Road Trike: Weather-Proofing and Enclosures

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by

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Problem Statement

In an ever-expanding world, personal transportation has become a necessity for billions of people. The most common form of personal transportation in the United States are cars. As of 2016, there were approximately 253 million licensed drivers in the US (1). With the price of used and new cars increasing to $19,657 and $36,113 respectively, this creates a large financial burden for a lot of families. The median household income as of 2016 was $59,039 (2). Most cars also have a lot of moving parts and end up requiring significant and often expensive maintenance and repairs over the years,

With personal transportation being such a necessity for so many people, many have turned towards using bicycles to commute. According to the US Census, Americans that commute via bicycling increased by 61% from 2000-2012 (3). Unfortunately, most cyclists are unable to commute via cycling during inclement weather.

In Europe, several companies have begun popularizing velomobiles (small 2-4 wheeled, enclosed vehicles which are either electric or pedal powered. New velomobiles are still quite expensive and will cost $10,000-$18,000.

We will develop a mode of transportation that will be easy to maintain, less expensive than traditional personal vehicles, and will be usable in inclement weather.

I specifically will develop the weather enclosure and electrical systems for said mode of transportation.

Research

Background of the Problem -

In 2012, there were reportedly 768,000 cycling commuters, according to USA today. This number has been slowly but steadily growing over the past several decades. According to information from the 2016 census data, cyclists still currently only account for about 0.6% of commuters (4).

Greater Greater Washington reported a survey with almost 10,000 responses from Americans throughout the nation (5). This survey concluded that about half of Americans have in interest in biking more. Some of the biggest factors for not biking as much as they would like included dissatisfaction with existing infrastructure. Most people in the survey agreed that there should be more protected bike lanes. Others were worried about being hit by cars. One of the biggest barriers for most people though, was just owning a bike. Many people simply don't own bikes, as they can be expensive and are often considered more of luxury items, and often aren't sustainable for being a primary source of transportation.

Our end product will most like be categorized as a velomobile. Velomobiles are 2,3, or 4 wheeled vehicles with a frame similar to that of a recumbent bicycle and a fully enclosed body around it. These are often described as more comfortable and faster than standard bicycles. The biggest issue with velomobiles is there high price of entry (6). Currently, a new velomobile will cost about $10,000-$18,000 (7). Meanwhile, USA Today reports the average used car is selling for $19,657 currently (8). People are just not interested in velomobiles currently with such a steep starting price that could be instead spent on a used car.

State of the Art –

Regarding weatherproof enclosures, cars often use bodies of mostly aluminum and magnesium alloys (9). These hard materials have the advantage of being fairly rigid and offer a waterproof enclosure for vehicles. The downside of these type of enclosures is that they are prone to rust, scratches, and are difficult to repair if there are cracks or pieces that break off (10).

Another option is a canvas material, similar to that of a soft top on a jeep or a convertible. These enclosures are supported by a frame of plastics or aluminum alloys with the soft top being attached to said frame. Within these types of tops there are different materials, including polyester, cotton, and multi-layered vinyl materials. Within these there are also different types of windows, including rolled and pressed. With rolled windows being more distorted and having poorer visibility (11).

Vinyl tops are easier to maintain, more economical, and are waterproof. Fabric-like canvas tops are known to “breathe” which makes them lighter and more for aesthetics, as well as not being naturally waterproof.

Soft tops are prone to holes and tears. This leads to the soft tops often needing to be replaced if not properly maintained. Alternately, these tops also have the benefit of being easily repaired and replaced. Patches can easily be sewn in over holes and the entire top can be taken off and replaced relatively simply and inexpensively (11).

Other enclosures that are used in weatherproofing on velomobiles are mostly made of hard plastics. Some of these are fully enclosed, some have open bottoms, and some have open tops. Those with open tops are similar to bicycles in that they are ineffective at protecting the user from precipitation or severe temperatures.

The open bottom concept is better for hotter days, allowing for more ventilation. It also provides cover for precipitation and wind. Furthermore, it allows for the user to more easily get in and out of the vehicle.

Depending on the type of enclosure style chosen, lifting the enclosure could be necessary. Automobiles often use gas springs to allow for the trunk or hood of a car to be easily opened and closed (12). Gas springs are sturdy and consistent. Another option would be a spring hinge, which would also hold open the enclosure. A spring hinge is less sturdy than a gas spring but is cheaper and easier to install (13).

An entirely closed plastic enclosure provides protection from the wind and is better suited to keep heat within the vehicle. This is better for extreme colds but worse for hot days.

The electric systems used in fuel cell electric cars run off of large batteries (14). They convert hydrogen gas into electricity to power the motor and the battery. In this case, only the battery needs to be powered and since the trike is much smaller, it would require a significantly smaller battery. Electric vehicles also use regenerative braking which helps to charge the battery when braking since there is no alternator (15).

The majority of electrical systems are fairly straight-forward. Since there won't be a starter or alternator in the electric system of the trike due to it not being a traditional gasoline powered vehicle, the majority of the electric system will be dedicated to lighting. Since one of the stipulations of the trike is that it is to be useable in inclement weather, headlights are a must.

