Road Trike: Suspension and Drivetrain

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by

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Problem Statement

Personal transportation is a balance of convenience, ecologic impact, and economic investment. As of 2016, in the US 28% of greenhouse gas emissions are created by transportation and 60% of the greenhouse gas emissions of transportation are created by light-duty vehicles, according to the EPA. From this statistic we can tell that light-duty vehicles are to blame for majority of the transportation greenhouse gas emission in the US.

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 while motorcycles and bicycles are not convenient 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

According to the Bureau of Transportation, there are 8 different main categories of means of transportation for regular commutes. These categories are Personal Vehicle, Public Transportation, Walk, Bicycle, Motorcycle, Taxi, and Other Means. In the year of 2016, 85.4% of the American worker over the age of 16 commuted by personal vehicle (1). This is down from 87.9% in 2000 (1). Public transportation was recorded as 5.1% in 2016, up 0.4% from 2000 (1). 3.3 % of Americans used their own power to commute by walking or bicycling in 2016; this was the same in 2000, but a larger portion of this 3.3% has transitioned to bicycling over walking (1).

The average price of owning a new car for a year in 2017 was 8,469$ according to AAA (2). This breaks down to 706$/month. Another source, 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" (3). This is not to say that public transit is 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 (4).

The cheapest transportation is walking or bicycling. These modes of transportation have obvious physical limitations, safety concerns, and exertion concerns. The State Government of Victoria has a list of walking safety precautions such as wearing comfortable clothing, reflective attire, and hydrating (5). These actions could be applied to bicycling as well. 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.

Furthermore, automobiles that the majority of the American workers use to commute mainly run on burning fossil fuels. The statistics of emissions from transportation in America are well stated by Linda Brinson, a freelance author for HowStuffWorks, below.

> "According to the EPA, 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." (6)

State of the Art

There are several different types of suspension systems. Automobiles have 2 main types of suspension systems: dependent suspension systems and independent systems. Dependent systems have the axle fixed on along a shaft and any movement on one end will affect the other end due to this connection; this is the oldest and cheapest type of automotive suspension system (7). Independent systems do not share this pit fall but have other downfalls. There are 4 main types of independent suspension systems: McPherson struts, double wishbone, multi-link, and torsion bar systems (7).

The McPherson strut has the wheel mounted to a control arm that can rotate about a fixed point on the chassis and a strut that dampens that is connected to the control arm and another point of the chassis. This strut dampens the rotation of the control arm. This system creates independence from one side of the axle to the other, but at the expense of simplicity offered by the dependent systems (7). This system is the cheapest strut based independent system but is still more expensive than the dependent system and the torsional system (described below) (7). This added cost is generated from the costly strut and the increase in part numbers (7). The advantage is a greater performance when compared to the dependent system and torsional systems.

Double wishbone systems have the wheel mounted to a four-bar linkage that mounts to two different locations on the chassis and a strut that dampens the travel of this linkage. This system is a bit costlier than the McPherson strut system due to the added components (7). These added components also increase the likelihood of required maintenance and maintenance costs (7). This system sacrifices upfront cost, weight, and required maintenance for better performance and handling (7).

The multi-link system is very similar to the double wishbone system with one major difference; instead of two wishbone style control arms, the multi-link system has 5 linkages that mount from the wheel to the chassis with a strut to dampen the motion (7). These linkages all control the motion of the wheel with one degree of freedom (7). The fact that these linkages all control one degree of freedom means that one could easily adjust the performance of the design by altering the length and location of these linkages (7). The added components also translate to more manufacturing costs as well as more maintenance possibility and cost.

The torsion bar system is a very simplified system. It was developed after the development of the strut systems explained previously (7). The torsion bar suspension system is comprised of a bar that connects from the chassis to a rotatable control arm and the travel of this control arm forces the bar in to torsion and the resistance of this bar is what generates the dampening force (8). The systems simplicity reduces cost in manufacturing and maintenance costs as the dampening forces result from the mechanical properties of a material rather than the hydraulic pressure in the struts of the previous suspension systems (8). The downside to this design is that the suspension cannot handle bumpy surfaces with the same ease as the strut systems (8). One of the greatest advantages of the torsion bar system is that it does not take up much space on the vehicle and is able to be easily used in tandem with other suspension systems to improve performance (7).

