AUXILIARY POWER SYSTEM

by

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Introduction

The main objective for this project is to design and build a prototype for an all-electric SUV for the start-up company, Sharpell Technologies. This vehicle will comprise of the following configurations: auxiliary power system (APS), battery management system, battery pack wiring, CAN bus system, DC-DC charging converter, DC/DC auxiliary converter, instrument cluster, and motor controller/inverter. Each car configuration is a project assigned to a 2-4 student team; in total, eight EE senior projects and one ME project is produced. New lightweight batteries are also in the process of being developed to provide a viable electric source for the car. A mobile application, used by Internet of Things, will allow the user to check one's vehicle at any time of the day. The complete prototype is expected in 2020.

Our section of this project is to design and implement the Auxiliary Power System (APS) for this vehicle. To complete this project the group will follow a provided structure to finish within the three allotted quarters. These steps include receiving the project requirements for Sharpell Technologies, creating a test plan, implementing a project design, ordering the parts and developing the product, integrating and testing the components and then discussing our results and possible shortcomings.

Background

The electric car dates back to before the year 1900. Thomas Edison was one of the largest proponents and believers in electric cars, predicting they would claim the future of automotive transport. As Edison worked long and hard to engineer a commercially viable electric vehicle (EV), Henry Ford created the internal combustion engine powered Model T, which found profound success around the world. It wouldn't be for almost 100 more years until a commercially viable EV was mass-produced. A small, well-funded EV company, Tesla Motors, created and dominated the EV market for five or so years before the more common car companies could design and sell their take on an EV. Almost every EV available for purchase in today's market is a sedan. Sharpell Technologies, a small start-up based out of California is seeking to design a luxury electric SUV that is affordable. There are many systems in an EV, which are almost all entirely either low or high voltage. The auxiliary power system (APS) uses an input voltage of 12V DC to power many separate units, including the instrument cluster, headlights, tail lights, cabin lights, power steering, power braking, and all other electrical systems apart from the drivetrain and motor.

Requirements

The requirements given by Sharpell Technologies is to produce an APS that could run solely off of a 12V battery. This battery would be backed up and supported by the electric vehicle when it was running. The APS is to be independent of drive train in the electric vehicle. The project should produce a prototype of a working, professional APS. This should include all of the necessary components normally included in a APS (headlights, cabin lights, brake lights, heater, air conditioner, seat adjusters, radio) and also a number of luxury extra components. Each component should be researched and tested before added to the system. The appropriate precautions, including fuses and relays, will be taken to protect the components, from destruction due to an overloading of current. Another requirement is to produce the prototype in an organized and understandable fashion. Each component should be labeled and connected in a regulated manner. There should also be a final layout produced, showing how the components are linked through various wires, relays and fuses.

Test Plans

The testing design for the Auxiliary Power System was given careful consideration throughout the first steps of this project. Before ordering the desired components for this project there was a discussion about each one. The development of a plausible testing method for every part had a large impact on the decision of purchasing the component. With a limited budget the team must understand that there are certain testing needs that are not possible with this budgetary constraint.

Research will be done on each purchased component to find the current limits through documentation provided by the seller. With this information the selection of an appropriately sized fuse will be verified. This was later measured and verified that all components would use a 5A fuse, and the window motor required a 10A fuse. Also this will make it easy to calculate the power consumption, given the voltage and current. A portable power meter will be used to check the power consumption of these components once hard-wired within the final project.

Design

Modern professionally designed auxiliary power systems (APS) are typically complex and expensive. Low-budget, low-time, and ground-up design constraints guided the purchasing and designing choices. The extent of the components in an APS would be impossible with the provided budget. Compromises would be necessary. There were two clear paths: a variety of affordable components or a few expensive ones. With the Senior Project Exposition in mind the route of variety was followed.

It was essential to have key APS components including headlights, tail lights, and cabin lights. The model was designed for more diverse components by including a USB power source and two motors, shown in Figure 1. Affordable components were selected, with contributions from the team members' personal collections, and buying used when possible. LEDs were preferred over incandescent lights to reduce power consumption. A larger budget could have afforded energy-efficient motors.

