

# Road Trike: Frame

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by

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## **Problem Statement**

Biking to work has grown in popularity recently, increasing 60% in the past decade (1). But many people who are willing to bike their commutes, are deterred by various reasons. One of these reasons is that common cycles offer no shielding from inclement weather (2). Some higher-end tricycles offer enclosures that allow the driver to remain dry from rain, but these vehicles easily run upwards of \$6000. There are currently no cost-effective weather-resistant tricycles available on the market.

## **Research**

### **Background of the Problem**

In 2015, a study was performed by The Brookings Institution to determine the average commute distance (3). Using information from the 2011 U.S. Census Bureau, they determined that the average commute is around 13 km. There are many ways individuals go about their commutes. The most popular being by personal motorized vehicle, dominating the other forms with an 85% share (4). The primary other means are public transportation, taxiing, walking, and bicycling. According to separate Census data collected from 2000 to 2012, interest in bicycling commutes has drastically increased in the past decade, with a 60% increase from 2000 to 2012 (1). There are multiple reasons why individuals have not fully committed to riding bicycles to make their commutes though. These reasons range from poor road conditions to a lack of urban bicycle integration. But another primary reason is due to more environmentally based conditions, rain specifically (2). There are cycle-type vehicles that allow for transportation in the rain that offer weather protection, but, on average, they tend to run upwards of \$6000. This price-wall is what has forced many individuals from allowing bicycling to become their primary form of transportation for their regular commuting needs.

### **State of the Art**

Primary Component: Vehicle Frame

For pre-existing similar vehicles, there is a common trend for the design of the chassis. Most of the popular concepts being based on designs for vehicles that already exist. A very popular frame design is based on the traditional bicycle frame. It is all based around a shaft structure that follows down the center axis of the vehicle. The axles are built off this structure, forming a “T” or “I” shape. The seat is also centered on this structure. This style frame is also similar to that of a recumbent tricycle frame, where the seat positions the user’s waist at or lower than the height of the pedals. The frame is typically made using either circular or rectangular metal tubing, in either aluminum or steel. The weight of this style of frame on a bicycle can vary greatly. Running 4-5 kgs on a cheaper bicycle, to 1.5-2 kgs on a more competitive bike (5). Benefits of this style frame are its low weight and its smaller volume (requires less physical space).

Another popular frame design is taken from the standard go-kart frame. While the bicycle frame is more based around a single structure following down along the center of the vehicle, the go-kart frame is more rectangular in shape, encompassing the whole vehicle body. It is made from similar materials as the bicycle frame, utilizing circular or rectangular metal tubing. Benefits of this design for a frame are a more rigid construction and more opportunity for weather proofing due to the bottom area typically being enclosed via sheet metal, whereas the bottom is typically left open on the bicycle-based chassis.

### **End User**

The ideal end user for this product will be 15 to 50 years of age. No mechanical aptitude or inclination will need to be attributed by this individual to effectively operate the product. They will most likely have a low to medium financial income. They can be either male or female. They will have to be able bodied to operate this product. They will have an average commute of 16 km or less. They will need to be able to take the vehicle over some hills.

### **Summary of Research**

There is an available market for an affordable weather-resistant tricycle. The frame of said tricycle will likely be inspired by either a bicycle/recumbent tricycle frame, due to its space and price efficiencies, or a go-kart frame, due to its rigidity and enclosing attributes. The material of the frame will likely feature circular or rectangular metal tubing made of either aluminum or steel.

# Quality Function Deployment

## Customer Features

\*[#]: Importance Weighting

- Can be relied upon [0.22]
- Easily Maintained [0.14]
- Ease of Use - versatility [0.15]
- Requires low financial investing [0.18]
- Can be operated without discomfort [0.11]
- Can fit in a small space [0.08]
- Can carry luggage [0.06]
- Can drive fast [0.03]
- Looks aesthetically pleasing [0.03]

## Engineering Characteristics

- Weight (*kg*) [0.69]
- Suspension travel (*cm*) [1.62]
- Overall Footprint (*m<sup>2</sup>*) [1.14]
- Turn Radius (*m*) [1.62]
- Steering Torque (*Nm*) [0.56]
- Cost of Manufacturing (\$) [1.93]
- Storage Space (*m<sup>2</sup>*) [0.78]
- Noise (*dB*) [0.99]
- Loading Limits (*kg*) [1.56]
- Output Power Required (*W*) [1.44]
- Number of Relative Moving Parts (#) [3.24]
- Open Volume per Component (*cm<sup>3</sup>*) [1.50]
- Number of surfaces in friction (#) [1.08]
- Is Weatherproof (y/n) [2.34]
- Time Between Servicing (*months*) [3.24]
- Top Speed (*km/hr*) [0.81]



