Economic Street Trike: Steering and Braking

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by

Alexander Faulkner

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Thesis Advisor: Dr. Ahmed Elgafy

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Problem Statement

Personal transportation is a balance of convenience, ecologic impact, and economic investment. The common consumer in the US will drive a car as their main mode of transportation. Per the consumer site, Roadloans.com, "The average new-car price stood at $36,113 toward the end of 2017…".

The convenience of transportation can easily be described as getting where you want to go on your own schedule in the fastest and most desired manner reasonable. This encompasses many aspects of transportation. Public transportation runs on a schedule and is therefore inconvenient when in terms of quick travel. While motorcycles and cheaper options such as bicycles and scooters are not convenient in inclement weather. *Our goal is to meet an in between need that is still an economic personal transportation vehicle but can be relied upon for use in inclement weather.*

We will be developing a mode of transportation that will be more environmentally friendly, easier to maintain and less expensive.

Research

Background of the Problem

The primary impact of the type of trike we aimed to build is that it is economic. The average savings of $18 per week or $936 per year would yield a return on investment of 2 years. This trike would also have an environmental impact. 29% of greenhouse gas emissions are generated through transportation so if 1% of UC students use this vehicle for their daily commutes for one year the emissions saved would be equal to the amount of CO2 that 60% of the trees in Central Park absorb. The health of the rider would be a significant personal impact. The riders would burn 1,410 calories per week and get 2.5 hours of cardiovascular exercise.

"The most important transport challenges are often related to urban areas and take place when transport systems, for a variety of reasons, cannot satisfy the numerous requirements of urban mobility." – Dr. Jean-Paul Rodrigue (1)

Solving problems transportation problems include tackling issues from varies angles, from forward thinking city planning to government regulations, tax funding public services to creating cultures that encourage citizens to behave a certain way. The challenges are complex and the different solution can be even more complex. Peoples habits don't change easily and so in order the cause change a transportation need must be fully addressed and all factors accounted for. Data collected by the US Census Bureau shows that Americans still prefer to take a car to work over public transit, bike, or a smaller personal vehicle like a motorcycle. The numbers have barely changed in the last 10 years (2).

There are only so many ways that the average person commutes to work. The different main categories of means of transportation are personal vehicle such as truck, van, or car; public transportation, walking, bicycle, motorcycle, taxi, and other. (see appendix) Between the years 2006 and 2016 the percentage of people using a personal vehicle to commute has only decreased by 1.4% from 86.7% in 2006 to 85.4% in 2016 (2). However, this means there are actually more people taking their own vehicle because the workforce has increased by 9 million in the last decade. (2) 3.3 % of Americans used their own power to commute by walking or bicycling in 2016; the sum was the same in 2000, there has been a small increase of bicycling over walking (3).

The average price of owning a new car for a year in 2017 was 8,469$ according to AAA (4). This breaks down to 706$/month. The American Public Transit Association, reported that, "Over the course of a year, parking costs for a vehicle can amount to an average of $1,995" (5). Furthermore, the automobiles that most American workers use to commute mainly run on burning fossil fuels. The EPA (Environmental Protection Agency) website states that A typical passenger vehicle emits about 4.6 metric tons of carbon dioxide per year (6). Motor vehicles collectively cause 75 percent of carbon monoxide pollution in the U.S. The Environmental Defense Fund (EDF) estimates that on-road vehicles cause one-third of the air pollution that produces smog in the U.S., and transportation causes 27 percent of greenhouse gas emissions. The U.S. has 30 percent of the world's automobiles, yet it contributes about half of the world's emissions from cars." (7)

Unfortunately the alternative of public transportation is not perfect; according to Dr. Jean-Paul Rodrigue, the common inadequacies of public transit are comfort for riders during peak hours where large crowds of people will gather and the financial burden on the city or county government subsidizing the system (1).

The most fuel efficient, cost saving method of transportation is walking or bicycling. These modes of transportation have obvious physical limitations you simply cannot cross certain rode barriers safely by walking. The pathways of travel often time are not designed with these modes in mind. Not every street has sidewalks or bike paths. And there is a limited to how far you can exert yourself and travel in a timely manner. The State Government of Victoria has a list of walking safety precautions such as wearing comfortable clothing, reflective attire, and hydrating (8). These modes of transportation pose a threat of being hit by other vehicles, being affected by weather and the elements, and physical exertion that is not comfortable for long travels.

Often times a commuter uses a combination of the above-mentioned method. Especially in an urban setting invaluable have to deal with a "first or last mile." The "last-mile" or "first and last-mile" connection describes the beginning or end of an individual trip made primarily by public transportation. In many cases, people will walk to transit if it is close enough. However, on either end of a public transit trip, the origin or destination may be difficult or impossible to access by a short walk. This gap from public transit to destination is termed a last mile connection. (9) There has been a recent surge of commuters taking advantage of electric scooter such as Lime and Bird and electric skateboards or publicly docked bikes. These methods help fit a niche in the market however to not address the issue of inclement weather and therefore are not reliable on a daily basis.

State of the Art

There many different ways to steer a vehicle and the different methods are dependent upon if you are steering one wheel or two wheels. The main basic steering systems for a two wheeled vehicles are called rack and pinion and recirculating ball. For steering one wheel the basic methods are over seat steering (OSS) and under seat steering (USS).

The concepts trike listed below include ideas using two wheels in the front known as the tadpole method as well as two wheels at the rear known as delta. (10) Both configuration will be investigated therefore multiple methods of steering need to be delved into.

When it comes to steering two wheels at once the geometry of steering in more complex than you might think. It may be surprising that in order to steer smoothly the two wheels are not pointing in the same direction. If you draw a line perpendicular to each wheel, the lines will intersect at the center point of the turn. (11) When you steer two wheels at once you need to use a steering gear system to translate torque. The most common are rack – and—pinion and recirculating ball.

Rack-and-pinion steering is actually a simple mechanism, a rack-and-pinion gearset is enclosed in a metal tube, with each end of the rack protruding from the tube. A rod, called a tie rod, connects to each end of the rack. The pinion gear is attached to the steering shaft and when you turn the wheel it moves the rack from side to side. A tie rod connects the shaft to the steering arm. This gearset converts rotational motion of a wheel in linear motion needed to turn the wheels. It also provides a gear reduction making it easier to turn the wheels. This allows the design to incorporate a steering ratio. The higher the steering ratio the more you rotate the steering wheel in order to turn the tires, but the force required is less. (11)

The recirculating bearing system contains an “endless belt” of ball bearings that serve to reduce friction between the steering wheel shaft and the main linkage (12) The recirculating-ball steering gear contains a worm gear. You can image the gear in two parts. The first part is a block of metal with a threaded hole in it. The threads are designed to be filled with bearing balls. The steering wheel connects to a threaded rod, similar to a bolt, that sticks into the hole in the block. When the steering wheel turns, it turns the bolt. Instead of twisting further into the block the way a regular bolt would, this bolt is held fixed so that when it spins, it moves the block, which moves the gear that turns the wheels.

For one wheel steering the methods are simpler mechanisms. There are roughly two methods for steering recumbent trikes. The most common way of steering is called over seat steering (OSS). With OSS, hand are held in front of you much like driving a car, there is no weight on your hands. (13) The advantages of OSS is that is the most intuitive to learn. It is less expensive to design and manufacture. You also have the ability to mount devices or rearview mirrors. (14)

The other type is called under seat steering(USS) with under seat steering the handle bar connect beneath the seat. Sometimes your hands may be beneath where you are sitting. The main advantage to under seat steering is the comfort. There are two types of USS, direct and indirect.