Bicycles utilize different forms of suspensions, among these is seat suspensions. In this concept the frame of the bicycle is rigid and the seat that the operator sits on deforms to absorb shock from the road. There are two different methods of accomplishing this: suspension seat posts and in-seat spring suspensions. The seat post suspension is comprised of a damper in the post that connects the seat to the bicycle frame while the in-seat spring suspension dampens movement between the seat and the post that seat connects too.

The seat post suspension is more expensive than the in-seat spring suspension system (9). These both create a problem of having a variable length from the seat to the pedals that would be greater than that of an in-seat spring suspension (9). This concern with this variation is that the change in length will be compensated by the operator's legs which will create a difficult situation for riding (10). These systems also have the potential of being too loose. If the rider bounces relative to the bike frame when pedaling on flat ground, then the ride then the ride will become more uncomfortable (9; 10).

Full suspension on a bicycle refers to having a suspension in the bike frame as well as on the front wheel (11). This type of suspension is commonly used on mountain bikes due to its ability to compensate impacts from rough trails where there are roots and large rocks (11). This type of suspension usually has a shock absorber in the frame that dampens relative motion between the rider and the back wheel (11). This relative motion is rotational at the point of rotation. This relative motion can cause a variable length for the drivetrain. Because of this the pivot point is generally placed at the pedals to create a constant length for the drivetrain. This type of suspension is used for rough trails on mountain bikes, the dual suspension allows for the frame to absorb the impact of large root, rocks, and inconsistencies in the trail (11; 12). This system is more expensive than the previously mentioned suspension systems for bicycles but are more robust in their performance.

A fork damper suspension system, also known as hard tail bicycles, is like a full suspension system on a bicycle except there is no in-frame shock absorber (11). All parts of the frame are rigidly fixed and the front wheel is allowed one degree of freedom from the handle bars, this allows the fork to absorb impacts. This type of when compared to the full suspension style this system is slightly lighter, cheaper, and more of an all-purpose system (11). This system does not have as much travel and does not absorb large impacts as well as the full suspension system (11). Fork suspension bicycles are also more efficient when riding on smooth pavement when compared to their full suspension counterparts (12). This system does create better dampening when compared to seat post and seat spring suspension systems though.

There are many different drivetrain systems that are used in vehicle transportation. There is shaft driven, direct drive, chain and sprocket, belt and pulley, gear train, and even rope driven. Each type of system has its own perks and draw backs inherent in their design. The current

The shaft drivetrain is comprised of a shaft that generally has beveled gears to translate the rotation of the motor or power source to the drive axle. This system is used in rear-wheel drive automobiles and trucks, motorcycles, and even a few bicycle designs. The bevel gears alter the direction of rotation. This system is very low maintenance because the system has very few parts, it is very smooth due to the tight relation between the drivetrain and the axle, and is long lasting due to the lack of wear and relatively low stresses in a well-designed shaft (13). This system is also relatively heavy, allows the vehicle to roll when removing or adding torque, and removes responsiveness of the suspension system (13).

The chain and sprocket system is comprised of the two sprockets and a chain connected them. This system is often used on both motorcycles and bicycles. One sprocket is attached to the drive shaft and the other sprocket is attached to the drive wheel axle while the chain translates the torque of the drive shaft to a torque on the wheel axle. The positive points of this type of system is that it is very simple, very cheap, adaptable to different situations, easy repair, and simple gear ration changes (14). The disadvantages to this system are that the chain requires lubrication, the chain will deform under the stress of operation and need replaced, the sprockets wear down and need replaced, noise generation from the constant chain link and sprocket impact, and there is a delay in the drivetrain due to slack in the chain (14) (15). The fact that the chain cannot slip on the sprocket like a belt on a pulley means that there is less efficiency loss in slipping, but there is also nothing preventing a caught finger or hand from receiving a crushing blow from the chain (15).

The direct drive system is the simplest drivetrain. In this system the drive shaft is or is directly connected to the axle of the drive wheel. This system is used in children's Big Wheel toys and hub motors on electric bicycles. This system's lack of popularity is due to its inefficiencies. This system cannot take advantage of any gear ratio or shifts in gear ratios. This system is very low maintenance due to the lack of moving parts, has low manufacturing costs due to the low number of parts, is very reliable due to the low possibility of failure. The system is very inefficient because the source of power will need to have a lot of torque and be able to reach a high rpm.