Main headlights used to be pretty much exclusively filament bulbs (16). These bulbs worked similarly to household filament bulbs, in that they would run electricity through a filament, heating up said filament and producing light. To make the bulbs brighter, they would also often be filled with halogen or xenon gas. However, these types of bulbs have begun being phased out by LEDs.

A more expensive option is HID or High Intensity Discharge headlights (16). These bulbs don't use filaments and are instead operate off of the gas discharge principle where and arc of electricity jumps between two electrodes and, along with xenon gas in the bulb, creates the light.

LEDs have become a more popular option on newer cars (16). LEDs are more reliable than the other options, lasting for much longer before needing to be replaced. They also use less power than their counterparts, allowing for a longer time period between a battery recharge is required. The downside is that they cost considerably more upfront than standard filament bulbs, but they aren't any more complicated to install or replace.

End User -

Ideally, the end user would be between 15 and 50 years of age. The user would likely have low to medium income. They would be able bodied and would have a commute of 10 miles or less.

The 15 to 50 year age range and able-bodied requirements were included to ensure the user would be able to adequately able to operate the trike. It was decided that the trike would be made with an “average” user in mind, meaning the trike wouldn’t be designed with a child or elderly person in mind since children would be smaller and weaker while those over 50 would likely be less agile.

It was decided to make the trike fairly simple in nature to allow for as many people to be able to use the vehicle as possible. This is further demonstrated by the design choice to have few moving parts.

Summary of Research -

The main concerns for the enclosure involved being waterproof, visibility, and weight. The concerns with weight included keeping the center of mass low. One of the reasons steel wasn't chosen as the material for the enclosure was its high density, which would've made the center of mass rise, which would make the trike much easier to tip over.

Concerning enclosures, a soft canvas or vinyl top would be the most inexpensive and the easiest to maintain. Another option that doesn't seem to have been done would be a beetle style enclosure. This type of enclosure is similar to a beetle's wings, in which the entire enclosure flips up, rotating around one hinge. It's similar to the cockpit of a jet. These types of enclosures make it so doors don't have to be included and the body can be made entirely with aesthetics/aerodynamics in mind. It's not used in commercial vehicles because it would be ineffective with the weight of most vehicles. The light weight of the trike allows for this to be a viable option, in combination with a vinyl enclosure for waterproofing.

Concerning electrical systems, a small, single, rechargeable battery would be sufficient for powering the electrical requirements of the trike. LEDs would be the best option for headlights, being the most effective, allowing for a long period of use between required recharges. LEDs also take less maintenance than standard bulbs, needing to be replaced far less often (17).

Going with the beetle enclosure also introduced another concern of how to easily open close the enclosure. It was decided to go with a spring hinge to help open the enclosure, since it was it's less expensive, and simpler to install than a gas spring, which is in line with our design philosophies.

The canopy material and headlights had clear front runners for my purposes. I used a selection matrix to decide on the material for the skeleton of the enclosure based off my research

		Steel	Aluminum	Plastic
0.40	Weight	1	3	4
0.15	Cost	3	2	4
0.15	Manufacturability	5	4	2
0.15	Strength	5	4	3
0.15	Rigidness	5	5	2
	Total	3.1	3.45	3.25

Aluminum ended up being the best choice based off my criteria. Plastics such as PVC were much cheaper than aluminum or steel, but were slightly lower strength, and more much less rigid. Ultimately, aluminums biggest weakness is the cost, which is why we'll only be using it to make a skeleton for the enclosure, rather than using sheets of it for the entire enclosure.

Manufacturing

Manufacturing for the enclosure began with using 3/4" Diameter tubing with a wall thickness of 1/8". These aluminum rods were chosen to create the skeleton for the weather enclosure, which would hold up the canopy and the windshield. Using the machines and space provided by 1819 Makerspace, the aluminum rods were cut to length with a cold saw and then TIG welded together.

After cutting and welding several of the aluminum rods, it was realized that there were several design flaws with the front part of the enclosure. The dimensions of the user ended up being larger than what was previously anticipated. This meant that the aluminum rods that were cut were too short and in their current state would end up hitting the rider.

Moving the rods forward along the seat would put them out of the way of the user, but then it would interfere with the steering handles, so that wasn't a viable option. Unfortunately, due to our own budgetary and time restraints – reordering more aluminum rods wasn't an option, as it would've cost another $111, and would have taken at least 2 more days to get the material.

A last-minute redesign was required so that manufacturing could be finished before the tech expo. Since aluminum was more expensive to be purchased again, it was decided that a cheaper material in PVC would be used for the redesign. PVC is similar in strength to annealed aluminum 6061, with a tensile strength of 55.2 MPA (18) for PVC compared to 83 MPA for aluminum (19).

The redesign included changing the hinge to two round pieces of PVC that would rotate around two pieces of steel tubing at the back of the trike as a replacement for the spring hinge. This wouldn't hold the enclosure up like the spring hinge. but would act just as a hinge point for the enclosure. This was easier to install and cheaper than the spring hinge, which is why it was chosen.