## Product Objectives

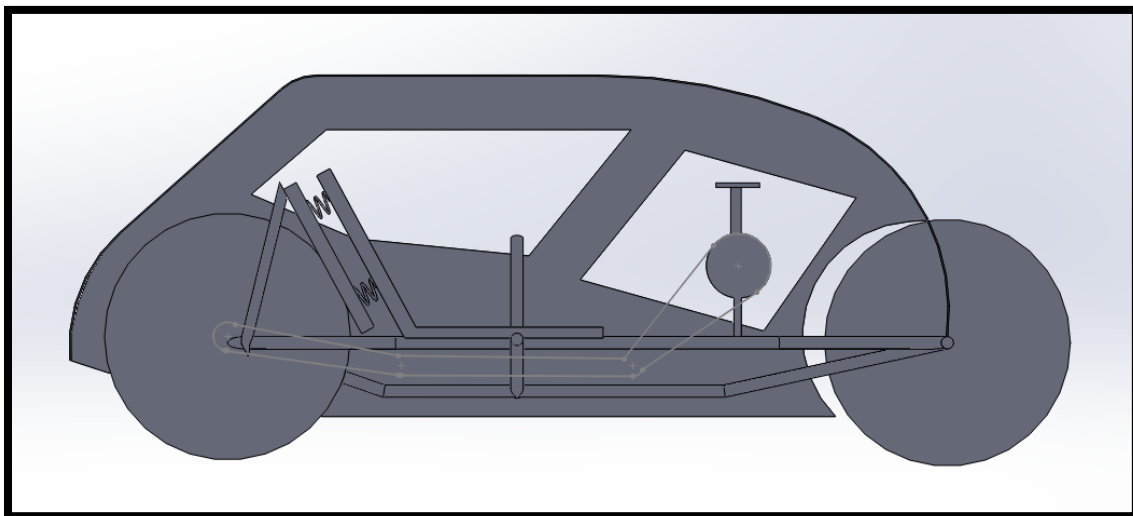
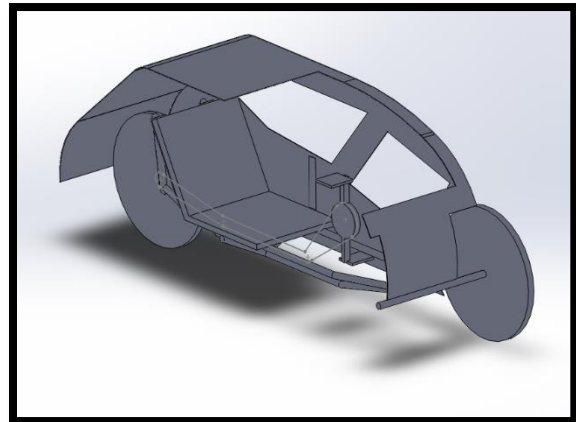
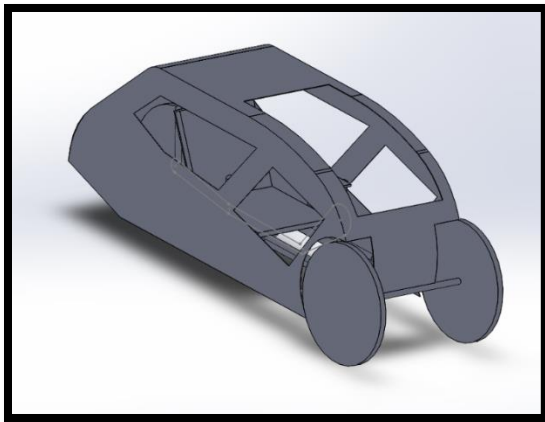
Determined from the House of Quality, the top five Product Objectives are:

1. Number of Relative Moving Parts (#) [3.24]
2. Time Between Servicing (*months*) [3.24]
3. Is Weatherproof (y/n) [2.34]
4. Cost of Manufacturing (\$) [1.93]
5. Loading Limits (*kg*) [1.56]

## Design Analysis

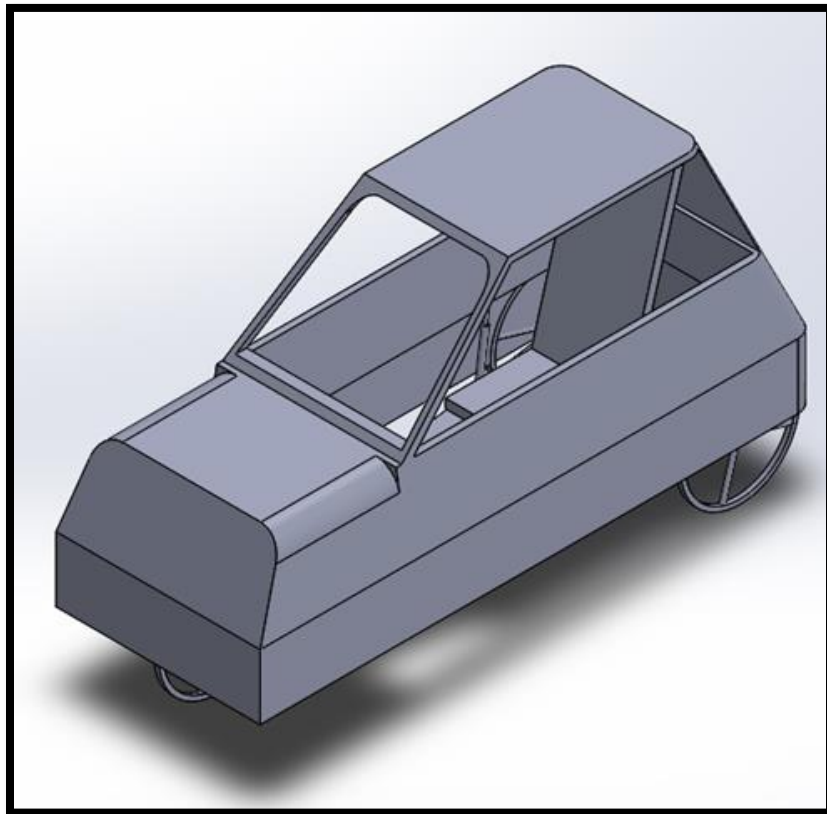
### Concepts

- **Concept 1**
  - This concept has the user in a recumbent position. The frame was inspired by a standard recumbent tricycle chassis, it also has two wheels in the front for steering and one in the back for driving. It features seat springs to function as the suspension of the vehicle. It uses a standard sprocket and chain assembly for the drive train. For steering, it uses a system referred to as paddle steering, where there is a handle on each side of the seat which is used to control the direction of the vehicle. The weather-resistant encloser is similar to a canopy, draping across the entire vehicle, made with a metal wire structure and a loose weather proof material.



