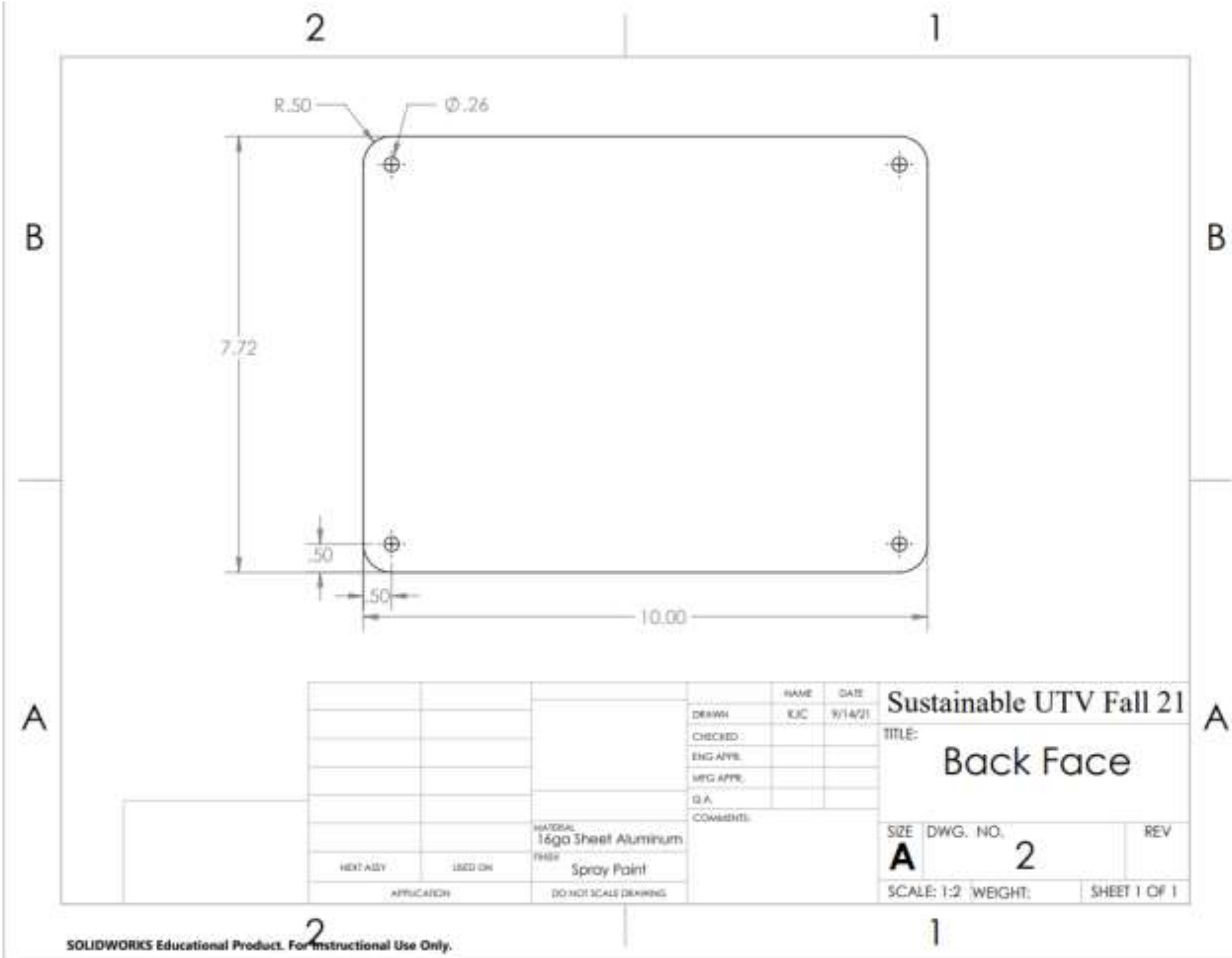
11 APPENDICES

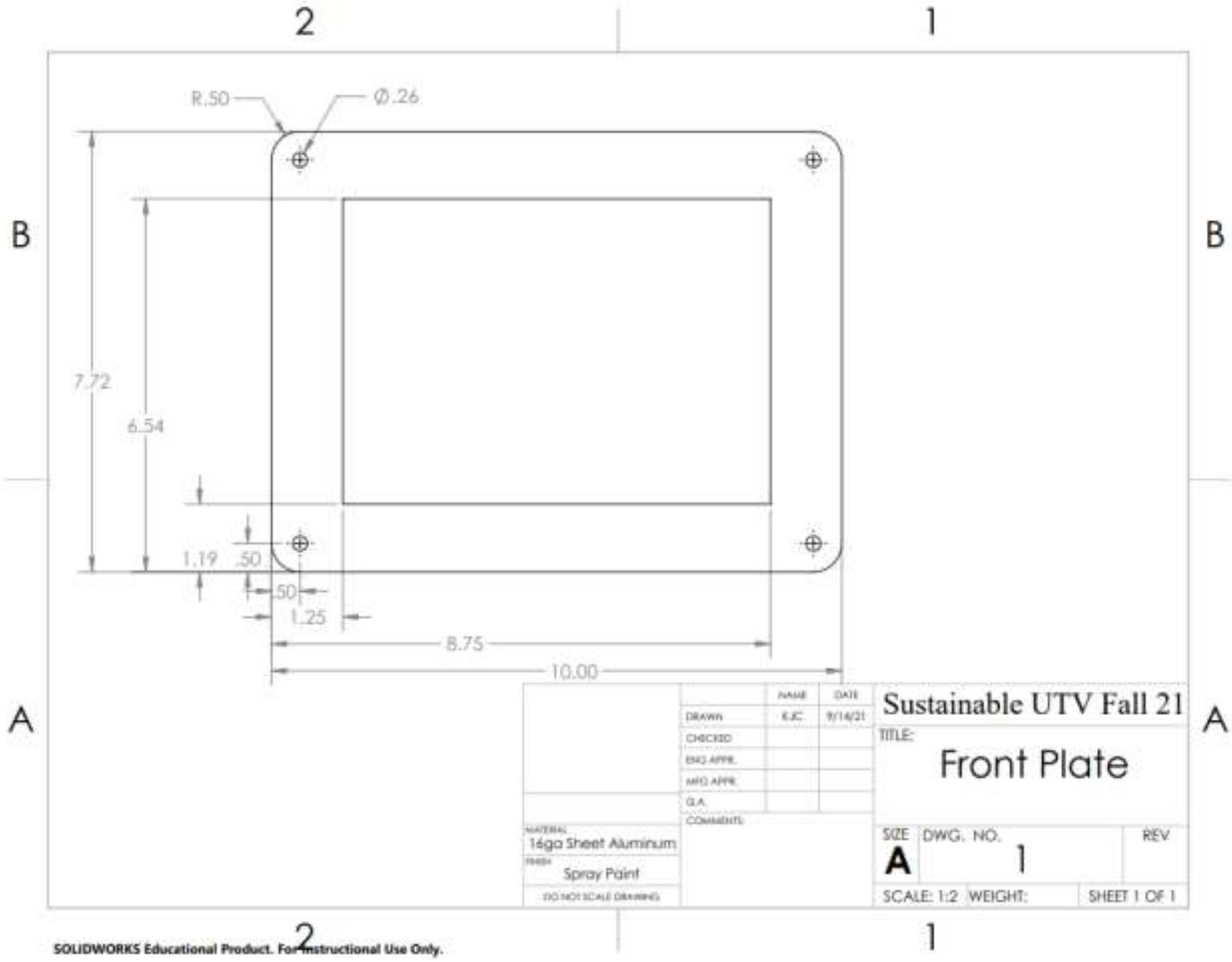
11.1 PM/HUMAN FACTORS

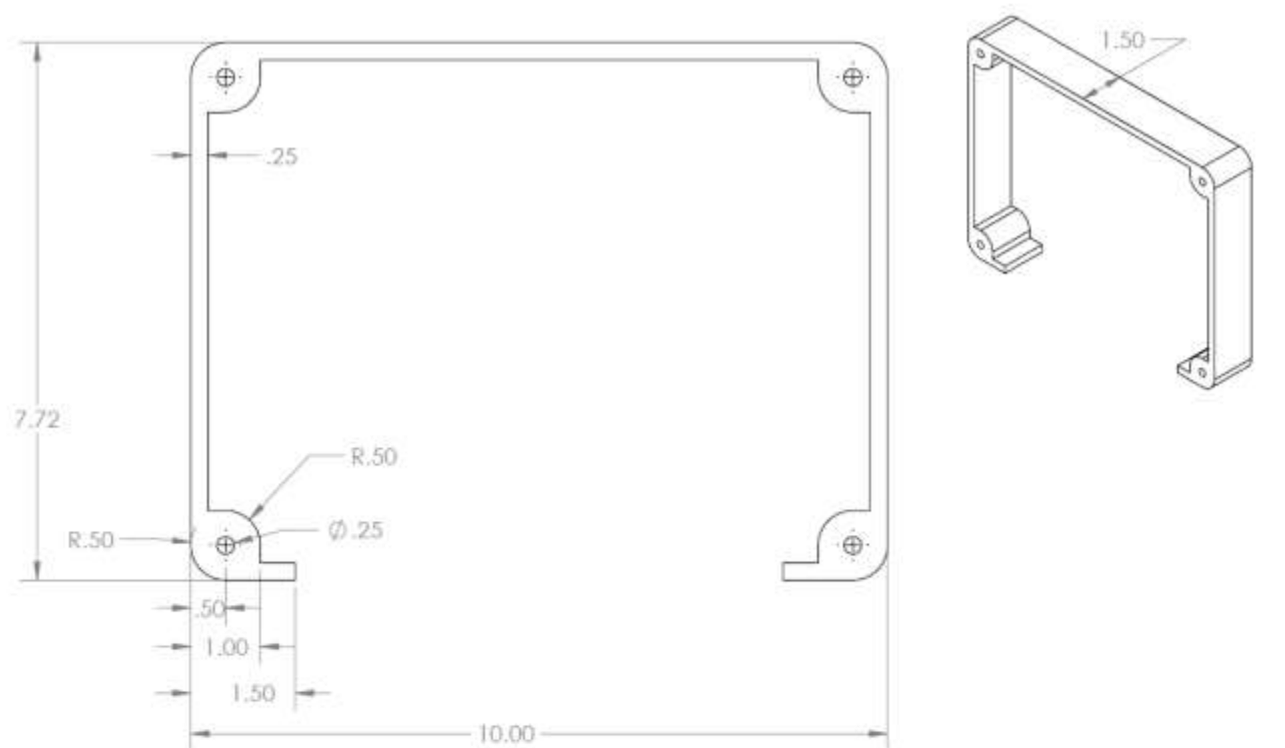
11.1.1 Table 1-1 from NIOSH (1998): Combinations of noise exposure levels and durations that no worker exposure shall equal or exceed

Exposure level, *L* (dBA)	Duration, *T*			Exposure level, *L* (dBA)	Duration, *T*		
	Hours	Minutes	Seconds		Hours	Minutes	Seconds
80	25	24	–	106	–	3	45
81	20	10	–	107	–	2	59
82	16	–	–	108	–	2	22
83	12	42	–	109	–	1	53
84	10	5	–	110	–	1	29
85	8	–	–	111	–	1	11
86	6	21	–	112	–	–	56
87	5	2	–	113	–	–	45
88	4	–	–	114	–	–	35
89	3	10	–	115	–	–	28
90	2	31	–	116	–	–	22
91	2	–	–	117	–	–	18
92	1	35	–	118	–	–	14
93	1	16	–	119	–	–	11
94	1	–	–	120	–	–	9
95	–	47	37	121	–	–	7
96	–	37	48	122	–	–	6
97	–	30	–	123	–	–	4
98	–	23	49	124	–	–	3
99	–	18	59	125	–	–	3
100	–	15	–	126	–	–	2
101	–	11	54	127	–	–	1
102	–	9	27	128	–	–	1
103	–	7	30	129	–	–	1
104	–	5	57	130–140	–	–	<1
105	–	4	43	–	–	–	–

11.1.2 Detailed drawings of the screen mounting box components




R.50
Ø.26
7.72
6.54
1.19
.50
.50
1.25
8.75
10.00
NAME
DATE
DRAWN
KJC
9/14/21
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
16ga Sheet Aluminum
FINISH
Spray Paint
DO NOT SCALE DRAWING
Sustainable UTV Fall 21
TITLE:
Front Plate
SIZE
A
DWG. NO.
1
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
SOLIDWORKS Educational Product. For Instructional Use Only.



	NAME	DATE
DRAWN	KJC	9/14/21
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

MATERIAL: PLA

FINISH: None

NEXT ASSY | USED ON

APPLICATION

DO NOT SCALE DRAWING

Sustainable UTV Fall 21

TITLE: Center

SIZE: A | DWG. NO. 3 | REV

SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

11.1.3 PDR Project Plan

ID	Indicators	Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			**Project Overview**	**79 days**	**Tue 8/17/21 8:0**	**Fri 12/10/21 5:0**	
2	✓		**Conceptual Design**	**14 days**	**Tue 8/17/21 8:0**	**Fri 9/3/21 5:00 F**	
3	✓		Preliminary Design Review	0 days	Tue 8/31/21 8:0	Tue 8/31/21 8:0	
4			**Detailed Design**	**20 days**	**Mon 9/6/21 8:0**	**Fri 10/1/21 5:00**	
5			SOP to Project Mentor	0 days	Fri 9/17/21 8:00	Fri 9/17/21 8:00	
6			SOP to SRB	0 days	Fri 9/24/21 8:00	Fri 9/24/21 8:00	
7			Critical Design Presentation	0 days	Tue 9/28/21 8:0	Tue 9/28/21 8:0	
8			Critical Design Report	0 days	Fri 10/1/21 8:00	Fri 10/1/21 8:00	
9			**Fabrication**	**20 days**	**Mon 10/4/21 8:**	**Fri 10/29/21 5:0**	
10			SOP Approval secured	0 days	Fri 10/8/21 8:00	Fri 10/8/21 8:00	
11			Peer Eval 1	0 days	Fri 10/8/21 8:00	Fri 10/8/21 8:00	
12			Project mechanically complete and ESI passed	0 days	Fri 10/29/21 8:0	Fri 10/29/21 8:0	
13			**Testing and Validation**	**15 days**	**Mon 11/1/21 8:**	**Fri 11/19/21 5:0**	
14			Project Video	0 days	Tue 11/9/21 8:0	Tue 11/9/21 8:0	
15			Final Presentation and Expo	2 days	Thu 11/18/21 8:	Fri 11/19/21 5:0	
16			**Complete Documentation**	**10 days**	**Mon 11/29/21 8**	**Fri 12/10/21 5:0**	
17			Peer Evaluation 2	0 days	Fri 12/3/21 8:00	Fri 12/3/21 8:00	
18			Final Report	0 days	Fri 12/3/21 8:00	Fri 12/3/21 8:00	
19			All Project Files Due	0 days	Fri 12/10/21 8:0	Fri 12/10/21 8:0	
20			**Battery Cart**	**83 days?**	**Wed 8/18/21 8**	**Fri 12/17/21 5:**	
1			**Conceptual Development**	**13 days**	**Wed 8/18/21 8:**	**Fri 9/3/21 5:00 F**	
2			Research Spring 2021 designs/files	6 days	Wed 8/18/21 8:(	Wed 8/25/21 5:(	
3	✓		Identify relevant stakeholders and define problem stateme	4 days	Thu 8/19/21 8:0	Tue 8/24/21 5:0	
4	✓		**Develop multiple concepts for UTV battery cart redesign**	**6 days**	**Thu 8/19/21 8:0**	**Thu 8/26/21 5:0**	
5	✓		Redesign cart tray/table	5 days	Thu 8/19/21 8:0	Wed 8/25/21 5:(	
6	✓		Redesign latches	5 days	Thu 8/19/21 8:0	Wed 8/25/21 5:(	
7	✓		Add rollers/guides for battery box	6 days	Thu 8/19/21 8:0	Thu 8/26/21 5:0	
8	✓		Frame coating for electrical insulation	4 days	Thu 8/19/21 8:0	Tue 8/24/21 5:0	
9	✓		Raise charging station (potential hazard prevention)	6 days	Thu 8/19/21 8:0	Thu 8/26/21 5:0	
10	✓		Redesign frame mounts	5 days	Thu 8/19/21 8:0	Wed 8/25/21 5:(	

Page 1

Master.mpp

ID	Indicators	Task Mode	Task Name	Duration	Start	Finish	Predecessors
11	✓		Define specifications for future battery alternatives	6 days	Thu 8/19/21 8:0	Thu 8/26/21 5:0	
12	✓		Develop design for universal battery cart (Li Ion, Lead Acid, etc.)	6 days	Thu 8/19/21 8:00 AM	Thu 8/26/21 5:00 PM	
13	✓		Redesign cart raising mechanism (hydraulic, electric motor, etc.)	6 days	Thu 8/19/21 8:00 AM	Thu 8/26/21 5:00 PM	
14	✓		Identify relevant codes	4 days	Tue 8/24/21 8:0	Fri 8/27/21 5:00	4FF+1 day
15	✓		Identify relevant hazards and develop Prelim. Hazard Analy	4 days	Tue 8/24/21 8:0	Fri 8/27/21 5:00	4FF+1 day
16	✓		Develop preliminary bill of materials	3 days	Wed 8/25/21 8:(	Fri 8/27/21 5:00	4FS-2 days
17	✓		Estimate cost and contingency for team budgeting	3 days	Thu 8/26/21 8:0	Sat 8/28/21 5:0(	4FS-1 day
18			Preliminary Design Presentation and Review	0 days	Mon 8/30/21 8:(	Mon 8/30/21 8:(	4FS+1 day
19			Post-PDR concept development follow-up	5 days	Mon 8/30/21 8:(	Fri 9/3/21 5:00 F	18
20			**Detailed Design**	**26 days**	**Mon 8/30/21 8:**	**Mon 10/4/21 5:**	**1**
21			Complete detailed analysis for each design concept	26 days	Mon 8/30/21 8:(	Mon 10/4/21 5:(	
22			Prepare detailed fabrication drawings, CAD models, schematics, etc.	20 days	Mon 8/30/21 8:00 AM	Fri 9/24/21 5:00 PM	
23			Identify and select appropriate materials/components for each design concept	15 days	Mon 8/30/21 8:00 AM	Fri 9/17/21 5:00 PM	
24			Detailed bill of materials	10 days	Mon 9/20/21 8:(	Fri 10/1/21 5:00	
25			Develop battery cart SOP	5 days	Mon 9/6/21 8:0(	Fri 9/10/21 5:00	4FS+6 days
26			Submit SOP to project mentor	0 days	Mon 9/13/21 8:(	Mon 9/13/21 8:(	25
27			Submit SOP to safety review board	0 days	Mon 9/20/21 8:(	Mon 9/20/21 8:(	26FS+5 days,25FS
28			Complete relevant machine trainings	20 days	Mon 8/30/21 8:(	Fri 9/24/21 5:00	
29			NO machine trainings available after Oct. 1!	0 days	Fri 10/1/21 8:00	Fri 10/1/21 8:00	28FS+1 day
30			**Critical design review**	**3 days**	**Tue 9/28/21 8:0**	**Thu 9/30/21 5:0**	**21FS-2 days,22FS**
31			Critical design presentation	0 days	Tue 9/28/21 8:0	Tue 9/28/21 8:0	
32			Critical design report	0 days	Thu 9/30/21 8:0	Thu 9/30/21 8:0	
33			**Procurement**	**32 days**	**Tue 8/24/21 8:0**	**Wed 10/6/21 5:**	
34			Specialty or long lead component identification	4 days	Tue 8/24/21 8:0	Fri 8/27/21 5:00	16FF,4FS-3 days
35			Specialty or long lead component procurement	7 days	Thu 8/26/21 8:0	Fri 9/3/21 5:00 F	16FS-2 days,34FS
36			Low cost items (design testing, early fabrication, etc.)	10 days	Mon 9/6/21 8:0(	Fri 9/17/21 5:00	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
37			Moderate lead items (identified during detailed design, need earlier than bulk)	10 days	Mon 9/6/21 8:00 AM	Fri 9/17/21 5:00 PM	
38			Bulk procurement (remaining items for fabrication, construction, testing, etc.)	8 days	Mon 9/27/21 8:00 AM	Wed 10/6/21 5:00 PM	
39			**Fabrication**	**26 days**	**Mon 9/20/21 8:**	**Mon 10/25/21 5**	**33FS-12 days,20F**
40			Fabricate cart tray/table design concept	15 days	Mon 9/20/21 8:(	Fri 10/8/21 5:00	
41			Fabricate latch design concept	15 days	Mon 9/20/21 8:(	Fri 10/8/21 5:00	
42			Add rollers/guides for battery box	20 days	Mon 9/20/21 8:(	Fri 10/15/21 5:0	
43			Frame coating application	10 days	Mon 10/11/21 8	Fri 10/22/21 5:0	
44			Raise charging station (potential hazard prevention)	10 days	Mon 9/20/21 8:(	Fri 10/1/21 5:00	
45			Fabricate frame mounts	10 days	Mon 10/4/21 8:(	Fri 10/15/21 5:0	
46			Construct cart raising mechanism (hydraulic, electric motor, etc.)	15 days	Mon 10/4/21 8:00 AM	Fri 10/22/21 5:00 PM	
47			Construction complete cart	6 days	Wed 10/13/21 8	Wed 10/20/21 5	
48			**Testing and Validation**	**26 days?**	**Mon 10/11/21 8**	**Mon 11/15/21 5**	**39FS-15 days**
49			Test cart tray/table design concept	26 days	Mon 10/11/21 8	Mon 11/15/21 5	
50			Test latch design concept	26 days	Mon 10/11/21 8	Mon 11/15/21 5	
51			Test rollers/guides for battery box	26 days	Mon 10/11/21 8	Mon 11/15/21 5	
52			Test frame coating conductivity	26 days	Mon 10/11/21 8	Mon 11/15/21 5	
53			Test charging station	26 days	Mon 10/11/21 8	Mon 11/15/21 5	
54			Test frame mounting mechanism	26 days	Mon 10/11/21 8	Mon 11/15/21 5	
55			Test cart raising mechanism (hydraulic, electric motor, etc.)	26 days	Mon 10/11/21 8:00 AM	Mon 11/15/21 5:00 PM	
56			Test complete cart	6 days	Mon 11/8/21 8:(	Mon 11/15/21 5	
57			**Final Project Documentation**	**25 days**	**Mon 11/8/21 8:**	**Fri 12/17/21 5:0**	
58			Project video	0 days	Mon 11/8/21 8:(	Mon 11/8/21 8:(	
59			EXPO and final presentation	0 days	Mon 11/15/21 8	Mon 11/15/21 8	
60			Final design report	0 days	Mon 11/29/21 8	Mon 11/29/21 8	
61			Digital file submission	5 days	Mon 12/6/21 8:(	Fri 12/10/21 5:0	
21			**Controller**	**36.5 days?**	**Mon 8/16/21 5**	**Fri 10/29/21 9:**	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
1			**Conceptual Design**	**75 hrs?**	**Mon 8/16/21 5:**	**Thu 9/2/21 9:00**	
2	✓		Initial Gantt Chart	28 hrs	Tue 8/17/21 8:0	Sun 8/22/21 9:0	
3	✓		Review Old Sensor Wiring	8 hrs	Tue 8/24/21 8:0	Wed 8/25/21 9:(	
4	✓		Review Arduino/Python Logic	26 hrs	Tue 8/24/21 8:0	Fri 8/27/21 9:00	
5	✓		Review Velocio connections	26 hrs	Tue 8/24/21 8:0	Fri 8/27/21 9:00	
6	✓		Build Flow Chart	8 hrs	Tue 8/31/21 8:0	Wed 9/1/21 9:0(	
7	✓		New Wiring Plan/Overview	20 hrs	Mon 8/23/21 5:(	Thu 8/26/21 9:0	
8	✓		Purchase Velocio components	4.25 hrs?	Tue 8/24/21 8:0	Fri 8/27/21 12:0	
9	✓		Discuss Testing Plan	8 hrs	Thu 8/26/21 5:0	Fri 8/27/21 9:00	
10	✓		Start Presentaion Products	8 hrs	Thu 8/26/21 5:0	Fri 8/27/21 9:00	
11			Preliminary Design Presentation	0 hrs	Tue 8/31/21 5:0	Tue 8/31/21 5:0	
12			**Detailed Design**	**123 hrs?**	**Mon 8/30/21 5:**	**Thu 9/30/21 5:0**	
13			Velocio Relay Logic (vBuilder)	28 hrs	Mon 8/30/21 5:(	Sun 9/5/21 9:00	
14			Unwire current controller/ Label wires	13 hrs?	Tue 8/31/21 8:0	Thu 9/2/21 2:00	
15			Remove and label relay switches	8 hrs?	Fri 9/3/21 8:00 /	Sun 9/5/21 11:0	14
16			Arduino Dismantle/Remove	18 hrs	Sat 9/11/21 12:(	Wed 9/15/21 8:	14
17			Build test circuit	32.5 hrs	Mon 9/6/21 9:3(	Fri 9/10/21 9:00	13,15
18			Test relay switching logic	8 hrs?	Sat 9/11/21 12:(	Mon 9/13/21 2:	17
19			SOP Submitted	0 hrs	Thu 9/16/21 5:0	Thu 9/16/21 5:0	
20			Critical Design Presentation	0 hrs	Tue 9/28/21 5:0	Tue 9/28/21 5:0	
21			Critical Design Report Due	0 hrs	Thu 9/30/21 5:0	Thu 9/30/21 5:0	
22			**Fabrication**	**108.5 hrs**	**Mon 10/4/21 5:**	**Fri 10/29/21 9:0**	
23			Peer Review #1	0 hrs	Thu 10/7/21 5:0	Thu 10/7/21 5:0	
24			Energization Safety Inspection	0 hrs	Fri 10/29/21 5:0	Fri 10/29/21 5:0	
22			**Speed, Generator, Solar Gantt**	**83 days**	**Wed 8/18/21 8**	**Fri 12/10/21 5:**	
1			**Conceptual Development**	**13 days**	**Wed 8/18/21 8:**	**Fri 9/3/21 5:00 F**	
2	✓		Identify Problem Statement	6 days	Wed 8/18/21 8:(	Wed 8/25/21 5:(	
3	✓		Locate diagram, find regulator and shutoff valve location	4 days	Thu 8/19/21 8:00 AM	Tue 8/24/21 5:00 PM	
4	✓		**Develop Concepts**	**6 days**	**Thu 8/19/21 8:0**	**Thu 8/26/21 5:0**	

ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
5	✓		Accquire Krimp Sets	1 day	Thu 8/19/21 8:0	Thu 8/19/21 5:0	
6	✓		Identify Ignition wires for Kill Switch	1 day	Thu 8/19/21 8:0	Thu 8/19/21 5:0	
7	✓		Connect Kill Switch to ignition	1 day	Thu 8/19/21 8:0	Thu 8/19/21 5:0	
8	✓		Conversation with Dr. Taylor about propane flow	2 days	Thu 8/19/21 8:0	Fri 8/20/21 5:00	
9	✓		create BOM Document	6 days	Thu 8/19/21 8:0	Thu 8/26/21 5:0	
10	✓		Research Regulators and Shutoff Valves	5 days	Thu 8/19/21 8:0	Wed 8/25/21 5:(	
11	✓		Generator Manual Deep Dive	6 days	Thu 8/19/21 8:0	Thu 8/26/21 5:0	
12	✓		Complete three design concepts and testing plan	6 days	Thu 8/19/21 8:0	Thu 8/26/21 5:0	
13	✓		Discussion with Dr. Taylor on Speed Measurement options	2 days	Thu 8/19/21 8:00 AM	Fri 8/20/21 5:00 PM	
14	✓		define 3 speed measurement options	4 days	Tue 8/24/21 8:0	Fri 8/27/21 5:00	13
15	✓		Identify relevant hazards and develop Prelim. Hazard Analysis	4 days	Tue 8/24/21 8:00 AM	Fri 8/27/21 5:00 PM	13
16	✓		Select Speed Measurement design option that we will pursue	3 days	Wed 8/25/21 8:00 AM	Fri 8/27/21 5:00 PM	13,14
17	✓		Estimate cost and contingency for team budgeting	2 days	Thu 8/26/21 8:0	Fri 8/27/21 5:00	9
18			Preliminary Design Presentation and Review	0 days	Mon 8/30/21 8:(	Mon 8/30/21 8:(	2,3,4,5,6,7,8,9,10
19			Post-PDR concept development follow-up	5 days	Mon 8/30/21 8:(	Fri 9/3/21 5:00 P	18
20			**Detailed Design**	**26 days**	**Mon 8/30/21 8:**	**Mon 10/4/21 5:**	**1**
21			Complete detailed analysis for speed measurement system	4 days	Tue 8/24/21 8:00 AM	Fri 8/27/21 5:00 PM	
22			Prepare CAD drawing for speed display	1 day	Mon 8/30/21 8:(	Mon 8/30/21 5:(	16
23			Create a plan for speed testing				
24			Detailed bill of materials	1 day	Fri 8/27/21 8:00	Fri 8/27/21 5:00	9
25			Material Procurement				
26			Develop Speed Sensor SOP	5 days	Mon 8/30/21 8:(	Fri 9/3/21 5:00 P	16
27			Develop Solar Lockout SOP	0 days	Mon 9/6/21 8:0(	Mon 9/6/21 8:0(	7
28			Develop Generator SOP	0 days	Fri 8/27/21 8:00	Fri 8/27/21 8:00	12
29			Complete relevant machine trainings	23 days	Mon 8/30/21 8:(	Wed 9/29/21 5:(	
30			Detailed plan for putting the propane tank into a vertical position	0 days	Fri 10/1/21 8:00 AM	Fri 10/1/21 8:00 AM	

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ID		Task Mode	Task Name	Duration	Start	Finish	Predecessors
31			**Critical design review**	**3 days**	**Tue 9/28/21 8:0**	**Thu 9/30/21 5:0**	
32			Critical design presentation	0 days	Tue 9/28/21 8:0	Tue 9/28/21 8:0	
33			Critical design report	0 days	Thu 9/30/21 8:0	Thu 9/30/21 8:0	
34			**Procurement**	**23 days**	**Mon 9/6/21 8:0**	**Wed 10/6/21 5:**	
35			New Case for propane tank	4 days	Fri 10/1/21 8:00	Wed 10/6/21 5:(	28,30
36			Speen sensor display	7 days	Mon 9/6/21 8:0(	Tue 9/14/21 5:0	26
37			Speed sensor drive shaft component	10 days	Mon 9/6/21 8:0(	Fri 9/17/21 5:00	26
38			**Fabrication**	**58 days**	**Mon 9/20/21 8:**	**Wed 12/8/21 5:**	
39			Fabricate Speed sensor display case	15 days	Wed 9/15/21 8:(	Tue 10/5/21 5:0	36
40			Fabricate speed sensor case (for drive shaft)	15 days	Mon 9/20/21 8:(	Fri 10/8/21 5:00	37
41			Install Vertical propane tank holder	20 days	Thu 10/7/21 8:0	Wed 11/3/21 5:(	35
42			Install speed sensor	10 days	Wed 9/15/21 8:(	Tue 9/28/21 5:0	36
43			Install speed sensor display	20 days	Mon 9/20/21 8:(	Fri 10/15/21 5:0	37
44			**Testing and Validation**	**36 days**	**Mon 10/11/21 8**	**Mon 11/29/21 5**	
45			Test Speed display works (we have power)	2 days	Mon 10/18/21 8	Tue 10/19/21 5:	42,43
46			Test Speed on display vs speed gun	3 days	Mon 10/25/21 8	Wed 10/27/21 5	42,43
47			Test Solar Lockout with ATV in motion	3 days	Mon 10/25/21 8	Wed 10/27/21 5	7
48			Test Generator with current setup	3 days	Tue 10/19/21 8:	Thu 10/21/21 5:	
49			Remove Actuator, Run the Generator	3 days	Tue 10/26/21 8:	Thu 10/28/21 5:	48
50			Place regulator closer to propane tank, test generator	3 days	Tue 11/2/21 8:0	Thu 11/4/21 5:0	48,49
51			Replace Actuator, test Generator	3 days	Mon 11/8/21 8:(	Wed 11/10/21 5	48,49,50
52			**Final Project Documentation**	**25 days**	**Mon 11/8/21 8:**	**Fri 12/10/21 5:0**	
53			Project video	0 days	Mon 11/8/21 8:(	Mon 11/8/21 8:(	
54			EXPO and final presentation	0 days	Mon 11/15/21 8	Mon 11/15/21 8	
55			Final design report	0 days	Mon 11/29/21 8	Mon 11/29/21 8	
56			Digital file submission	5 days	Mon 12/6/21 8:(	Fri 12/10/21 5:0	
23			**PM**	**64 days?**	**Wed 8/18/21 8**	**Mon 11/15/21**	
1			**Conceptual Design**	**18 days?**	**Wed 8/18/21 8:**	**Sun 9/12/21 8:0**	
2	✓		**PDR Prep**	**5 days**	**Mon 8/23/21 8:**	**Fri 8/27/21 5:00**	
3	✓		Assist groups with PDR Presentations	4 days	Mon 8/23/21 8:(	Thu 8/26/21 5:0	

ID	Indicators	Task Mode	Task Name	Duration	Start	Finish	Predecessors
4			Make reuired edits to PDR presentation slides	2 days	Thu 8/26/21 8:0	Fri 8/27/21 5:00	
5			**SOP Prep**	**13 days?**	**Wed 8/25/21 8:**	**Sun 9/12/21 8:0**	
6			Meet with team leads on SOPs	0.25 days	Wed 8/25/21 5:	Wed 8/25/21 7:	
7			Work with teams on SOPs	12 days	Thu 8/26/21 8:0	Fri 9/10/21 5:00	6
8			**Create Progress Report**	**6 days**	**Mon 8/23/21 8:**	**Mon 8/30/21 5:**	
9			Create Progress Report 1	1 day	Mon 8/23/21 8:	Mon 8/23/21 5:	
10			Create Progress Report 2	1 day	Mon 8/30/21 8:	Mon 8/30/21 5:	
11			**Update Project Schedule**	**6 days**	**Mon 8/23/21 8:**	**Mon 8/30/21 5:**	
12			Update Project Schedule 1	1 day	Mon 8/23/21 8:	Mon 8/23/21 5:	
13			Update Project Schedule 2	1 day	Mon 8/30/21 8:	Mon 8/30/21 5:	
14			**Radio**	**7 days**	**Wed 8/18/21 8:**	**Thu 8/26/21 5:0**	
15			Research FCC regulations regarding different types of radios and their usage	2 days	Wed 8/18/21 8:00 AM	Thu 8/19/21 5:00 PM	
16			Decide type of radio needed	1 day	Mon 8/23/21 8:	Mon 8/23/21 5:	15
17			Determine mounting locations for radio and antenna	1 day	Tue 8/24/21 8:00 AM	Tue 8/24/21 5:00 PM	
18			Research how radio will get power from the UTV	1 day	Tue 8/24/21 8:0	Tue 8/24/21 5:0	16
19			Finish rough draft of PDR slides	2 days	Wed 8/25/21 8:	Thu 8/26/21 5:0	17,18
20			**Detailed Design**	**27 days**	**Mon 9/6/21 8:0**	**Tue 10/12/21 5:**	
21			SOP submitted to project mentor	0 days	Mon 9/13/21 8:	Mon 9/13/21 8:	7
22			**Create Progress Report**	**16 days**	**Mon 9/6/21 8:0**	**Mon 9/27/21 5:**	
23			Create Progress Report 1	1 day	Mon 9/6/21 8:0	Mon 9/6/21 5:0	
24			Create Progress Report 2	1 day	Mon 9/13/21 8:	Mon 9/13/21 5:	
25			Create Progress Report 3	1 day	Mon 9/20/21 8:	Mon 9/20/21 5:	
26			Create Progress Report 4	1 day	Mon 9/27/21 8:	Mon 9/27/21 5:	
27			**Update Project Schedule**	**16 days**	**Mon 9/6/21 8:0**	**Mon 9/27/21 5:**	
28			Update Project Schedule 1	1 day	Mon 9/6/21 8:0	Mon 9/6/21 5:0	
29			Update Project Schedule 2	1 day	Mon 9/13/21 8:	Mon 9/13/21 5:	
30			Update Project Schedule 3	1 day	Mon 9/20/21 8:	Mon 9/20/21 5:	
31			Update Project Schedule 4	1 day	Mon 9/27/21 8:	Mon 9/27/21 5:	

ID	Indicators	Task Mode	Task Name	Duration	Start	Finish	Predecessors
32			**Radio**	**13 days**	**Tue 9/7/21 8:00**	**Thu 9/23/21 5:0**	
33			Determine specific radio to be used	1 day	Tue 9/7/21 8:00	Tue 9/7/21 5:00	
34			Find antenna to be used	1 day	Tue 9/7/21 8:00	Tue 9/7/21 5:00	
35			Finalize solution for waterproofing radio	3 days	Wed 9/8/21 8:0	Fri 9/10/21 5:00	33
36			Finalize mounting solution for antenna	1 day	Wed 9/8/21 8:0	Wed 9/8/21 5:0	34
37			Create SOP for radio	4 days	Mon 9/13/21 8:	Thu 9/16/21 5:0	
38			finalize mounting solution for radio	1 day	Tue 9/14/21 8:0	Tue 9/14/21 5:0	35
39			Determine radio power wire routing	1 day	Wed 9/15/21 8:	Wed 9/15/21 5:	38
40			Finalize bill of materials	1 day	Thu 9/16/21 8:0	Thu 9/16/21 5:0	36,38
41			Order materials	1 day	Fri 9/17/21 8:00	Fri 9/17/21 5:00	40
42			Create Slides for CDR	4 days	Mon 9/20/21 8:	Thu 9/23/21 5:0	
43			Create radio portion of critical design report	4 days	Mon 9/20/21 8:	Thu 9/23/21 5:0	
44			**Fabrication**	**16 days**	**Mon 10/4/21 8:**	**Mon 10/25/21 5**	
45			**Create Progress Report**	**16 days**	**Mon 10/4/21 8:**	**Mon 10/25/21 5**	
46			Create Progress Report 1	1 day	Mon 10/4/21 8:	Mon 10/4/21 5:	
47			Create Progress Report 2	1 day	Mon 10/11/21 8	Mon 10/11/21 5	
48			Create Progress Report 3	1 day	Mon 10/18/21 8	Mon 10/18/21 5	
49			Create Progress Report 4	1 day	Mon 10/25/21 8	Mon 10/25/21 5	
50			**Update Project Schedule**	**16 days**	**Mon 10/4/21 8:**	**Mon 10/25/21 5**	
51			Update Project Schedule	1 day	Mon 10/4/21 8:	Mon 10/4/21 5:	
52			Update Project Schedule 2	1 day	Mon 10/11/21 8	Mon 10/11/21 5	
53			Update Project Schedule 3	1 day	Mon 10/18/21 8	Mon 10/18/21 5	
54			Update Project Schedule 4	1 day	Mon 10/25/21 8	Mon 10/25/21 5	
55			**Radio**	**8 days**	**Tue 10/5/21 8:0**	**Thu 10/14/21 5:**	
56			Mount radio and antenna	1 day	Tue 10/5/21 8:0	Tue 10/5/21 5:0	
57			Run power wiring	1 day	Wed 10/6/21 8:	Wed 10/6/21 5:	56
58			Work on radio final report	4 days	Mon 10/11/21 8	Thu 10/14/21 5:	
59			**Testing and Validation**	**11 days**	**Mon 11/1/21 8:**	**Mon 11/15/21 5**	
60			**Create Progress Report**	**11 days**	**Mon 11/1/21 8:**	**Mon 11/15/21 5**	
61			Create Progress Report 1	1 day	Mon 11/1/21 8:	Mon 11/1/21 5:	

ID	Indicators	Task Mode	Task Name	Duration	Start	Finish	Predecessors
62			Create Progress Report 2	1 day	Mon 11/8/21 8:	Mon 11/8/21 5:	
63			Create Progress Report 3	1 day	Mon 11/15/21 8	Mon 11/15/21 5	
64			**Update Project Schedule**	**11 days**	**Mon 11/1/21 8:**	**Mon 11/15/21 5**	
65			Update Project Schedule 1	1 day	Mon 11/1/21 8:	Mon 11/1/21 5:	
66			Update Project Schedule 2	1 day	Mon 11/8/21 8:	Mon 11/8/21 5:	
67			Update Project Schedule 3	1 day	Mon 11/15/21 8	Mon 11/15/21 5	
68			**Radio**	**8 days**	**Tue 11/2/21 8:0**	**Thu 11/11/21 5:**	
69			Test mobile radio with HT	1 day	Tue 11/2/21 8:0	Tue 11/2/21 5:0	
70			Fix any issues with the radio	3 days	Wed 11/3/21 8:	Fri 11/5/21 5:00	69
71			Complete final report for radio	4 days	Mon 11/8/21 8:	Thu 11/11/21 5:	
72			create expo slides for radio	4 days	Mon 11/8/21 8:	Thu 11/11/21 5:	

11.1.4 CDR Project Plan

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ID	Task Name	Duration	Start	Finish	% Complete	Resource Names
1	**Project Overview**	**79 days**	**Tue 8/17/21 8:0**	**Fri 12/10/21 5:0**	**0%**	
20	**Battery Cart**	**83 days?**	**Wed 8/18/21 8**	**Fri 12/17/21 5:**	**48%**	
1	**Conceptual Development**	**13 days**	**Wed 8/18/21 8:**	**Fri 9/3/21 5:00 I**	**99%**	**Aaron Katada,Braydon**
20	**Detailed Design**	**26 days?**	**Mon 8/30/21 8:**	**Mon 10/4/21 5:**	**99%**	**Aaron Katada,Braydon**
29	**Procurement**	**32 days**	**Tue 8/24/21 8:0**	**Wed 10/6/21 5:**	**33%**	**Braydon Leger**
45	**Fabrication**	**30 days?**	**Mon 9/20/21 8:**	**Fri 10/29/21 5:0**	**0%**	**Aaron Katada,Justin La**
46	Prepare cart for fabrication	5 days	Wed 9/29/21 8:(	Tue 10/5/21 5:0	0%	Aaron Katada,Justin La
47	Battery case replication - Stillwater Steel outsourced	8 days	Fri 10/1/21 8:00 AM	Tue 10/12/21 5:00 PM	0%	Michael Willhoite
48	Complete battery case assembly	4 days	Tue 10/12/21 8:	Fri 10/15/21 5:0	0%	Michael Willhoite
49	Grind old welds from existing cart (table, axles)	4 days	Tue 10/5/21 8:00 AM	Fri 10/8/21 5:00 PM	0%	Justin LaNoue,Aaron Katada
50	Water jet cutting for rotating tabletop (Alu., HDPE)	5 days	Mon 10/11/21 8:00 AM	Fri 10/15/21 5:00 PM	0%	Michael Willhoite
51	Cut and fabricate structural support for rotating tabletop	5 days	Mon 10/11/21 8:00 AM	Fri 10/15/21 5:00 PM	0%	Aaron Katada,Justin LaNoue
52	Cut and fabricate frame mounts	5 days	Mon 10/11/21 8	Fri 10/15/21 5:0	0%	Aaron Katada,Justin La
53	Cut and fabricate axles and caster mounts	5 days	Mon 10/11/21 8:00 AM	Fri 10/15/21 5:00 PM	0%	Aaron Katada,Justin LaNoue
54	Fabricate linear actuator mounts and install actuator	5 days	Mon 10/11/21 8:00 AM	Fri 10/15/21 5:00 PM	0%	Justin LaNoue,Michael Willhoite,Aaron
55	Cut and mill tabletop rails and install latches	5 days	Mon 10/18/21 8:00 AM	Fri 10/22/21 5:00 PM	0%	Michael Willhoite
56	3D print rail insulation	5 days	Mon 10/18/21 8	Fri 10/22/21 5:0	0%	Michael Willhoite
57	Frame coating application	5 days	Mon 10/25/21 8	Fri 10/29/21 5:0	0%	Braydon Leger
58	Construction complete cart	5 days	Mon 10/25/21 8	Fri 10/29/21 5:0	0%	Aaron Katada,Braydon
59	**Testing and Validation**	**26 days?**	**Mon 10/11/21 8**	**Mon 11/15/21 5**	**0%**	**Aaron Katada,Braydon**
60	Test rotatating tabletop	15 days	Mon 10/11/21 8	Fri 10/29/21 5:0	0%	Michael Willhoite
61	Test latch design concept	15 days	Mon 10/11/21 8	Fri 10/29/21 5:0	0%	Justin LaNoue
62	Test guides for battery boxes	15 days	Mon 10/11/21 8	Fri 10/29/21 5:0	0%	Aaron Katada
63	Independent load testing - tabletc	5 days	Mon 10/25/21 8	Fri 10/29/21 5:0	0%	Aaron Katada,Justin La
64	Independent load testing - wheels/axles	5 days	Mon 10/25/21 8:00 AM	Fri 10/29/21 5:00 PM	0%	Aaron Katada,Justin LaNoue,Michael
65	Frame coating inspection	15 days	Mon 10/25/21 8	Fri 11/12/21 5:0	0%	Braydon Leger
66	Test charging station	5 days	Mon 10/18/21 8	Fri 10/22/21 5:0	0%	Braydon Leger
67	Test frame mounting mechanism	10 days	Mon 10/11/21 8	Fri 10/22/21 5:0	0%	Aaron Katada
68	Test linear actuator	10 days	Mon 10/18/21 8	Fri 10/29/21 5:0	0%	Justin LaNoue,Michael
69	Test actuator circuit	10 days	Mon 10/18/21 8	Fri 10/29/21 5:0	0%	Aaron Katada,Justin La
70	Final visual weld inspection	5 days	Mon 10/25/21 8	Fri 10/29/21 5:0	0%	Aaron Katada,Justin La
71	Test complete cart	5 days	Mon 11/1/21 8:(	Fri 11/5/21 5:00	0%	Aaron Katada,Braydon
72	**Final Project Documentation**	**25 days**	**Mon 11/8/21 8:**	**Fri 12/17/21 5:0**	**0%**	**Aaron Katada,Braydon**
73	Project video	0 days	Mon 11/8/21 8:(	Mon 11/8/21 8:(	0%	Aaron Katada,Braydon
74	EXPO and final presentation	0 days	Mon 11/15/21 8	Mon 11/15/21 8	0%	Aaron Katada,Braydon

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ID	Task Name	Duration	Start	Finish	% Complete	Resource Names
75	Final design report	0 days	Mon 11/29/21 8	Mon 11/29/21 8	0%	Aaron Katada,Braydon
76	Digital file submission	5 days	Mon 12/6/21 8:(	Fri 12/10/21 5:0	0%	Aaron Katada,Braydon
21	**Controller**	**46.31 days?**	**Mon 8/16/21 5**	**Thu 11/18/21 5**	**55%**	
1	**Conceptual Design**	**75 hrs?**	**Mon 8/16/21 5:**	**Thu 9/2/21 9:00**	**100%**	
12	**Detailed Design**	**123 hrs?**	**Mon 8/30/21 5:**	**Thu 9/30/21 5:0**	**98%**	
27	**Fabrication**	**126 hrs?**	**Fri 10/1/21 5:00**	**Fri 10/29/21 9:0**	**0%**	
28	Display Data Test	8 hrs	Tue 10/5/21 8:0	Wed 10/6/21 9:(	0%	Levi,Cody
29	Begin Velocio install	26 hrs	Mon 10/4/21 5:(	Fri 10/8/21 9:00	0%	Tamidayo,Cody
30	Rewiring/compnent install	26 hrs	Mon 10/4/21 5:(	Fri 10/8/21 9:00	0%	Levi,Cody
31	Peer Review #1	0 hrs	Fri 10/8/21 8:00	Fri 10/8/21 8:00	0%	Team
32	Load Testing	26 hrs	Tue 10/12/21 8:	Fri 10/15/21 9:0	0%	Levi
33	Testing Phase---	81 hrs	Mon 10/11/21 5	Fri 10/29/21 9:0	0%	Team
34	Energization Safety Inspection	0 hrs	Fri 10/29/21 5:0	Fri 10/29/21 5:0	0%	Team
35	**Testing and Validation**	**17 hrs**	**Tue 11/2/21 8:0**	**Fri 11/5/21 9:00**	**0%**	
36	End-Product Wire Cleanup and Labeling	26 hrs	Tue 11/2/21 8:00 AM	Fri 11/5/21 9:00 PM	0%	Levi,Tamidayo
37	Final UTV Sub-Energy System Test	8 hrs	Thu 11/4/21 5:0	Fri 11/5/21 9:00	0%	Team
38	Final Presentation work	26 hrs	Mon 11/8/21 5:(	Fri 11/12/21 9:0	0%	Team
39	Final Report Work	26 hrs	Thu 11/11/21 5:	Wed 11/17/21 1	0%	Team
40	**Expo**	**4 hrs**	**Thu 11/18/21 5:**	**Thu 11/18/21 9:**	**0%**	
41	Final presentation and Expo	0 hrs	Thu 11/18/21 5:	Thu 11/18/21 5:	0%	
42	**Final Documentation**	**0 hrs**	**Thu 11/18/21 5:**	**Thu 11/18/21 5:**	**0%**	
43	Final Report Due	0 hrs	Thu 11/18/21 5:	Thu 11/18/21 5:	0%	
44	Peer Eval #2	0 hrs	Thu 11/18/21 5:	Thu 11/18/21 5:	0%	
45	Final Exam	0 hrs	Thu 11/18/21 5:	Thu 11/18/21 5:	0%	
46	All Project files submitted electronically	0 hrs	Thu 11/18/21 5:00 PM	Thu 11/18/21 5:00 PM	0%	
22	**Speed, Generator, Solar Gantt**	**84 days?**	**Tue 8/17/21 8:**	**Fri 12/10/21 5:**	**53%**	
1	**Conceptual Development**	**14 days**	**Tue 8/17/21 8:0**	**Fri 9/3/21 5:00 I**	**100%**	
20	**Detailed Design**	**26 days?**	**Mon 8/30/21 8:**	**Mon 10/4/21 5:**	**100%**	
35	**Procurement**	**20 days**	**Mon 9/6/21 8:0**	**Fri 10/1/21 5:00**	**25%**	
41	**Fabrication**	**58 days?**	**Mon 9/20/21 8:**	**Wed 12/8/21 5:**	**4%**	
42	Complete coding for speed sensor	14 days	Mon 9/20/21 8:(	Thu 10/7/21 5:0	25%	Evan,Heba
43	Remove 12V charger from Genera	1 day	Thu 9/9/21 8:00	Thu 9/9/21 5:00	100%	Brandon,Evan
44	Order a case for speed sensor dis	15 days	Wed 9/15/21 8:(	Tue 10/5/21 5:0	0%	Cullin,Heba
45	Complete SolidWorks case design for hall effect sensor	14 days	Mon 9/20/21 8:00 AM	Thu 10/7/21 5:00 PM	0%	Evan,Cullin,Heba,Brand
46	3D print hall effect sensor case	7 days	Tue 10/12/21 8:	Wed 10/20/21 5	0%	
47	Install Vertical propane tank holde	6 days	Fri 10/1/21 8:00	Fri 10/8/21 5:00	0%	Evan,Cullin,Heba,Brand
48	Install actuator bypass valve	2 days	Fri 10/1/21 8:00	Mon 10/4/21 5:(	0%	Cullin,Evan
49	Install propane - Generator pipe / connections	4 days	Tue 10/5/21 8:00 AM	Fri 10/8/21 5:00 PM	0%	Evan,Cullin,Heba,Brand