The PVC hinges are each attached to a triangular structure of PVC, which connects to the windshield at the other end. The windshield is supported by pieces of PVC that were shaped by heat and attached with screws. This combination of pieces forms the skeleton of the enclosure.

Once the skeleton is finished, the vinyl is cut to shape, including cutting out windows and attaching the clear vinyl to the rest of the canopy. The clear vinyl was attached to the canopy by an epoxy. The canopy was then attached to the PVC skeleton with screws. The headlights are then screwed to the front of the enclosure

At this point, the enclosure just needs to be attached to the rest of the frame. This is done by attaching the round PVC attachment points to the steel tubing that's been welded to the back of the frame. This involves picking the enclosure up and placing the attachment points on one at a time to create the hinges. Once on, screws are screwed into the steel tubing to ensure the attachment points don't move left or right and just rotate.

Testing

Testing for the enclosure was to test the visibility and whether the enclosure was waterproof or not. The first test involved printing out signs with at least 250mm tall letters, or about 720 point font, which is the size of the letters of stop signs in the United States (20). While inside the enclosure, 10 signs were to be read at 3m, 6m, 9m… up to 30m. The signs were legible through the windshield for every distance, however, after 9m the words were illegible through the side windows and thus, the enclosure failed the vision test.

The waterproof test involved spraying a hose on the enclosure while it was detached on the ground, spraying a hose onto the enclosure while the enclosure was attached the trike with a rider on it, and riding the trike with the enclosure in the rain. All three of these tests were passed and the enclosure was proven to be waterproof.

Quality Function Deployment

Customer Features -

- 1) Can be relied upon (0.22)
- 2) Requires low financial investing (0.18)
- 3) Ease of Use (versatility) (0.15)
- 4) Easily Maintained (0.14)
- 5) Can be operated without discomfort (0.11)
- 6) Can fit in a small space (0.08)
- 7) Can carry luggage (0.06)
- 8) Can drive fast (0.03)
- 9) Looks aesthetically pleasing (0.03)

Engineering Characteristics -

- # of Relative Moving Parts (3.2)
- Time Between Maintenance (months) (3.2)
- Is Weatherproof (2.3)
- Cost of Manufacturing ($) (1.9)
- Suspension travel (cm) (1.6)
- Turn Radius (m) (1.6)
- Loading Limits (kg) (1.6)
- Open Volume per Component (cm^3) (1.5)
- Output Power Required (W) (1.44)
- # of surfaces in friction (1.1)
- Overall Footprint (m^2) (1.1)
- Noise (dB) (1)
- Top Speed (km/hr) (0.8)
- Storage Space (m^3) (0.8)
- Weight (kg) (0.7)
- Steering Torque (Nm) (0.6)

House of Quality -

	Customer Requirements	Importance wt.	Weight (kg)	Suspension travel (cm)	Overall Footprint (m^2)	Turn Radius (m)	Steering Torque (Nm)	Cost of Manufacturing ($$)	Storage Space (m^2)	Noise (dB)	Loading Limits (kg)	Output Power Required (W)	# of Relative Moving Parts	Open Volume per Component (cm^3)	# of surfaces in friction	Is Weatherproof	Time Between Maintainencing (months	Top Speed (km/hr)	Customer Satisfaction Rating (0.00 - 1.00)			
			Engineering Requirements (units)																			
	Customer Requirements		1	2	3	4	5	6	7	8	9	10	12	13	14	15	16	17	CP	A	B	C
1	Can be relied upon	0.22						1					9		3		9			0.9	0.8	0.8
2	Easily Maintained	0.14		3	3								9	9	3		9			0.8	0.8	0.7
3	Ease of Use (versatility)	0.15				9	3				9	3				9				0.7	0.8	0.8
4	low financial investing	0.18	1	1				9										3		0.1	0.4	0.3
5	operating without discomfort	0.11		9			1			9		9				9				0.7	0.6	0.5
6	can fit in a small space	0.08	3		9	3			3					3						0.6	0.8	0.7
7	can carry luggage	0.06							9		3									0.8	0.3	0.4
8	can drive fast	0.03	9	1		1					1							9		1	0.6	0.5
9	it looks aesthetically pleasing	0.03						3												0.8	0.9	0.9
10																						
	Total Importance	1.00																				
	Engineering requirement importance		0.7	1.6	1.1	1.6	0.6	1.9	0.8	1	1.6	1.44	3.2	1.5	1.1	2.3	3.2	0.8				
	Performance	Current Product																				
	Twike	itor A	246	20	3.3	3.5	TBD	26K	0.3	90	500	3000	25	5	10	Y	6	85				
	WAW	itor B	30	5	2.5	9.5	TBD	7K	0.15	65	125	75	25	5	8	Y	4	40				
	Quest	itor C	34	7	2.2	5.5	TBD	7.6K	0.2	65	140	75	25	3	5	Y	3	40				
	New Product Targets		80	8	2.5	6	20	2K	0.2	60	140	70	20	4	6	Y	3	35				