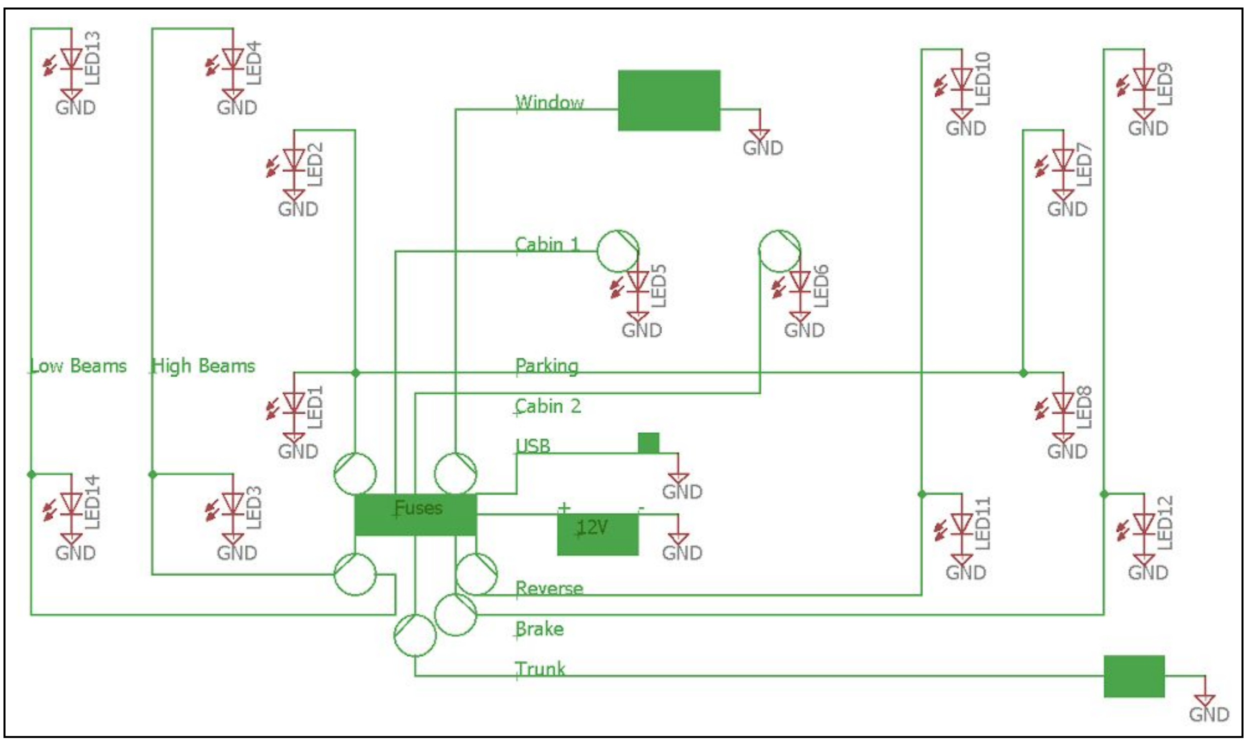

Figure 1: *Full Schematic*

Besides components and a place to put them other parts were necessary too. The effects of different gauge wire in an APS were researched. It was determined various sizes would be needed depending on the distance between battery and component and how much current would flow through the wire. An assorted fuse kit was purchased to cover the different current ratings of our components. Relays were also purchased to keep larger current components isolated from switches to keep the user safe.

After components, wires, relays, and fuses were purchased, the method of showcasing had to be decided on. Deliberation led to an agreement on a PVC 3D frame over a large demo board. The frame was to be 6’x3’x2’ with two rib supports for rigidity and component fastening.

With the components, pieces, and small budget in mind, the next step was to begin the construction of the APS.

Development and Construction

In order to create the auxiliary power system, a lot of planning had to be accomplished. During Winter 2016, the main goal was to complete the background research and to study what was going to go in the APS. After researching multiple components, it was decided that the APS would include a USB power port, headlights, tail lights, brake lights, reverse lights, cabin lights, a window motor, and a trunk motor. After figuring out the components that were used, it was needed to figure out the parts that were needed to combine everything, and safety precautions. It was researched that a fuse box would be needed along with some relays to protect the system from drawing too much power and compromising the system and other components.

The goal of this project was to achieve (within our price range) an APS as efficient as possible. To accomplish this, LEDs were used for all of the lighting after extensive research. It was thought that either Xenon lights or LEDs would be used, and it was researched that Xenon lights took way too much power to initially light up. Although Xenon lights didn't use much power after ignition, the battery that was purchased for this project wouldn't be able to accomplish the power draw to successfully light up a Xenon light. Also, this light was much more expensive to purchase. Due to a limited budget, the window motor and trunk motor were purchased for being inexpensive rather than being efficient. Before purchasing, these motors didn't have any ratings on them, so the power ratings for these components were unknown. After receiving the components and measuring them with a power meter, the window motor used about 45 W, while the trunk motor used about 17 W.

After planning what components were going to be used, the next step was figuring out how the APS would be displayed. A couple ideas floated around with using a piece of plywood and gluing the components on it, but this didn't seem to accurately represent an APS for a vehicle. So it was decided to

build a PVC frame and attach the lights and other components to the frame where they would be located (approximately) in a vehicle. A 6’ x 3’ x 2’ frame was built to accomplish this with two supporting bars in the middle to hold the cabin lights. Special PVC glue was used to attach the pipes and connectors together, and Gorilla Tape was used to attach specific components to the frame.

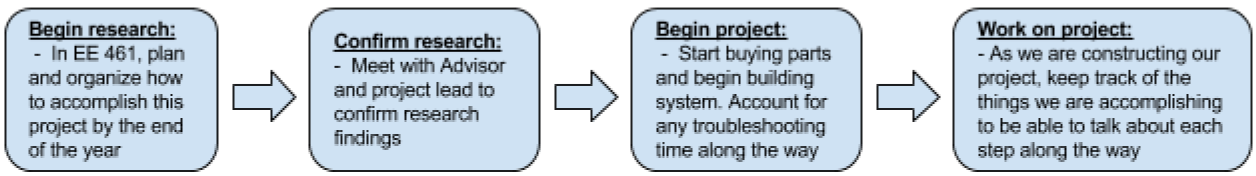

Figure 2: *Basic timeline of project completion*

Figure 2 shown above shows a basic schedule that was followed throughout EE 461 and EE 462 to accomplish this project. The main goal during EE 461 was to fully research and understand the extent of an APS. After thorough research, it was realized that all components wouldn’t be able to be implemented into this project that are used in most vehicles today. Due to this, the components that were chosen were due to their importance to the vehicle and the affordability of the components. It was attempted to include components that had some diversity from each other. Indoor and outdoor lighting are essential for a vehicle, so these were included. It was also thought that a couple of motors would be a good thing to include seeing as though many motors are included in today’s vehicles (automatic seats, windows, trunk, hood opener, windshield wipers, etc).

Table 1 is displayed below showing the process, planning and outline that was followed to complete this project on time. The things listed are only a few things that were accomplished during that week. Due to not wanting to list every little detail, the major tasks were only listed.

Week	Things Accomplished	Things To Do The Following Week
Week 1	- Found USB port, relays, and fuse box to be ordered - Headlights and tail lights researched - Schedule made for upcoming weeks	- Bring parts to meeting to start assembling (battery, charger, wires, fuses, cabin lights) - Bring tools to strip wires, solder wires, and other tools that may be necessary
Week 2 and 3	- Ordered tail lights and LED bulbs - Ordered fusebox - Headlights from Carter's home will be used and will be shipped to SLO - Ordered relays, window motor, and switches - Ordered trunk motor	- Buy push button to turn on brakes - Buy 2 buttons and switches for components - Get and test components first then figure out what switches to use - Look up ratings for motors - Buy PVC stuff at Home Depot
Week 4	- Bought supplies at Home Depot: PVC pipes and connectors, and zip ties - Brought window motor and switches - Brought the trunk motor and relays - Built PVC shell using zip ties to lay out first	- Cut 1 ½ PVC shorter - Use plexiglass to hold switches for trunk motor, brake, and headlights - Cut holes to match each switch size - Go to RadioShack to check out switches
Week 5	- Received all components - observed motors - Started stripping wire and connecting 10 gauge wire - Started soldering wires together - Agreed to start meeting on weekends - Bought corner parts for the PVC frame (they didn't carry these parts at Home Depot) - Finished building frame	- Start wiring up components - Get heat shrink at Radio Shack - Start updating report and putting new material into report
Week 6	- Bought heat shrink at RadioShack - Started soldering wires on the headlights - Attached trunk motor - Attached tail lights - Bought velcro to help mount relays - Attached window motor	- Buy duct tape, PVC cutter, ground terminal hub and PVC glue - Figure out window motor switch diagram to wire up properly - Cut plexiglass to mount switches and buttons - Get labels to label wires at fuse box and to label ground wires
Week 7	- Switch turns on high and low beams on	- Cut plexiglass to mount switches