Direct is best thought of as a handle bar mounted to the back side of the fork and extending back far enough to drop your arms straight down beside the seat and grab on. A couple of the drawbacks to this design are hand position and interference with the seat in sharp turns. Long bikes uses an indirect steering. Indirect in that the handle bar is mounted to the frame and uses linkage (in automotive terms, a drag link) to connect to the fork. A couple of advantages are that the steering ratio or speed can be adjustable and the handle bar rotates about a pivot point under the seat. (15) (16)

As for braking systems most tadpole trikes only use a front wheel brake, either drum or disc. Drum brakes use two brake shoes inside a cylinder drum. Disc brakes applies a set of flat pads on opposing sides of a revolving rotor (17). There are also rim brakes that are very common on most cycles and within that there are even many variations. Rim brakes are inexpensive, light, mechanically simple, easy to maintain, and powerful. However, they perform relatively poorly when the rims are wet, and will brake unevenly if the rims are even slightly warped. Because rims can carry debris from the ground to the brake pads, rim brakes are more prone to clogging with mud or snow than disc brakes (where braking surfaces are higher from the ground), particularly when riding on unpaved surfaces. The low price and ease of maintenance of rim brakes makes them popular in low- to mid-price commuter bikes (18).

End User and Customer Needs

The ideal end user will be 15 to 50 years of age. No mechanical aptitude or inclination will be required. They will have a low to medium income. Male or female. They are able bodied. They will have an average commute of less than 10 miles. They may have to endure hills.

The targeted end user for our product is a male or female, able bodied, person aged 15-50 years with low to medium income, little to no mechanical aptitude or inclination, and a commute of less than 10 miles where they may have to endure hills. The decision to include all genders as a targeted end user is to make this product accessible and targeted to more people.

The stipulation of being able bodied person of 15-50 years of age is relevant to the fact that this product will not be designed for any specialized handicaps or medical requirements. This decision stems from not wanting to design to a child or elderly person due to ergonomic variation (children being smaller and weaker and people over 50 being less agile). The classification of having no required level of mechanical know-how stems from the desire to design this product to a larger group of people and the general public. The conditions that the end user has a usual commute of less than 10 miles with a chance of hills allows the design to be targeted to a reasonable range and a geographic scenario that is not necessarily favorable for transportation.

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 and also for the ease of *maintenance, reliability and affordability*. This is further demonstrated by the design choice to have few moving parts.

Summary of Research

The main advantage of the recirculating ball assembly is that the ball bearings reduce friction considerably. There is a steering wheel play and it is adjustable, usually by a slotted bolt with a securing nut mounted on top of the housing. The rack and pinion, while giving the driver a sense of directly steering the vehicle, it is not adjustable. Once the rack and pinion assembly wear out, they have to be replaced. Newer cars use the more economical rack-and-pinion system while the recirculating balls are found in older vehicles. Both types of steering can be powered. For this application it will not be necessary to add power steering.

The above methods are for using a conventional steering wheel. The OSS and USS methods are for using some type of handle bars. They are applicable in much smaller personal vehicles such a bike or trike. The advantages are that they are cheaper and simpler to design, however the disadvantage is that they do not incorporate power steering and are therefore for smaller vehicles. Between these two handle bar methods it is clear that most cyclist prefer USS because of comfort.

The advantages and disadvantages of drum braking is that it provides solid and reliable braking, yet it performs poorly in weather conditions if moisture gets into the drum and its susceptible to heat fading. As for disc braking it provides smooth braking even during the harshest weather conditions which is more applicable for our design. Although it is heavier when compared to drum brakes. The rim brakes would be the lightest option but may not be applicable if our application is the perform efficiently under inclement weather.

Quality Function Deployment

Customer Features

- Can be relied upon
- Easily Maintained
- Ease of Use (versatility)
- Requires low financial investing
- Can be operated without discomfort
- Can fit in a small space
- Can carry luggage
- Can drive fast
- Looks aesthetically pleasing

Engineering Characteristics

- Weight (kg)
- Suspension travel (cm)
- Overall Footprint (m^2)
- Turn Radius (m)
- Steering Torque (Nm)
- Cost of Manufacturing ($$)
- Storage Space (m^3)
- 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 Maintenance (months)
- Top Speed (km/hr)

House of Quality

Engineering Requirements (units)

Customer Requirements	Importance wt.	1 Weight (kg)	2 Suspension travel (cm)	3 Overall Footprint (m^2)	4 Turn Radius (m)	5 Steering Torque (Nm)	6 Cost of Manufacturing ($$)	7 Storage Space (m^2)	8 Noise (dB)	9 Loading Limits (kg)	10 Output Power Required (W)	12 # of Relative Moving Parts	13 Open Volume per Component (cm^3)	14 # of surfaces in friction	15 Is Weatherproof	16 Time Between Maintainencing (months)	17 Top Speed (km/hr)	CP	A	B	C
Can be relied upon	0.22						1					9		3		9			0.9	0.8	0.8
Easily Maintained	0.14		3	3								9	9	3		9			0.8	0.8	0.7
Ease of Use (versatility)	0.15				9	3				9	3				9				0.7	0.8	0.8
low financial investing	0.18	1	1				9										3		0.1	0.4	0.3
operating without discomfort	0.11		9			1			9		9				9				0.7	0.6	0.5
can fit in a small space	0.08	3		9	3			3					3						0.6	0.8	0.7
can carry luggage	0.06							9		3									0.8	0.3	0.4
can drive fast	0.03	9	1		1					1							9		1	0.6	0.5
it looks aesthetically pleasing	0.03						3												0.8	0.9	0.9
Total Importance	1.00																				
ngineering requirement importance		0.69	1.62	1.14	1.62	0.56	1.93	0.78	0.99	1.56	1.44	3.24	1.5	1.08	2.34	3.24	0.81				
formance Current Product																					
Twike itor A		246	20	3.25	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	2.18	5.5	TBD	7.6K	0.15	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				

Customer Satisfaction Rating (0.00 - 1.00)

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 (cm	12																
# of surfaces in friction	13															-3	
Is Weatherproof	14															1	
Time Between Maintainencing (mo	15																
Top Speed (km/hr)	16																

Product Objectives

#1: # of relative moving parts (<20)

#2: is weatherproof (yes)

#3: Time between maintenance (≥ 3 months)