Interaction Matrix																	
	Engineering Requirements	Weight (kg)	Suspension travel (cm)	Overall Footprint (m^2)	Turn Radius (m)	Steering Torque (Nm)	Cost of Manufacturing ($$)	Storage Space (m^2)	Noise (dB)	Loading Limits (kg)	Output Power Required (W)	# of Relative Moving Parts	Open Volume per Component (cm^3)	# of surfaces in friction	Is Weatherproof	Time Between Maintainencing (months	Top Speed (km/hr)
Engineering Requirements		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Weight (kg)	1		3	1		1	-3			9	9	1					9
Suspension travel (cm)	2								-3			1	-1			1	
Overall Footprint (m^2)	3				3		3	1									
Turn Radius (m)	4					3											
Steering Torque (Nm)	5						-3					-3					
Cost of Manufacturing ($$)	6								-1	1	3	9			3	3	9
Storage Space (m^2)	7								1	1							
Noise (dB)	8											9		3			
Loading Limits (kg)	9																-1
Output Power Required (W)	10																9
# of Relative Moving Parts	11												-3	3		-9	
Open Volume per Component (c	12																
# of surfaces in friction	13															-3	
Is Weatherproof	14															1	
Time Between Maintainencing (m	15																
Top Speed (km/hr)	16																

Product Objectives -

1) # of relative moving parts (20 or less)
2) Is weatherproof (yes)
3) Time between maintenance (3 months or more)

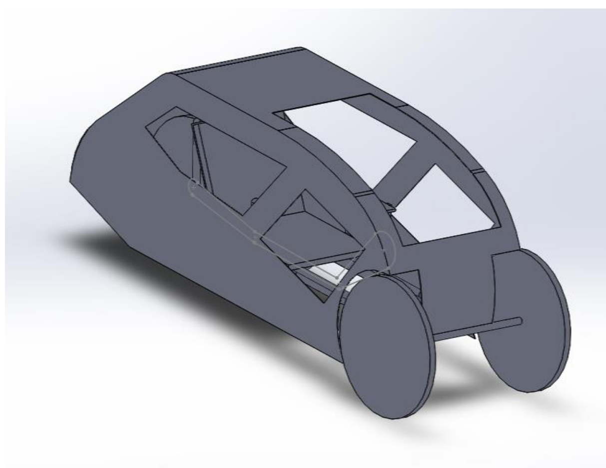
Concepts Drawings

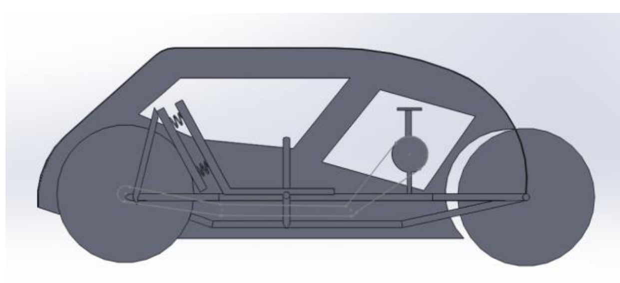
Initial Concepts took inspiration from golf carts, go carts, jeeps, and various designs of velomobiles. These designs included several different versions of enclosures, suspensions systems, steering systems, drivetrains, frame designs, and wheel locations.

The original concepts for the enclosure included a fully hard plastic enclosure with either a door or a hinged windshield similar to that of a cockpit in a jet. Other concepts were either a soft canopy with a zipper for a door, or a "beetle style" enclosure where the entire enclosure lifts up from a single hinge point.

<u>Concept 1</u>

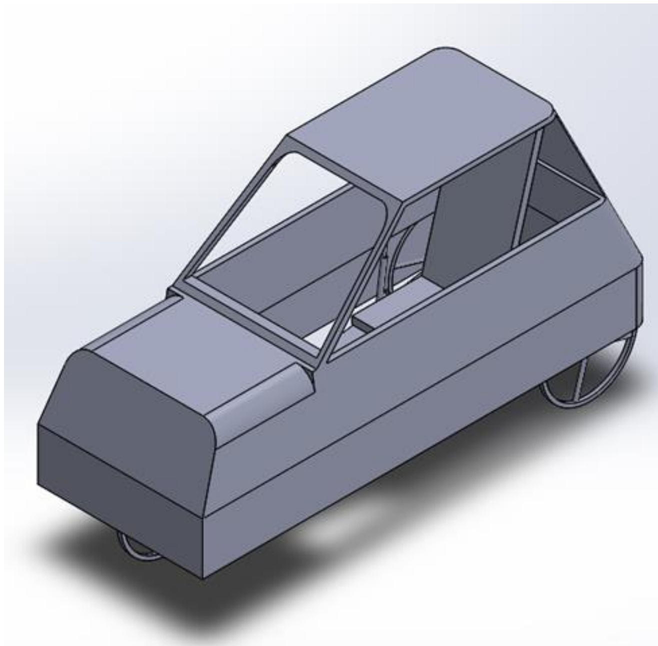
Concept 1 uses a bicycle style frame, a seat spring, a sprocket and drivetrain, paddle steering, a soft canopy style enclosure, two rear wheels, and one front wheel.