	headlights - Soldered ground terminal to car battery - Set up grounding bus block - Wired up trunk motor and soldered wires to the motor (this required taking apart the motor and finding a way to attach the wires and putting the motor back together) - Got window motor to work with the switch - Wired up reverse light switch and brake lights switch - Obtained power meter to measure power drawn from the battery	and buttons - Label wires at fusebox - Tidy up wires and organize the wiring - Cut and re-solder some wires to be able to fit switches into plexiglass
Week 8	- Brought plexiglass to Mustang 60 to cut holes - Filed rough edges and verified the correct measurements for each switch and button	- Finish cutting, stripping, and re-soldering wires to allow switches and buttons to fit nicely into the drilled holes - Create poster board, or a sign for senior project expo
Week 9	- Cut, re-stripped, and soldered wires to buttons and switches to fit into the holes on the control panel - Zip tie wires to better organize display, and to clean up - Labeled switches, buttons, and fusebox - Made a name display for the expo - Printed off measured results to display at expo	- Wrap things up and to make sure everything is complete for the expo
Week 10	- Senior project expo!!! - Displayed APS project, and answered any questions anyone had regarding our project	

***Table 1**: Chart displaying what was accomplished each week during Spring 2017 Quarter*

Integration and Test Results

After designing the system layout and purchasing the parts, five subsystems were devised: motor, lights, PVC shell, fuse box, and switch systems. The motor subsystem consists the trunk and window motors. The headlights, tail lights, and cabin lights are the lights subsystem. Six switches used to activate the two motors, parking lights, brake lights, reverse lights, high beams and low beams. The motors and lights were configured to the fusebox where fuses protect each component from exceeded power or incorrect wiring. All the components except the window motor required a 5A fuse, while the window motor required a 10A fuse. The window motor required a 10A fuse because due to the mechanics of the motor, once the limit of the lever was reached (either the window was rolled all the way up, or rolled all the way down), the current continued to rise quite quickly. So when a 5A fuse was used, the second the motor reached it's limit, the fuse blew. To account for this, the 10A fuse was used to allow the user enough time to release the button after the limit was reached. Less than a $900 budget and a three quarter schedule caused problems in purchasing high quality parts and building the APS. Building and modifying the PVC pipe structure consumed the most time as this suits for mechanical engineers. Referencing a hand-drawn schematic and having multiple trials, the PVC shell was eventually constructed. Adding corner connectors and applying adhesive glue to the pipes stabilized the structure.

The 12V car battery powered each subsystem. As expected, the window motor required the most power at 45 W between both motors, shown in Table 2 below. The high beams on the headlights had the largest power consumption at 55.3 W, which was unexpected. The LED headlights were selected for their energy efficiency and greater brightness over dull Halogen bulbs yet LED bulbs require fairly large power. For high beams to sustain their brightness, they are expected to consume more power than low beams. However, it was figured out that these LED lights included a small built-in fan to cool the LEDs.

This was thought to be the reason for the larger power consumption. Drivers who travel at night use high beams and maintaining these lights requires large power from the car battery. Low beams best used in harsh weather conditions like fog and rain. Like the high beams, low beams also have large power consumption to maintain their brightness. Moving a window uses power but requires no consistency. Some drivers will leave their windows up or down throughout the whole trip. It was also expected for low power components (below 2.3 W) like the parking, reverse, and brake lights to have low current (less than 200 mA) plus push-buttons and rocker switches activate each part. From the low power parts, the cabin lights had the greatest current at 620 mA because a large current ensures low power and constant 12V for these lights. The USB charging port recharges electrical devices so it delivers a higher current at 400mA in the mA range since it's also a low power component.

Measured Consumption Values

	Current	**Power**
Headlights High Beam	4.5A	55.3W
Headlights Low Beam	3.2A	39W
Parking Lights	60mA	0.7W
Brake Lights	160mA	1.9W
Reverse Lights	180mA	2.2W
Cabin Lights (2)	620mA	7.5W
Cabin Light (1)	300mA	3.7W
Trunk Motor	1.5A	17W
Window Motor	3A	45W
USB Charging Port (5V)	400mA	4 W

Table 2: *Power consumption for each component*

Conclusion

The project and the product was a success. The requirements of this APS project, considering the constraints, were achieved. While the preliminary goal from December 2016 of a complex and robust APS was not achieved, a suitable and extrapolatable model was created in good time and budget. Through the full process, budget and time were found to be the biggest constraints. All the technology and components that would be needed for a bigger, better APS exist but were out of the question.

The intention of the project definitely had a shift in direction from December to June as dreams turned to reality. Compromises were made, but the project still made a stunning performance at the Senior Project Exposition. Every component functioned, all switches and wiring worked neatly, and the frame stood sturdy. We were able to keep energy consumption down to with our component choices and monitor it real time with our power meter (provided by Professor Dolan).

This APS could be scaled up for more extravagant use in the future with additional components added as seen fit. Sharpell Technologies recently made a transition away from engineering an electric-SUV to large-scale lithium-ion battery packs. Our APS will not be seen in any production vehicle, but served as invaluable practice of product development.