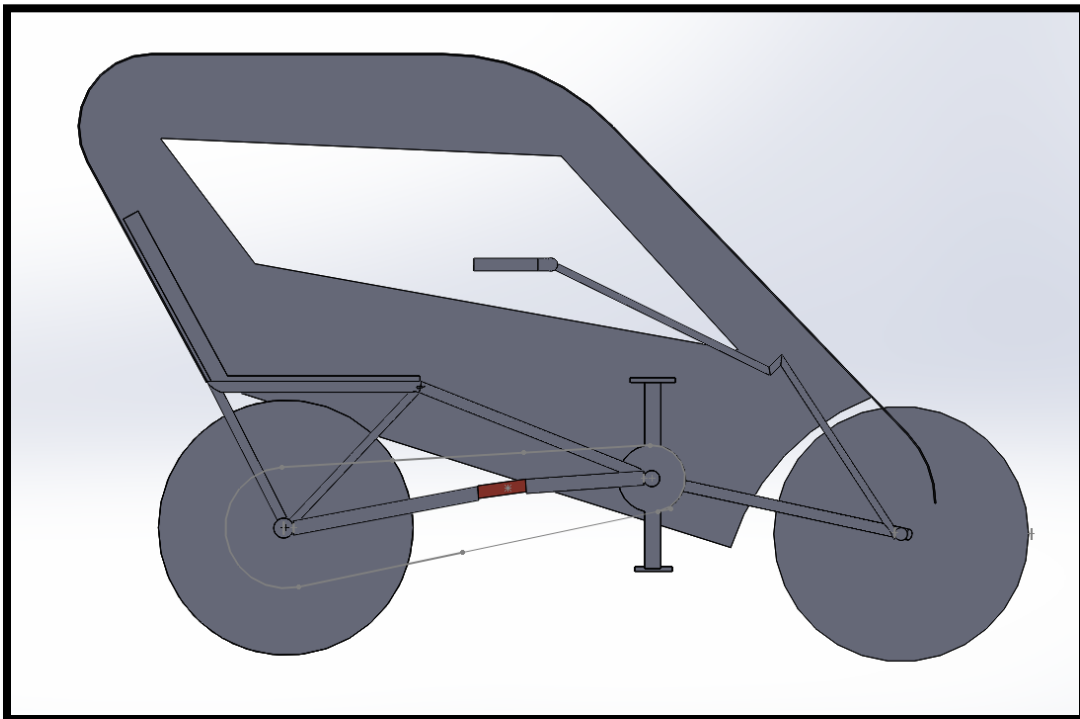
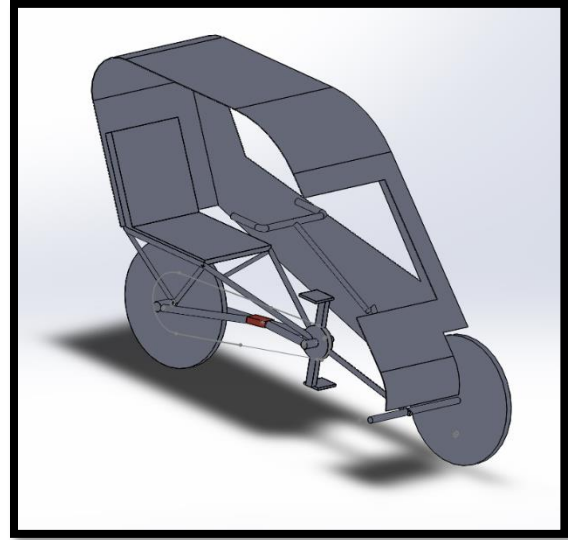
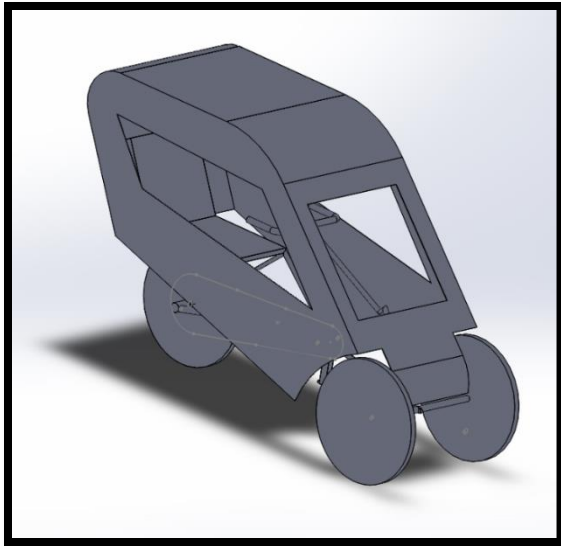
- **Concept 2**

- This concept also has the operator in a recumbent position, similar to Concept 1. The frame design was based on the go-kart inspired frame, in which the bottom is enclosed by sheet metal and it features a wider structure. Due to the style of frame, two wheels are located in the back of the vehicle for driving and one wheel is in the front for steering. It also features a spring seat to serve as the suspension. Like Concept 1, it uses the paddle steering mechanism for control. The enclosure of this concept has more of a structured design. It also will feature a hinge system at the back of the vehicle in order to allow the entire body of the vehicle to be raised up, similar to a car hood. This is how the user will enter and exit the vehicle.