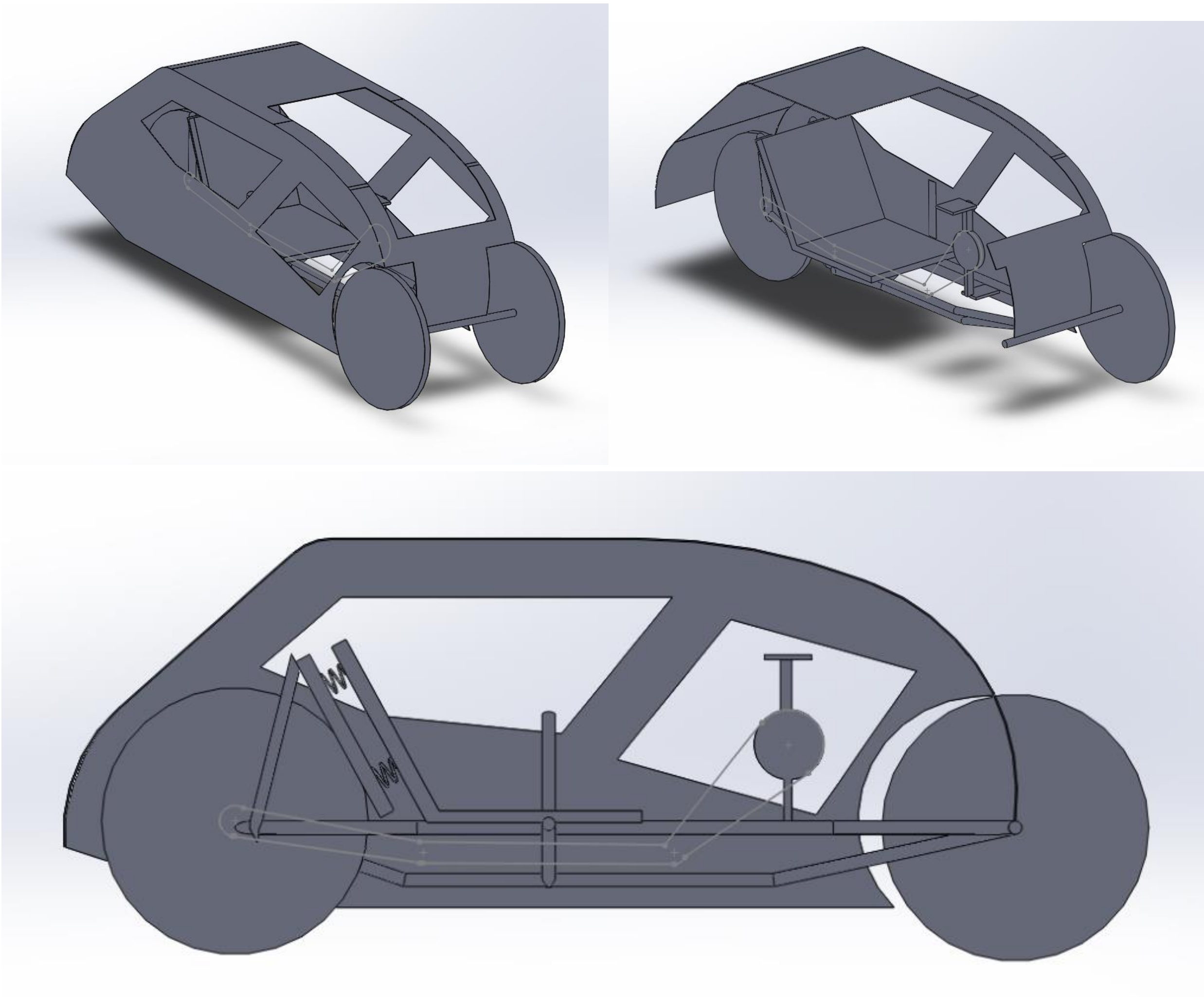
#4: Cost of manufacturing (<2000$)

#5: Turn Radius (6m)

#6: Suspension travel (8cm)

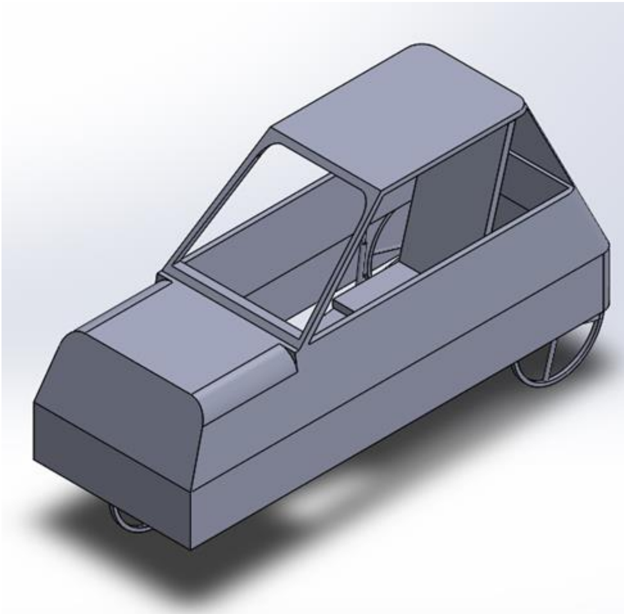
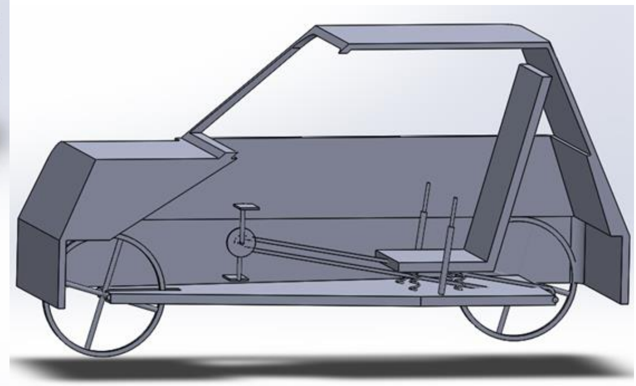
Design Concepts

Concept 1:



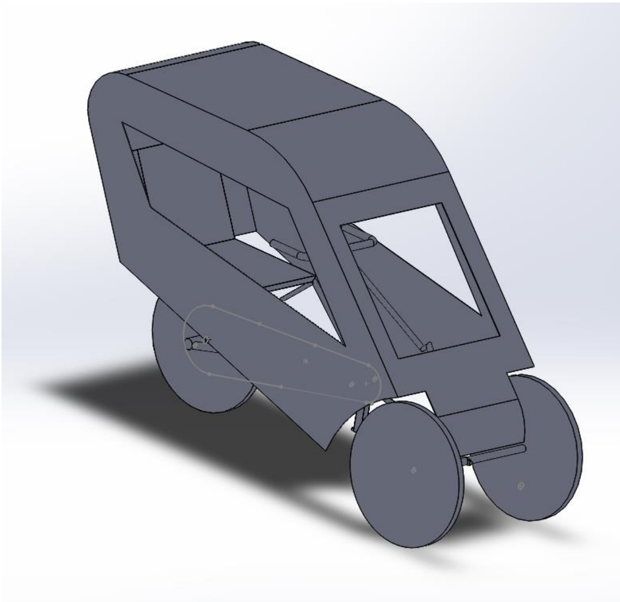
Concept 1 utilizes a bicycle style frame (has centered tubes that create the chassis), seat spring style suspension, sprocket and chain drive train, paddle steering, a canopy style enclosure, and two wheels in the back and one in the front. The drive train is a sprocket and chain design. This means that the operator will rotate a shaft by pedaling, this shaft will be attached to a sprocket that has a chain around it, as the operator rotates this sprocket the chain will transfer the energy to another sprocket that will rotate a shaft that has the drive wheels fixed to it. The suspension system is comprised of a seat that the operator rests in being suspended by springs that absorb energy from impact in order to increase the operator's comfort.

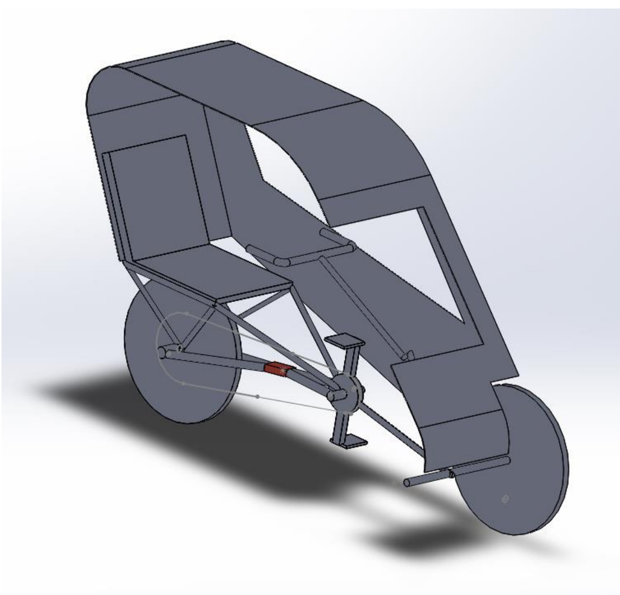
Concept 2:

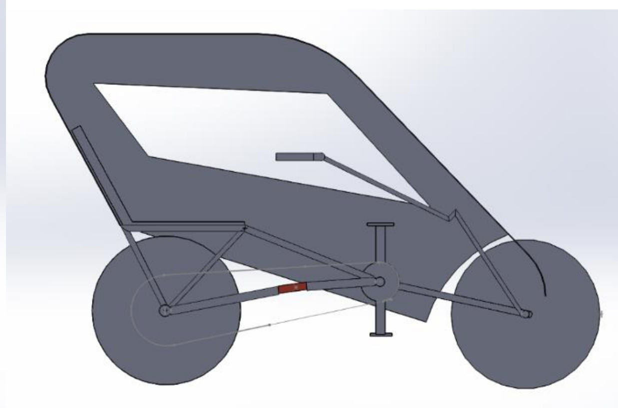



Concept 2 is comprised of a “go-kart” style frame, a spring seat and torsion bar suspension systems, a pulley and belt drive train, paddle style steering system, and what is referred to as a “beetle” style enclosure. The drive train is comprised of a belt and pulley system; the operator will rotate one of the pulleys and the belt will transfer this energy to rotate the other pulley which will drive the wheels. The suspensions system is a compilation of having the seat suspended by springs that absorb energy as well as a torsion bar that connects from the chassis to a control arm that dampens the motion between the relative motion between them and in turn dampens the motion between the wheel and the chassis.