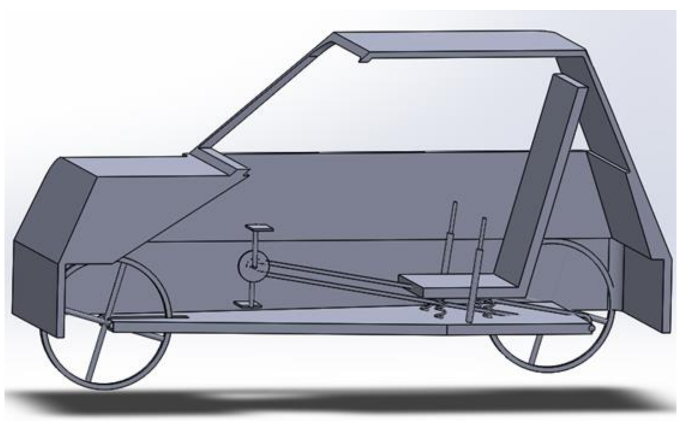




Concept 2

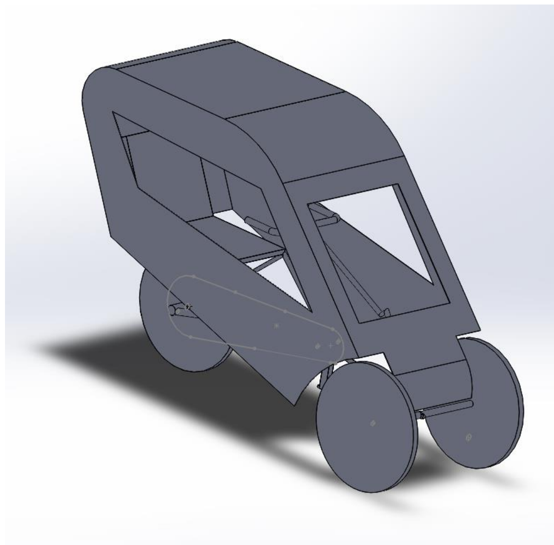
Concept 2 uses a frame similar to that of a go-cart, involving a closed bottom, the suspension system is comprised of a spring seat and a torsion bar, the drive train utilizes a belt a pulley, and the steering uses a paddle system, and the enclosure is a "beetle" style.

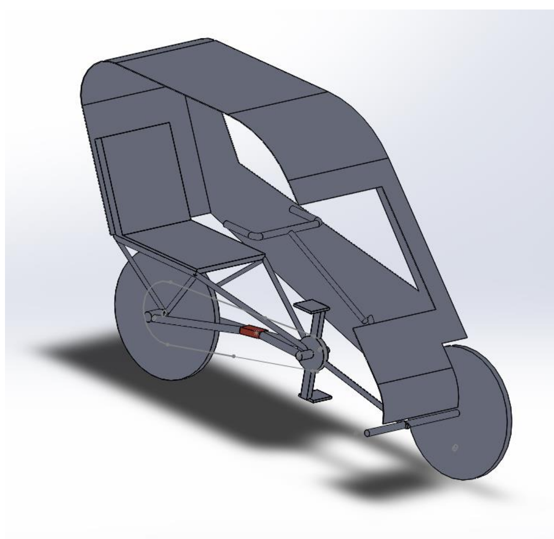


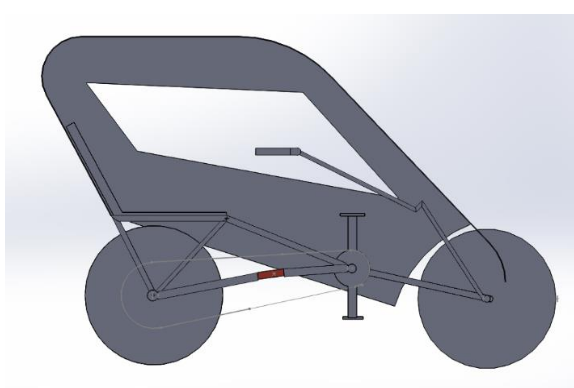


Concept 3

Concept 3 uses a bicycle style frame with an open bottom, a shock absorber in the body for a suspension system, a chain and sprocket drive train, another beetle style enclosure, and a steering wheel steering system.