ID		Task Mode	Task Name	Duration	Start	Finish	% Complete	Resource Names
50			Install speed sensor	10 days	Wed 9/15/21 8:(	Tue 9/28/21 5:0	0%	Evan,Cullin,Heba,Brand
51			Mount voltage regulator	1 day	Mon 10/4/21 8:(	Mon 10/4/21 5:(	0%	Brandon,Evan
52			Mount Pressure Reducer	7 days	Thu 10/7/21 8:0	Fri 10/15/21 5:0	0%	Cullin,Heba
53			Install speed sensor display	20 days	Mon 9/20/21 8:(	Fri 10/15/21 5:0	0%	Evan,Cullin,Heba,Brand
54			**Testing and Validation**	**36 days?**	**Mon 10/11/21 8**	**Mon 11/29/21 5**	**31%**	
55			Test Speed display works (we have power)	2 days	Mon 10/18/21 8:00 AM	Tue 10/19/21 5:00 PM	0%	Evan,Cullin,Heba,Brand
56			Test Speed on display vs speed gu	3 days	Mon 10/25/21 8	Wed 10/27/21 5	0%	Evan,Cullin,Heba,Brand
57			Test Solar Lockout with ATV in motion	3 days	Mon 10/25/21 8:00 AM	Wed 10/27/21 5:00 PM	0%	Evan,Cullin,Heba,Brand
58			Test Generator with new propane tank	3 days	Thu 9/9/21 8:00 AM	Mon 9/13/21 5:00 PM	100%	Evan,Cullin,Heba,Brand
59			Remove Actuator, Run the Genera	3 days	Thu 9/16/21 8:0	Mon 9/20/21 5:(	100%	Evan,Cullin,Heba,Brand
60			Place regulator closer to propane tank, test generator	3 days	Thu 9/9/21 8:00 AM	Mon 9/13/21 5:00 PM	100%	Evan,Cullin,Heba,Brand
61			Test Generator bypass valve (without actuator)	2 days	Tue 10/12/21 8:00 AM	Wed 10/13/21 5:00 PM	0%	Brandon,Cullin,Evan,He
62			Test Generator bypass valve (with actuator)	2 days	Tue 10/19/21 8:00 AM	Wed 10/20/21 5:00 PM	0%	Brandon,Cullin,Evan,He
63			Replace Actuator, test Generator	3 days	Mon 11/8/21 8:(	Wed 11/10/21 5	0%	Evan,Cullin,Heba,Brand
64			Testing of all systems	3 days	Mon 11/8/21 8:(	Wed 11/10/21 5	0%	Brandon,Cullin,Evan,He
65			Test battery life on flat terrain (Drive utv until battery dies)	1 day	Mon 11/8/21 8:00 AM	Mon 11/8/21 5:00 PM	0%	Cullin
66			Test Battery Life on all terrain (drive until utv battery dies)	1 day	Mon 10/11/21 8:00 AM	Mon 10/11/21 5:00 PM	0%	Evan
67			**Final Project Documentation**	**25 days**	**Mon 11/8/21 8:**	**Fri 12/10/21 5:0**	**0%**	
68			Project video	0 days	Mon 11/8/21 8:(	Mon 11/8/21 8:(	0%	Evan,Cullin,Heba,Brand
69			EXPO and final presentation	0 days	Wed 11/10/21 8	Wed 11/10/21 8	0%	Evan,Cullin,Heba,Brand
70			Final design report	0 days	Mon 11/29/21 8	Mon 11/29/21 8	0%	Evan,Cullin,Heba,Brand
71			Digital file submission	5 days	Mon 12/6/21 8:(	Fri 12/10/21 5:0	0%	Evan,Cullin,Heba,Brand
33			**PM**	**68 days?**	**Wed 8/18/21 8**	**Fri 11/19/21 5:**	**60%**	
1			**Conceptual Design**	**18 days?**	**Wed 8/18/21 8:**	**Sun 9/12/21 8:0**	**100%**	
20			**Detailed Design**	**27 days?**	**Mon 9/6/21 8:0**	**Tue 10/12/21 5:**	**100%**	
40			**Fabrication**	**16 days**	**Mon 10/4/21 8:**	**Mon 10/25/21 5**	**3%**	
41			**Create Progress Report**	**16 days**	**Mon 10/4/21 8:**	**Mon 10/25/21 5**	**0%**	
42			Create Progress Report 1	1 day	Mon 10/4/21 8:(	Mon 10/4/21 5:(	0%	Maggie Goodin
43			Create Progress Report 2	1 day	Mon 10/11/21 8	Mon 10/11/21 5	0%	Maggie Goodin
44			Create Progress Report 3	1 day	Mon 10/18/21 8	Mon 10/18/21 5	0%	Maggie Goodin
45			Create Progress Report 4	1 day	Mon 10/25/21 8	Mon 10/25/21 5	0%	Maggie Goodin
46			**Update Project Schedule**	**16 days**	**Mon 10/4/21 8:**	**Mon 10/25/21 5**	**0%**	
47			Update Project Schedule	1 day	Mon 10/4/21 8:(	Mon 10/4/21 5:(	0%	Kaiser Cleburn
48			Update Project Schedule 2	1 day	Mon 10/11/21 8	Mon 10/11/21 5	0%	Kaiser Cleburn
49			Update Project Schedule 3	1 day	Mon 10/18/21 8	Mon 10/18/21 5	0%	Kaiser Cleburn
50			Update Project Schedule 4	1 day	Mon 10/25/21 8	Mon 10/25/21 5	0%	Kaiser Cleburn
51			**Human Factors**	**15 days**	**Mon 10/4/21 8:**	**Fri 10/22/21 5:0**	**4%**	
52			Order mounting arm	1 day	Mon 10/4/21 8:(	Mon 10/4/21 5:(	0%	Braydon Leger
53			Order Aluminum sheet	1 day	Mon 10/4/21 8:(	Mon 10/4/21 5:(	0%	Braydon Leger
54			**Print mounting box for Display**	**4 days**	**Mon 10/11/21 8**	**Thu 10/14/21 5:**	**0%**	**Kaiser Cleburn,Maggie**
55			Create STL file of model	1 day	Mon 10/11/21 8	Mon 10/11/21 5	0%	Kaiser Cleburn
56			Have model printed	3 days	Tue 10/12/21 8:	Thu 10/14/21 5:	0%	
57			**Fabricate front and back plate of mounting box**	**3 days**	**Mon 10/4/21 8:00 AM**	**Wed 10/6/21 5:00 PM**	**33%**	**Kaiser Cleburn,Maggie Goodin**
58			Create drawings	1 day	Mon 10/4/21 8:(	Mon 10/4/21 5:(	100%	Kaiser Cleburn
59			Schedule time to have NCL cut out on waterjet	1 day	Tue 10/5/21 8:00 AM	Tue 10/5/21 5:00 PM	0%	Maggie Goodin
60			Lay out and drill holes for arm mount	1 day	Wed 10/6/21 8:00 AM	Wed 10/6/21 5:00 PM	0%	Kaiser Cleburn
61			Install display in UTV	1 day	Thu 10/7/21 8:0	Thu 10/7/21 5:0	0%	Kaiser Cleburn,Maggie
62			Work with controller team to implement the UI	15 days	Mon 10/4/21 8:00 AM	Fri 10/22/21 5:00 PM	0%	Maggie Goodin
63			**Testing and Validation**	**15 days**	**Mon 11/1/21 8:**	**Fri 11/19/21 5:0**	**0%**	
64			**Create Progress Report**	**11 days**	**Mon 11/1/21 8:**	**Mon 11/15/21 5**	**0%**	
65			Create Progress Report 1	1 day	Mon 11/1/21 8:(	Mon 11/1/21 5:(	0%	Maggie Goodin
66			Create Progress Report 2	1 day	Mon 11/8/21 8:(	Mon 11/8/21 5:(	0%	Maggie Goodin
67			Create Progress Report 3	1 day	Mon 11/15/21 8	Mon 11/15/21 5	0%	Maggie Goodin
68			**Update Project Schedule**	**11 days**	**Mon 11/1/21 8:**	**Mon 11/15/21 5**	**0%**	
69			Update Project Schedule 1	1 day	Mon 11/1/21 8:(	Mon 11/1/21 5:(	0%	Kaiser Cleburn
70			Update Project Schedule 2	1 day	Mon 11/8/21 8:(	Mon 11/8/21 5:(	0%	Kaiser Cleburn
71			Update Project Schedule 3	1 day	Mon 11/15/21 8	Mon 11/15/21 5	0%	Kaiser Cleburn
72			**Retest generator sound pressure**	**4 days**	**Mon 11/1/21 8:**	**Thu 11/4/21 5:0**	**0%**	**Kaiser Cleburn,Maggie**
73			Test generator sound pressure while under load and moving	1 day	Mon 11/1/21 8:00 AM	Mon 11/1/21 5:00 PM	0%	
74			Update reccomendations for hearing protection	3 days	Tue 11/2/21 8:00 AM	Thu 11/4/21 5:00 PM	0%	Kaiser Cleburn
75			**Make sure display works properl**	**15 days**	**Mon 11/1/21 8:**	**Fri 11/19/21 5:0**	**0%**	**Maggie Goodin**
76			Coordinate with the controller team for testing	1 day	Mon 11/1/21 8:00 AM	Mon 11/1/21 5:00 PM	0%	
77			Validate display is presenting proper information	5 days	Mon 11/8/21 8:00 AM	Fri 11/12/21 5:00 PM	0%	
78			Make sure display location works ergonomically	5 days	Mon 11/8/21 8:00 AM	Fri 11/12/21 5:00 PM	0%	
79			Make any adjustments	5 days	Mon 11/15/21 8	Fri 11/19/21 5:0	0%	

11.1.5 Final Project Schedule

ID	Task Name	Duration	Start	Finish	% Complete	Resource Names	Predecessors
1	**Project Overview**	**79 days**	**Tue 8/17/21 8:0**	**Fri 12/10/21 5:0**	**99%**		
2	**Conceptual Design**	**14 days**	**Tue 8/17/21 8:0**	**Fri 9/3/21 5:00 I**	**100%**		
3	Preliminary Design Review	0 days	Tue 8/31/21 8:0	Tue 8/31/21 8:0	100%		
4	**Detailed Design**	**20 days**	**Mon 9/6/21 8:0**	**Fri 10/1/21 5:00**	**100%**		
5	SDP to Project Mentor	0 days	Fri 9/17/21 8:00	Fri 9/17/21 8:00	100%		
6	SDP to SRB	0 days	Fri 9/24/21 8:00	Fri 9/24/21 8:00	100%		
7	Critical Design Presentation	0 days	Tue 9/28/21 8:0	Tue 9/28/21 8:0	100%		
8	Critical Design Report	0 days	Fri 10/1/21 8:00	Fri 10/1/21 8:00	100%		
9	**Fabrication**	**20 days**	**Mon 10/4/21 8:**	**Fri 10/29/21 5:0**	**100%**		
10	SDP Approval secured	0 days	Fri 10/8/21 8:00	Fri 10/8/21 8:00	100%		
11	Peer Eval 1	0 days	Fri 10/8/21 8:00	Fri 10/8/21 8:00	100%		
12	Project mechanically complete and ESI passed	0 days	Fri 10/29/21 8:00 AM	Fri 10/29/21 8:00 AM	100%		
13	**Testing and Validation**	**15 days**	**Mon 11/1/21 8:**	**Fri 11/19/21 5:0**	**100%**		
14	Project Video	0 days	Tue 11/9/21 8:0	Tue 11/9/21 8:0	100%		
15	Final Presentation and Expo	2 days	Thu 11/18/21 8:	Fri 11/19/21 5:0	100%		
16	**Complete Documentation**	**10 days**	**Mon 11/29/21 8**	**Fri 12/10/21 5:0**	**0%**		
17	Peer Evaluation 2	0 days	Fri 12/3/21 8:00	Fri 12/3/21 8:00	100%		
18	Final Report	0 days	Fri 12/3/21 8:00	Fri 12/3/21 8:00	100%		
19	All Project Files Due	0 days	Fri 12/10/21 8:0	Fri 12/10/21 8:0	75%		
20	**Battery Cart**	**83 days?**	**Wed 8/18/21 8**	**Fri 12/17/21 5:**	**99%**		
1	**Conceptual Development**	**13 days**	**Wed 8/18/21 8:**	**Fri 9/3/21 5:00 I**	**100%**	**Aaron Katada,Brayd**	
2	Research Spring 2021 designs/file	6 days	Wed 8/18/21 8:	Wed 8/25/21 5:	100%		
3	Identify relevant stakeholders and define problem statement	4 days	Thu 8/19/21 8:00 AM	Tue 8/24/21 5:00 PM	100%		
4	**Develop multiple concepts for UTV battery cart redesign**	**6 days**	**Thu 8/19/21 8:00 AM**	**Thu 8/26/21 5:00 PM**	**100%**		
5	Redesign cart tray/table	5 days	Thu 8/19/21 8:0	Wed 8/25/21 5:	100%	Aaron Katada,Braydo	
6	Redesign latches	5 days	Thu 8/19/21 8:0	Wed 8/25/21 5:	100%	Aaron Katada,Justin I	
7	Add rollers/guides for battery b	6 days	Thu 8/19/21 8:0	Thu 8/26/21 5:0	100%	Aaron Katada,Justin I	
8	Frame coating for electrical insulation	4 days	Thu 8/19/21 8:00 AM	Tue 8/24/21 5:00 PM	100%	Braydon Leger,Michael	
9	Raise charging station (potential hazard prevention)	6 days	Thu 8/19/21 8:00 AM	Thu 8/26/21 5:00 PM	100%	Braydon Leger	
10	Redesign frame mounts	5 days	Thu 8/19/21 8:0	Wed 8/25/21 5:	100%	Aaron Katada,Justin I	
11	Define specifications for future battery alternatives	6 days	Thu 8/19/21 8:00 AM	Thu 8/26/21 5:00 PM	100%	Braydon Leger,Michael	
12	Develop design for universal battery cart (Li Ion, Lead Acid,	6 days	Thu 8/19/21 8:00 AM	Thu 8/26/21 5:00 PM	100%	Braydon Leger	
13	Redesign cart raising mechanism (hydraulic, electric	6 days	Thu 8/19/21 8:00 AM	Thu 8/26/21 5:00 PM	100%	Aaron Katada,Braydon	
14	Identify relevant codes	4 days	Tue 8/24/21 8:0	Fri 8/27/21 5:00	100%	Michael Wilhoite	4FF+1 day

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ID	Task Name	Duration	Start	Finish	% Complete	Resource Names	Predecessors
15	Identify relevant hazards and develop Prelim. Hazard Analysis	4 days	Tue 8/24/21 8:00 AM	Fri 8/27/21 5:00 PM	100%	Braydon Leger	4FF+1 day
16	Develop preliminary bill of materi	3 days	Wed 8/25/21 8:	Fri 8/27/21 5:00	100%	Braydon Leger	4FS-2 days
17	Estimate cost and contingency for team budgeting	3 days	Thu 8/26/21 8:00 AM	Sat 8/28/21 5:00 PM	100%	Braydon Leger,Michael	4FS-1 day
18	Preliminary Design Presentation and Review	0 days	Mon 8/30/21 8:00 AM	Mon 8/30/21 8:00 AM	100%	Aaron Katada,Braydon	4FS+1 day
19	Post-PDR concept development follow-up	5 days	Mon 8/30/21 8:00 AM	Fri 9/3/21 5:00 PM	100%	Aaron Katada,Braydon	18
20	**Detailed Design**	**26 days?**	**Mon 8/30/21 8:**	**Mon 10/4/21 5:**	**100%**	**Aaron Katada,Brayd**	**1**
21	**Complete detailed analysis for each design concept**	**26 days?**	**Mon 8/30/21 8:00 AM**	**Mon 10/4/21 5:00 PM**	**100%**	**Aaron Katada,Braydon**	
22	General static loading analysis	6 days	Thu 9/2/21 8:00	Thu 9/9/21 5:00	100%	Aaron Katada,Justin I	
23	Dynamic loading analysis	6 days	Thu 9/2/21 8:00	Thu 9/9/21 5:00	100%	Braydon Leger,Micha	
24	Linear actuator stress/strain calculations and general sizing	5 days	Mon 9/6/21 8:00 AM	Fri 9/10/21 5:00 PM	100%	Braydon Leger,Michael	
25	Bending stress/strain analysis at critical points	5 days	Mon 9/6/21 8:00 AM	Fri 9/10/21 5:00 PM	100%	Aaron Katada,Justin LaNoue	
26	Bolt, fastener, and pin shear analysis	5 days	Mon 9/6/21 8:00 AM	Fri 9/10/21 5:00 PM	100%	Braydon Leger,Michael	
27	Finite element analysis at critical points	11 days	Fri 9/3/21 8:00 AM	Fri 9/17/21 5:00 PM	100%	Aaron Katada,Justin LaNoue	
28	Prepare detailed fabrication drawings, CAD models, schematics, etc.	20 days	Mon 8/30/21 8:00 AM	Fri 9/24/21 5:00 PM	100%	Aaron Katada,Braydon Leger,Justin	
29	Identify and select appropriate materials/components for each design concept	15 days	Mon 8/30/21 8:00 AM	Fri 9/17/21 5:00 PM	100%	Aaron Katada,Braydon Leger,Justin	
30	Detailed bill of materials	10 days	Mon 9/20/21 8:	Fri 10/1/21 5:00	100%	Braydon Leger	
31	Develop battery cart SOP	5 days	Mon 9/6/21 8:0	Fri 9/10/21 5:00	100%	Aaron Katada,Braydo	4FS+6 days
32	Submit SOP to project mentor	0 days	Mon 9/13/21 8:	Mon 9/13/21 8:	100%	Aaron Katada,Braydo	31
33	Submit SOP to safety review boar	0 days	Mon 9/20/21 8:	Mon 9/20/21 8:	100%	Aaron Katada,Braydo	32FS+5 days,31FS+3
34	Complete relevant machine traini	20 days	Mon 8/30/21 8:	Fri 9/24/21 5:00	100%	Aaron Katada,Braydo	
35	NO machine trainings available after Oct. 1!	0 days	Fri 10/1/21 8:00 AM	Fri 10/1/21 8:00 AM	100%		34FS+1 day
36	**Critical design review**	**3 days**	**Tue 9/28/21 8:0**	**Thu 9/30/21 5:0**	**100%**	**Aaron Katada,Brayd**	**21FS-2 days,28FS+2**
37	Critical design presentation	0 days	Tue 9/28/21 8:0	Tue 9/28/21 8:0	100%	Aaron Katada,Braydo	
38	Critical design report	0 days	Thu 9/30/21 8:0	Thu 9/30/21 8:0	100%	Aaron Katada,Braydo	
39	**Procurement**	**32 days**	**Tue 8/24/21 8:0**	**Wed 10/6/21 5:**	**100%**	**Braydon Leger**	
40	Specialty or long lead component identification	4 days	Tue 8/24/21 8:00 AM	Fri 8/27/21 5:00 PM	100%	Braydon Leger	18FF,4FS-3 days
41	Specialty or long lead component procurement	7 days	Thu 8/26/21 8:00 AM	Fri 9/3/21 5:00 PM	100%	Braydon Leger	18FS-2 days,40FS-2 days

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ID	Task Name	Duration	Start	Finish	% Complete	Resource Names	Predecessors
42	Low cost items (design testing, early fabrication, etc.)	10 days	Mon 9/6/21 8:00 AM	Fri 9/17/21 5:00 PM	100%	Braydon Leger	
43	Moderate lead items (identified during detailed design, need earlier than bulk)	10 days	Mon 9/6/21 8:00 AM	Fri 9/17/21 5:00 PM	100%	Braydon Leger	
44	Bulk procurement (remaining items for fabrication, construction, testing, etc.)	8 days	Mon 9/27/21 8:00 AM	Wed 10/6/21 5:00 PM	100%	Braydon Leger	
45	**Fabrication**	**30 days?**	**Mon 9/20/21 8:**	**Fri 10/29/21 5:0**	**100%**	**Aaron Katada,Justin**	**39FS-12 days,20FS-1**
46	Prepare cart for fabrication	5 days	Wed 9/29/21 8:	Tue 10/5/21 5:0	100%	Aaron Katada,Justin L	
47	Battery case replication - Stillwater Steel outsourced fabrication	8 days	Fri 10/1/21 8:00 AM	Tue 10/12/21 5:00 PM	100%	Michael Wilhoite	
48	Complete battery case assembly	4 days	Tue 10/12/21 8:00 AM	Fri 10/15/21 5:00 PM	100%	Michael Wilhoite	
49	Grind old welds from existing cart (table, axles)	4 days	Tue 10/5/21 8:00 AM	Fri 10/8/21 5:00 PM	100%	Justin LaNoue,Aaron Katada	
50	Water jet cutting for rotating tabletop (Alu., HDPE)	5 days	Mon 10/11/21 8:00 AM	Fri 10/15/21 5:00 PM	100%	Michael Wilhoite	
51	Cut and fabricate structural support for rotating tabletop	5 days	Mon 10/11/21 8:00 AM	Fri 10/15/21 5:00 PM	100%	Aaron Katada,Justin LaNoue	
52	Cut and fabricate frame mounts	5 days	Mon 10/11/21 8:00 AM	Fri 10/15/21 5:00 PM	100%	Aaron Katada,Justin LaNoue	
53	Cut and fabricate axles and caster mounts	5 days	Mon 10/11/21 8:00 AM	Fri 10/15/21 5:00 PM	100%	Aaron Katada,Justin LaNoue	
54	Fabricate linear actuator mounts and install actuator	5 days	Mon 10/11/21 8:00 AM	Fri 10/15/21 5:00 PM	100%	Justin LaNoue,Michael	
55	Cut and mill tabletop rails and install latches	5 days	Mon 10/18/21 8:00 AM	Fri 10/22/21 5:00 PM	100%	Michael Wilhoite	
56	3D print rail insulation	5 days	Mon 10/18/21 8	Fri 10/22/21 5:0	100%	Michael Wilhoite	
57	Frame coating application	5 days	Mon 10/25/21 8	Fri 10/29/21 5:0	100%	Braydon Leger	
58	Construction complete cart	5 days	Mon 10/25/21 8	Fri 10/29/21 5:0	100%	Aaron Katada,Braydo	
59	**Testing and Validation**	**26 days?**	**Mon 10/11/21 8**	**Mon 11/15/21 5**	**100%**	**Aaron Katada,Brayd**	**45FS-15 days**
60	Test rotatating tabletop	15 days	Mon 10/11/21 8	Fri 10/29/21 5:0	100%	Michael Wilhoite	
61	Test latch design concept	15 days	Mon 10/11/21 8	Fri 10/29/21 5:0	100%	Justin LaNoue	
62	Test guides for battery boxes	15 days	Mon 10/11/21 8	Fri 10/29/21 5:0	100%	Aaron Katada	
63	Independent load testing - tableto	5 days	Mon 10/25/21 8	Fri 10/29/21 5:0	100%	Aaron Katada,Justin L	
64	Independent load testing - wheels/axles	5 days	Mon 10/25/21 8:00 AM	Fri 10/29/21 5:00 PM	100%	Aaron Katada,Justin LaNoue,Michael	
65	Frame coating inspection	15 days	Mon 10/25/21 8	Fri 11/12/21 5:0	100%	Braydon Leger	
66	Test charging station	5 days	Mon 10/18/21 8	Fri 10/22/21 5:0	100%	Braydon Leger	
67	Test frame mounting mechanism	10 days	Mon 10/11/21 8	Fri 10/22/21 5:0	100%	Aaron Katada	
68	Test linear actuator	10 days	Mon 10/18/21 8	Fri 10/29/21 5:0	100%	Justin LaNoue,Micha	
69	Test actuator circuit	10 days	Mon 10/18/21 8	Fri 10/29/21 5:0	100%	Aaron Katada,Justin L	