Concept 3:







Concept 3 is comprised of a bicycle style frame, an in-body shock absorber, a chain and sprocket drive train, a beetle style enclosure, and a steering wheel steering system. The suspension system is created using a shock absorber in the frame that allows the frame to “flex” much more than if the frame was made of only stiff tubing or bars. The drive train is comprised of a chain and sprocket system; the operator will rotate one of the sprockets and the chain will transfer this energy to rotate the other sprocket which will drive the wheels.

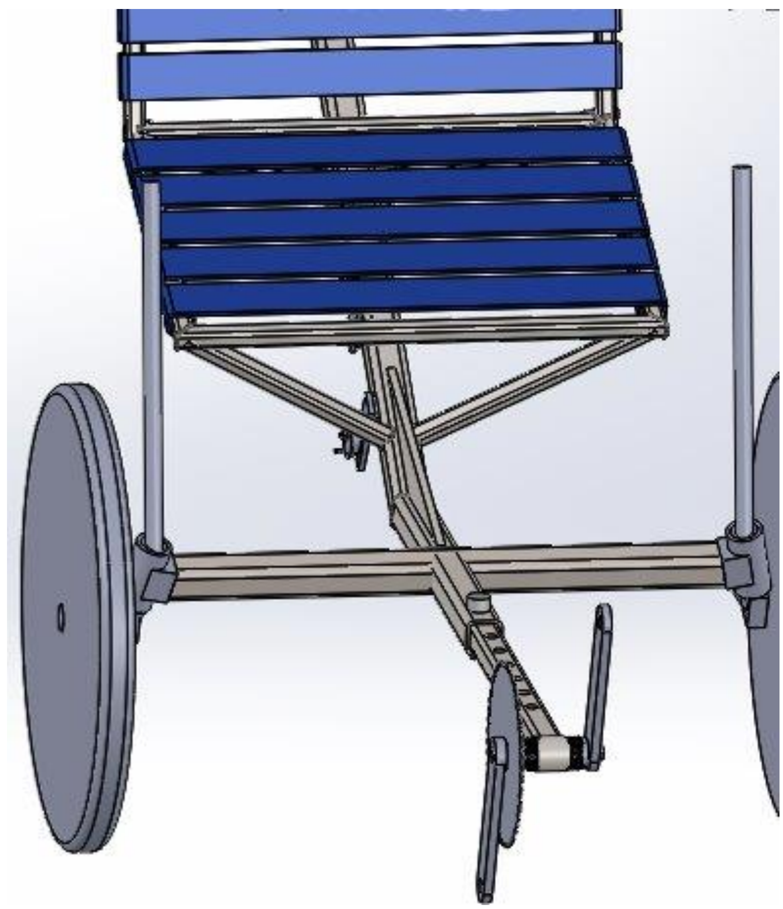
Design Analysis

Steering Design

Over seat direct Steering

Over seat steering is the handle bar design that was selected for this project. Although the alternative of under seat indirect steering is typically more ergonomic and gives more leg clearance the over seat steering was decided upon in order to align with our goals of affordability, ease of use and maintenance. The over seat steering mechanism are less complex because there are less parts. If we had went with under seat indirect steering there would be another tie bar increasing the amount of linkages and the possibility that when you turn the handle bar the wheels would not turn an equal amount. The direct steering arms connect directly to the top of the kingpin. Because the handle bars pivot in direct correlation with the front wheels the movement is intuitive for any user to sit down and understand how to steer. The angle of the handle bars is designed to be parallel with the angle of the seat creating a natural resting place for the arms. Some of the cons of over seat steering is that it can make it difficult to get on and off the bike and as you steer hard I one direction the handle bars can begin to interfere with the person's legs or the enclosure.

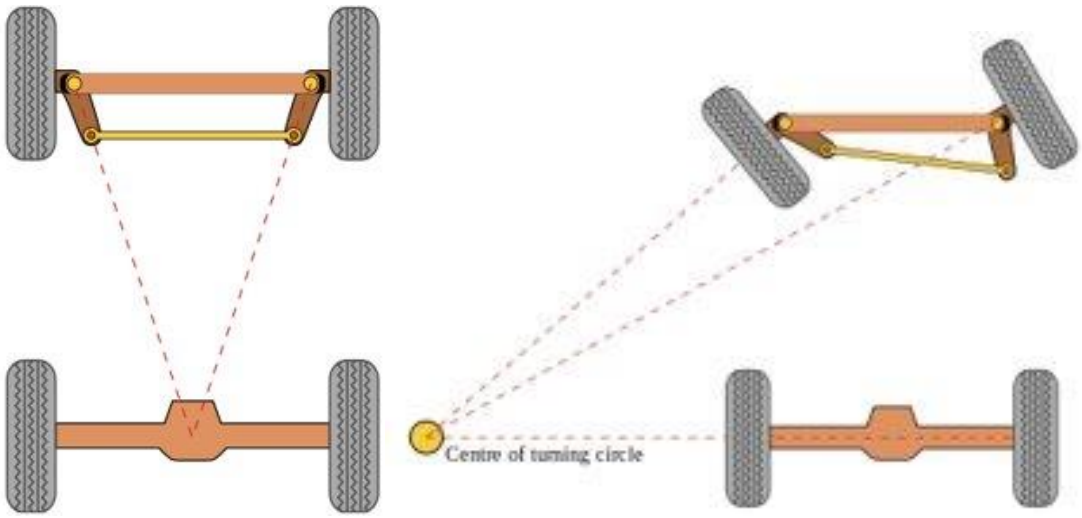
Over seat Direct steering



Under seat Indirect Steering (alternative)

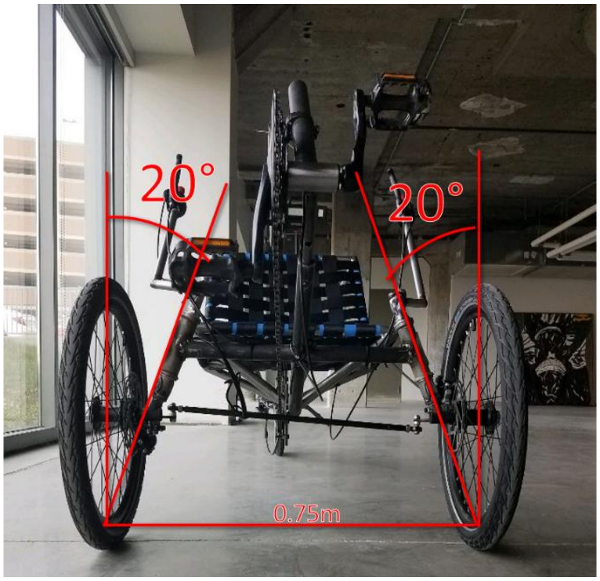
Ackerman Steering Compensation

The Ackerman Steering Compensation is requiring whenever there is more than one-wheel steering. This is because as a vehicle turns the two front wheels must be turning at two different radii otherwise the wheels will scrape against the ground. The inner wheels must have a smaller turning radius and therefore rotate to a greater angle than the outer wheels which must have a larger turning radius and therefore rotate at a lesser angle. The geometry of the linkages connecting the two wheels is designed to solve this problem. The geometrical solution to this is for all wheels to have their axles arranged as radii of circles with a common center point. As the rear wheels are fixed, this center point must be on a line extended from the rear axle.