Belt and pulley systems are very similar to that of chain and sprocket systems. Instead of a chain there is a belt and instead of a sprocket there is a pulley. This system runs on friction. The friction between the pulley and the belt is what transfers the power from the drive shaft to the wheel axle. This system's major positives are that this system is low maintenance (it does not require lubrication and if given automatic tensioning system will not need adjusting) and belts are less expensive than chains, but can slip relative to the pulleys causing a poor response from the drive shaft to the wheel axle (15). This slip can also act as a safety feature though, under high forces such as a jam the slippage can prevent a crushing force on the jammed material, whether that be a hand or a piece of metal (15).

End User

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.

Summary of Research

There are many forms of suspension systems and drivetrain systems. The modern automobiles commonly use suspension systems that absorb large impacts at higher speeds. When designing the suspension systems for automobiles there does not seem to be much consideration for added weight, but the suspension systems designed for bicycles seem to consider and even design to have simpler systems that do not add as much weight to the machine. Common automobile suspension systems are Dependent systems, the McPherson strut, double wishbone systems, the multi-link system, and the torsion bar system. Common bicycle suspension systems are seat-spring systems, seat post suspensions, full suspension systems, and hardtail/fork damper systems.

The different automobile suspension systems have evolved over time to increase handling and performance (with the exception of the torsion bar suspension system which was designed for simplicity). The oldest design was the dependent suspension system: a shaft that held the wheels that was suspended over the chassis with springs and dampeners. The McPherson strut system made each wheel's travel dependent from the other by having the wheel rotate around a pivot point and dampening the movement between the rotating connection and the chassis. The double wishbone suspension system improved upon the McPherson strut by fixing the wheel to a four-bar linkage to improve handing by not allowing the wheel to rotate relative to the ground and dampened the motion of this four bar linkage relative to the chassis. The multi-link suspension system is very similar to the double wishbone system with added modification abilities by having more than two connections to the wheel hub.

Bicycle suspension systems are comprised of seat spring systems, seat post suspension systems, full suspension system, and hardtail/fork damper systems. These are more simplified suspension systems when compared to the automobile suspension systems. The seat spring systems and seat post suspension systems are systems separate from the bicycle frame and only dampen motion between the operator and the bicycle frame. The full suspension systems and hardtail systems are dampening systems that dampen the motion between the bicycle frame and the trail. The full suspension system has a damper for the from wheel and one in the frame that dampens the rear wheel travel. The hardtail system only has the damper on the front wheel.

There are also a few common drivetrain systems used across automobile, motorcycle, and bicycle technology. There are shaft drive designs, chain and sprocket designs, and belt and pulley systems. The shaft design translates supplied rotational motion, generally using bevel gears, through a shaft and then through another set of bevel gears in to another shaft that is fixed to wheels. Chain and sprocket designs translate the supplied rotational motion into a sprocket and through a chain that is connected to another sprocket that drives the wheels. Belt and pulley systems operate in a very similar way to the chain and sprocket design, the main differences is that there is a chance for belt slipping and the belts do not need lubrication like chains.

Quality Function Deployment

Customer Features

- Can be relied upon-------------------------------22%
- Easily Maintained -------------------------------14%
- Ease of Use (versatility) ------------------------15%
- Requires low financial investing --------------18%
- Can be operated without discomfort ----------11%
- Can fit in a small space -------------------------8%
- Can carry luggage -------------------------------6%
- Can drive fast ------------------------------------3%
- Looks aesthetically pleasing -------------------3%

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 Satisfaction Rating (0.00 - 1.00)			
	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 Requirements		1	2	3	4	5	6	7	8	9	10	12	13	14	15	16	17	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				

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 ($\geq$ 3 months)