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ID	Task Name	Duration	Start	Finish	% Complete	Resource Names	Predecessors
70	Final visual weld inspection	5 days	Mon 10/25/21 8	Fri 10/29/21 5:0	100%	Aaron Katada,Justin L	
71	Test complete cart	5 days	Mon 11/1/21 8:	Fri 11/5/21 5:00	100%	Aaron Katada,Braydo	
72	**Final Project Documentation**	**25 days**	**Mon 11/8/21 8:**	**Fri 12/17/21 5:0**	**90%**	**Aaron Katada,Brayd**	**45,59FS+5 days**
73	Project video	0 days	Mon 11/8/21 8:	Mon 11/8/21 8:	100%	Aaron Katada,Braydo	
74	EXPO and final presentation	0 days	Mon 11/15/21 8	Mon 11/15/21 8	100%	Aaron Katada,Braydo	
75	Final design report	0 days	Mon 11/29/21 8	Mon 11/29/21 8	100%	Aaron Katada,Braydo	
76	Digital file submission	5 days	Mon 12/6/21 8:	Fri 12/10/21 5:0	90%	Aaron Katada,Braydo	
21	**Controller**	**46.31 days?**	**Mon 8/16/21 5**	**Thu 11/18/21 5**	**95%**		
1	**Conceptual Design**	**75 hrs?**	**Mon 8/16/21 5:**	**Thu 9/2/21 9:00**	**100%**		
2	Initial Gantt Chart	28 hrs	Tue 8/17/21 8:0	Sun 8/22/21 9:0	100%	Cody	
3	Review Old Sensor Wiring	8 hrs	Tue 8/24/21 8:0	Wed 8/25/21 9:	100%	Levi	
4	Review Arduino/Python Logic	26 hrs	Tue 8/24/21 8:0	Fri 8/27/21 9:00	100%	Temidayo	
5	Review Velocio connections	26 hrs	Tue 8/24/21 8:0	Fri 8/27/21 9:00	100%	Cody,Levi,Dr. Taylor	
6	Build Flow Chart	8 hrs	Tue 8/31/21 8:0	Wed 9/1/21 9:0	100%	Cody	
7	New Wiring Plan/Overview	20 hrs	Mon 8/23/21 5:	Thu 8/26/21 9:0	100%	Levi	
8	Purchase Velocio components	4.25 hrs?	Tue 8/24/21 8:0	Fri 8/27/21 12:0	100%	Cody	
9	Discuss Testing Plan	8 hrs	Thu 8/26/21 5:0	Fri 8/27/21 9:00	100%	Temidayo,Levi,Cody	
10	Start Presentaion Products	8 hrs	Thu 8/26/21 5:0	Fri 8/27/21 9:00	100%	Cody,Levi,Temidayo	
11	Preliminary Design Presentation	0 hrs	Tue 8/31/21 5:0	Tue 8/31/21 5:0	100%	Team	
12	**Detailed Design**	**123 hrs?**	**Mon 8/30/21 5:**	**Thu 9/30/21 5:0**	**100%**		
13	Velocio Relay Logic (vBuilder)	28 hrs	Mon 8/30/21 5:	Sun 9/5/21 9:00	100%	Cody	
14	Unwire current controller/ Label wires	13 hrs?	Tue 8/31/21 8:00 AM	Thu 9/2/21 2:00 PM	100%	Levi,Temidayo	
15	Remove and label relay switches	8 hrs?	Fri 9/3/21 8:00 A	Sun 9/5/21 11:0	100%	Levi,Temidayo	14
16	Arduino Dismantle/Remove	18 hrs	Fri 9/3/21 5:00 F	Sun 9/5/21 9:00	100%	Levi,Temidayo	14
17	Build test circuit	32.5 hrs	Mon 9/6/21 9:3	Fri 9/10/21 9:00	100%	Levi,Temidayo	13,15
18	Finalize Main Relay logic	8 hrs?	Sat 9/11/21 12:	Mon 9/13/21 2:	100%	Cody	17
19	SOP Submitted	0 hrs	Thu 9/16/21 5:0	Thu 9/16/21 5:0	100%	Cody	
20	Logic Diagram	7 hrs?	Wed 9/15/21 7:	Thu 9/16/21 9:0	100%	Cody	
21	Wiring Diagram	20 hrs	Wed 9/15/21 7:	Fri 9/17/21 9:00	100%	Levi	
22	CDR Slide Creation	13 hrs	Mon 9/20/21 5:	Tue 9/21/21 9:0	100%	Team	20,21
23	Report Rough Draft	30.5 hrs	Fri 9/17/21 5:00	Tue 9/21/21 9:0	100%		
24	Critical Design Presentation	0 hrs	Tue 9/28/21 5:0	Tue 9/28/21 5:0	100%	Team	
25	Purchase Circuit parts	4 hrs	Thu 9/23/21 5:0	Thu 9/23/21 9:0	100%	Cody	
26	Critical Design Report Due	0 hrs	Thu 9/30/21 5:0	Thu 9/30/21 5:0	100%	Team	
27	**Fabrication**	**126 hrs?**	**Fri 10/1/21 5:00**	**Fri 10/29/21 9:0**	**100%**		
28	Display Data Test	8 hrs	Tue 10/5/21 8:0	Wed 10/6/21 9:	100%	Levi,Cody	
29	Begin Velocio install	26 hrs	Mon 10/4/21 5:	Fri 10/8/21 9:00	100%	Temidayo,Cody	
30	Rewiring/compnent install	26 hrs	Mon 10/4/21 5:	Fri 10/8/21 9:00	100%	Levi,Cody	
31	Peer Review #1	0 hrs	Fri 10/8/21 8:00	Fri 10/8/21 8:00	100%	Team	
32	Load Testing	26 hrs	Tue 10/12/21 8:	Fri 10/15/21 9:0	100%	Levi	

ID	Task Name	Duration	Start	Finish	% Complete	Resource Names	Predecessors
33	Testing Phase—	81 hrs	Mon 10/11/21 5	Fri 10/29/21 9:0	100%	Team	
34	Energization Safety Inspection	0 hrs	Fri 10/29/21 5:0	Fri 10/29/21 5:0	100%	Team	
35	**Testing and Validation**	**17 hrs**	**Tue 11/2/21 8:0**	**Fri 11/5/21 9:00**	**100%**		
36	End-Product Wire Cleanup and Labeling	26 hrs	Tue 11/2/21 8:00 AM	Fri 11/5/21 9:00 PM	100%	Levi,Tamidayo	
37	Final UTV Sub-Energy System Test	8 hrs	Thu 11/4/21 5:0	Fri 11/5/21 9:00	100%	Team	
38	Final Presentation work	26 hrs	Mon 11/8/21 5:	Fri 11/12/21 9:0	100%	Team	
39	Final Report Work	26 hrs	Thu 11/11/21 5:	Wed 11/17/21 1	0%	Team	
40	**Expo**	**4 hrs**	**Thu 11/18/21 5:**	**Thu 11/18/21 9:**	**100%**		
41	Final presentation and Expo	0 hrs	Thu 11/18/21 5:	Thu 11/18/21 5:	100%		
42	**Final Documentation**	**0 hrs**	**Thu 11/18/21 5:**	**Thu 11/18/21 5:**	**100%**		
43	Final Report Due	0 hrs	Thu 11/18/21 5:	Thu 11/18/21 5:	100%		
44	Peer Eval #2	0 hrs	Thu 11/18/21 5:	Thu 11/18/21 5:	100%		
45	Final Exam	0 hrs	Thu 11/18/21 5:	Thu 11/18/21 5:	100%		
46	All Project files submitted electronically	0 hrs	Thu 11/18/21 5:00 PM	Thu 11/18/21 5:00 PM	100%		
22	**Speed, Generator, Solar Gantt**	**84 days?**	**Tue 8/17/21 8:**	**Fri 12/10/21 5:**	**99%**		
1	**Conceptual Development**	**14 days**	**Tue 8/17/21 8:0**	**Fri 9/3/21 5:00 I**	**100%**		
2	Identify Problem Statement	6 days	Wed 8/18/21 8:	Wed 8/25/21 5:(	100%	Brandon	
3	Locate diagram, find regulator and shutoff valve location	4 days	Thu 8/19/21 8:00 AM	Tue 8/24/21 5:00 PM	100%	Heba	
4	**Develop Concepts**	**6 days**	**Thu 8/19/21 8:0**	**Thu 8/26/21 5:0**	**100%**		
5	Accquire Krimp Sets	0 days	Thu 8/19/21 8:0	Thu 8/19/21 8:0	100%	Heba,Brandon	
6	Identify ignition wires for Kill Switch	0 days	Thu 8/19/21 8:00 AM	Thu 8/19/21 8:00 AM	100%	Evan,Brandon	
7	Connect Kill Switch to ignition	1 day	Thu 8/19/21 8:0	Thu 8/19/22 5:0	100%	Evan,Cullin,Heba,Bra	
8	Conversation with Dr. Taylor about propane flow	2 days	Thu 8/19/21 8:00 AM	Fri 8/20/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	
9	create BOM Document	6 days	Thu 8/19/21 8:0	Thu 8/26/22 5:0	100%	Evan,Brandon	
10	Research Regulators and Shutoff Valves	5 days	Thu 8/19/21 8:00 AM	Wed 8/25/21 5:00 PM	100%	Evan,Cullin	
11	Generator Manual Deep Dive	6 days	Thu 8/19/21 8:0	Thu 8/26/22 5:0	100%	Evan,Cullin,Heba,Bra	
12	Complete three design concepts and testing plan	6 days	Tue 8/17/21 8:00 AM	Tue 8/24/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	
13	Discussion with Dr. Taylor on Speed Measurement options	2 days	Thu 8/19/21 8:00 AM	Fri 8/20/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	
14	define 3 speed measurement opti	4 days	Tue 8/24/21 8:0	Fri 8/27/21 5:00	100%	Evan	13
15	identify relevant hazards and develop Prelim. Hazard Analysis	4 days	Tue 8/24/21 8:00 AM	Fri 8/27/21 5:00 PM	100%	Heba	13
16	Select Speed Measurement design option that we will pursue	3 days	Wed 8/25/21 8:00 AM	Fri 8/27/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	13,14
17	Estimate cost and contingency for team budgeting	2 days	Thu 8/26/21 8:00 AM	Fri 8/27/21 5:00 PM	100%	Evan,Cullin	9

ID	Task Name	Duration	Start	Finish	% Complete	Resource Names	Predecessors
18	Preliminary Design Presentation and Review	0 days	Mon 8/30/21 8:00 AM	Mon 8/30/21 8:00 AM	100%	Evan,Cullin,Heba,Bra	2,3,4,5,6,7,8,9,10,11
19	Post-PDR concept development follow-up	5 days	Mon 8/30/21 8:00 AM	Fri 9/3/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	18
20	**Detailed Design**	**26 days?**	**Mon 8/30/21 8:**	**Mon 10/4/21 5:**	**100%**		1
21	Complete detailed analysis for speed measurement system	26 days	Tue 8/24/21 8:00 AM	Tue 9/28/21 5:00 PM	100%	Heba,Brandon,Cullin,	
22	Create Propane Tank to Generator diagrams	1 day	Thu 9/2/21 8:00 AM	Thu 9/2/21 5:00 PM	100%	Cullin	
23	Design Actuator Bypass valve	7 days	Thu 9/2/21 8:00	Fri 9/10/21 5:00	100%		
24	Prepare CAD drawing for speed display	1 day	Thu 9/23/21 8:00 AM	Thu 9/23/21 5:00 PM	100%	Cullin,Brandon	16
25	Prepare electrical plan for removing 12 volt battery	5 days	Thu 9/9/21 8:00 AM	Wed 9/15/21 5:00 PM	100%	Cullin,Evan	
26	Create a plan for speed testing	1 day	Mon 8/30/21 8:	Mon 8/30/21 5:(	100%	Cullin	
27	Detailed bill of materials	14 days	Fri 8/27/21 8:00	Wed 9/15/21 5:(	100%	Heba,Brandon	9
28	Develop Generator SOP	7 days	Wed 8/25/21 8:	Thu 9/2/21 5:00	100%	Cullin,Brandon	12
29	Generator SOP NCL revisions	4 days	Fri 9/3/21 8:00 /	Wed 9/8/21 5:0(	100%	Brandon,Cullin,Evan,	28
30	Complete relevant machine traini	18 days	Mon 8/30/21 8:	Wed 9/22/21 5:	100%	Evan,Cullin,Heba,Bra	
31	Detailed plan for putting the propane tank into a vertical	0 days	Fri 10/1/21 8:00 AM	Fri 10/1/21 8:00 AM	100%	Evan,Cullin,Heba,Bra	
32	**Critical design review**	**3 days**	**Tue 9/28/21 8:0**	**Thu 9/30/21 5:0**	**100%**		
33	Critical design presentation	0 days	Tue 9/28/21 8:0	Tue 9/28/21 8:0	100%	Evan,Cullin,Heba,Bra	
34	Critical design report	0 days	Thu 9/30/21 8:0	Thu 9/30/21 8:0	100%	Evan,Cullin,Heba,Bra	
35	**Procurement**	**29 days**	**Mon 9/6/21 8:0**	**Thu 10/14/21 5:**	**100%**		
36	New Propane Tank	1 day	Tue 9/21/21 8:0	Tue 9/21/21 5:0	100%	Evan	
37	Propane - Generator hose & connections	2 days	Tue 9/14/21 8:00 AM	Wed 9/15/21 5:00 PM	100%	Evan,Cullin	
38	Speem sensor display	4 days	Mon 9/6/21 8:0	Thu 9/9/21 5:00	100%	Evan	
39	Voltage regulator	7 days	Thu 9/23/21 8:0	Fri 10/1/21 5:00	100%	Evan,Heba	
40	Speed Sensor Test Bed	7 days	Wed 10/6/21 8:	Thu 10/14/21 5:	100%		
41	New Actuator	7 days	Thu 9/30/21 8:0	Fri 10/8/21 5:00	100%	Evan	
42	Speed sensor drive shaft compone	10 days	Mon 9/6/21 8:0	Fri 9/17/21 5:00	100%	Evan,Cullin,Heba,Bra	
43	**Fabrication**	**58 days?**	**Mon 9/20/21 8:**	**Wed 12/8/21 5:**	**100%**		
44	Complete coding for speed sensor	14 days	Mon 9/20/21 8:	Thu 10/7/21 5:0	100%	Evan,Heba	
45	Remove 12V charger from Genera	1 day	Thu 9/9/21 8:00	Thu 9/9/21 5:00	100%	Brandon,Evan	
46	Complete SolidWorks case design for hall effect sensor	14 days	Mon 9/20/21 8:00 AM	Thu 10/7/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	42
47	3D print hall effect sensor case	7 days	Tue 10/12/21 8:	Wed 10/20/21 5	100%		
48	Weld verticle sheet metal for propane tank	6 days	Fri 10/1/21 8:00 AM	Fri 10/8/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	31
49	Install actuator bypass valve	2 days	Fri 10/1/21 8:00	Mon 10/4/21 5:(	100%	Cullin,Evan	

ID	Task Name	Duration	Start	Finish	% Complete	Resource Names	Predecessors
50	Install propane - Generator pipe / connections	4 days	Tue 10/5/21 8:00 AM	Fri 10/8/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	48
51	Install speed sensor	10 days	Wed 9/15/21 8:	Tue 9/28/21 5:0	100%	Evan,Cullin,Heba,Bra	38
52	Mount voltage regulator	1 day	Mon 10/4/21 8:	Mon 10/4/21 5:(	100%	Brandon,Evan	39
53	Mount Pressure Reducer	7 days	Thu 10/7/21 8:0	Fri 10/15/21 5:0	100%	Cullin,Heba	
54	Install speed sensor display	20 days	Mon 9/20/21 8:	Fri 10/15/21 5:0	100%	Evan,Cullin,Heba,Bra	42
55	**Testing and Validation**	**36 days?**	**Mon 10/11/21 8**	**Mon 11/29/21 5**	**100%**		
56	Test Speed display works (we have power)	2 days	Mon 10/18/21 8:00 AM	Tue 10/19/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	51,54
57	Test Speed on display vs speed gu	3 days	Mon 10/25/21 8	Wed 10/27/21 5	100%	Evan,Cullin,Heba,Bra	51,54
58	Test Solar Lockout with ATV in motion	3 days	Mon 10/25/21 8:00 AM	Wed 10/27/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	7
59	Test Generator with new propane tank	3 days	Thu 9/9/21 8:00 AM	Mon 9/13/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	36,37
60	Remove Actuator, Run the Genera	3 days	Thu 9/16/21 8:0	Mon 9/20/21 5:(	100%	Evan,Cullin,Heba,Bra	59,36,37
61	Place regulator closer to propane tank, test generator	3 days	Thu 9/9/21 8:00 AM	Mon 9/13/21 5:00 PM	100%	Evan,Cullin,Heba,Bra	59,60
62	Test Generator bypass valve (without actuator)	2 days	Tue 10/12/21 8:00 AM	Wed 10/13/21 5:00 PM	100%	Brandon,Cullin,Evan,	
63	Test Generator bypass valve (with actuator)	2 days	Tue 10/19/21 8:00 AM	Wed 10/20/21 5:00 PM	100%	Brandon,Cullin,Evan,	
64	Replace Actuator, test Generator	3 days	Mon 11/8/21 8:	Wed 11/10/21 5	100%	Evan,Cullin,Heba,Bra	59,60,61
65	Testing of all systems	3 days	Mon 11/8/21 8:	Wed 11/10/21 5	100%	Brandon,Cullin,Evan,	
66	Test battery life on flat terrain (Drive atv until battery dies)	1 day	Mon 11/8/21 8:00 AM	Mon 11/8/21 5:00 PM	100%	Cullin	
67	Test Battery Life on all terrain (drive until atv battery dies)	1 day	Mon 10/11/21 8:00 AM	Mon 10/11/21 5:00 PM	100%	Evan	
68	**Final Project Documentation**	**25 days**	**Mon 11/8/21 8:**	**Fri 12/10/21 5:0**	**75%**		
69	Project video	0 days	Mon 11/8/21 8:	Mon 11/8/21 8:	100%	Evan,Cullin,Heba,Bra	
70	EXPO and final presentation	0 days	Wed 11/10/21 8	Wed 11/10/21 8	100%	Evan,Cullin,Heba,Bra	65,66,67
71	Final design report	0 days	Mon 11/29/21 8	Mon 11/29/21 8	100%	Evan,Cullin,Heba,Bra	
72	Digital file submission	5 days	Mon 12/6/21 8:	Fri 12/10/21 5:0	75%	Evan,Cullin,Heba,Bra	
73	**PM**	**78 days?**	**Wed 8/18/21 8**	**Fri 12/10/21 5:**	**99%**		
1	**Conceptual Design**	**18 days?**	**Wed 8/18/21 8:**	**Sun 9/12/21 8:0**	**100%**		
2	**PDR Prep**	**5 days**	**Mon 8/23/21 8:**	**Fri 8/27/21 5:00**	**100%**		
3	Assist groups with PDR Presentations	4 days	Mon 8/23/21 8:00 AM	Thu 8/26/21 5:00 PM	100%	Maggie Goodin,Kaiser	
4	Make reuired edits to PDR presentation slides	2 days	Thu 8/26/21 8:00 AM	Fri 8/27/21 5:00 PM	100%	Kaiser Cleburn,Maggie	
5	**SOP Prep**	**13 days?**	**Wed 8/25/21 8:**	**Sun 9/12/21 8:0**	**100%**		
6	Meet with team leads on SOPs	0.25 days	Wed 8/25/21 5:	Wed 8/25/21 7:	100%	Maggie Goodin	
7	Work with teams on SOPs	12 days	Thu 8/26/21 8:0	Fri 9/10/21 5:00	100%		6
8	**Create Progress Report**	**6 days**	**Mon 8/23/21 8:**	**Mon 8/30/21 5:**	**100%**		

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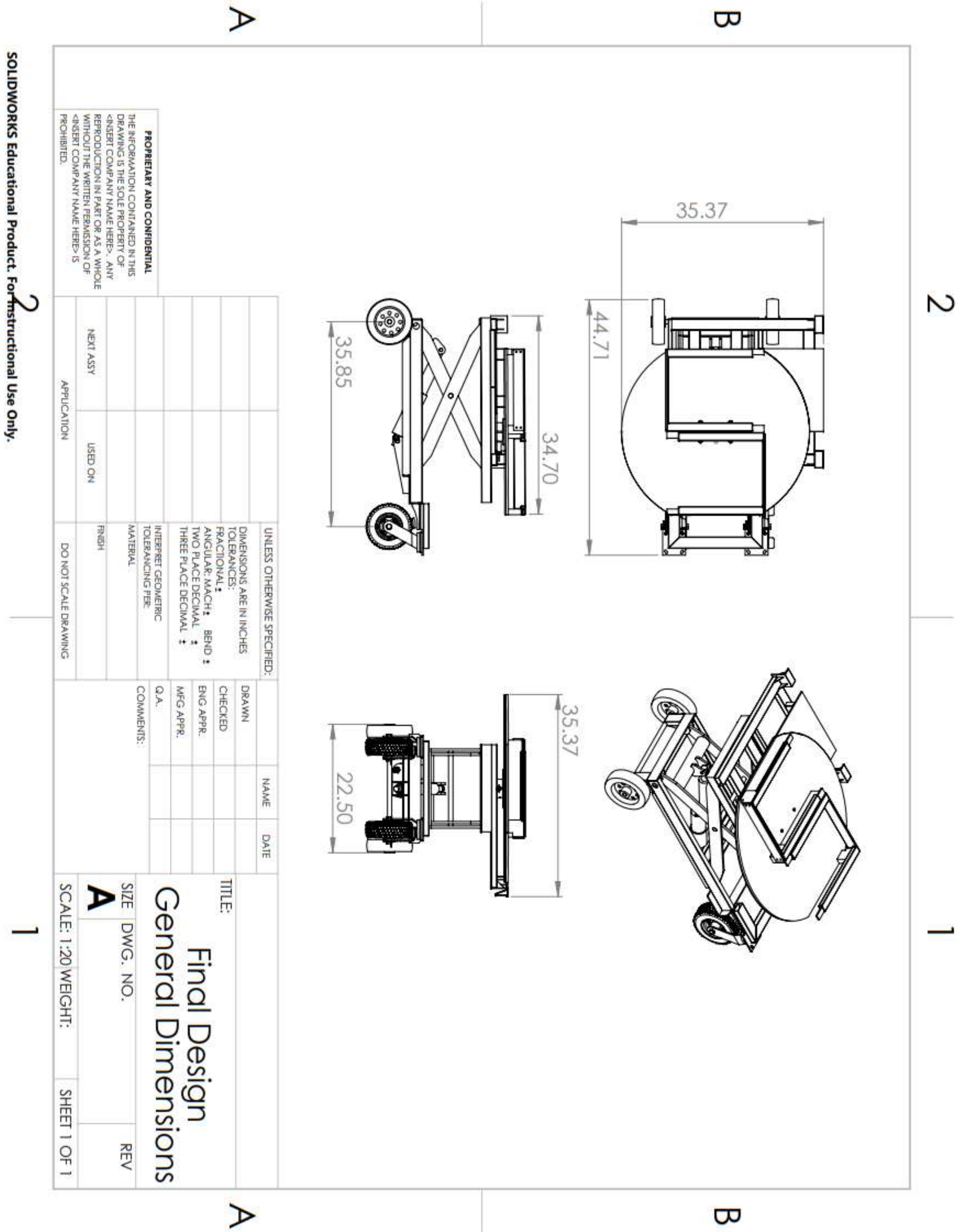
ID	Task Name	Duration	Start	Finish	% Complete	Resource Names	Predecessors
9	Create Progress Report 1	1 day	Mon 8/23/21 8:	Mon 8/23/21 5:(	100%	Maggie Goodin	
10	Create Progress Report 2	1 day	Mon 8/30/21 8:	Mon 8/30/21 5:(	100%	Maggie Goodin	
11	**Update Project Schedule**	**6 days**	**Mon 8/23/21 8:**	**Mon 8/30/21 5:**	**100%**		
12	Update Project Schedule 1	1 day	Mon 8/23/21 8:	Mon 8/23/21 5:(	100%	Kaiser Cleburn	
13	Update Project Schedule 2	1 day	Mon 8/30/21 8:	Mon 8/30/21 5:(	100%	Kaiser Cleburn	
14	**Radio**	**7 days**	**Wed 8/18/21 8:**	**Thu 8/26/21 5:0**	**100%**		
15	Research FCC regulations regarding different types of radios and their usage	2 days	Wed 8/18/21 8:00 AM	Thu 8/19/21 5:00 PM	100%	Kaiser Cleburn	
16	Decide type of radio needed	1 day	Mon 8/23/21 8:	Mon 8/23/21 5:(	100%	Kaiser Cleburn	15
17	Determine mounting locations for radio and antenna	1 day	Tue 8/24/21 8:00 AM	Tue 8/24/21 5:00 PM	100%	Kaiser Cleburn,Maggie	
18	Research how radio will get power from the UTV	1 day	Tue 8/24/21 8:00 AM	Tue 8/24/21 5:00 PM	100%	Kaiser Cleburn	16
19	Finish rough draft of PDR slides	2 days	Wed 8/25/21 8:	Thu 8/26/21 5:0	100%	Maggie Goodin	17,18
20	**Detailed Design**	**27 days?**	**Mon 9/6/21 8:0**	**Tue 10/12/21 5:**	**100%**		
21	SOP submitted to project mentor	0 days	Mon 9/13/21 8:	Mon 9/13/21 8:(	100%	Maggie Goodin	7
22	**Create Progress Report**	**16 days**	**Mon 9/6/21 8:0**	**Mon 9/27/21 5:**	**100%**		
23	Create Progress Report 1	1 day	Mon 9/6/21 8:0	Mon 9/6/21 5:0(	100%	Maggie Goodin	
24	Create Progress Report 2	1 day	Mon 9/13/21 8:	Mon 9/13/21 5:(	100%	Maggie Goodin	
25	Create Progress Report 3	1 day	Mon 9/20/21 8:	Mon 9/20/21 5:(	100%	Maggie Goodin	
26	Create Progress Report 4	1 day	Mon 9/27/21 8:	Mon 9/27/21 5:(	100%	Maggie Goodin	
27	**Update Project Schedule**	**16 days**	**Mon 9/6/21 8:0**	**Mon 9/27/21 5:**	**100%**		
28	Update Project Schedule 1	1 day	Mon 9/6/21 8:0	Mon 9/6/21 5:0(	100%	Kaiser Cleburn	
29	Update Project Schedule 2	1 day	Mon 9/13/21 8:	Mon 9/13/21 5:(	100%	Kaiser Cleburn	
30	Update Project Schedule 3	1 day	Mon 9/20/21 8:	Mon 9/20/21 5:(	100%	Kaiser Cleburn	
31	Update Project Schedule 4	1 day	Mon 9/27/21 8:	Mon 9/27/21 5:(	100%	Kaiser Cleburn	
32	**Human Factors**	**19 days**	**Mon 9/6/21 8:0**	**Thu 9/30/21 5:0**	**100%**		
33	SOP	1 day	Thu 9/9/21 8:00	Thu 9/9/21 5:00	100%	Maggie Goodin	
34	Design mounting box for Displa	4 days	Mon 9/6/21 8:0	Thu 9/9/21 5:00	100%	Kaiser Cleburn	
35	Finalize mount choice	4 days	Mon 9/6/21 8:0	Thu 9/9/21 5:00	100%	Kaiser Cleburn	
36	Research good UI design	10 days	Mon 9/6/21 8:0	Fri 9/17/21 5:00	100%	Maggie Goodin	
37	Work with controller team to design UI	19 days	Mon 9/6/21 8:00 AM	Thu 9/30/21 5:00 PM	100%	Maggie Goodin,Kaiser	
38	Finalize BOM	1 day	Thu 9/9/21 8:00	Thu 9/9/21 5:00	100%	Kaiser Cleburn	35
39	Create CDR report	9 days	Mon 9/13/21 8:	Thu 9/23/21 5:0	100%	Kaiser Cleburn,Magg	
40	**Fabrication**	**16 days**	**Mon 10/4/21 8:**	**Mon 10/25/21 5**	**100%**		
41	**Create Progress Report**	**16 days**	**Mon 10/4/21 8:**	**Mon 10/25/21 5**	**100%**		
42	Create Progress Report 1	1 day	Mon 10/4/21 8:	Mon 10/4/21 5:(	100%	Maggie Goodin	
43	Create Progress Report 2	1 day	Mon 10/11/21 8	Mon 10/11/21 5	100%	Maggie Goodin	
44	Create Progress Report 3	1 day	Mon 10/18/21 8	Mon 10/18/21 5	100%	Maggie Goodin	
45	Create Progress Report 4	1 day	Mon 10/25/21 8	Mon 10/25/21 5	100%	Maggie Goodin	