- **Concept 3**

- This concept has the operator in a more bicycle-style sitting position, with the pedals lower than the waist. Because of this, the frame was designed with a bicycle frame in mind. It features two wheels in the front for steering and one in the back for driving. It uses a standard shock and strut system for the suspension, marked in red on the model. It employs a sprocket and chain system for the drive train. The steering of this concept functions similar to a bicycle, utilizing bike handles. Like Concept 2, it features a hinged enclosure in order to ensure easy access for the user, as well as keeping the cabin of the vehicle weather-resistant.

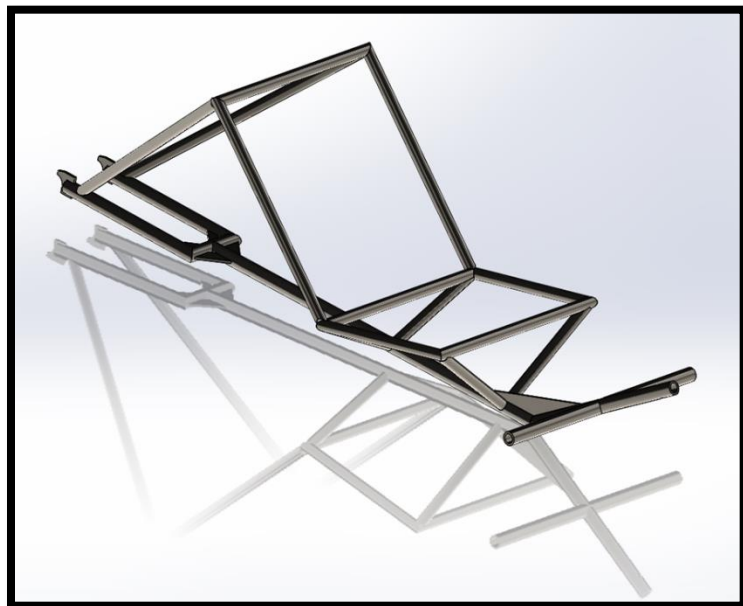


- **Concept Selection Matrix**

Criteria	Importance Weight (%)	Concept Alternatives					
		Concept #1		Concepts #2		Concept #3	
		Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Can be relied upon	0.22	4	0.88	4	0.88	4	0.88
Easily Maintained	0.14	3	0.42	3	0.42	3	0.42
Ease of Use (versatility)	0.15	4	0.60	3	0.45	4	0.60
low financial investing	0.18	3	0.54	2	0.36	2	0.36
operating without discomfort	0.11	3	0.33	3	0.33	3	0.33
can fit in a small space	0.08	3	0.24	2	0.16	3	0.24
can carry luggage	0.06	4	0.24	3	0.18	4	0.24
can drive fast	0.03	3	0.09	1	0.03	3	0.09
it looks aesthetically pleasing	0.03	2	0.06	3	0.09	2	0.06
	100	NA	<b>3.40</b>	NA	<b>2.9</b>	NA	<b>3.22</b>
					Value		
	Unsatisfactory				0		
	Just tolerable				1		
	Adequate				2		
	Good				3		
	Very Good				4		

- **Concept Finalization**

- The concluding concept that was decided upon for the frame of this vehicle was to have the recumbent style frame with a seat-integral design, where the structure of the seat adds to the overall rigidity of the frame. The frame would also feature the “delta” wheel layout, having two wheels in the front for steering and one wheel in the rear for power. Having this wheel layout improves the handling of the steering and greatly simplifies the design of the drive train. The pedals would be mounted on an adjustable extension shaft that would allow different sized riders to operate the vehicle comfortably.

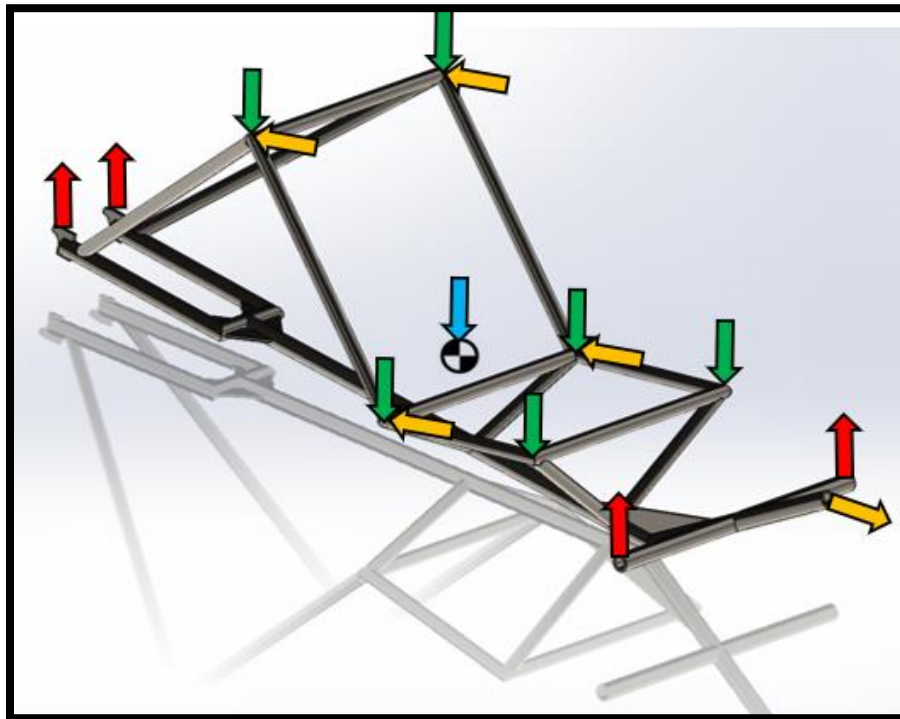


## Loading Conditions and Analysis

The frame experiences several different loads when in use:

- The weight of the rider (125 kg)
  - Distributed to both the bottom and back parts of the seat.
    - The bottom part received 80% of the load due to most of the rider's weight being concentrated there, with the remaining 20% going to the back part of the seat
- The force output by the rider onto the pedals (490 N)
- The reaction forces from the pedaling on the back part of the seat
- The reaction forces of the weight of the entire system [frame (16 kg) + rider (125 kg)] at the wheel connection points

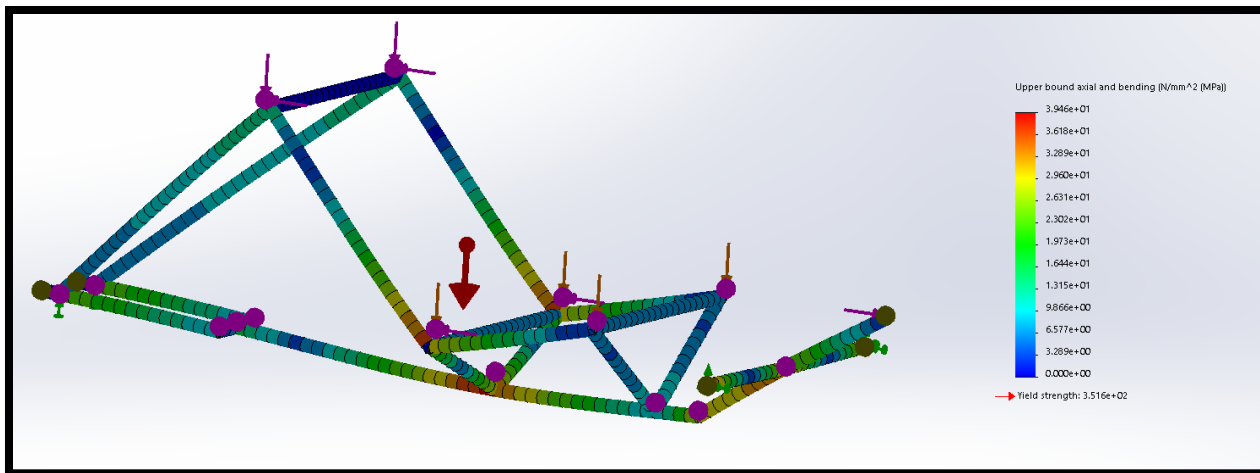
The listed loads on the system can be seen in this schematic:



Weight of Frame	
Weight of Rider	
Pedal Force	
Reaction Forces	

The beams of the frame were decided to be made from circular tubing due to its improved second moment of area value when compared to other cross-sectional shapes for tubes. This allowed the amount of material required to be decreased while still being able to withstand the same amount of loading, due to the circular cross-section's resistance to bending.

A finite element analysis (FEA) was ran using the loading conditions listed previously. It yielded a maximum stress of 39.46 MPa at the lower seat connection point on the main beam.



The vehicle will be experiencing impact loads when being operated. This is due to both the rider falling onto the seat to get into the vehicle and from bumps from the road when the vehicle is being driven. The safety factor that is utilized for impact loading is typically 8, but due to the generally passive intended use of this vehicle and lower maximum speed when compared to other road vehicles, a safety factor of 6 was designated to account for the type of loading the frame would experience. This yields a design stress of 240 MPa.

### Material Selection

Due to the determined type of loading and the selected safety factor, the material chosen for the tubing of the vehicle must feature a yield strength higher than the design stress of 240 MPa.

Low Carbon Steel (Circular Tubing) was selected for the beams of the frame. This material was chosen due to its yield strength of 310 MPa, Modulus of Elasticity of 205 GPa, and its comparatively affordable price when related to other steels with higher carbon contents. The tube sizes selected were 1¼" OD x 0.188" Wall Thickness for the main beams and 1" OD x 0.065" Wall Thickness for the seat structure beams. The combination of these sizes yielded the most optimal strength-to-weight ratio for this frame when using this material. Both of these tube sizes meet with ASTM A513 specifications.

4130 Alloy Steel (Circular Tubing) was selected for the material of the extension shaft of the frame. It features a yield strength of 345 MPa and a modulus of elasticity of 205 GPa. The tube size selected was ¾" OD x 0.12" Wall Thickness and it complies with ASTM A29 specifications.

## Fabrication and Assembly

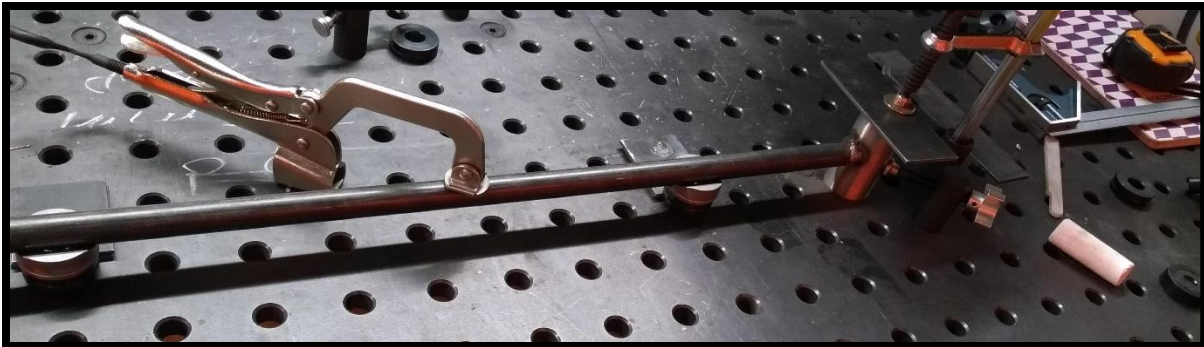
Due to the complexity of the frame structure and our team's limited welding ability, we decided to have the frame fabricated by a third party. In order for the fabricators to accurately and effectively cut and weld the frame together, I created a detailed assembly drawing of the frame along with several detailed part drawings of all of the individual members. These drawings can be found in the appendix to this report.