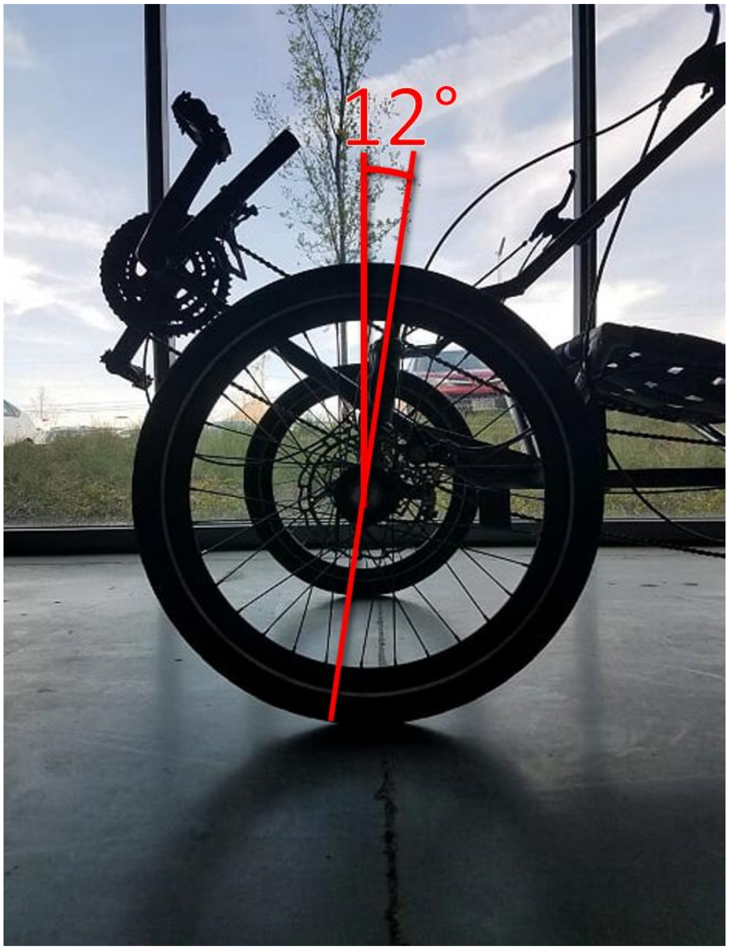
Kingpin Inclination

Kingpin inclination works alongside the Ackerman steering compensation to prevent the scrubbing along the ground and prevent the tires from wearing down over time. The inclination of the Kingpin allows the steering axis to turn precisely on the center patch of tire contacting the pavement. The intersection of the wheel and kingpin axis is called scrub patch. If they do not intersect there will be a scrub radius that will wear down the tire faster over time. The selected angle is determined by the geometry of the wheel and axis such that the angle intersects at the center point of the wheel. The angle we went with is 20 degrees because of the purchased components. This ultimately results in slightly enhanced handling.



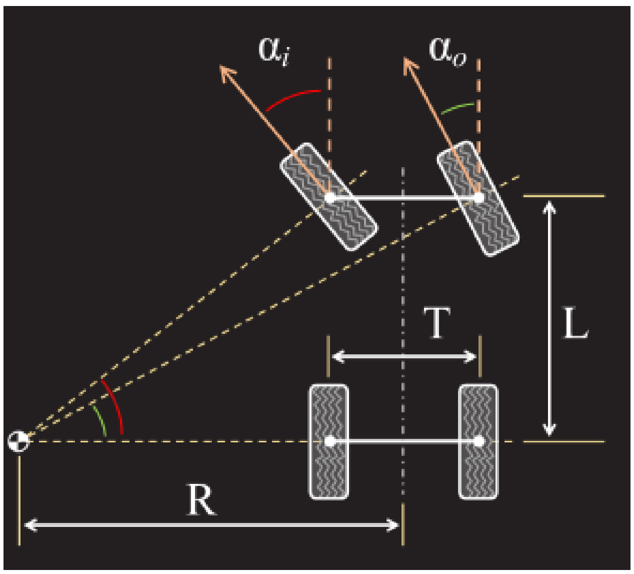
Caster

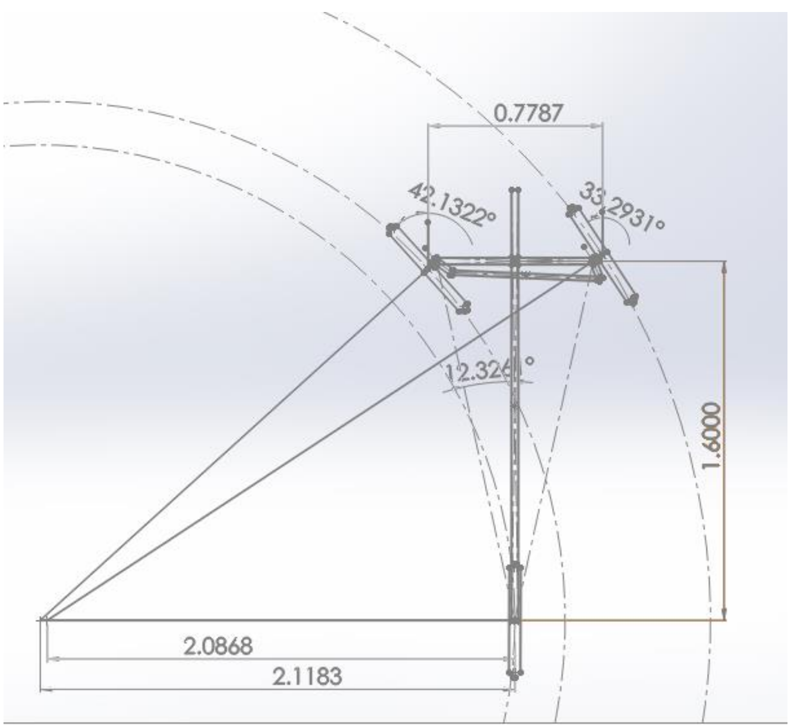
Caster is another important design angle because this allows the front wheels to self-stabilize during movement. The kingpin points down in front of the tire's contact patch. The resulting forces creates a lot of align torque that straightens the wheels back to neutral position when you go forward. Too much caster (positive caster) and the front of the car will understeer more, too little (negative caster) and you will get oversteer handling characteristics. If caster is not symmetric it will cause the steering to pull towards side with less caster. Professional recommended selecting an angle around 12 degrees for a recumbent trike.



Turning Radius

The target turning radius is 2.5 meters. There are three variables that factor in to the turning radius of our trike, they include: The distance between the front and the back wheels, the distance between the left and right front wheels, and the angle that the front tires rotate at. Calculating for all these design variable with the front to back being 1.6 meters, the width from left to right being 0.7 meters and the max angle of the inside tire being 45 degrees theoretically a 2.5 meter turning radius is capable.