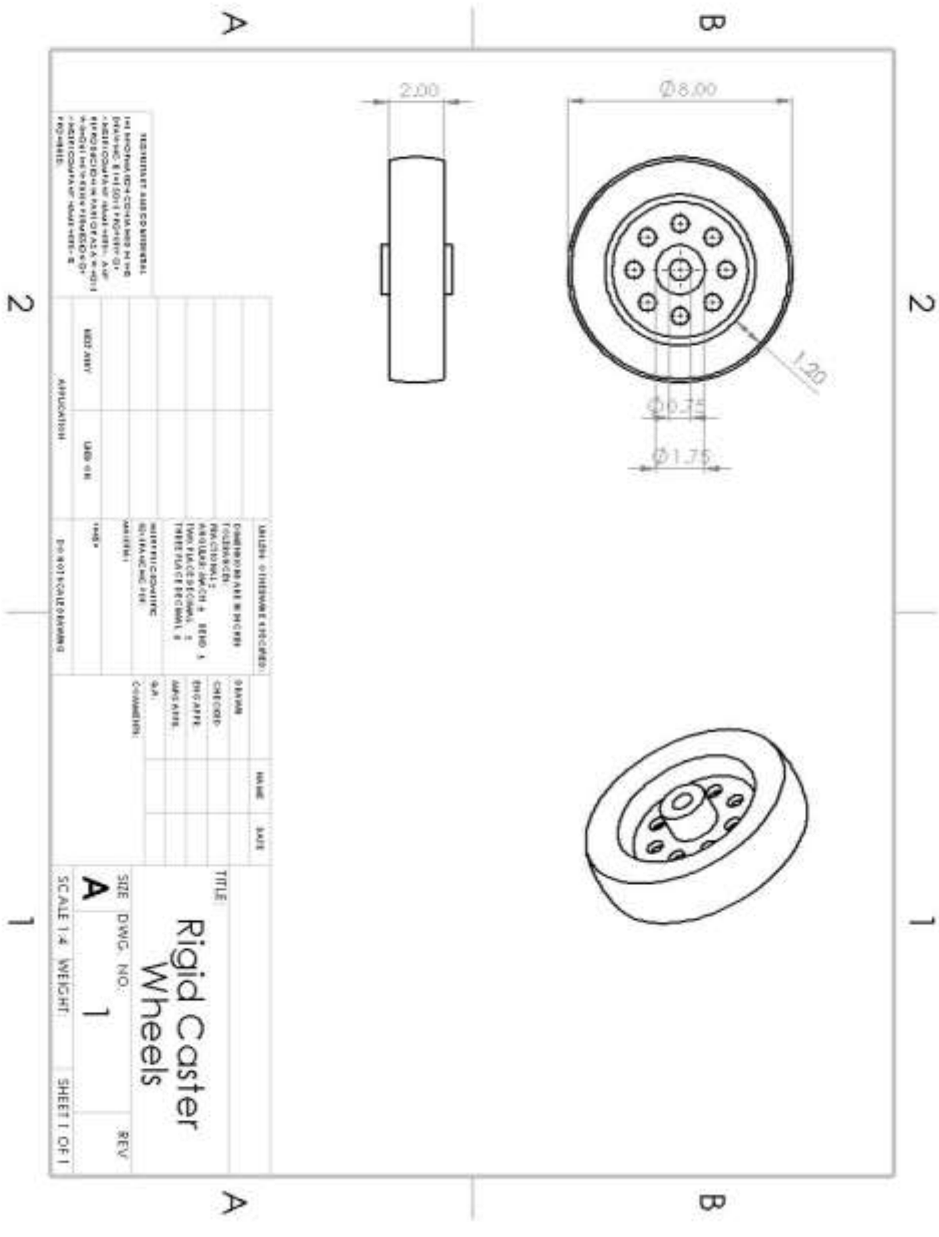
ID	Task Name	Duration	Start	Finish	% Complete	Resource Names	Predecessors
46	**Update Project Schedule**	**16 days**	**Mon 10/4/21 8:**	**Mon 10/25/21 5**	**100%**		
47	Update Project Schedule	1 day	Mon 10/4/21 8:(	Mon 10/4/21 5:(	100%	Kaiser Cleburn	
48	Update Project Schedule 2	1 day	Mon 10/11/21 8	Mon 10/11/21 5	100%	Kaiser Cleburn	
49	Update Project Schedule 3	1 day	Mon 10/18/21 8	Mon 10/18/21 5	100%	Kaiser Cleburn	
50	Update Project Schedule 4	1 day	Mon 10/25/21 8	Mon 10/25/21 5	100%	Kaiser Cleburn	
51	**Human Factors**	**15 days**	**Mon 10/4/21 8:**	**Fri 10/22/21 5:0**	**100%**		
52	Order mounting arm	1 day	Mon 10/4/21 8:(	Mon 10/4/21 5:(	100%	Braydon Leger	38
53	Order Aluminum sheet	1 day	Mon 10/4/21 8:(	Mon 10/4/21 5:(	100%	Braydon Leger	38
54	**Print mounting box for Display**	**4 days**	**Mon 10/11/21 8**	**Thu 10/14/21 5:**	**100%**	**Kaiser Cleburn,Magg**	
55	Create STL file of model	1 day	Mon 10/11/21 8	Mon 10/11/21 5	100%	Kaiser Cleburn	
56	Have model printed	3 days	Tue 10/12/21 8:	Thu 10/14/21 5:	100%		55
57	**Fabricate front and back plate of mounting box**	**3 days**	**Mon 10/4/21 8:00 AM**	**Wed 10/6/21 5:00 PM**	**100%**	**Kaiser Cleburn,Maggie**	
58	Create drawings	1 day	Mon 10/4/21 8:(	Mon 10/4/21 5:(	100%	Kaiser Cleburn	34
59	Schedule time to have NCL cut out on waterjet	1 day	Tue 10/5/21 8:00 AM	Tue 10/5/21 5:00 PM	100%	Maggie Goodin	58,53
60	Lay out and drill holes for arm mount	1 day	Wed 10/6/21 8:00 AM	Wed 10/6/21 5:00 PM	100%	Kaiser Cleburn	59
61	Install display in UTV	1 day	Thu 10/7/21 8:0	Thu 10/7/21 5:0	100%	Kaiser Cleburn,Magg	54,57
62	Work with controller team to implement the UI	15 days	Mon 10/4/21 8:00 AM	Fri 10/22/21 5:00 PM	100%	Maggie Goodin	37
63	**Testing and Validation**	**15 days**	**Mon 11/1/21 8:**	**Fri 11/19/21 5:0**	**100%**		
64	**Create Progress Report**	**11 days**	**Mon 11/1/21 8:**	**Mon 11/15/21 5**	**100%**		
65	Create Progress Report 1	1 day	Mon 11/1/21 8:(	Mon 11/1/21 5:(	100%	Maggie Goodin	
66	Create Progress Report 2	1 day	Mon 11/8/21 8:(	Mon 11/8/21 5:(	100%	Maggie Goodin	
67	Create Progress Report 3	1 day	Mon 11/15/21 8	Mon 11/15/21 5	100%	Maggie Goodin	
68	**Update Project Schedule**	**11 days**	**Mon 11/1/21 8:**	**Mon 11/15/21 5**	**100%**		
69	Update Project Schedule 1	1 day	Mon 11/1/21 8:(	Mon 11/1/21 5:(	100%	Kaiser Cleburn	
70	Update Project Schedule 2	1 day	Mon 11/8/21 8:(	Mon 11/8/21 5:(	100%	Kaiser Cleburn	
71	Update Project Schedule 3	1 day	Mon 11/15/21 8	Mon 11/15/21 5	100%	Kaiser Cleburn	
72	**Retest generator sound pressure**	**4 days**	**Mon 11/1/21 8:**	**Thu 11/4/21 5:0**	**100%**	**Kaiser Cleburn,Magg**	
73	Test generator sound pressure while under load and moving	1 day	Mon 11/1/21 8:00 AM	Mon 11/1/21 5:00 PM	100%		
74	Update reccomendations for hearing protection	3 days	Tue 11/2/21 8:00 AM	Thu 11/4/21 5:00 PM	100%	Kaiser Cleburn	
75	**Make sure display works properly**	**15 days**	**Mon 11/1/21 8:**	**Fri 11/19/21 5:0**	**100%**	**Maggie Goodin**	
76	Coordinate with the controller team for testing	1 day	Mon 11/1/21 8:00 AM	Mon 11/1/21 5:00 PM	100%		
77	Validate display is presenting proper information	5 days	Mon 11/8/21 8:00 AM	Fri 11/12/21 5:00 PM	100%		
78	Make sure display location works ergonomically	5 days	Mon 11/8/21 8:00 AM	Fri 11/12/21 5:00 PM	100%		
79	Make any adjustments	5 days	Mon 11/15/21 8	Fri 11/19/21 5:0	100%		

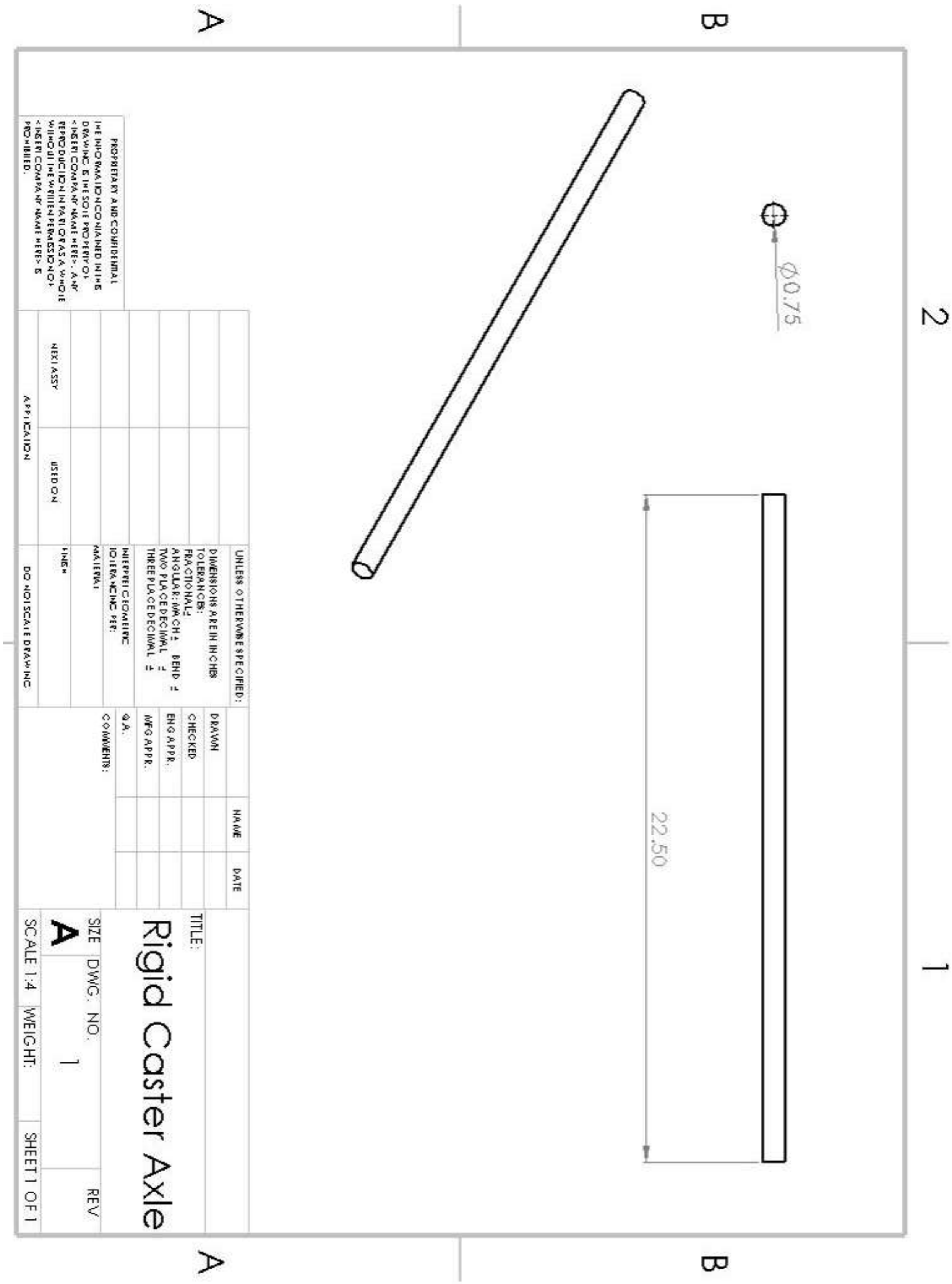
ID	Task Name	Duration	Start	Finish	% Complete	Resource Names	Predecessors
80	**Final Project Documentation**	**20 days**	**Mon 11/8/21 8:**	**Fri 12/10/21 5:0**	**98%**		
81	Project video	0 days	Mon 11/8/21 8:(	Mon 11/8/21 8:(	100%	Evan,Cullin,Heba,Bra	
82	EXPO and final presentation	0 days	Wed 11/10/21 8	Wed 11/10/21 8	100%	Evan,Cullin,Heba,Bra	
83	Final design report	21 days	Mon 11/1/21 8:(	Mon 12/6/21 5:(	100%	Evan,Cullin,Heba,Bra	
84	Digital file submission	5 days	Mon 12/6/21 8:(	Fri 12/10/21 5:0	90%	Evan,Cullin,Heba,Bra	

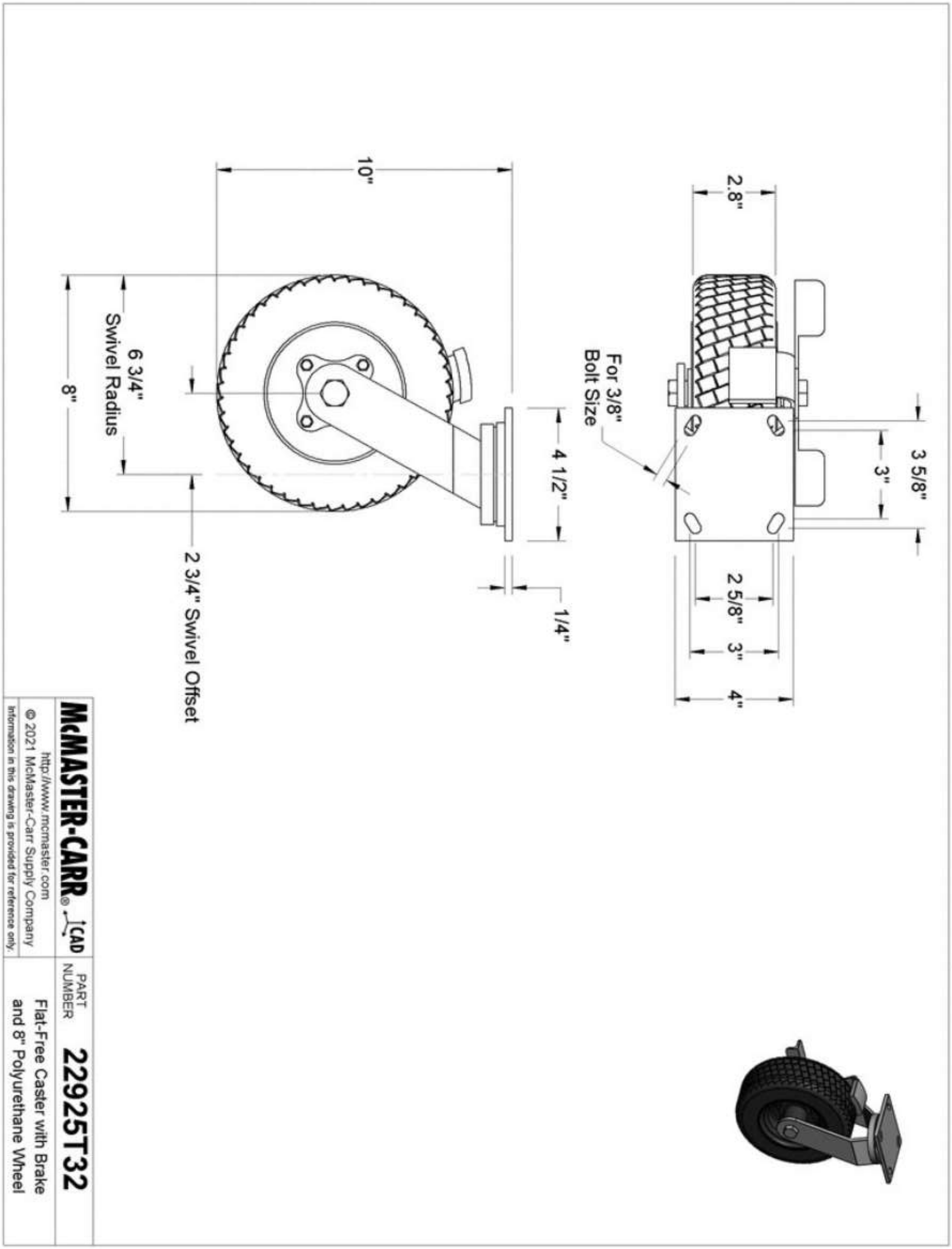
11.2 BATTERY CART

11.2.1 Detailed drawings for new or modified cart components




Ø8.00
2.00
1.20
Ø0.75
Ø1.75
TITLE:
Rigid Caster Wheels
SIZE
A
DWG. NO.
1
REV
SCALE 1:4
WEIGHT:
SHEET 1 OF 1


Ø0.75
22.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
PROPRIETARY AND CONFIDENTIAL
TITLE:
Rigid Caster Axle
SIZE
A
DWG. NO.
1
REV
SCALE 1:4
WEIGHT:
SHEET 1 OF 1


10"
2.8"
6 3/4"
Swivel Radius
8"
For 3/8"
Bolt Size
4 1/2"
3 5/8"
3"
2 3/4" Swivel Offset
1/4"
2 5/8"
3"
4"
McMASTER-CARR®
CAD
http://www.mcmaster.com
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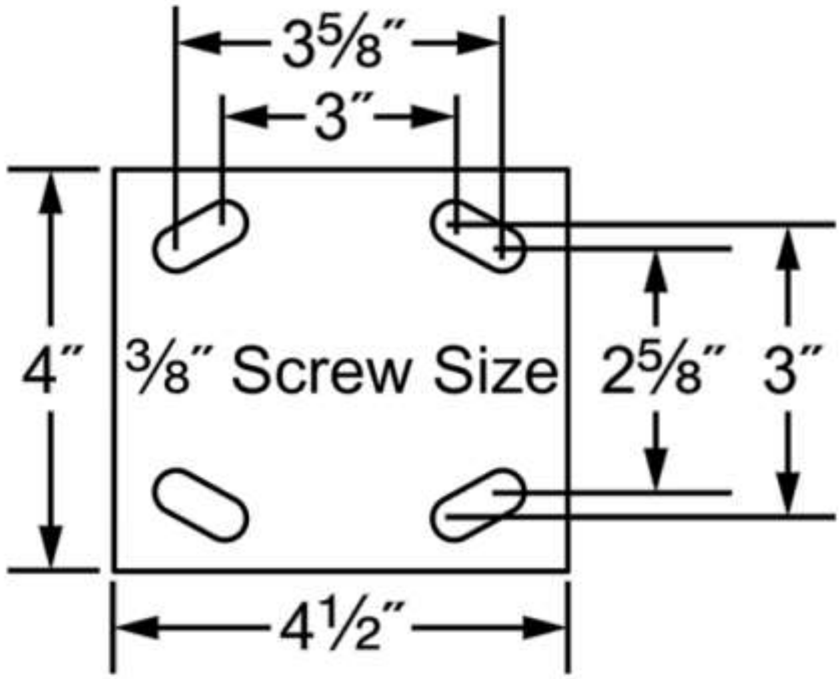
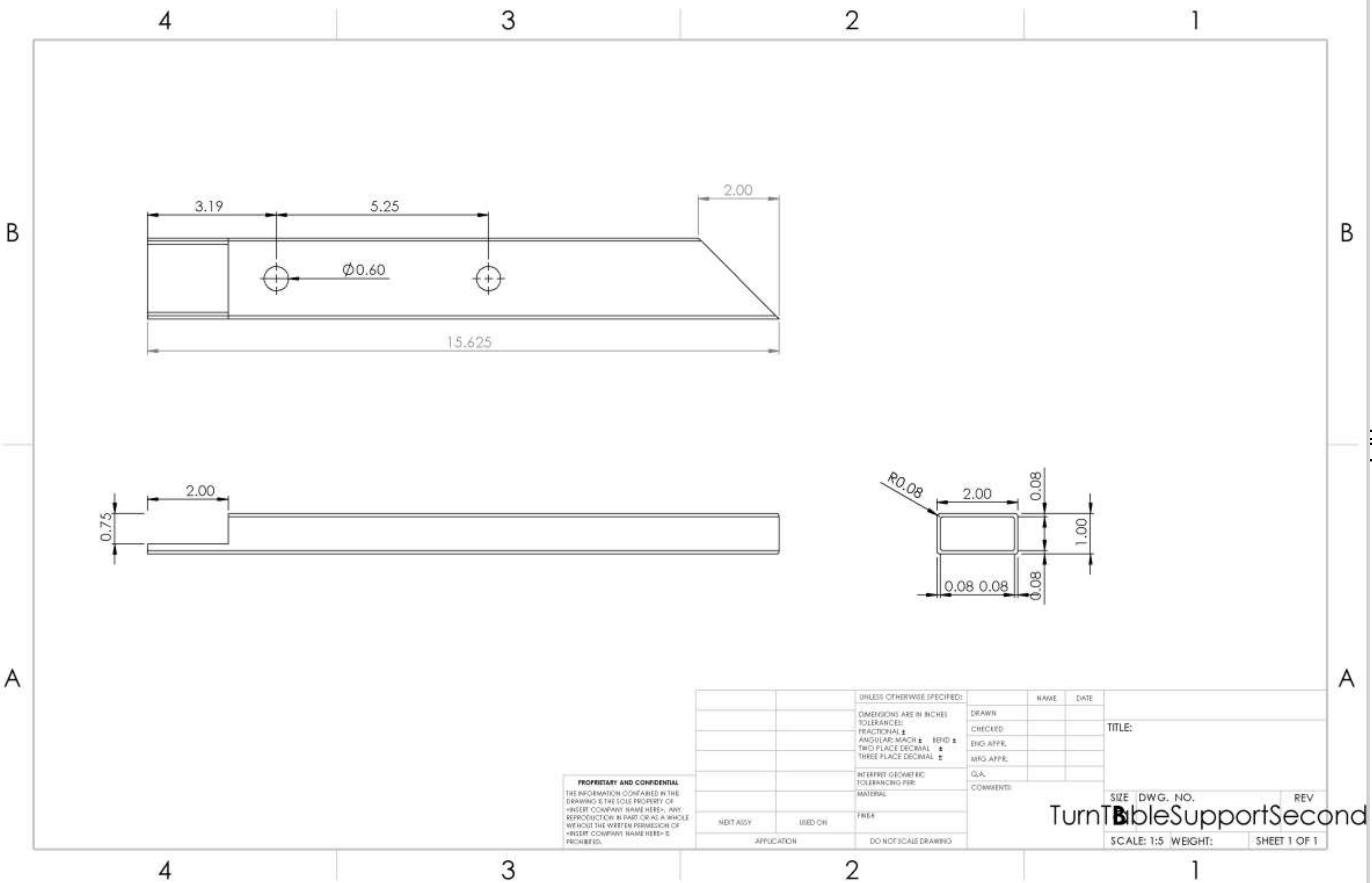
Information in this drawing is provided for reference only.
PART NUMBER
22925T32
Flat-Free Caster with Brake
and 8" Polyurethane Wheel