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Appendices

A. Senior Project Analysis

Project Title: Auxiliary Power System

Group Members: Eve Wassenaar, Carter Whittington, Nidia Vara, and Karianne LaPlante

Advisor: Dale Dolan

1. **Summary of Functional Requirements**
    a. This auxiliary power system is able to power the automatic windows, headlights, tail lights, cabin lights, brake lights, parking lights, reverse lights, and trunk motor. In order to control these functions and components, there is a control panel located on the front of the frame.
    b. The APS gets it's power from a 12V lead acid battery that is rechargeable. This battery will be added to the additional higher voltage battery that will power the electric vehicle's motor. This is to allow additional power to the vehicle and to allow the car to be able to drive further without wasting power on powering the components.
2. **Primary Constraints**
    a. A challenge that was faced was figuring out how to incorporate all the components that were originally going to be put on the vehicle. Once beginning to work on the project, it was realized that the goal was a little out of reach with the time frame and budget limit that was provided.

b. Originally, it was planned to incorporate a fingerprint sensor to be able to start and unlock the vehicle. As the planning of the project began to take place, it was realized that this task was not a small one, and that it would have taken easily a whole quarter to just accomplish this fingerprint sensor - it was a senior project in and of itself. Due to this, it was decided to omit this task. This was the case for the dimmable headlights as well.

3. Economic

a. Human capital impacts: The big picture for this APS is to eventually become a bigger production with Sharpell Technologies and to be implemented in their vehicles down the line. This will then help to hire people to produce and develop more jobs.

b. Financial capital impacts: Although this APS, after implementing the rest of the components down the line, will be more expensive than other APS in other vehicles, the customer will save money by not purchasing gas. Instead of gas powering the vehicle to charge the battery, electricity will power the vehicle to power the battery.

c. Natural capital impacts: Overall, this electric vehicle will help eliminate gaseous pollution which will be considerably better for the environment than combustion vehicle pollution.

d. Costs:

i. The cost of the APS depends on what components are included. For the APS that was created for this project the cost list is mentioned in Appendix C. It cost a little under $900. However, if a full-functioning APS was created with all of the components, this price would have been significantly higher. Table 3 listed below is a rough estimation of how much the APS would have costed if all components were implemented.

Components	**Approximation Cost of Component**
Battery	$250
Misc. circuitry	$50
Microcontroller(s)	$50
HVAC system	~$1,500
Fingerprint sensor	$50
Lights (bulbs and harnesses)	$500
Miscellaneous	$1,500
Total	**$3,900**

Table 3: *Cost of Project if All Components Were Implemented*

ii. Table 4 below shows the actual bill of materials that were purchased to complete this project.

Components	**Cost of Component**
Battery	$116.32
PVC piping (and connectors and tools)	$61.19
Tools (soldering iron, etc)	$258.94
Misc. circuitry (wires and switches)	$86.53
Lights (bulbs and harnesses)	$146.75
Trunk motor	$53.78
Window motor	$75.73
USB power port	$9.99
Fuses and fuse box	$53.98
Relays	$11.87
Total	**$875.08**

Table 4: *Actual Cost of Project*

e. Timing: This product is expected to last anywhere from 6 months to 48 months (depending on how long/much it is used). This project includes a typical 12V lead acid battery, and this is the typical lifetime of a lead acid battery.

   i. The original estimated timeline as a Gantt chart can be observed below in Figures 3-5:

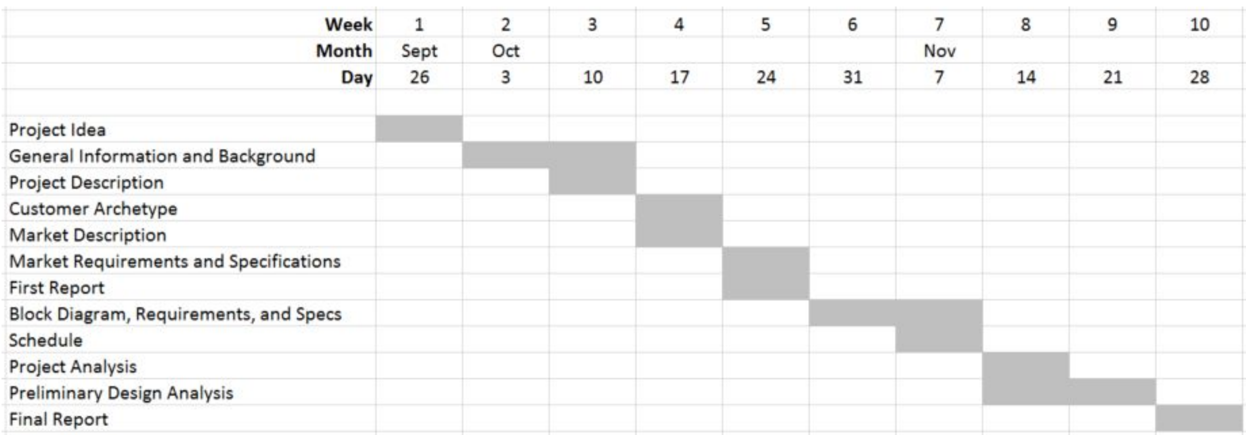


Figure 3: *Original Time Estimation - Gantt Chart for Fall 2016*

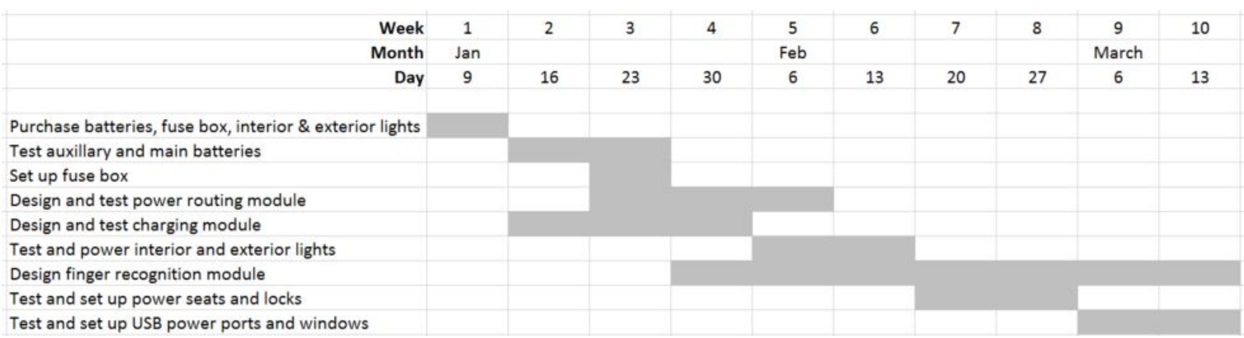


Figure 4: *Original Time Estimation - Gantt Chart for Winter 2017*

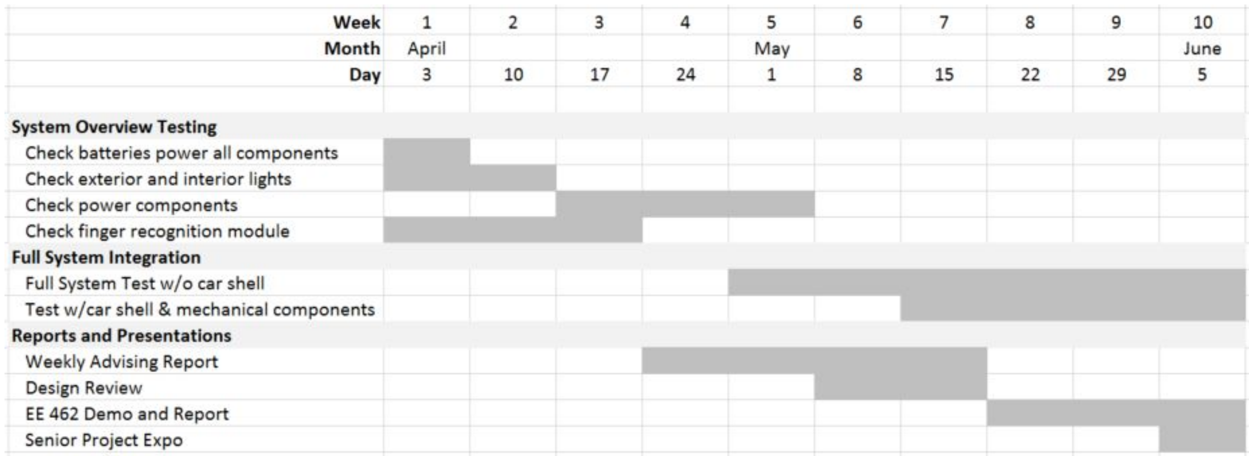


Figure 5: *Original Time Estimation - Gantt Chart for Spring 2017*

ii. The actual developed time of the project can be seen below in Figures 6-8:

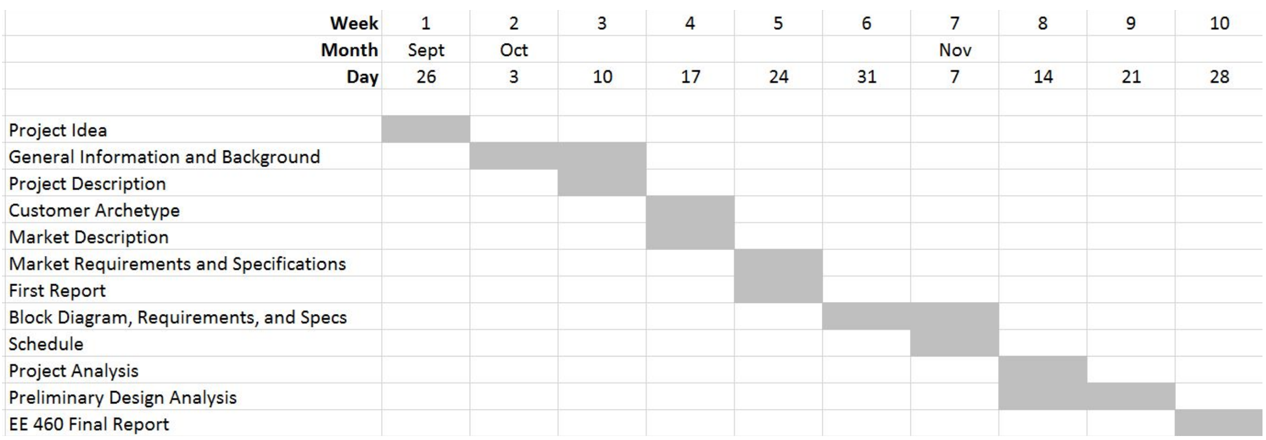


Figure 6*: Actual Development time - Fall 2016 Gantt chart*

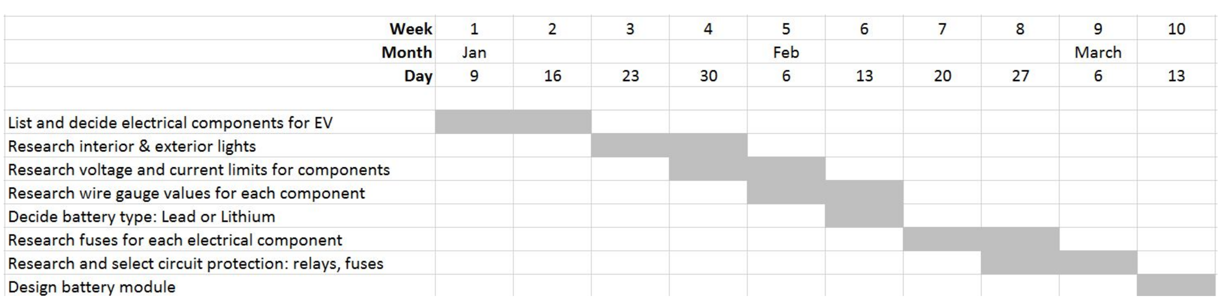


Figure 7: *Actual Development time - Winter 2017 Gantt chart*

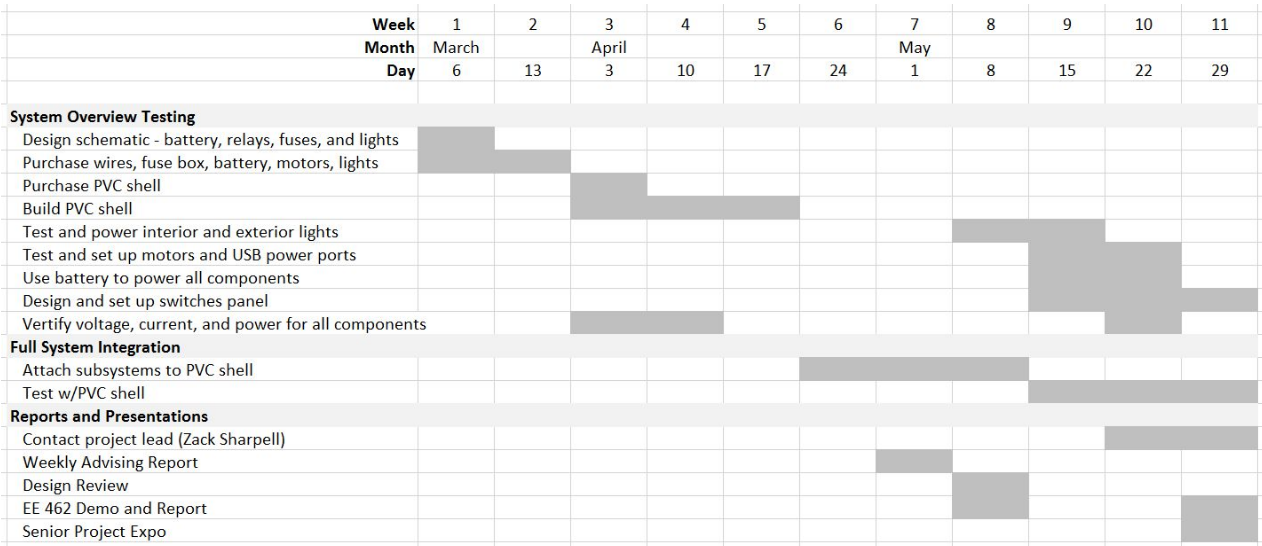


Figure 8: *Actual Development time - Spring 2017 Gantt chart*

4. If Manufactured on a Commercial Basis

a. Estimated number of devices sold per year: Expected 75,000 units sold in the first year.

b. Estimated manufacturing cost for each device (after complete production with all components included) will be about $3,900.

c. Estimated purchase price for each device will be around $10,000.

d. Estimated profit per year if each device sold for $10,000 would be approximately $457.5 million.

e. Estimated cost for user to operate device, per unit time will cost $8-$40 per kilowatt-hour.

5. Environmental

a. Some environmental impacts that this project has depends on how the project is chosen to be recycled. The lead acid battery would have the biggest impact on the environment. However, this can be taken to a proper recycling facility to be disposed of properly. The PVC piping that was used to build the frame for the project can also be recycled. The motors, lights, and other components will be properly recycled and/or reused.

b. Depending on how the user gets their electricity, this system would be able to use sun, water, or even wind power. Otherwise, they would most likely get the power to charge their vehicle by using the electric grid in their community and it would depend on how the user's city provides electricity. The most common way electricity is produced in California is from natural gas [5].

c. Some natural resources and ecosystem services that this project would help would be the atmosphere which in turn would help many living organisms. Since this car runs on electricity, it wouldn't produce any direct emissions. The emissions produced from the making of this vehicle would be the emissions used to generate the electricity. As stated before, this would be from renewable means, such as wind or solar, or it would most likely be from natural gas.

6. Manufacturability

a. One challenge with building this project was the production of the PVC frame to display the APS. This became a challenge because there wasn't a lot of experience with mechanical tasks. Due to this, it was also a slight challenge trying to wire up the motors and learn how the motors worked. After researching and trial and error, the PVC frame was built and the motors were figured out successfully.

7. Sustainability

a. A challenge associated with maintaining the completed system is figuring out how to store it and/or recycle it properly. Since a live battery is incorporated with this design, it is essential to take the proper precautions with storing the battery. After this project is finished, this battery and other components will need to be properly disposed of. This will be a slight challenge to find and research a place that will do this correctly.

b. Depending on how the user gets their electricity, this can be a sustainable and renewable APS. If the user uses solar panels or other means of renewable energy to get their power, then this battery and APS can be charged using those means.

c. An upgrade that this system could gain would be to implement the other components that were originally suggested such as the fingerprint sensor, dimmable headlights, pulsing tail lights, customizable cabin lights, etc. Apart from that, another upgrade to be able to maintain sustainability would be to incorporate solar panels on the top of the car to help charging the vehicle as it is running. This would eliminate the amount of stops users would need to make to charge their vehicles.

d. Some issues and/or challenges that may arise while attempting to upgrade the design may be a weight issue. If the solar panels weigh too much, this could affect the efficiency of the vehicle, and cause it to hinder the performance rather than improve the performance. Another challenge that may come up would be the implementation of the fingerprint sensor. It would need to be deeply researched with how to program the sensor to communicate with the vehicle's other components. Extensive knowledge with programming would also need to be required. With these upgrades comes increased prices and costs of the projects, therefore proper funding would be needed.

8. Ethical

a. A positive ethical implication of the design is to allow the customer to feel like their vehicle is unique. Down the road with the added components, this project would include customizable cabin lights and fingerprint sensors. With these added features, the user would be able to drive a truly unique vehicle while also feeling safe.

b. A negative ethical implication may be that users don't want to risk losing battery power while driving on a longer road trip. There aren't many charging stations around, and it

can be nerve-racking. However, with the growth of more electric vehicles on the road, charging stations will become more abundant throughout the years, so hopefully this fear and concern will diminish as time goes on.

9. Health and Safety

a. A concern that may surface would be the possibility of an exposed wire, or high voltages that may cause a car fire. If inadequate precautions are taken place, then a fault like this could arise. However, it is known how dangerous it can be if there are any exposed wires, faulty connections, and/or miscalculated safe voltage and/or current levels so the correct precautions will be taken.

10. Social and Political

a. The APS must deliver the expected output. If a delivered product is faulty, that would then lead to bad feedback from the customer which then could lead to a bad reputation causing the project to lose sales. Also, dealing with potentially high voltages, comes potential harm. Some may see this product as unsafe due to this.

b. This project will impact the start to a whole new automotive industry. The growth of EV will just keep rising, and there will be lots of room for improvement for APS's among other things.