Component and Material Selection

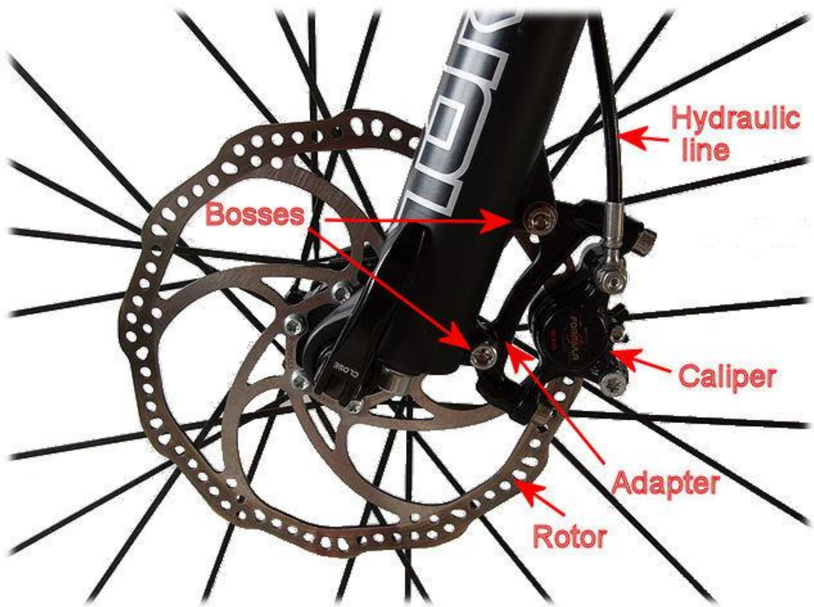
Many of the components for the entire steering system were purchased complete components ready to be assembled. The rims, the tires and tubes, tie rod were all purchased together from Fairfield Cyclery ready to be put on. However, there were specific bearings for the hubs that needed to be sourced separately. The kingpins were made by using the neck from old bicycles. The handle bars with made from stock ¾" steel tubing purchased from Lowes.

Braking Design

Disk Brakes

Disk brakes were selected due to the ease of mounting on the two front tires. Because the center of gravity is low and further forward than back it is only necessary to brake on the front two wheels without worry of the trike tipping over forward.

A few common alternative choices for braking include drum brake, hub brakes or caliper rim brakes. Drum brakes however perform poorly in weather inclement conditions which is one of our goals, Hub brakes would complicate the steering system. And caliper rim brakes would require creating a specific mounting bracket separately attached to the frame. Disk brakes typically have a high mechanical advantage generating an incredible amount of stopping force therefore there will be less muscle fatigue in the hands when pressing down the brake levers.



Factor of Safety of Concern

Variables to consider are the max velocity is 10m/s, total Weight is 182 kilograms. The target stopping distance is 10 meters. Therefore, the calculated the required force to stop is 910N. The disk caliper brakes are a high mechanical advantage making it possible that the force requires from the hand on the lever arm will not cause excessive fatigue.

$$E_k = \frac{1}{2}mv^2$$

$$E_k = kinetic\ energy\ of\ object$$
$$m = mass\ of\ object$$
$$v = speed\ of\ object$$

Component and Material Selection

All the components for the braking system are typical bike components purchased at Fairfield Cyclery. Components include the rotors, calipers, brake line and brake lever.

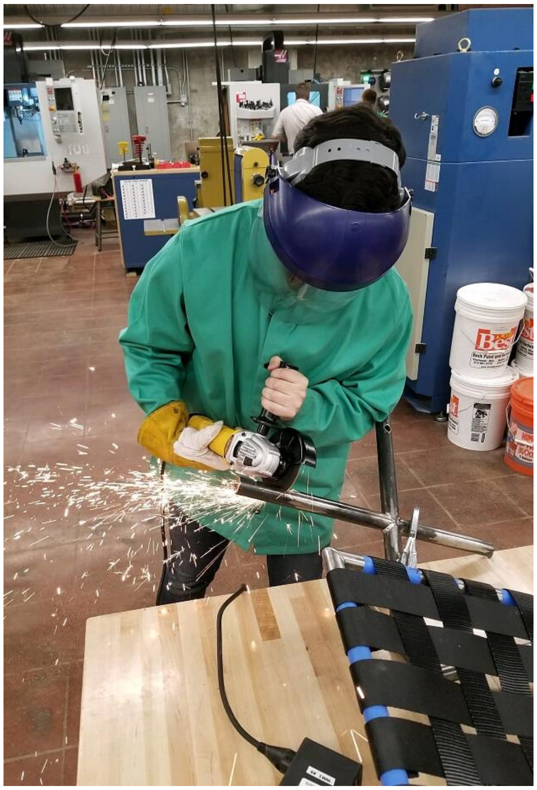
Fabrication and Assembly

Steering Fabrication and Assembly

Many of the manufacturing methods required to assemble the steering system was preparing for welds. All of the tools needed were provided by 1819 innovation hub. The largest and most important task was to cut frame and shape bars to prepare to weld on the kingpins. This is to weld the kingpins at designed kingpin and caster angle. This was critically important because that single weld placement accounted for three of the designed characteristics. It impacted the distance between right and left tire and therefore the turning radius, it impacted the kingpin angle and therefore if the tires would scrub and it impacted the caster angle and therefore if the wheels would self-stabilize. The kingpins themselves needed to be cut from their original bikes and be grinded down in order to weld to frame and axel connection. Once this was done the kingpin bearings could be assembled and greased.

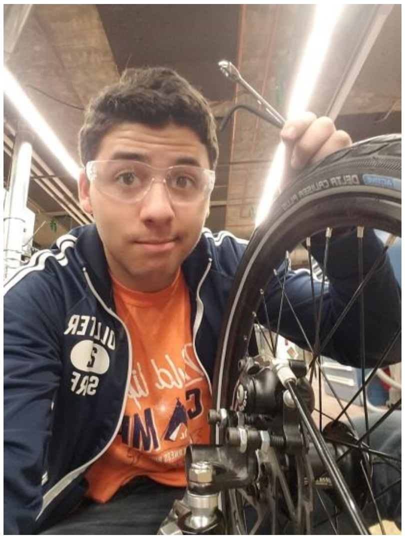
Next steps were to press the axel bearings into the wheel hub and mount them onto the axel. Then put on the tires and pump up the tubes. Then screw in tie rod and adjust to correct length.

The handle bars were the most custom build. They first needed to be cut to size and then cut at the right angle to prepare to weld them in place directly on the top of the kingpin assembly. Once the cuts would cause the handlebars to align parallel with the back of the seat for ergonomics the handle bar could be welded into place and the steering system was fully functional.



Braking Fabrication and Assembly

The rotors, calipers, brake line and brake lever simple has to be assembled onto the wheel hub and handlebars respectively. All components are designed to be mounted to each other. The majority of the assembly time was to cut wires to correct length and pretension them. Firstly the rotor was crewed onto the wheel hub, the calipers were mounted to align them with the rotors. The brake lines were routine from wheels to handlebars. The brake levers were mounted onto handle bars and then the position of the brake pads was adjusted.

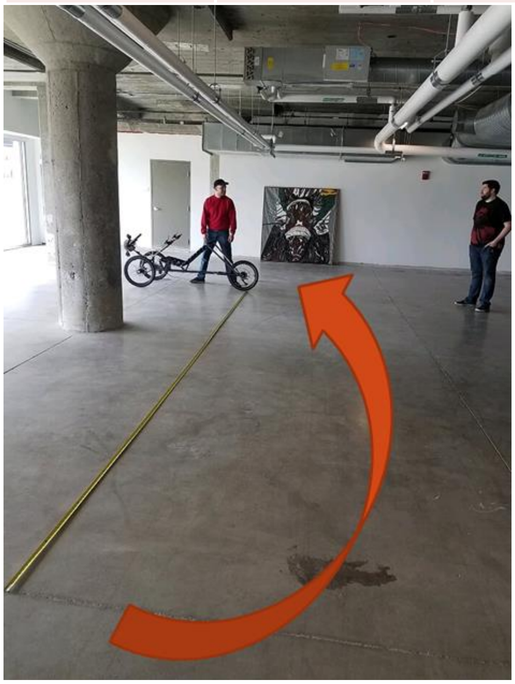


Testing and Proof of Design

Steering Testing and Proof of Design

Testing for the steering system was testing to determine if we indeed achieved the desired turn Radius. First was to measure the wheel distances because these are the variables that effect the turning radius. As shown in the table below the test failed because the wheels were not able to be turned enough due to interference between the person and the handle bars.