3⅝″
3″
4″
⅜″ Screw Size
2⅝″
3″
4½″


3.19
5.25
2.00
Ø0.60
15.625
2.00
0.75
R0.08
2.00
0.08
1.00
0.08 0.08
0.08
PROPRIETARY AND CONFIDENTIAL
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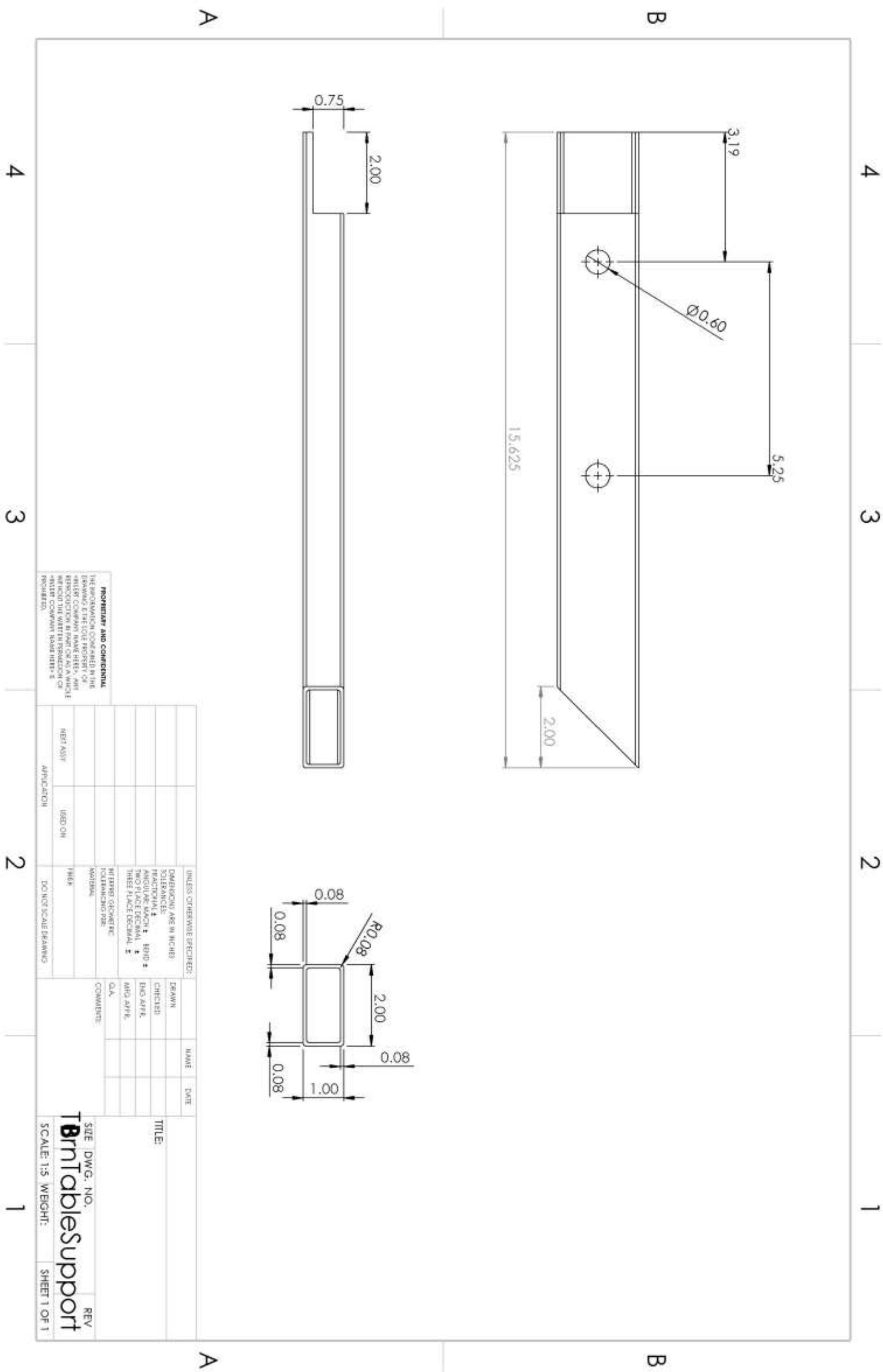
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE DWG. NO.
REV
B
TurnTableSupportSecond
SCALE: 1:5 WEIGHT:
SHEET 1 OF 1


0.75
2.00
3.19
Ø0.60
15.625
5.25
2.00
0.08
0.08
R0.08
2.00
0.08
0.08
1.00
PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
MATERIAL
FINISH
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SIZE
DWG. NO.
REV
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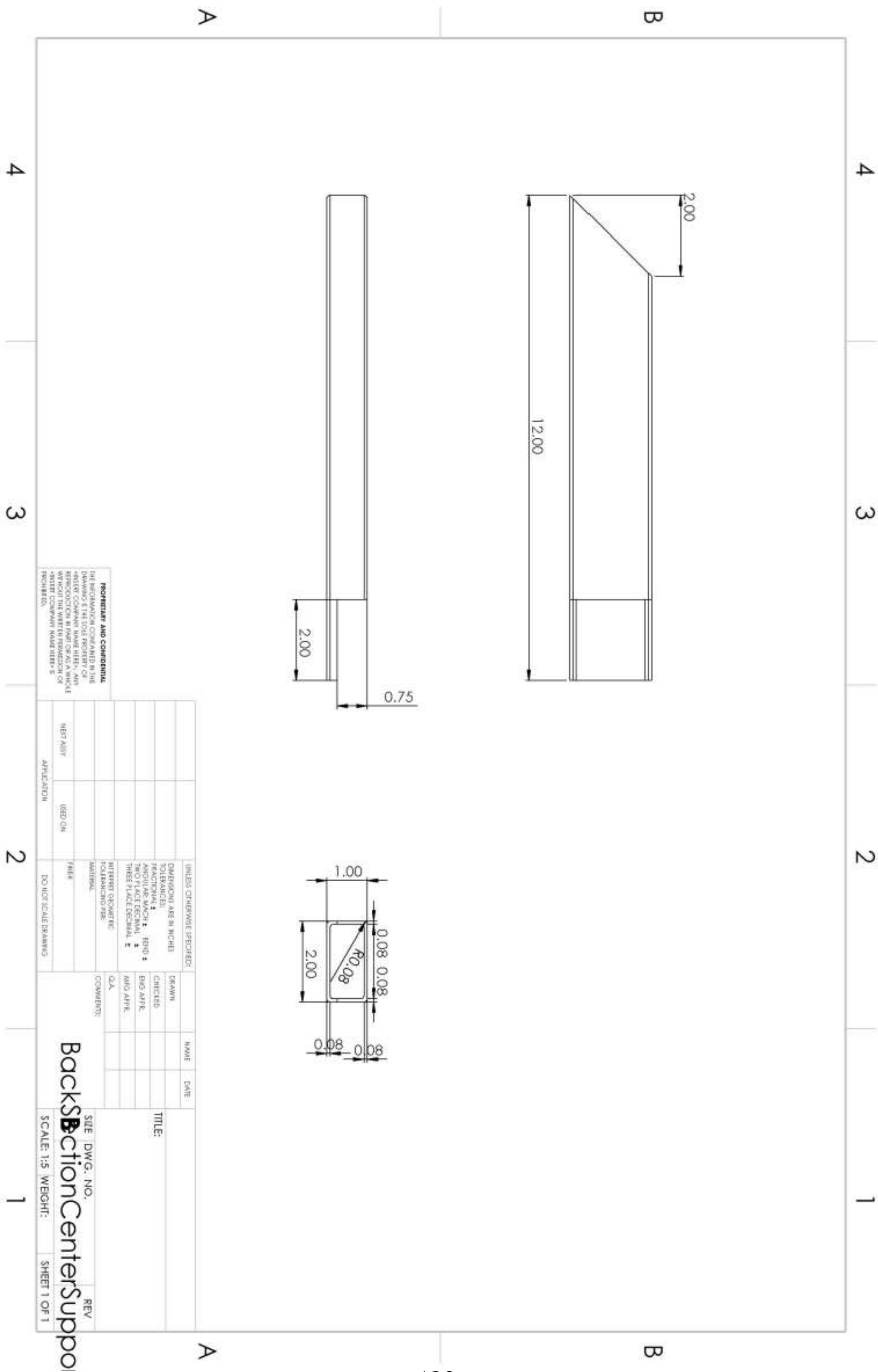
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1


2.00
12.00
2.00
0.75
1.00
2.00
R0.08
0.08
0.08
0.08
0.08
UNLESS OTHERWISE SPECIFIED:
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SIZE
DWG. NO.
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL

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APPLICATION

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

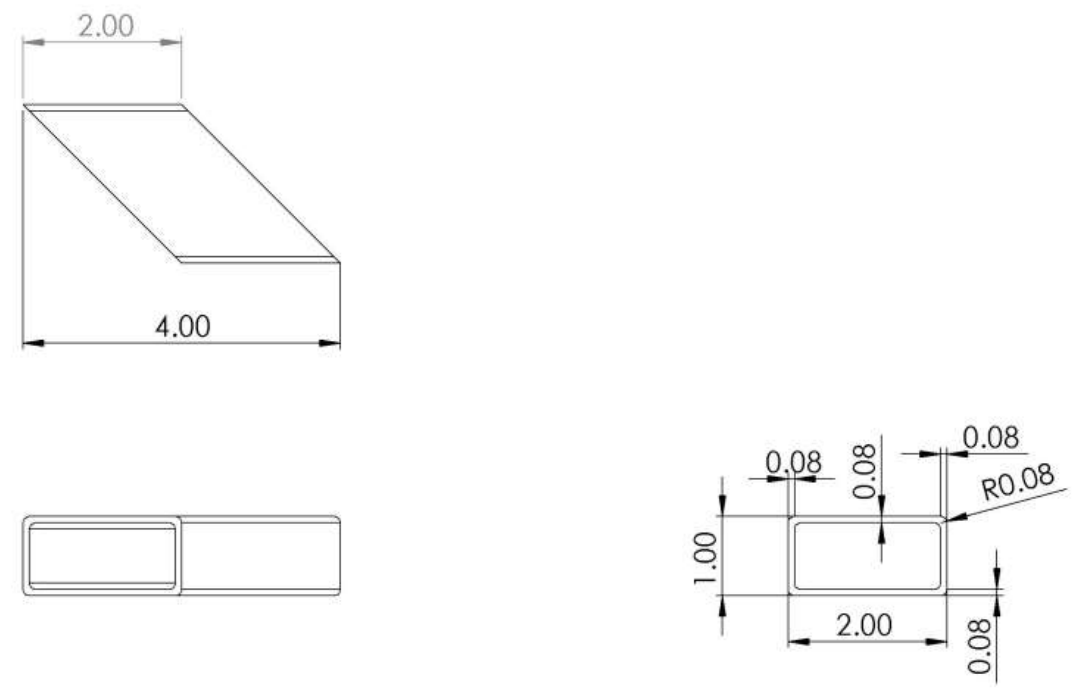
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE A DWG. NO. FrontSupportMember REV

SCALE: 1:5 WEIGHT: SHEET 1 OF 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

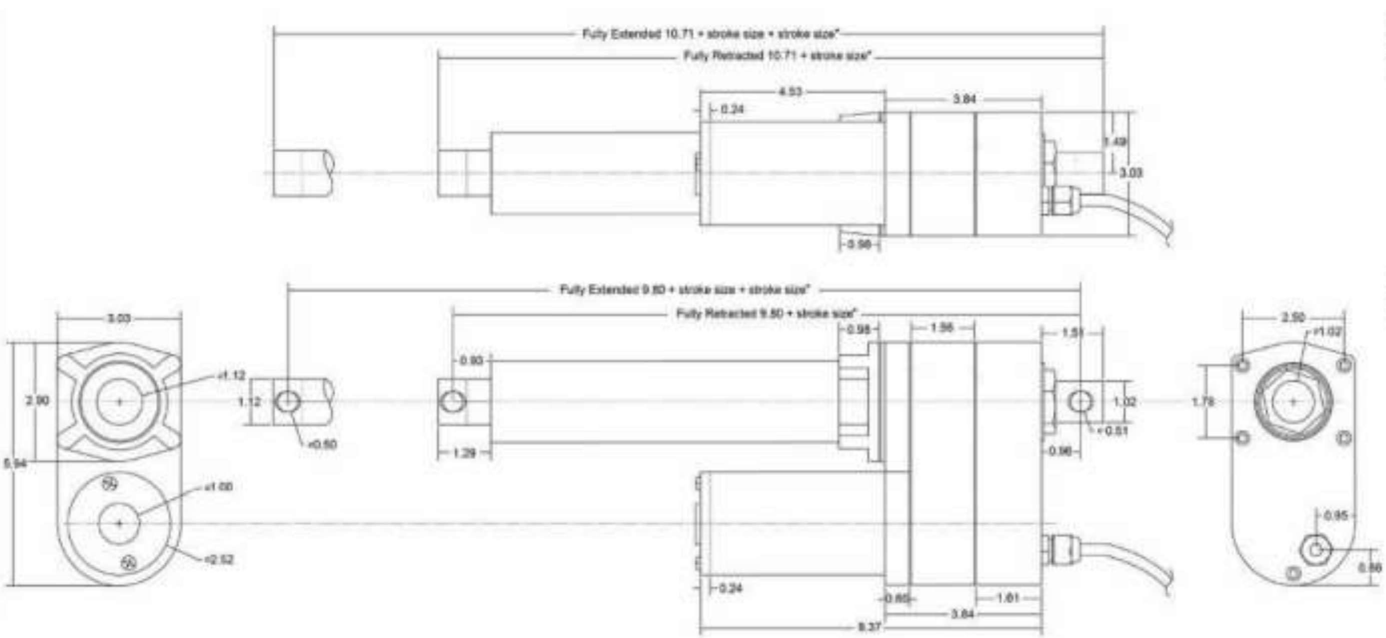
COMMENTS:

TITLE:

SIZE **A** DWG. NO. ShortTurn REV

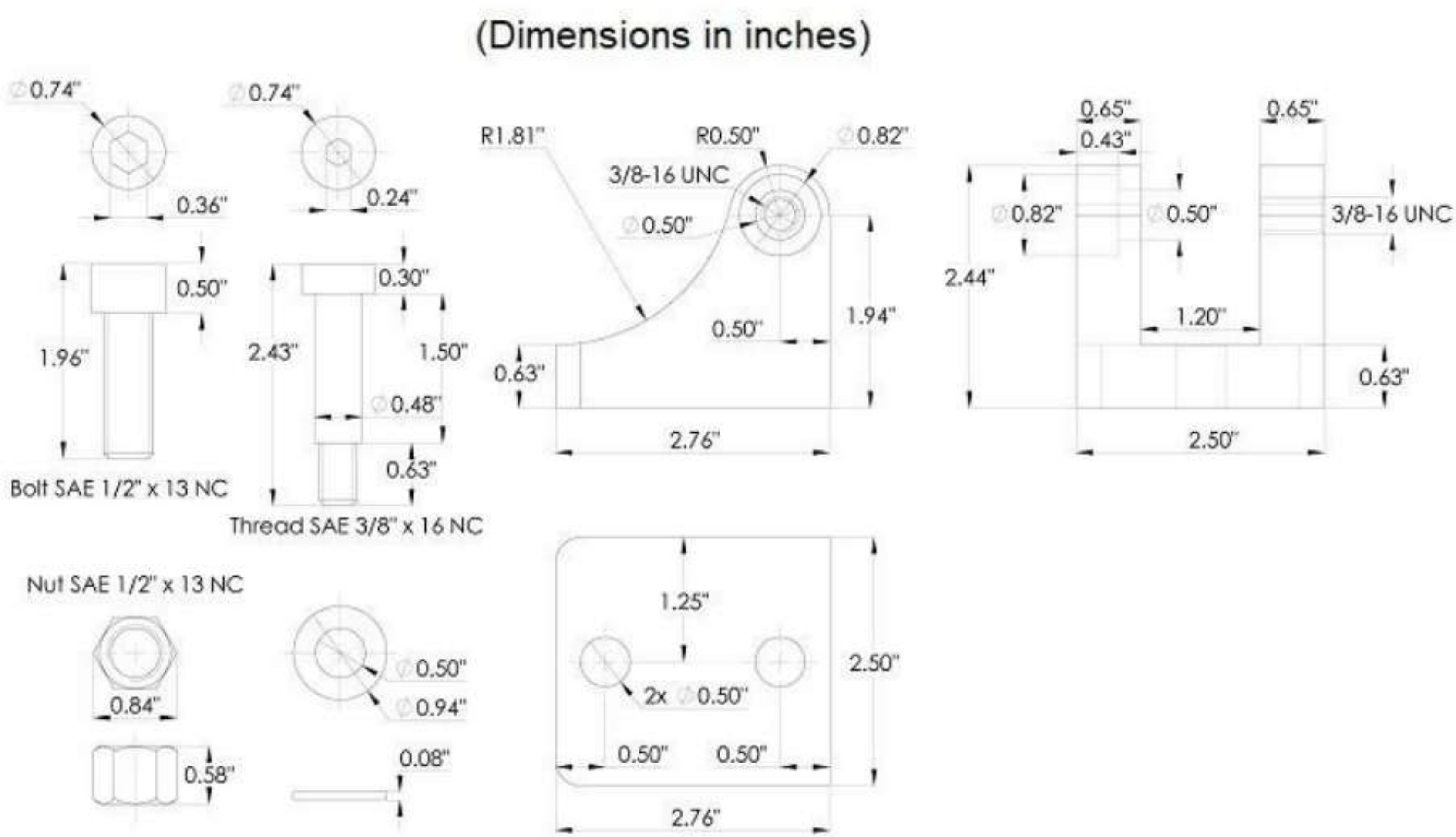
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

(Dimensions in inches)

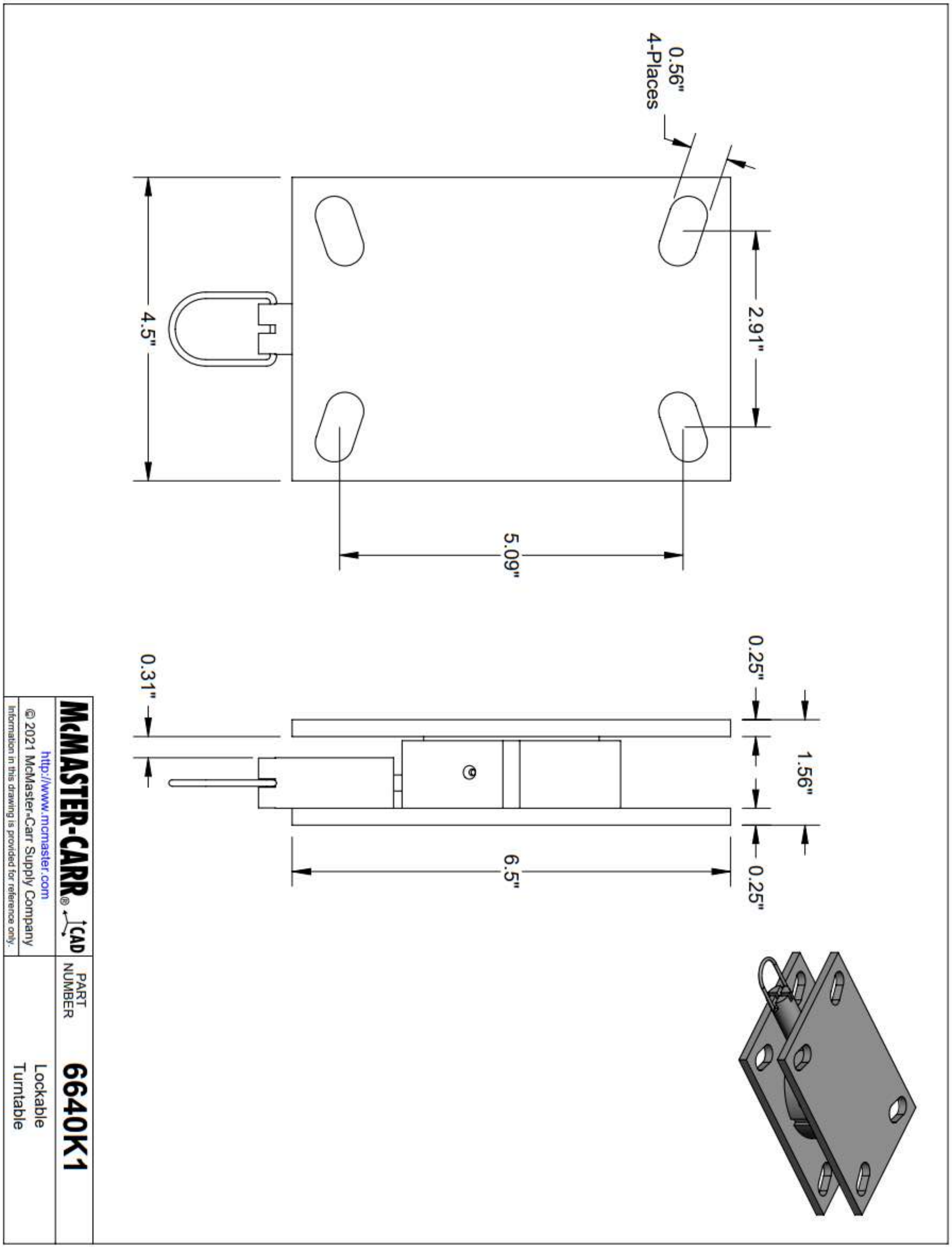


End to End
*For Stroke Length above 24"
Fully Extended 12.71" + stroke size + stroke size
Fully Retracted 12.71" + stroke size

Hole to Hole
*For Stroke Length above 24"
Fully Extended 11.8" + stroke size + stroke size
Fully Retracted 11.8" + stroke size



(Dimensions in inches)
Ø0.74"
0.36"
0.50"
1.96"
Bolt SAE 1/2" x 13 NC
Ø0.74"
0.24"
0.30"
2.43"
1.50"
Ø0.48"
0.63"
Thread SAE 3/8" x 16 NC
Nut SAE 1/2" x 13 NC
0.84"
0.58"
Ø0.50"
Ø0.94"
0.08"
R1.81"
R0.50"
Ø0.82"
3/8-16 UNC
Ø0.50"
0.50"
1.94"
0.63"
2.76"
1.25"
2.50"
2x Ø0.50"
0.50"
0.50"
2.76"
0.65"
0.43"
0.65"
Ø0.82"
Ø0.50"
3/8-16 UNC
2.44"
1.20"
0.63"
2.50"



0.56"
4-Places
4.5"
2.91"
5.09"
0.31"
0.25"
1.56"
0.25"
6.5"
McMASTER-CARR®
CAD
http://www.mcmaster.com
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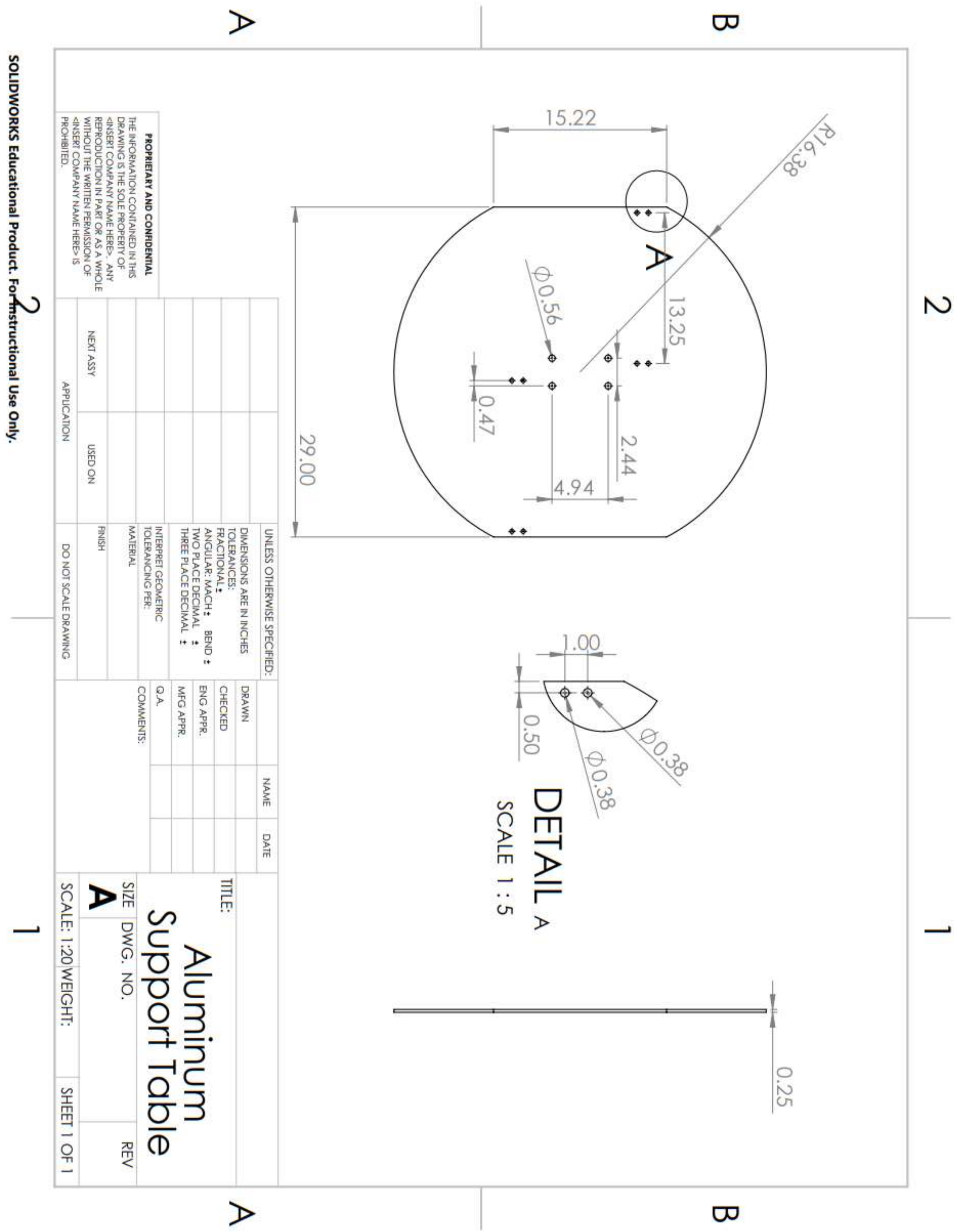
PART NUMBER
6640K1
Lockable
Turntable