### Extension Shaft

The fabrication of the extension shaft for the frame was not outsourced though. This is due to its featuring of a specialty bicycle part.

In order to fabricate this component, the follow processes took place:

1. A bandsaw was used to cut the 4130-circular tubing down to 0.5 m long
2. The cut tube was braced in a vice mounted on the table of the drill press
  - a. Using a metal-cutting hole saw as a bit, one end of the tube was coped to have the same radius as the specialty bicycle part, a bottom bracket.
3. The tube was fixed to a welding table with the bottom bracket fit into the radius that was previously coped for it. The tube was centered along the length of the bottom bracket and the two pieces were MIG welded together



4. The tube was remounted in the vice of the drill press and a 1/2" drill bit was used to drill holes into the tube. The placement of the holes would determine where the pedals could be adjusted to. The locations of these holes were determined by the anthropometric x-seam measurements of the average end user of this vehicle along with the members of the project team.
  - a. A level was used on the bottom bracket to verify that the holes drilled into the tube were centered on the same plane as the bottom bracket. This allowed for the pedals to be level with the rest of the vehicle when it was completed.
5. A file was used to remove any burrs left over after drilling



## Testing

Various tests were conducted in order to verify the integrity of the frame design. A strength test was performed to ensure that the frame could more than withstand the loading of a “worst-case-scenario”, and an endurance test was carried out to confirm that the frame could withstand long periods of use without failure.

### Strength Test

This test was conducted by supporting the frame near the support points. This was done by stacking cinderblocks and covering them with towels and placing them near the wheels. This allowed for the frame to be lifted higher than where the wheels would normally have it and the surface of the steel would not be damaged by the abrasive surface finish of the blocks. Wooden planks were also placed on the tubes of the bottom part of the seat over the seat straps. The way this test was conducted strictly tests the design and fabrication of the frame. This was accomplished due to the way the frame was rigged, which allowed for the wheels and seat straps to be bypassed from the testing. It was rigged this way because their influence would have dampened the effects of the testing on the frame due to their elastic nature.



For the test, a 125 kg individual would jump up and fall back onto the wooden planks from a height of 35 cm with their entire weight concentrated onto the seat. The individual did this a total of 10 times.

Failure of this test would yield cracked welds or bent/distorted/broken tubing in the frame.

**Results:** The frame did not develop any form of noticeable cracks or distortion after conducting this test. The testing was successful.

## Endurance Test

This test consisted of having an 80 kg rider drive the vehicle for 24 km on the roads of Cincinnati, Ohio. The roads featured various conditions ranging from smooth and flat to rough and inclined.

Failure of this test would yield cracked welds or bent/distorted/broken tubing in the frame.



**Results:** The frame did not develop any form of noticeable cracks or distortion after conducting this test. The testing was successful.

## Recommendations

Although all of the testing of this frame design passed, there are always areas that a product could be improved upon. If this project were to continue its development, I would:

- Reconsider the material of the frame. There are plenty of other materials that would be capable of withstanding the loads that this vehicle endures, but they might just not have been cost-effective enough to warrant the use of a less dense material for the frame at this time. I would form a more detailed material index to more effectively determine the most optimal material for this frame.
- Consider coating the frame. Whether its just painting or coating for improved weather-resistance, having a coating of some form on the frame would have helped the vehicle both aesthetically and functionally.

## Project Management

### Budget

Project Budget Limit: \$2000

### Estimated Expenses:

Sub-System:	Item:	Value (\$):
Frame	20mm Square Tubing	200
	30mm Square Tubing	70
	40mm Square Tubing	200
Suspension	Banding	60
	Hardware	10
Drive Train	Rear Wheel	85
	Cranks	50
	Hardware	175
Enclosure	Vinyl Tarp	60
	Aluminum Square Tubing	150
	Windshield	40
	Headlights	20
	Plastic Windows/Headlight Cover	15
Steering/Braking	Wheels	50
	V-Brakes	20
	Tie Bars	40
	Material for Kingpin	50
	Material for Ackerman	50
	Material for Handle Bar	30
<b>Estimated Manufacturing Total (\$):</b>		<b>1375</b>