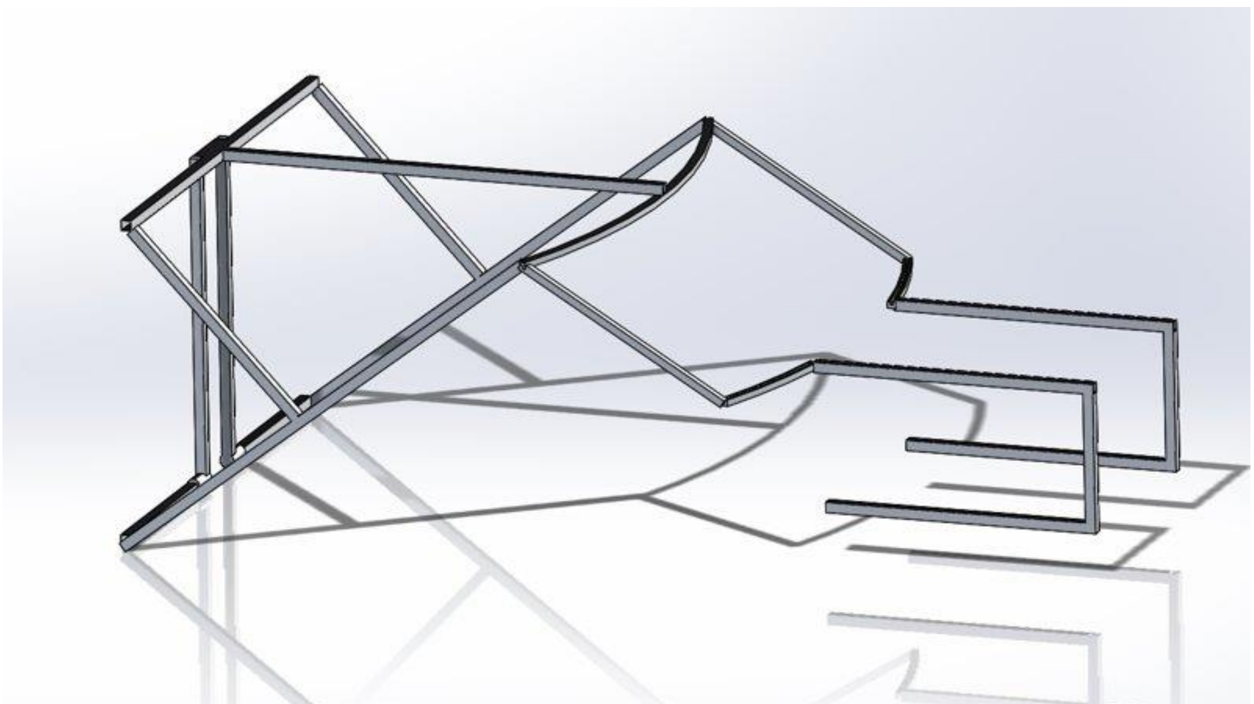


Final Concept

The final concept ended up being a mixture of the canopy and the beetle style enclosure. It was decided that making an entirely plastic enclosure would be costly and difficult to manufacture with our resources. Sticking with the design philosophies of being cost effective and not being too complex, the enclosure was decided to be a skeleton with a canopy being attached around it. Instead of a zipper door, it would use a version of the beetle style enclosure, where the back part of the enclosure would rotate up, along the rider to get in and out.

The front part of the enclosure with the windshield would remain stationary. This would keep the part of the enclosure that moves at a lower weight, which would allow the user to lift and close the enclosure more easily. The enclosure would be held closed by a latch at the top of the windshield that would click and be detached with a button.

An additional concept ended up including additional support below the windshield, as the design of the frame didn't allow for an attachment point at the front of the trike.



Project Management

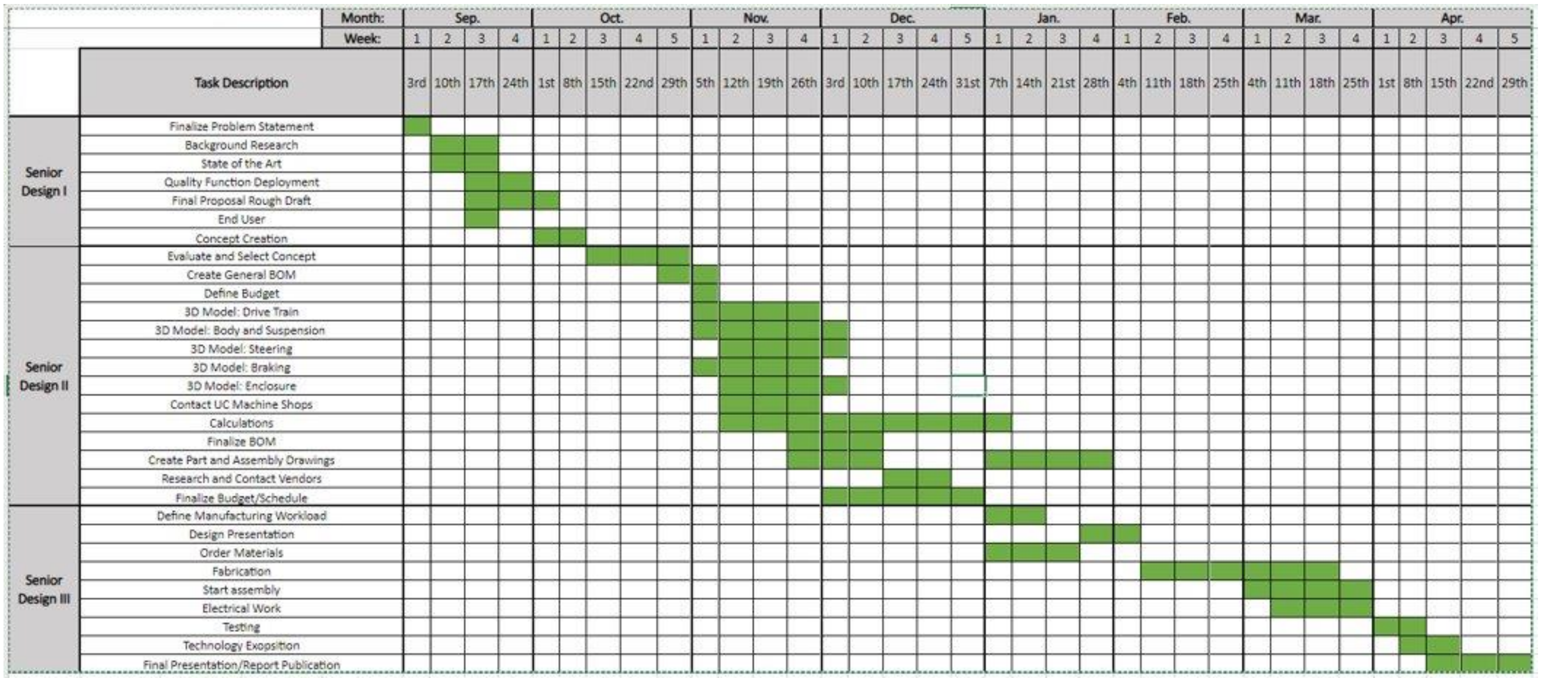
Actual Budget:

Frame	$823
Suspension	$83.99
Drive Train	$466.32
Enclosure	$190.41
Steering/Braking	$428
Total	**$1991.72**

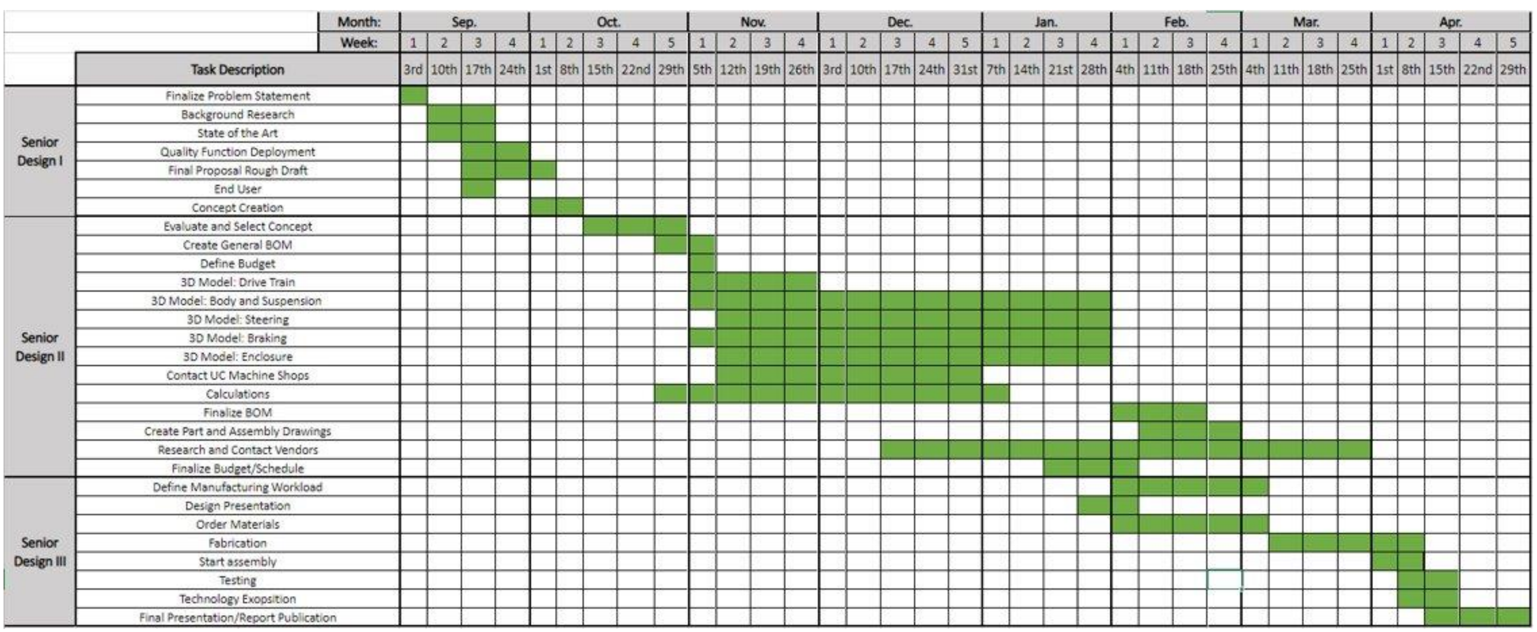
Proposed Budget:

Frame	$470
Suspension	$70
Drive Train	$310
Enclosure	$285
Steering/Braking	$240
Total	**$1375**

Proposed Schedule:



Actual Schedule:



Recommendations

My recommendation for improvement would include adding more structural support to the skeleton so that the clear vinyl can be stretched out to be attached at multiple ends to help improve visibility. The biggest reason the visibility test failed was because the windows of clear vinyl became bunched up and it distorted the visibility. If the vinyl had been pulled taut, it would've likely solved the visibility issue. I would also recommend using more clear vinyl to allow for more lines of sight, as well as adding rear view mirrors for the same reason.