15.22
R16.38
A
⌀0.56
13.25
0.47
2.44
4.94
29.00
1.00
0.50
⌀0.38
⌀0.38
DETAIL A
SCALE 1 : 5
0.25
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC
TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Aluminum
Support Table
SIZE
A
DWG. NO.
REV
SCALE: 1:20
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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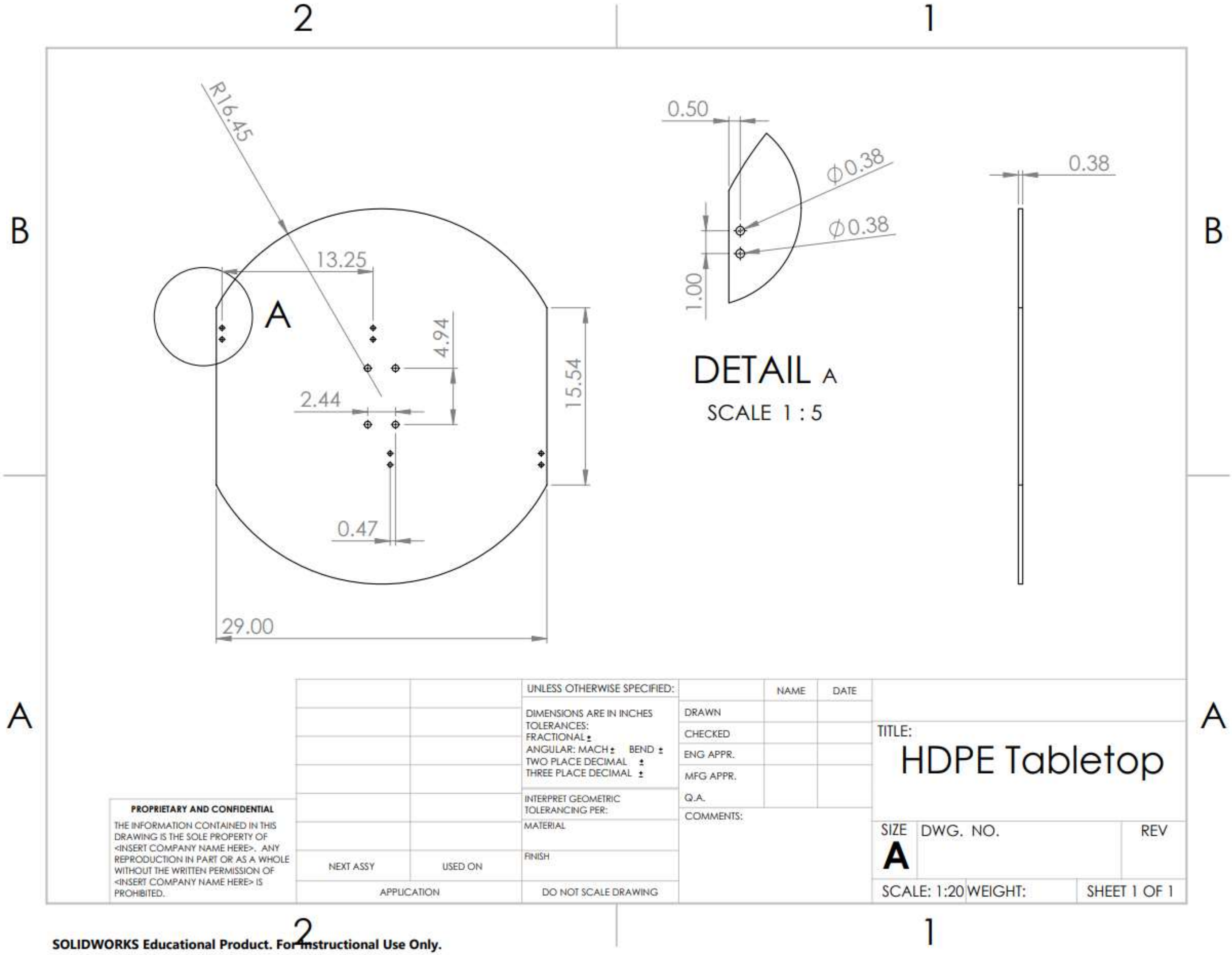
R16.45
13.25
A
4.94
2.44
15.54
0.47
29.00
0.50
⌀0.38
⌀0.38
1.00
DETAIL A
SCALE 1 : 5
0.38
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
HDPE Tabletop
SIZE
A
DWG. NO.
REV
SCALE: 1:20
WEIGHT:
SHEET 1 OF 1
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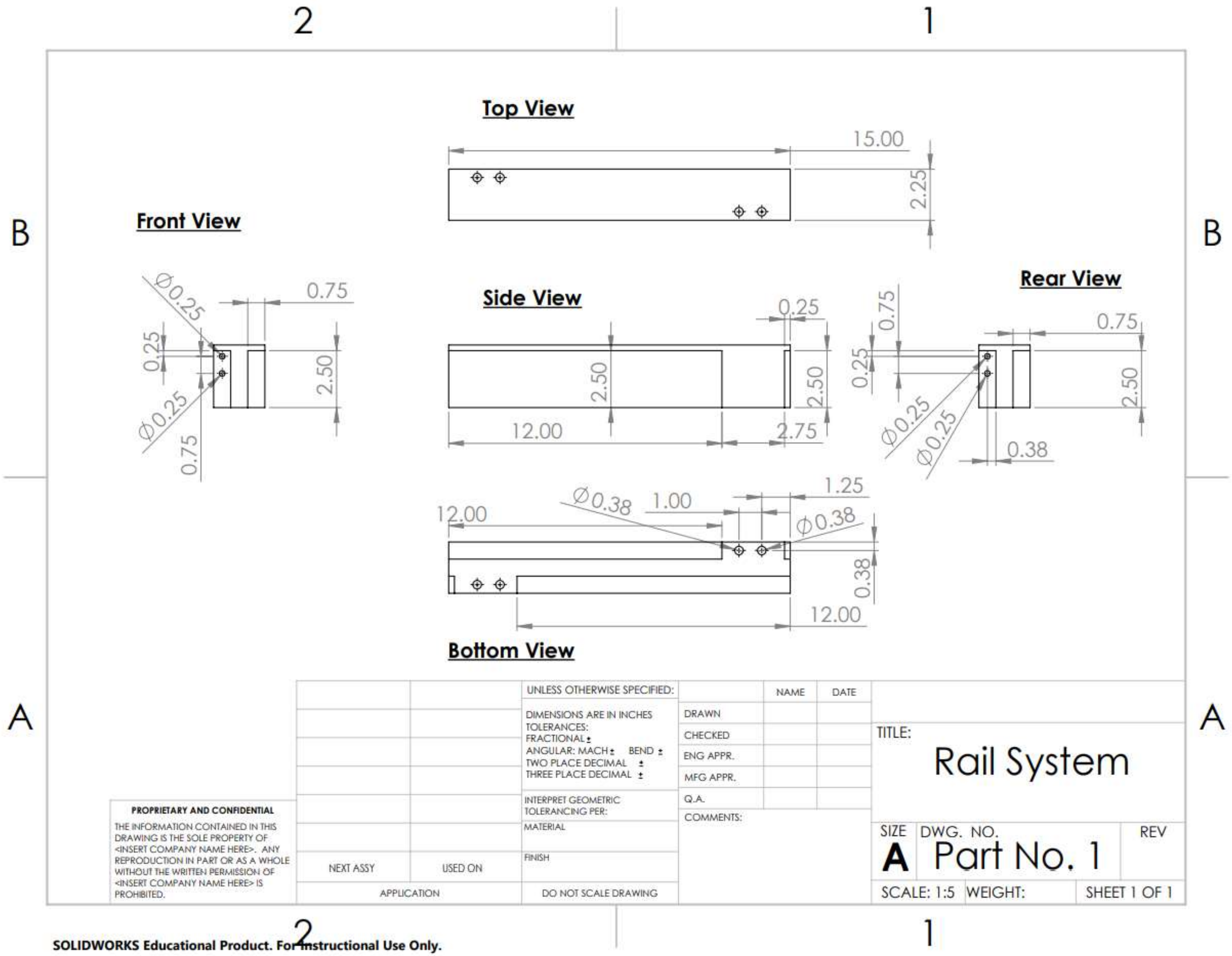
Top View
15.00
2.25
Front View
Ø0.25
0.75
0.25
Ø0.25
2.50
0.75
Side View
0.25
2.50
2.50
12.00
2.75
Rear View
0.75
0.75
0.25
Ø0.25
Ø0.25
2.50
0.38
Ø0.38
1.00
1.25
12.00
Ø0.38
0.38
12.00
Bottom View
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Rail System
SIZE
A
DWG. NO.
Part No. 1
REV
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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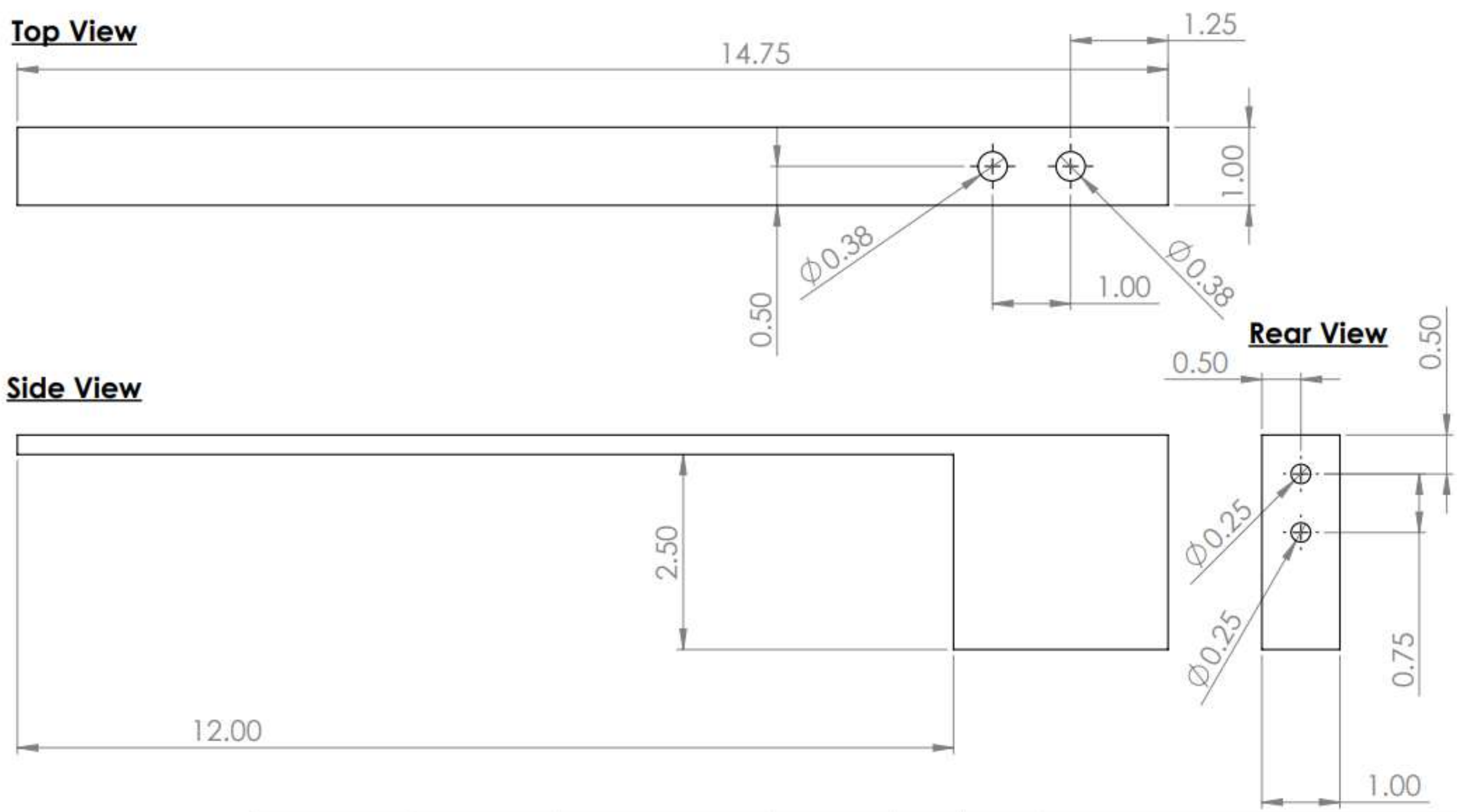
NEXT ASSY
USED ON
APPLICATION
SOLIDWORKS Educational Product. For Instructional Use Only.



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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TITLE: **Rail System**

SIZE	DWG. NO.	REV
A	Part No. 3	
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

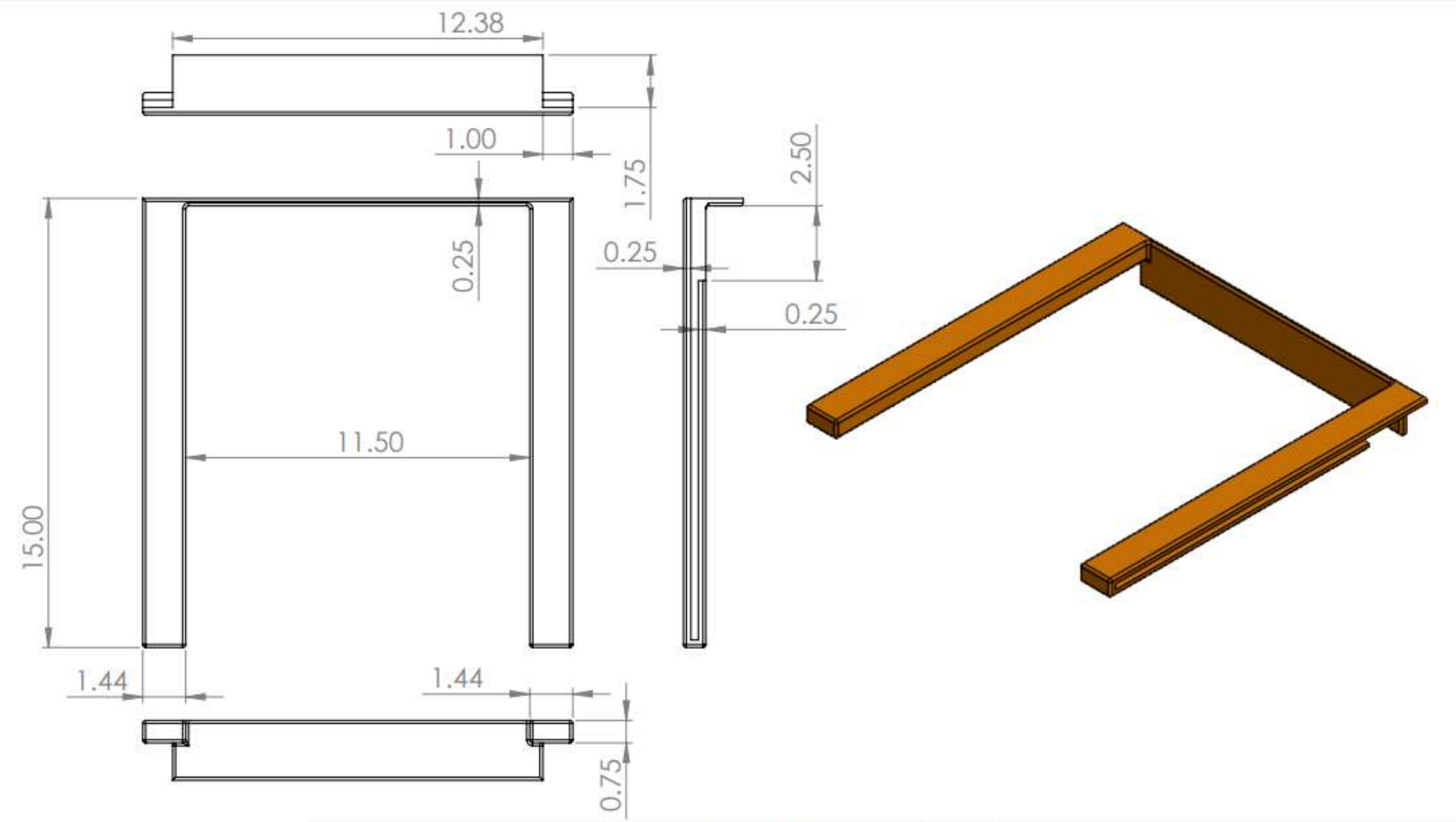
NEXT ASSY	USED ON
APPLICATION	

TITLE:

Rail System

SIZE **A** DWG. NO. Part No. 2 REV

SCALE: 1:5 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN		
	CHECKED		
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

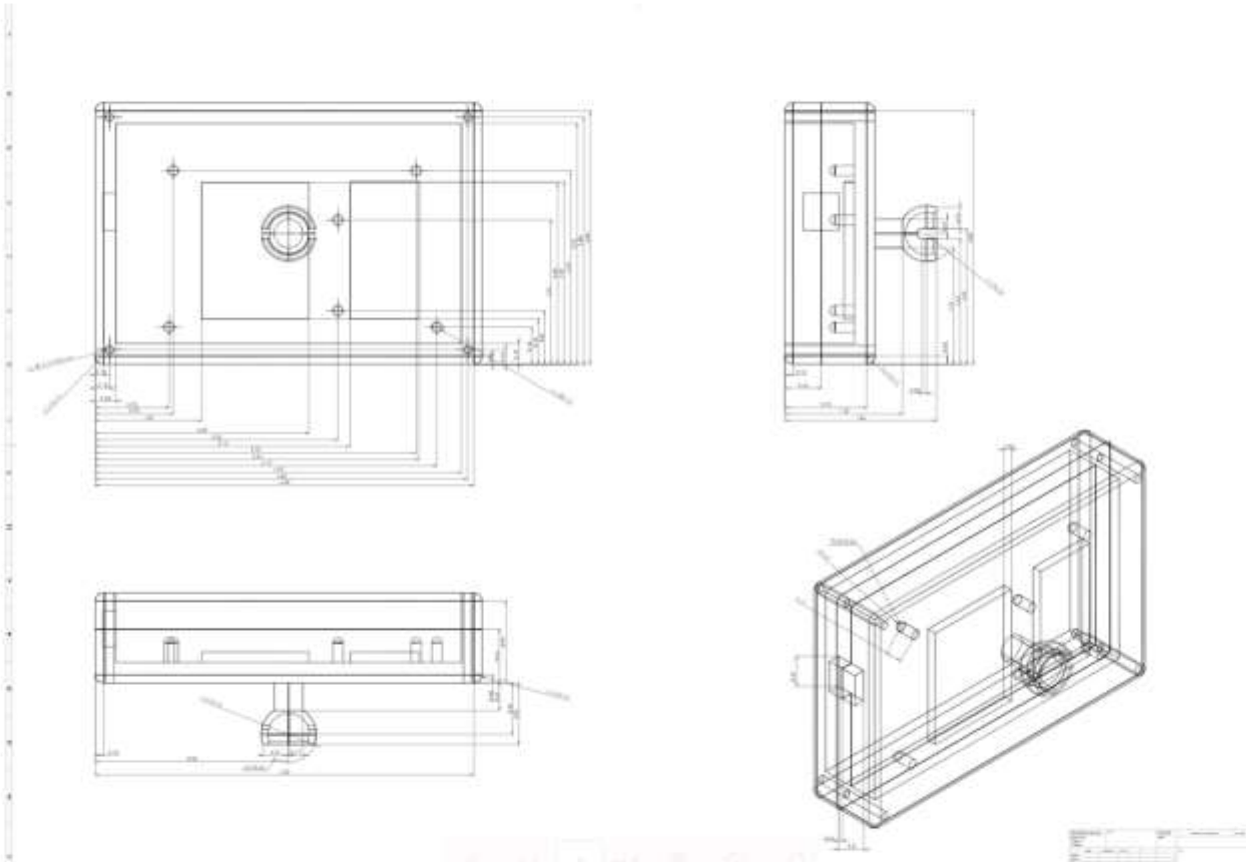
NEXT ASSY	USED ON
APPLICATION	

TITLE:

Rail Insulation

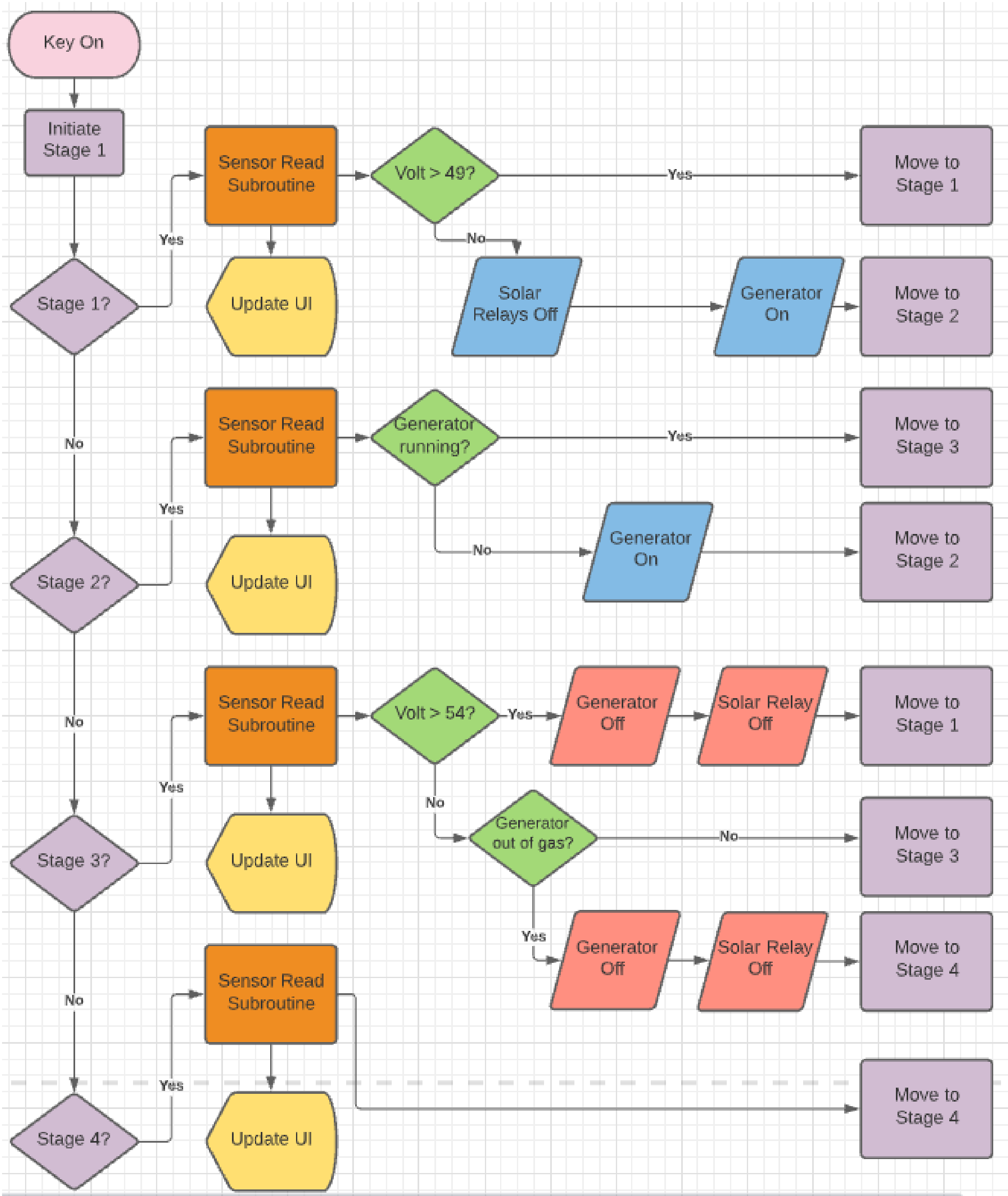
SIZE	DWG. NO.		REV
A			
SCALE: 1:5	WEIGHT:	SHEET 1 OF 1	