11. Development

a. Multiple tools had to be used to complete this project including tools that haven't been used before. One tool that was used was a ratcheting PVC cutter to cut the PVC pipes to correct length. Another tool that was used often was a soldering iron to solder components and wires together. A new tool that was used was a drill and special drill bit to drill holes for the control panel for the switches. It was required to go to the Mustang

60 Hanger to do this, but it was a good experience to learn how to use the tools to complete this task.

b. A measuring tool and instrument that was used was a power meter to measure how much power and current was being used from the battery to power each individual component. This allowed for easy and accurate measurements.

B. Parts List and Costs

System #	Part #	Part Name	Quantity	Manufacturer	Cost ($)
1	Interior Lights				
	1	Cabin Lights	2	Kohree	16.98
2	Exterior Lights				
	1	LED Headlights	2	Yitamotor	31.99
	2	Headlight sockets	2	AutoZone	5.98
	3	Tail Lights	2	Super Bright LEDs	91.80
3	Motor Components				
	1	Window Motor	1	Ebay	75.73
	2	Trunk Motor	1	Dorman	53.78
4	Switches				
	1	Push-buttons (trunk motor + brakes)	2	RadioShack	2.08
	2	Flip-switch (headlights)	1	RadioShack	5.84
	3	Rocker switches (parking + reverse)	2	RadioShack	9.08
	4	Window motor switch	1	Ebay	12.50
5	Protection				
	1	Relays	2	EP Auto Direct	11.87
	2	Ground Terminal	1	Home Depot	10.78
	3	5A-20A Fuses	150	Katzco	16.99
	4	Fusebox	1	Pegasu Auto Parts	36.99
	5	Heat Shrink	50	Radioshack	8.08
	6	Battery Ring Terminals	2	AutoZone	2.99

	7	Post Terminals	2	AutoZone	6.49
6	Power Components				
	1	USB charging port	1	Doinshop	9.99
	2	12V Car Battery	1	O'Reilly's	116.32
7	Wires				
	1	40ft 18 gauge copper	2	RGBSIGHT	12.99
	2	50ft 16 gauge copper	2	Best Connections	16.97
	3	30 ft 10/12/14 gauge	3	Hilitchi	18.99
8	PVC Shell				
	1	12" PVC pipes	6	Home Depot	31.31
	2	PVC cutter	1	Home Depot	11.98
	3	PVC elbows	8	Amazon	17.90
9	Tools, Office Supplies				
	1	Gorilla duct tape	1	Home Depot	6.97
	2	PVC (Adhesive) glue	1	Home Depot	2.00
	3	Zipties	100	Home Depot	9.97
	4	Tool chest	1	AutoZone	90.00
	5	Soldering iron	1	-	150.00
				TOTAL	**$895.34**

Table 5 *- Bill of Materials for APS Project*

C. Schedule

Week	1	2	3	4	5	6	7	8	9	10
Month	Sept	Oct					Nov			
Day	26	3	10	17	24	31	7	14	21	28
Project Idea	X									
General Information and Background		X	X							
Project Description			X							
Customer Archetype				X						
Market Description				X						
Market Requirements and Specifications					X					
First Report					X					
Block Diagram, Requirements, and Specs						X	X			
Schedule							X			
Project Analysis								X		
Preliminary Design Analysis								X	X	
EE 460 Final Report										X

Figure 9: *Fall 2016 Gantt chart*

Week	1	2	3	4	5	6	7	8	9	10
Month	Jan				Feb				March	
Day	9	16	23	30	6	13	20	27	6	13
List and decide electrical components for EV	X	X								
Research interior & exterior lights			X	X						
Research voltage and current limits for components				X	X					
Research wire gauge values for each component					X	X				
Decide battery type: Lead or Lithium						X				
Research fuses for each electrical component							X	X		
Research and select circuit protection: relays, fuses								X	X	
Design battery module										X

Figure 10: *Winter 2017 Gantt chart*

Week	1	2	3	4	5	6	7	8	9	10	11
Month	March		April				May				
Day	6	13	3	10	17	24	1	8	15	22	29
System Overview Testing											
Design schematic - battery, relays, fuses, and lights	X										
Purchase wires, fuse box, battery, motors, lights	X	X									
Purchase PVC shell			X								
Build PVC shell			X	X	X						
Test and power interior and exterior lights								X	X		
Test and set up motors and USB power ports									X	X	
Use battery to power all components									X	X	
Design and set up switches panel									X	X	X
Verify voltage, current, and power for all components			X	X						X	
Full System Integration											
Attach subsystems to PVC shell						X	X	X			
Test w/PVC shell									X	X	X
Reports and Presentations											
Contact project lead (Zack Sharpell)										X	X
Weekly Advising Report							X				
Design Review								X			
EE 462 Demo and Report								X			X
Senior Project Expo											X