	Length front to back wheels	Width from left and right wheel	Angle of inside wheel when turning	Turning Radius
Objective	1.6meters	0.7 meters	36 degrees	2.5 meters
Actual	1.6meters	0.75 meters	28 degrees	3.35 meters



Braking Testing and Proof of Design

Testing included riding the trike at 10m/s and apply brakes fully. The trike should stop within 10meters to successfully pass. We measure the time with stop watch recorded the distance with a tape measure.

At max speed of 10m/s the brakes stopped the bike in 6 seconds at 25meters. Goal was 2.5 secs and 10 meters. The braking test failed. This was likely due to the brake pads not being fully aligned with the rotors.

Project Management

Project Budget Limit

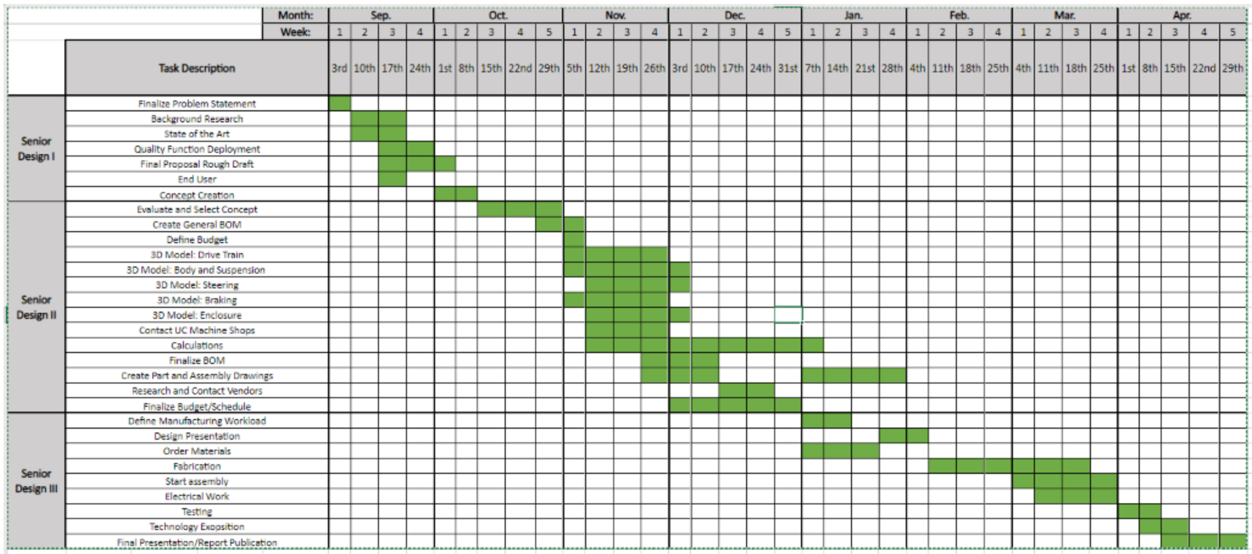
This project has a targeted cap of 2,000$.

- Materials: ~1,500$
- Labor: ~500$

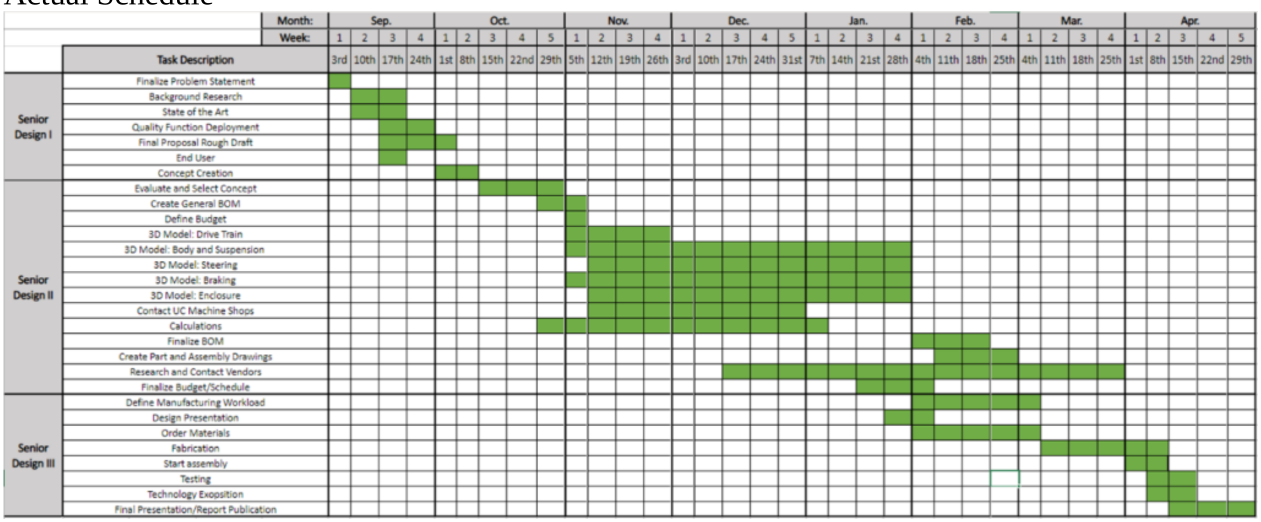
Key Milestones

- Design II (design development) –
    - Design decision – October 19, 2018
    - Meet with shop technicians – October 26, 2018
    - Calculations / Finite Element Analysis – November 16, 2018
    - Final design and drawings – December 1, 2018
- Design Presentation – January 2019
- Design III (manufacturing) –
    - Order Materials – At least 3 months before Expo
    - Manufacture – 3 months before Expo
    - Build – 6 weeks before Expo
    - Test – 3 weeks before Expo
- Tech Expo – April 2019
- Final Presentation April 2019

Proposed Schedule



Actual Schedule



As can be deduced from the previous graphics, the time spent on modeling and calculations was far greater than what was previously purposed. This is due to obstacles that were unforeseen and underestimation of the complexity of the designing stage. We also spent more time on talking to vendors due to the lead time for specific components. The actual building and testing phase took place immediately before the tech expo.

Proposed Budget

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

Actual Budget

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	58.92
DriveTrain	Chain Breaker	Amazon	6.99
Enclosure	Acryllic	Amazon	28.57
Enclosure	Adhesive	Amazon	15
Enclosure	Canopy	Amazon	38.99
Enclosure	PVC	Home Depot	24.82
Enclosure	Clear Vinyl	Jo Ann Fabrics	13.08
Enclosure	Clear Vinyl	Jo Ann 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	Lowes	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	28.83
Hardware	Bulk Order	McMaster-Carr	57
		Total	1991.72

We exceeded our expected budget mainly due to the cost of manufacturing the frame. Other unexpected costs within the steering and braking assemblies were the expensiveness of the wheels and the cost of the tires. I did not anticipate needing to get specialty hubs and then later needing to order specific types of bearing to work with said hub and axel. The rotors for the disk brakes were also more expensive than expected.

Recommendations

- Redesign handle bars for more clearance between human and bars
- Weld kingpins only frame with higher precision. Create more repeatable welding fixtures
- Decrease the distances between the front and back wheels to decrease turning radius
- Re-adjust the brake pads so they have less travel distance after lever arm is pressed.
- Select a larger rotor for larger mechanical advantage
- Select a caliper with a higher mechanical advantage
- Select a different brake pads for a higher coefficient of friction or larger contact area.