I would also recommend going with my initial proposal of using aluminum tubing rather than PVC, but to ensure that there's sufficient room to attach the aluminum to the frame without interfering with the rider or the other parts of the trike. This recommendation would also include using the original design of a 2-part beetle style enclosure, where the windshield remains stationary to decrease the moment at the hinge and allow for the rider to more easily lift and close the enclosure.

I would also recommend using a gas spring to lift and close the enclosure, as it turned out to be much more difficult than previously anticipated. The gas spring would allow the enclosure to be moved much more easily.

Another recommendation would be to add additional wiring so that the headlights can be turned on and off while inside the enclosure since, as it is, they can only be changed while the rider isn't in the vehicle.

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Appendices

Transportation Survey

*This survey is in reference to a partially/fully human-powered vehicle.

Importance

Please rate how important each category is to your current human-powered mode of transportation.
1: Unimportant
3: Reasonable importance
5: High importance

Reliability - 1 2 3 4 5
Comfort - 1 2 3 4 5
Style - 1 2 3 4 5
Size - 1 2 3 4 5
Storage - 1 2 3 4 5
Convenience - 1 2 3 4 5
Speed - 1 2 3 4 5
Upfront Cost - 1 2 3 4 5
Maintenance - 1 2 3 4 5

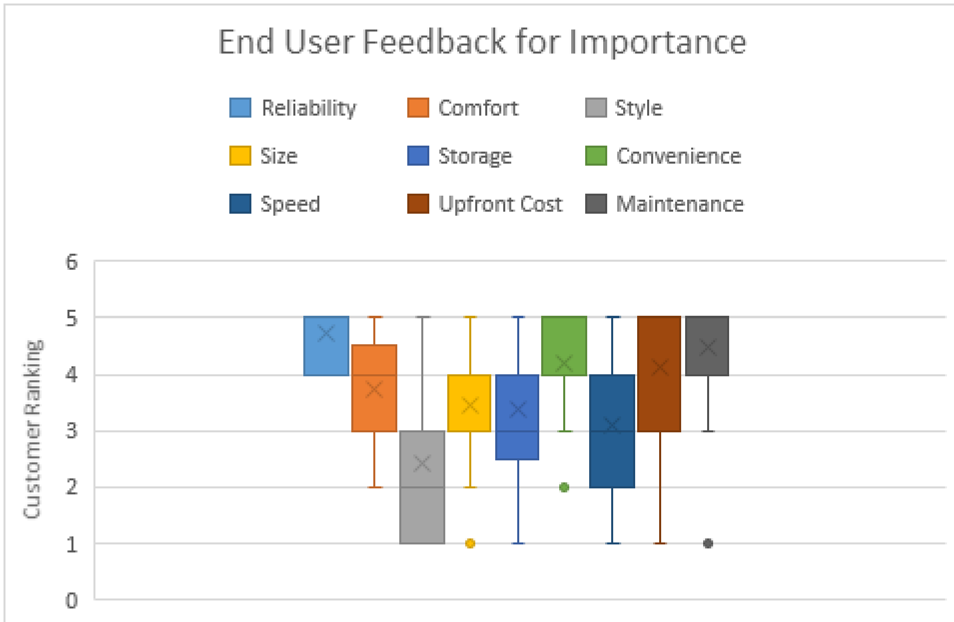
Satisfaction

Rate how satisfied you are with your current human-powered mode of transportation in each category.
1: Unsatisfied
3: Reasonable satisfied
5: High Satisfied

Reliability - 1 2 3 4 5 N/A
Comfort - 1 2 3 4 5 N/A
Style - 1 2 3 4 5 N/A
Size - 1 2 3 4 5 N/A
Storage - 1 2 3 4 5 N/A
Convenience - 1 2 3 4 5 N/A
Speed - 1 2 3 4 5 N/A
Upfront Cost - 1 2 3 4 5 N/A
Maintenance - 1 2 3 4 5 N/A

Are there any other points of your current human-powered mode of transportation that you are not satisfied with? Please list and explain.

Results from Survey



Customer Satisfaction Ratings

	Reliability	Comfort	Style	Size	Storage	Convenience	Speed	Upfront Cost	Maintenance
Average Resopnse	4.04	3.52	3.24	3.72	2.96	3.84	3.40	3.56	3.60
Average/5	0.808	0.704	0.648	0.744	0.592	0.768	0.68	0.712	0.72