11.3 Solar Cell Lockout, Speed Measurement, Generator

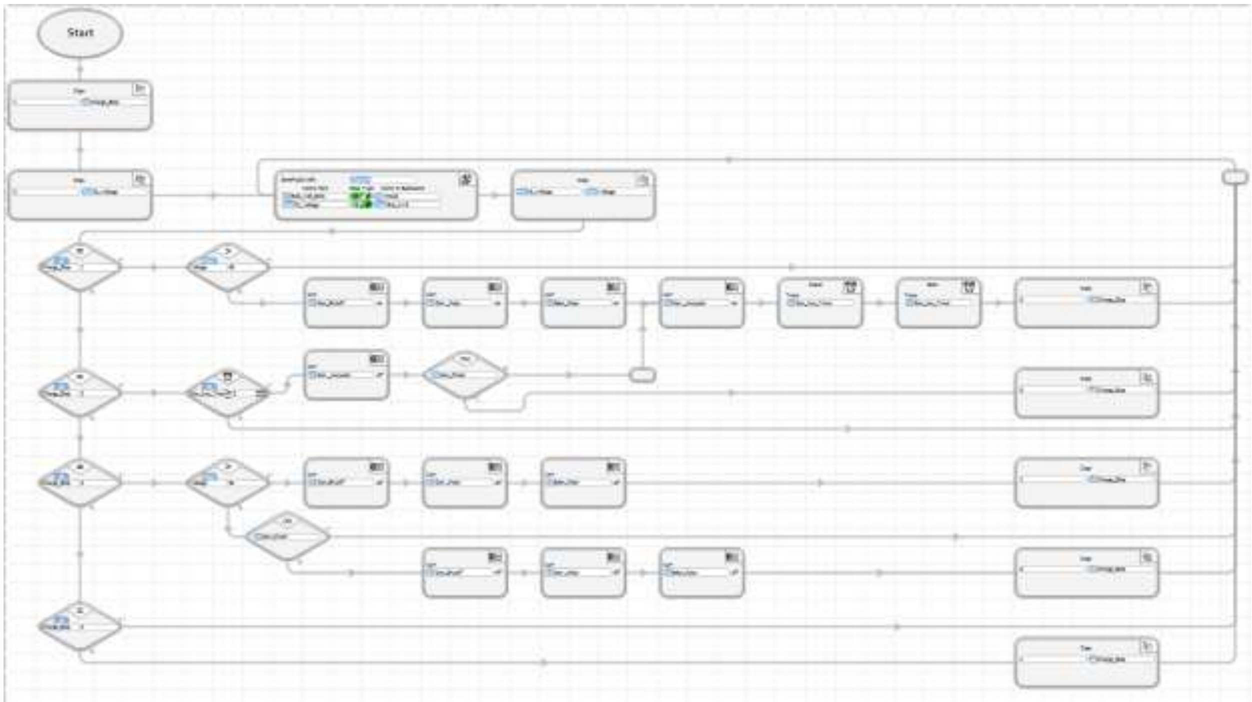


11.4 Controller Upgrade

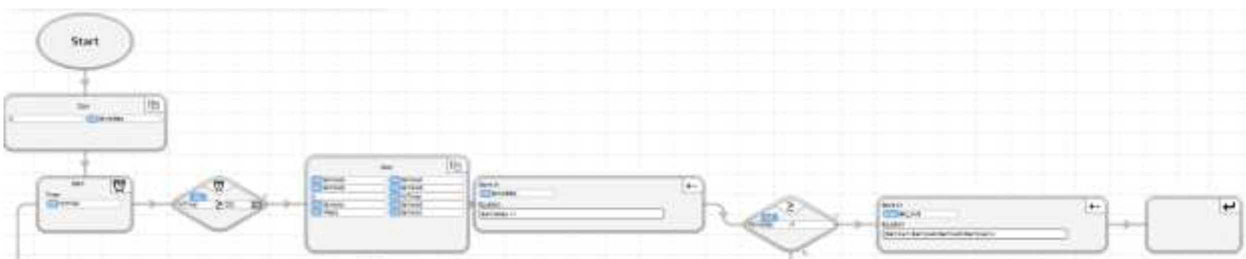
Controller Logic Flow Chart:



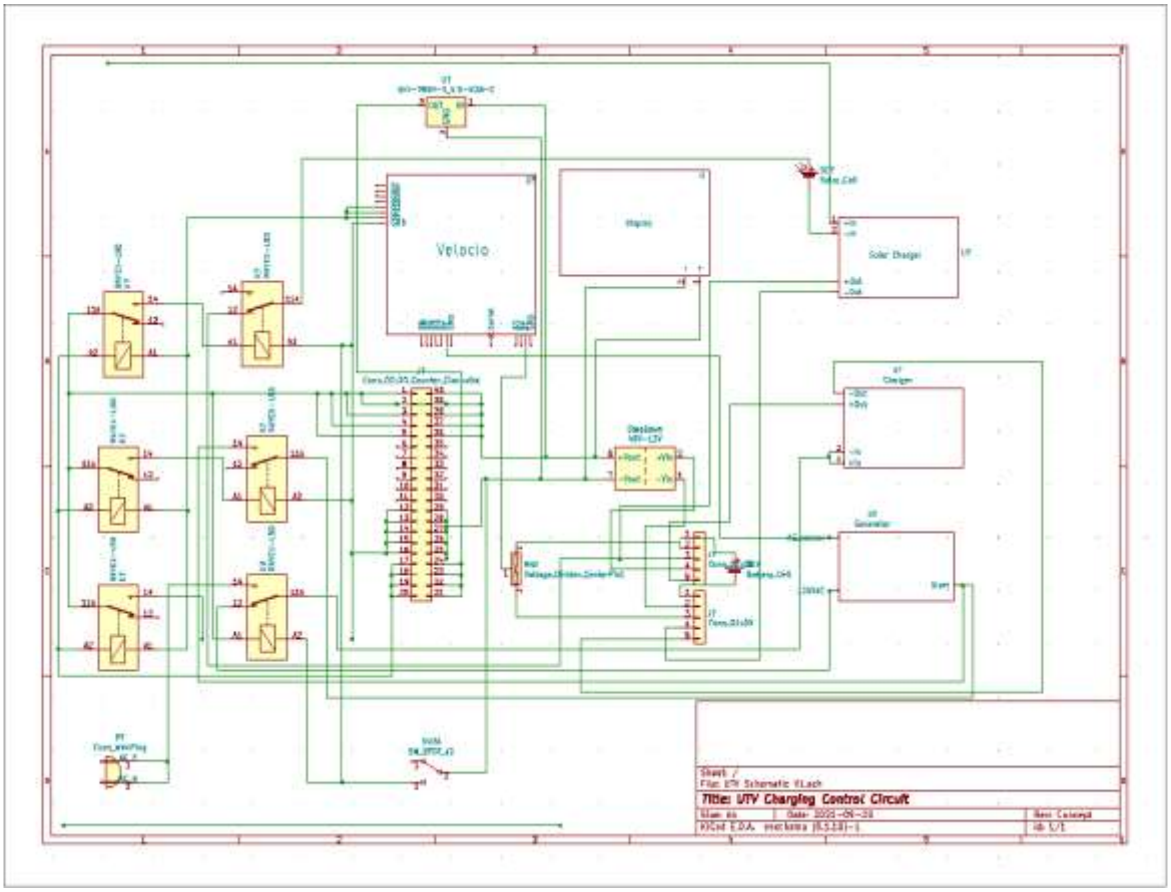
Velocio Main Controller Program:



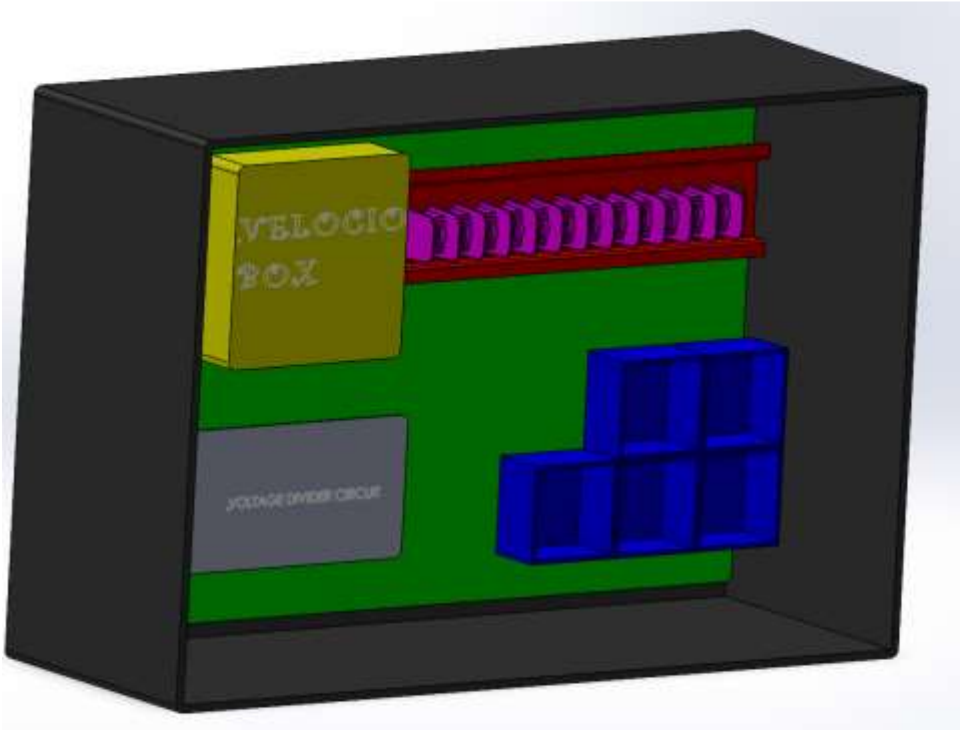
Velocio DAQ Subroutine Program:



Controls System Wiring Diagram:


Velocio
Solar Charger
Charger
Generator
Title: UTV Charging Control Circuit

Controller Box Solid Model:



Controller Box Legend:

Color	Device/component
Black	Box
Blue	Relay space
Grey	Voltage divider circuit
Red	DIN rail
Purple	Terminal block
Gold	Velocio controller
Green	Base plate

Controller Box Component Dimensions:

Device/Component	Dimensions (L x W x H)
Circuit box	12” x 7” x 3.63”
Velocio	2.5” x 2.5” x 0.25”

Velocio DIN rail	10” x 1.37” x 0.29”
Anti-vibration pad	12” x 8” x 0.125”
Relay	1” x 1” x 1.4”
Terminal block	6.46” x 1.18” x 0.75”
Tilt sensor voltage divider	3.5” x 2” x 0.04

11.5 CDR BOM

Overall BOM/Costs

Item:	Quantity:	Price:	Date Added:	Date Ordered:	Date Received:	Company Ordered From:	Contigency:	Priority Ordering:	Lead Time:
48V 30Ah Battery	2 Units	$1,750.00	8/19/2021	8/26/2021	TBD	Allied Battery	0%	N/A	4 Weeks
Protective Coating	2 Units	$78.00	8/20/2021	TBD	TBD	Amazon	30%	NO	Quick
Aluminum Primer (Tentative)	2 Units	$20.00	8/20/2021	TBD	TBD	Home Depot	30%	NO	Quick
Aluminum	17 ft²	$76.00	8/25/2021	TBD	TBD	Stillwater Steel	30%	YES	Wait until final decision
Steel Tubing	18 ft²	$40.00	8/25/2021	TBD	TBD	Stillwater Steel	30%	YES	Wait until final decision
Steel Bars	10' 2"X1/4"	$40.00	9/21/2021	TBD	TBD	Stillwater Steel	30%	YES	Wait until final decision
HDPE	18 ft²	TBD	8/25/2021	TBD	TBD	Tulsa Plastics	30%	YES	Wait until final decision
Battery Box Wheels Front	1 Unit	$50.00	8/20/2021	TBD	TBD	Multi-Cart	30%	NO	Quick
Battery Box Wheels Back	1 Unit	$164.00	8/20/2021	TBD	TBD	McMaster-Carr	30%	NO	Quick
Latches	6 Units	$390.00	8/19/2021	TBD	TBD	Grainger	30%	NO	2-3 Business Days
Battery Cart Wheels	1 Unit	$95.00	8/20/2021	TBD	TBD	Amazon	30%	NO	Quick
Linear Actuator	1 Unit	$317.00	8/25/2021	TBD	TBD	Progressive Automations	80%	YES	Ships within 24 Hours
Reverse Polarity Switch	1 Unit	$30.00	8/25/2021	TBD	TBD	Progressive Automations	30%	YES	Ships within 24 Hours
12V Battery	1 Unit	$100.00	9/21/2021	TBD	TBD	Dakota Lithium	35%	NO	Ships within 24 Hours
Mounting Bracket	1 Unit	$24.00	9/21/2021	TBD	TBD	Progressive Automations	20%	NO	Ships within 24 Hours
Linear Actuator Remote	1 Unit	$30.00	9/21/2021	TBD	TBD	Progressive Automations	20%	NO	Ships within 24 Hours
Linear Actuator Bolts	—	$40.00	9/21/2021	TBD	TBD	McMaster-Carr	20%	NO	Quick
Linear Actuator Nuts	—	$50.00	9/21/2021	TBD	TBD	McMaster-Carr	20%	NO	Quick
"Lazy Susan" Turntable	1 Unit	$88.00	8/25/2021	TBD	TBD	McMaster-Carr	30%	YES	Ships Same Day
OLED Screen/Processor	1 Unit	$40.00	8/25/2021	TBD	TBD	Tiny Circuits	25%	NO	N/A
Hall Effect Sensor	1 Unit	$6.00	8/25/2021	TBD	TBD	Tiny Circuits	25%	NO	N/A
Wiring Adapter/Regulator	1 Unit	$10.00	8/25/2021	TBD	TBD	Tiny Circuits	25%	NO	N/A
Micro USB	1 Unit	$4.00	8/25/2021	TBD	TBD	Tiny Circuits	25%	NO	N/A
5 Pin Wire Cables	2 Units	$4.00	8/25/2021	TBD	TBD	Tiny Circuits	25%	NO	N/A
Magnet	1 Unit	$2.00	8/25/2021	TBD	TBD	Tiny Circuits	25%	NO	N/A
Plastic for 3D Printing	1 Unit	$21.00	8/25/2021	TBD	TBD	Amazon	25%	NO	Quick
20 lb Propane Tank	1 Unit	$50.00	9/7/2021	9/7/2021	9/7/2021	Lowes (In-Store)	25%	N/A	N/A
Regulator Valve	1 Unit	$19.00	9/7/2021	9/7/2021	9/7/2021	Lowes (In-Store)	25%	N/A	N/A
Propane Hose	1 Unit	$17.00	9/7/2021	9/7/2021	9/7/2021	Lowes (In-Store)	25%	N/A	N/A
HiLetgo Arduino Mega	1 Unit	$19.00	9/2/2021	9/7/2021	TBD	Amazon	25%	NO	Quick
Velocio Controller	1 Unit	$148.00	8/25/2021	8/25/2021	8/30/2021	Velocio	40%	N/A	N/A
Velocio Display	1 Unit	$159.00	8/25/2021	8/25/2021	8/30/2021	Velocio	40%	N/A	N/A
Voltage Step Down	1 Unit	$20.00	9/9/2021	TBD	TBD	Amazon	25%	N/A	N/A
Equipment Rack	1 Unit	$50.00	9/14/2021	TBD	TBD	Amazon	25%	N/A	N/A
Helmets (S, M, L)	1 Unit	$360.00	9/15/2021	TBD	TBD	MotoSport	30%	NO	Quick
Goggles	3 Units	$180.00	9/15/2021	TBD	TBD	MotoSport	30%	NO	Quick
Class ABC Fire Extinguisher	1 Unit	$160.00	9/18/2021	TBD	TBD	Grainger	30%	NO	Quick

CONTINUED ON NEXT SLIDE

Overall BOM/Costs

Item:	Quantity:	Price:	Date Added	Date Ordered:	Date Received:	Company Ordered From:	Contigency:	Priority Ordering:	Lead Time:
Steel Round-Base Weld Nut	1 Unit	$7.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
Nylon Pull Handle	1 Unit	$16.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
Latching Power Connector (Plug)	1 Unit	$27.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
Latching Power Connector (Insert)	1 Unit	$40.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
Edge Mount Bracket Caster	4 Units	$20.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
Silicone Strip	3 Units	$27.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
Flat Head Drilling Screws	1 Unit	$7.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
Rounded Head Drilling Screws	1 Unit	$11.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
Flanged Hex Head Bolts	1 Unit	$8.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
Serrated Flange Locknut	1 Unit	$5.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
18-8 SS Pan Head Bolt	1 Unit	$9.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
18-8 Thin Hex Nuts	1 Unit	$5.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
18-8 Hex Nuts	1 Unit	$14.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
Squeeze Release T-Latch	1 Unit	$39.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
6 Gauge Wire - Black - 10ft	1 Unit	$23.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
6 Gauge Wire - Red - 10ft	1 Unit	$23.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
3/8" Grade 5 Bolts	1 Unit	$12.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
3/8" Grade 5 Nuts	1 Unit	$10.00	9/20/2021	TBD	TBD	McMaster-Carr	25%	NO	Quick
Battery Clamps	2 Units	$11.00	9/20/2021	TBD	TBD	Amazon	25%	NO	Quick
Battery Box Fabrication/Metals	1 Unit	$300.00	9/21/2021	TBD	TBD	Stillwater Steel	40%	NO	3-4 Day Build Time
HMI Mounting Plate	2 Units	$78.00	9/21/2021	TBD	TBD	Ram Mounts	25%	NO	Quick
HMI Mounting Arm	1 Unit	$52.00	9/21/2021	TBD	TBD	Ram Mounts	25%	NO	Quick
Total		$5,435.00							

11.6 FINAL BOM

Supplier Name	Product Description	Link to part	Comments/Additional Instructions	Quantity	Purchasing Shipping	Cost for all Units	Shipping charges
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

11.7 END-USER MANUAL

TURNING ON AND OPERATING THE UTV

1. **Make sure the UTV is Fully Charged (Battery charging procedure attached)**
   1.1. Charge time: 8 hours (dependent on depth of discharge)
   1.2. Ensure a minimum of 5 air changes per hour in the charging area.
   1.3. Remove any storage covers from vehicle and open cab doors (if equipped) before charging.
   1.4. The charging unit produces heat in the charging process. Open the hood to allow better cooling air flow over the charger unit.
   1.5. Check charge status indicator: Needs to be solid green indicating charge is complete. If not solid green, do not test. Charge indicator will not be accurate if not fully charged.
2. **Inspect UTV before Driving out of the Endeavor Lab**
   2.1. Before starting the UTV, complete a 360 walk around in search of any hazards, problems, and/or malfunctions on the UTV*
   2.2. Inspect Tire Pressure:

RANGER	4x4	Crew	EV
MAXIMUM CARGO BOX LOAD	500 lbs. (226 kg)	500 lbs. (226 kg)	500 lbs. (226 kg)
TIRE PRESSURE IN PSI (KPa)	FRONT 10 (69) REAR 12 (83)	FRONT 14 (97) REAR 16 (110)	FRONT 20 (138) REAR 20 (138)
MAXIMUM WEIGHT CAPACITY INCLUDES WEIGHT OF OPERATOR, PASSENGER, CARGO AND ACCESSORIES	1000 lbs. (454 kg)	1250 lbs. (547 kg)	1000 lbs. (454 kg)
Read Operation and Maintenance Manual for more detailed loading information.			

*__Checking for malfunctions includes doing a visual inspection looking for flat tire, loose wires/bolts, making sure the propane tank is secured properly, ensuring hood has been latched, batteries are locked in place.__

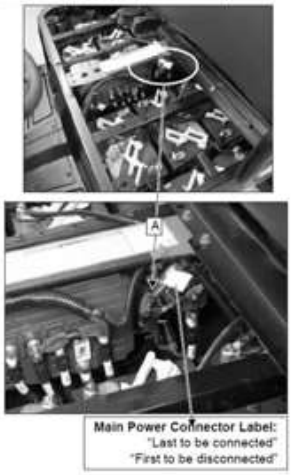
3. **Inspect Battery Module**
   3.1. If servicing the battery, make sure to always disconnect the Main Power Connector (A) or when unplugging any electrical components.

Main Power Connector

⚠ WARNING

Use insulated tools or insulate any tools used within the battery area to prevent sparks or battery explosion caused by shorting the battery terminals or wiring. Remove the batteries or cover the exposed terminals with an insulating material.

Always disconnect the Main Power Connector (A) before servicing or unplugging any electrical components.



3.2. Follow (To Maximize Battery Service Life section in the Battery Manual)
3.3. Check terminals and battery water levels monthly

4. **Operating the UTV**
   4.1. Read and understand the operator's manual before attempting to drive
   4.2. Make sure charging cable is unplugged!!
   4.3. Before UTV begins to move. Have all PPE equipped (Helmet and safety goggles)
   4.4. Assure all those riding on the vehicle are wearing their seatbelts.
   4.5. Assure everyone is aware of their responsibilities
   4.6. Follow all safety procedures listed within the UTV operator's manual.
   4.7. Apply the brakes.
   4.8. Place the direction selector in neutral (N).
   4.9. Turn the key to the ON position. Wait about a second for the contactor to close before continuing.
   4.10. Move the direction selector to forward or reverse.
   4.11. Move the drive mode switch to the desired setting.
   4.12. Release the park brake.
   4.13. Check your surroundings and determine your path of travel.
   4.14. Keeping both hands on the steering wheel, release the brake pedal and gradually push the accelerator toward the floor to begin driving.
   4.15. Drive slowly. Practice maneuvering and using the accelerator and brakes on level surfaces.
   4.16. Do not carry a passenger until you have at least two hours of driving experience with this vehicle. Never carry more than one passenger in this vehicle. Never allow a passenger to ride in the cargo box.
   4.17. To stop the vehicle, release the accelerator pedal completely and brake to a complete stop.

5. **Operating HMI and Speedometer**
   5.1. When the batteries are plugged in flip the switch on the dash to turn on the HMI and the speedometer. The switch is located to the right of the steering wheel.
   5.2. The speedometer does not require any manipulation
   5.3. To switch to the second screen on the HMI press the button called "UTV Info" on the bottom of the home screen. (To return back to home press the Home button)
   5.4. When done driving the UTV flip the switch to the off position.

6. **Operating Battery Cart**
   6.1. Position electric UTV on level surface and turn the key to OFF position.
   6.2. Inspect battery cart for any cracks, loose members, and any damages before use.
   6.3. Move battery cart in position to the battery module compartment.
   6.4. Decrease the height of the battery cart using the linear actuator.
   6.5. Align battery cart to UTV using alignment tabs (square tubing) on battery cart.
   6.6. Disconnect battery module from UTV (both electrical connection and latch retention) and slide the battery module safely to battery cart.
   6.7. When removing the battery module, avoid letting the electrical connector contact any metal surface on the UTV, Cart, or Charge Station as doing so will likely result in the batteries shorting out.,
   6.8. Secure battery module on the battery cart using latching mechanism located on the sides of the battery module.

6.9. Raise battery cart vertically with linear actuator until the alignment tabs have come out of square tubing.
6.10. Pull battery cart away from UTV and decrease the height of the battery cart for a smooth safe transport.
6.11. Transport battery module to the charging station.

TURNING OFF AND SHUTTING DOWN THE SYSTEM

1. **Shutting down the system**
   1.1. To shut down the system turn the key to the off position
   1.2. Mark sure the switch for turning on the controller, HMI, and speedometer is in the off position. (Switch is located to the right of the steering wheel)
   1.3. Unplug the battery module from the UTV
   1.4. Make sure the prone valve is closed and remove the propane tank from the UTV. (Storing the propane tank is discussed in the next section).
   1.5. Check to make sure that everything is turned off and that nothing is running before storing the UTV.

GENERATOR

2. **Before Operating UTV/ Starting Procedure (for generator):**
   2.1. Ensure that the generator clean and clear of debris
   2.2. Check the oil (if necessary, add oil)
   2.3. Ensure no loads are on generator (unplug anything in outlets)
   2.4. Ensure propane tank is vertical and secured into place.
   2.5. Make sure regulator is (hand) tightened to propane tank
   2.6. Fully open the LPG cylinder fuel knob
   2.7. Ensure there are not combustible materials within 5 feet of the generator
   2.8. Check the LPG tank connections for leaks
   2.9. When generator is running, wait for the engine to stabilize before connecting any loads

3. **In Case of 'no battery power' scenario**:
   3.1. Remove seat and locate the actuator bypass valve.
   3.2. Break zip tie the is securing the bypass valve.
   3.3. Move the actuator bypass valve into the "open" position.
   3.4. Utilize the pull chord until the generator starts. (Pause in between pulls when starting generator).

4. **Applying Electrical Loads to Generator:**
   4.1. Do NOT overload the generator, follow instructions given in the "capacity and power calculation section bellow
   4.2. Allow the generator engine to stabilize before applying any loads

4.3. Ensure that all electrical connections are clean of debris (electrical connections are not covered)
4.4. Choose the correct output that is clearly labeled on the interface of the generator
4.5. Plug in the device that you desire to run
4.6. After you no longer need the power supply follow the steps in the "stopping procedure" sections bellow.

5. **Stopping Procedure (for 'no battery power' scenario):**
    5.1. Turn off and unplug all loads. OSU NCL 7 Rev. 08/2018
    5.2. Let the generator run for a few minutes with no load to stabilize.
    5.3. Turn the LPG cylinder knob to the "CLOSE" position.
    5.4. Let the engine run until fuel starvation has stopped the engine.
    5.5. Return the actuator bypass valve to the 'closed' position.

6. **Storing Propane Tank After Use:**
    6.1. Ensure LPG valve is fully turned off.
    6.2. Disconnect pressure regulator from LPG tank.
    6.3. Store LPG tank in a safe area that is not covered by any other items and not exceeding 120 degrees Fahrenheit.
    6.4. Tank must remain vertical when stored.
    6.5. Ensure tank is not near anything that is combustible or has an open flame

**NOTE: Propane tanks should only be filled to 80 percent of the tank's capacity. This is to allow for some liquid propane expansion that might occur during hot days or if exposed to temperatures that are warmer than the propane in the tank.

**NOTE: this procedure is adequate for all types of propane tanks that have an approved OPD(overfilling prevention device) valve. We will only be using a 20lb propane tank