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Acknowledgements

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**

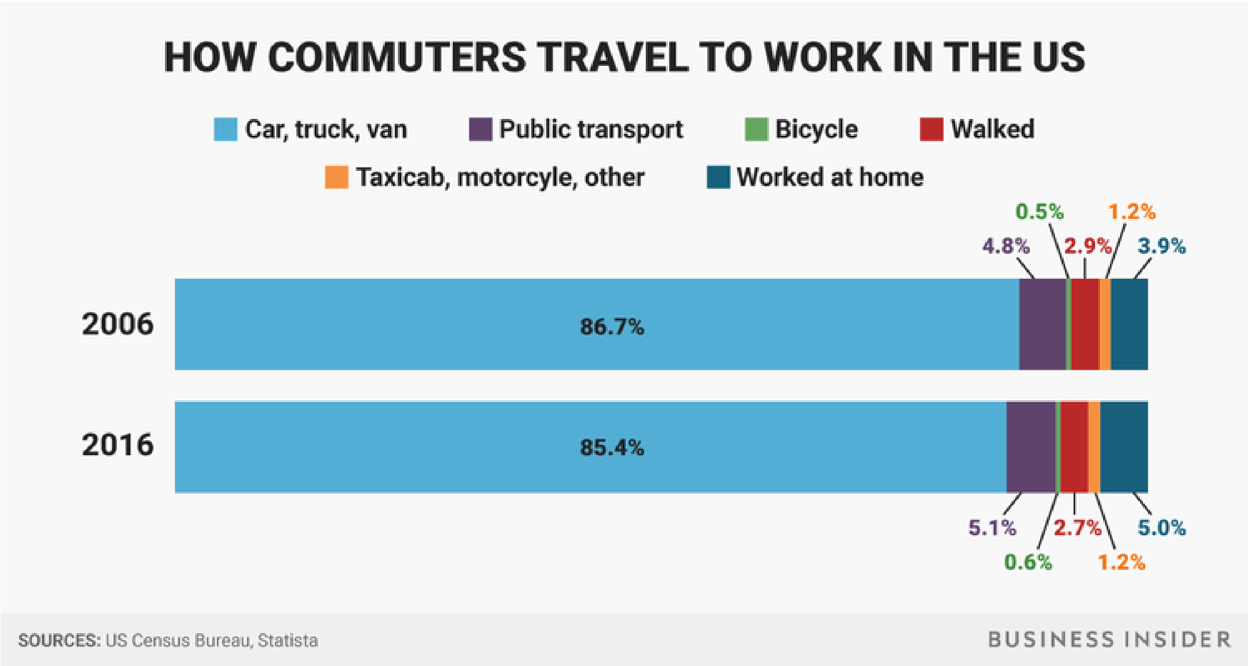
Reliability	1	2	3	4	5
Comfort	1	2	3	4	5
Style	1	2	3	4	5
Size	1	2	3	4	5
Storage	1	2	3	4	5
Convenience	1	2	3	4	5
Speed	1	2	3	4	5
Upfront Cost	1	2	3	4	5
Maintenance	1	2	3	4	5

<u>Satisfaction</u>

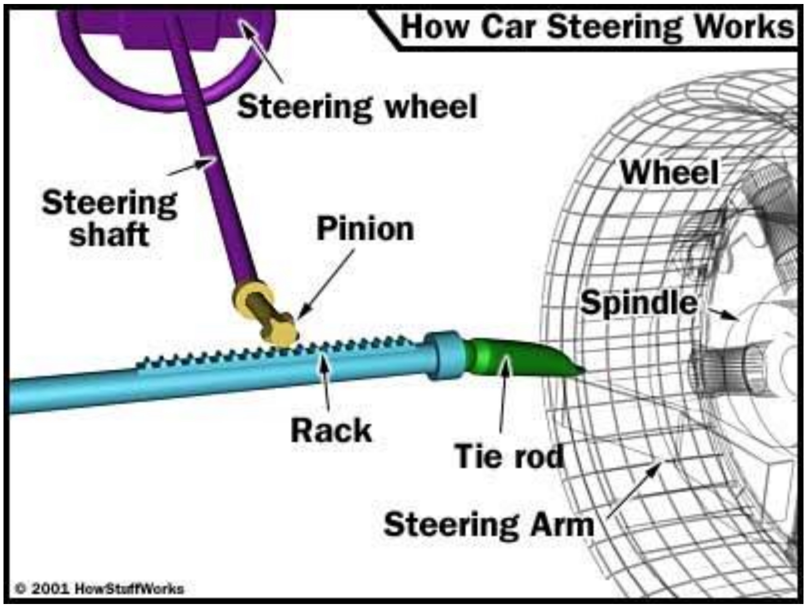
Rate how satisfied you are with your current **human-powered** mode of transportation in each category.
1: Unsatisfied **3: Reasonable satisfied** **5: High Satisfied**

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

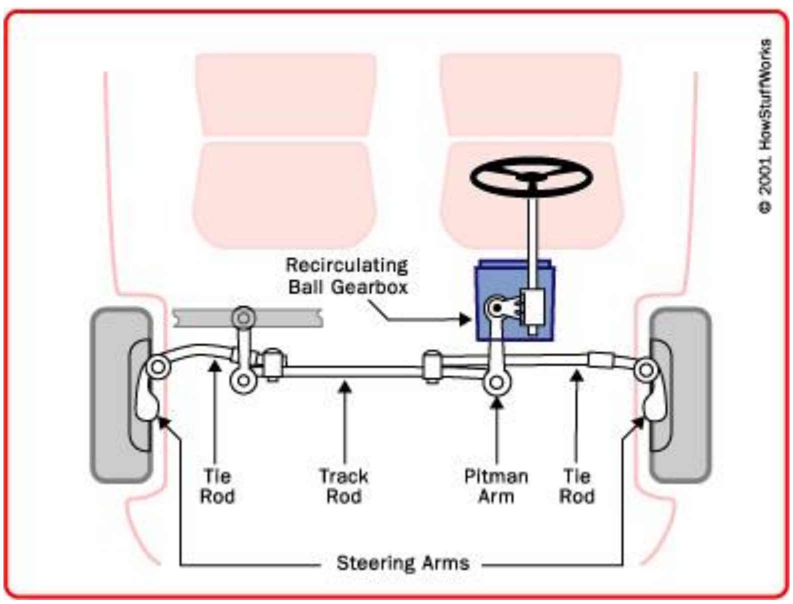
Are there any other points of your current human-powered mode of transportation that you are not satisfied with? Please list and explain.



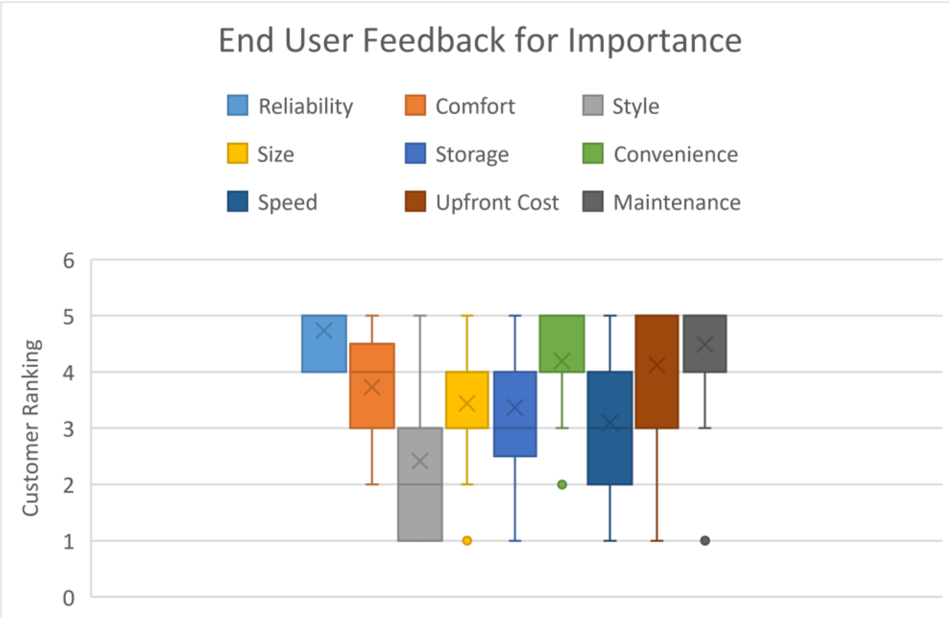
Rack-and-pinion



Recirculating-ball steering.



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