## Actual Expenses:

Subassembly	Item Name	Vendor Name	Cost (USD)
Frame	Frame Fabrication	Weldments	800
Frame	Hole Dozer	Home Depot	13
Suspension	Bands	Strap Works	73.99
Suspension	Grommet Tool	Amazon	10
DriveTrain	Wire covers	Spun Bicycles	30
Drivetrain	Rear Hub	Bike Parts	13.49
Drivetrain	Rear Wheel Rim	Bike Parts	26.99
Drivetrain	Rear Wheel Spokes	Bike Parts	19.99
Drivetrain	Rear Derailleur	Amazon	26.98
Drivetrain	Front Derailleur	365 Cycles	21.51
Drivetrain	Cassette	Bike Parts	22.5
Drivetrain	Crankset	Universal Cycles	58.84
Drivetrain	Chain	Amazon	35.98
Drivetrain	Bottom Bracket	Amazon	12.95
Drivetrain	Dropout	Paragon Machine Works	20.5
Drivetrain	Dropout Connection	Paragon Machine Works	20.5
Drivetrain	Bottom Bracket Shell	Frame Builder Supply	12.28
Drivetrain	Shifters	Amazon	30.9
DriveTrain	Chain	Amazon	53.92
DriveTrain	Chain Breaker	Amazon	6.99
Enclosure	Acrylic	Amazon	28.57
Enclosure	Adhesive	Amazon	15
Enclosure	Canopy	Amazon	38.99
Enclosure	PVC	Home Depot	24.82
Enclosure	Clear Vinyl	JoAnn Fabrics	13.08
Enclosure	Clear Vinyl	JoAnn Fabrics	7.48
Steering	Kingpins	Goodwill	4
Steering	Wheels, ackerman, parts and brakes	Fairfeild Cyclery	230
Steering	Bolts	Fastenal	20
Steering	Tires and Tubes	Fairfeild Cyclery	80
Steering	More Bolts	Fastenal	5
Steering	Tie rod and kingpin bearings	Fairfeild Cyclery	30
Steering	Handle bar	Lowe's	37
Steering	Bearings	Amazon	22
Steering	Grease	Autozone	5
Accessories	Lights	Amazon	17.99
Accessories	Reflective Tape	WalMart	15.63
Accessories	PVC and Lights	Home Depot	28.85
Hardware	Bulk Order	McMaster-Carr	57
		<b>Total</b>	<b>1991.72</b>

## Financial Analysis:

Although the team had to spend over what we had originally estimated, \$1375, we still came in slightly under budget at \$1992. On paper this is a success, but in reality, if this were an actual mass-produced product, some changes would have to be made. We were hoping to be able to sell the vehicle as a product for around \$2000, but because we spent that amount and did not include production man-hours or profit markup, this product price goal is not achievable at this time.

Of course, it must be considered that if this were a mass-produced vehicle, we would be able to purchase the components in bulk and not have shipping costs cut as much into the budget as it did. We would also ideally have the frame fabrication insourced as well to cut down on third party service expenses to help reduce overall cost.

## Schedule Proposed:

		Month: Sep.				Month: Oct.				Month: Nov.				Month: Dec.				Month: Jan.				Month: Feb.				Month: Mar.				Month: Apr.										
		Week:				Week:				Week:				Week:				Week:				Week:				Week:														
		1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	5
Task Description		3rd	10th	17th	24th	1st	8th	15th	22nd	29th	5th	12th	19th	26th	3rd	10th	17th	24th	31st	7th	14th	21st	28th	4th	11th	18th	25th	4th	11th	18th	25th	1st	8th	15th	22nd	29th				
Senior Design I	Finalize Problem Statement																																							
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	Concept Creation																																							
	Evaluate and Select Concept																																							
	Create General BOM																																							
	Define Budget																																							
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	3D Model: Body and Suspension																																							
	3D Model: Steering																																							
	3D Model: Braking																																							
	3D Model: Enclosure																																							
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	Finalize BOM																																							
	Create Part and Assembly Drawings																																							
	Research and Contact Vendors																																							
Senior Design III	Finalize Budget/Schedule																																							
	Define Manufacturing Workload																																							
	Design Presentation																																							
	Order Materials																																							
	Fabrication																																							
	Start assembly																																							
	Electrical Work																																							
	Testing																																							
Technology Exposition																																								
Final Presentation/Report Publication																																								

## Actual:

		Month: Sep.				Month: Oct.				Month: Nov.				Month: Dec.				Month: Jan.				Month: Feb.				Month: Mar.				Month: Apr.							
		Week:				Week:				Week:				Week:				Week:				Week:				Week:											
		1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	5	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	5	
Task Description		3rd	10th	17th	24th	1st	8th	15th	22nd	29th	5th	12th	19th	26th	3rd	10th	17th	24th	31st	7th	14th	21st	28th	4th	11th	18th	25th	4th	11th	18th	25th	1st	8th	15th	22nd	29th	
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## Schedule Examination:

When compared to the proposed schedule from the beginning of the project, the actual schedule varies in some ways. One of the most notable differences is that we spent significantly more time on the overall design process than we originally anticipated. There were more revisions than we had thought there would be, and it ended up prolonging the process more than expected. We also were working with vendors and purchasing materials for longer in the process than we predicted. We did not originally budget enough time to compensate for many problems and mistakes, and this ended up pushing the final assembly period to later in the schedule. Overall, if we could improve the design phase, and get it completed earlier, the final stages of the project wouldn't feel as dense and it would allow for more time to deal with occasional issues as they arise.

## References

1. **Copeland, Larry.** Biking to Work increases 60% in past decade. *USA TODAY*. [Online] USA TODAY, May 8, 2014. <https://www.usatoday.com/story/news/nation/2014/05/08/bike-commuting-popularity-grows/8846311/>.
2. **Walsh, James.** 10 things that put people off cycling. *The Guardian*. [Online] Guardian News and Media Limited, March 31, 2014. <https://www.theguardian.com/politics/2014/mar/31/10-things-that-put-people-off-cycling>.
3. **Goldstein, Steve.** Here are the typical commutes for every big metro area. *MarketWatch*. [Online] MarketWatch, Inc., March 25, 2015. <https://www.marketwatch.com/story/here-are-the-typical-commutes-for-every-big-metro-area-2015-03-25>.
4. **Danielle Muoio, Mike Nudelman.** Americans' commuting habits haven't changed at all in the last 10 years. *Business Insider*. [Online] Insider Inc., October 11, 2017. <https://www.businessinsider.com/how-people-commute-work-us-2017-10>.
5. **Weight Weenies.** Road Frames Listings. [Online] <https://weightweenies.starbike.com/listings/components.php?type=roadframes>.