Figure 11: *Spring 2017 Gantt chart*

D. Full Schematic

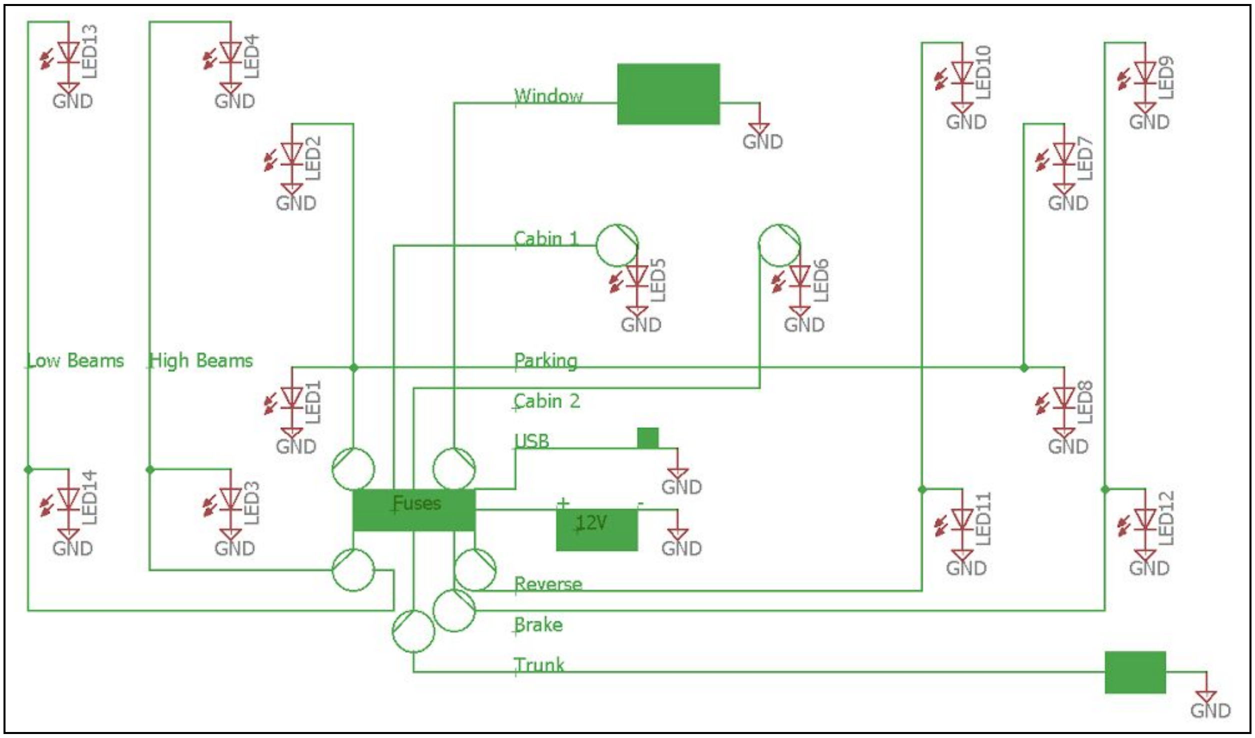


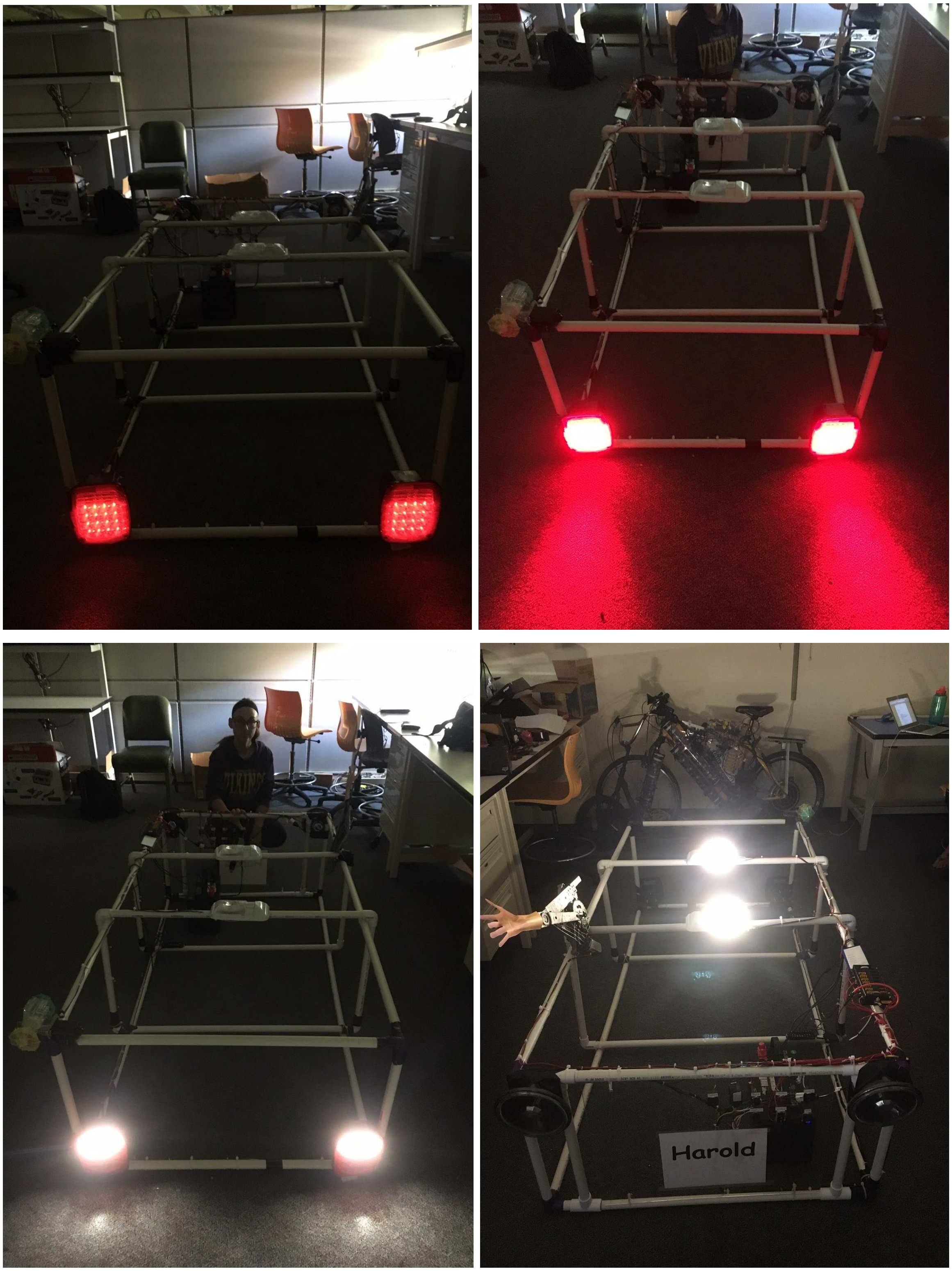
Figure 12: *Full Schematic*

The above figure depicts the full circuit for the APS. All components are included and labeled. The circle symbols depict where either switches or buttons would be used. All grounding would be wired to our grounding block which led to the negative terminal of a battery. In a production vehicle, these ground wires would tie to the chassis which would connect to the negative terminal of the battery.

E. Physical Layout

Figures 13-16: *(Clockwise, starting top left)*
Low beams, high beams, trunk motor, window motor

The heavy components are secured in corners of the PVC frame for necessary support. Additional framing was required to fasten the headlights.



Figures 17-20: *(Clockwise, starting top left)*

Parking lights, brake lights, cabin lights, reverse lights

As depicted in Figure 20, our control module consists of switches fastened to a plexiglass plate.