## Appendix

### Survey:

Transportation Survey						
*This survey is in reference to a partially/fully human-powered vehicle.						
<u>Importance</u>						
Please rate how important each category is to your current <b>human-powered</b> mode of transportation.						
	<b>1: Unimportant</b>		<b>3: Reasonable importance</b>		<b>5: High importance</b>	
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	
<u>Satisfaction</u>						
Rate how satisfied you are with your current <b>human-powered</b> mode of transportation in each category.						
	<b>1: Unsatisfied</b>		<b>3: Reasonable satisfied</b>		<b>5: High Satisfied</b>	
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 on back.						

**Survey Averages:**

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

**Governing Equations:**

Design Stress:

$$\sigma_d = \frac{S_y}{2N}$$

Combined Stress:

$$\sigma_{combined} = \pm \frac{F}{A} \pm \frac{M}{S}$$

Maximum Shear Stress:

$$\tau_{maximum} = \frac{1}{z_p} \sqrt{(M^2 + T^2)}$$

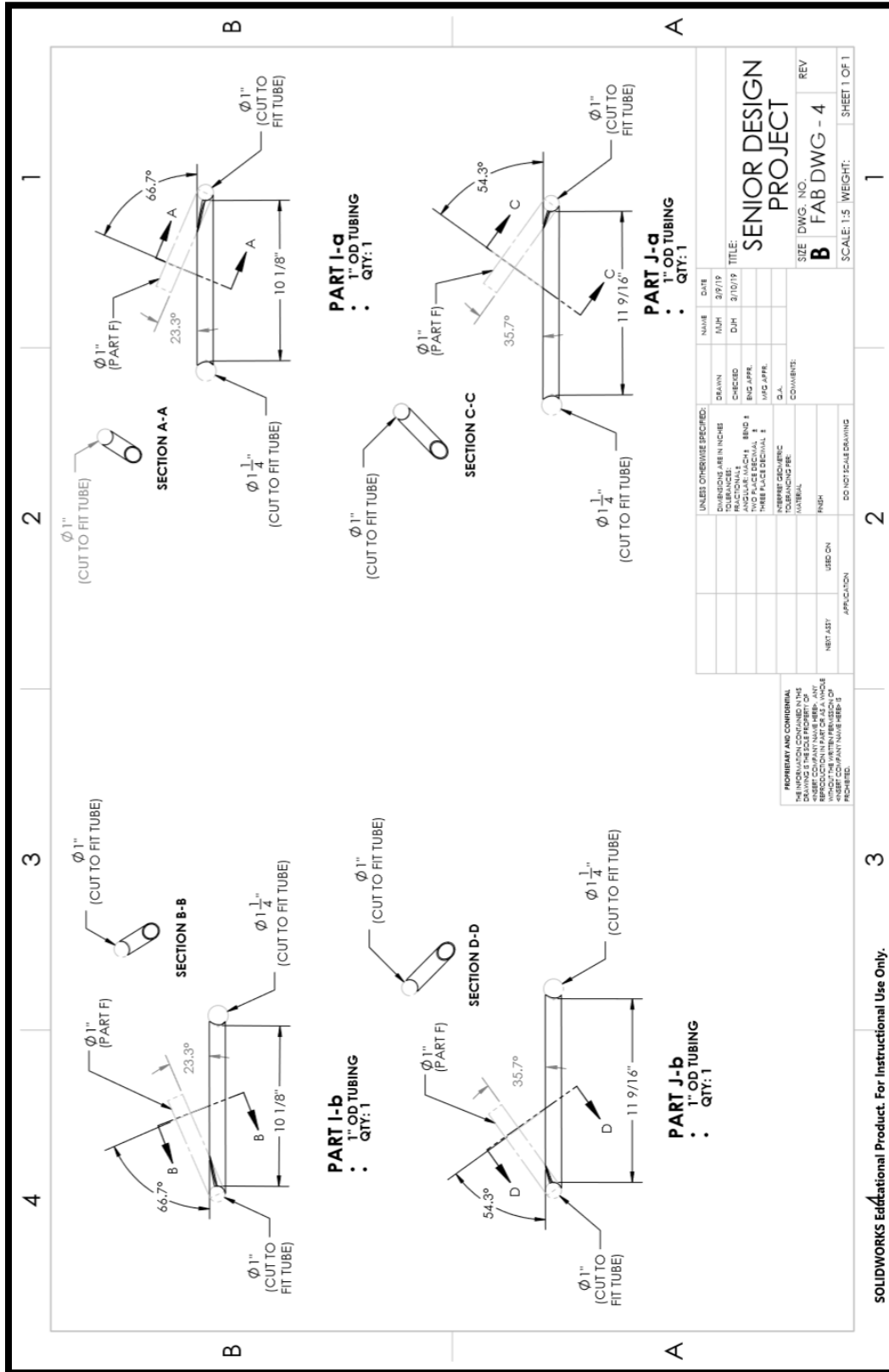








Detail Drawing 4:



UNLESS OTHERWISE SPECIFIED:	NAME	DATE
DIMENSIONS ARE IN INCHES	DATE	3/7/19
FRAC TIONS SHALL BE IN DECIMALS	DRAWN	
ANGLES SHALL BE IN DEGREES	CHECKED	
ALL DIMENSIONS SHALL BE TO UNLESS OTHERWISE SPECIFIED	ENG APPR.	
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TOLERANCES GOVERN	D.A.	
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APPLICATION	DO NOT SCALE DRAWING	

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**SENIOR DESIGN PROJECT**

SIZE DWG. NO. : **B**  
 FAB DWG - 4

SCALE: 1:5 WEIGHT: SHEET 1 OF 1



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