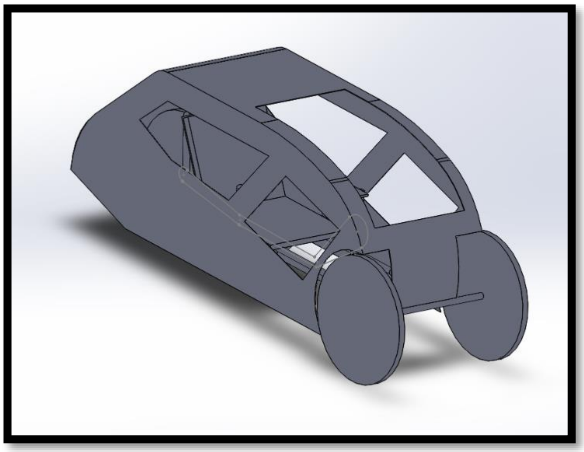
#4: Cost of manufacturing (<2000$)

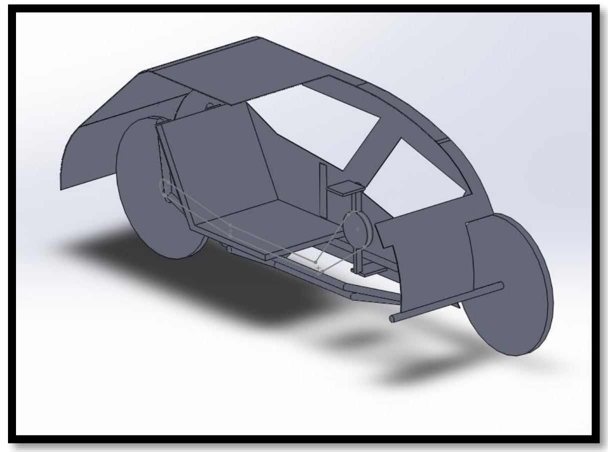
#5: Turn Radius (6m)

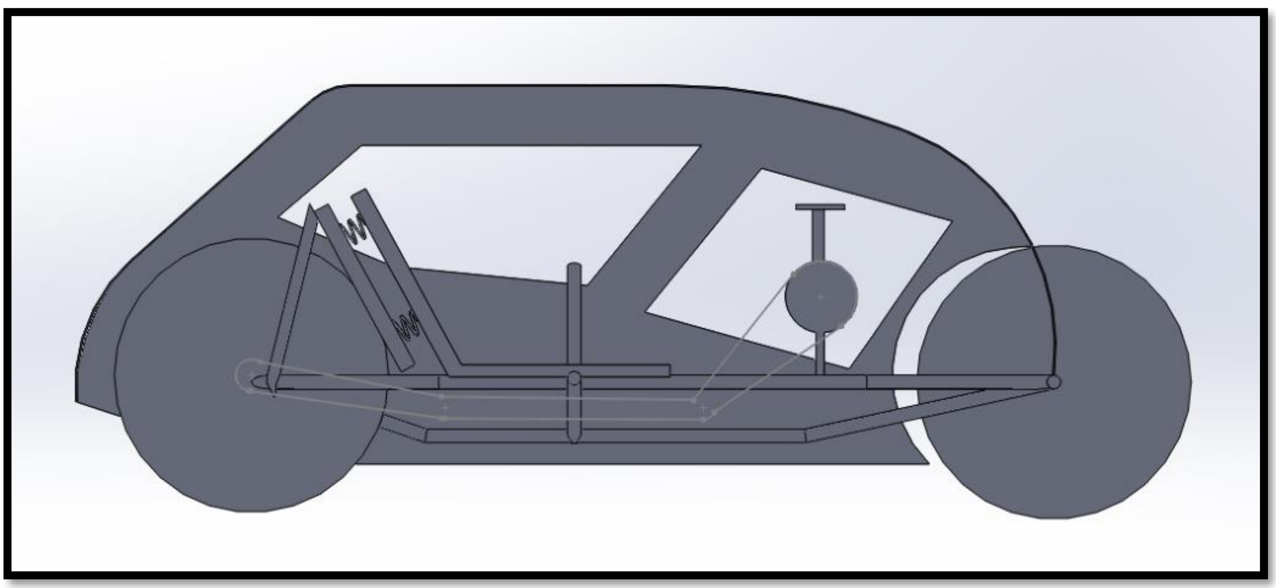
#6: Suspension travel (8cm)

Concepts Drawings

Concept 1:

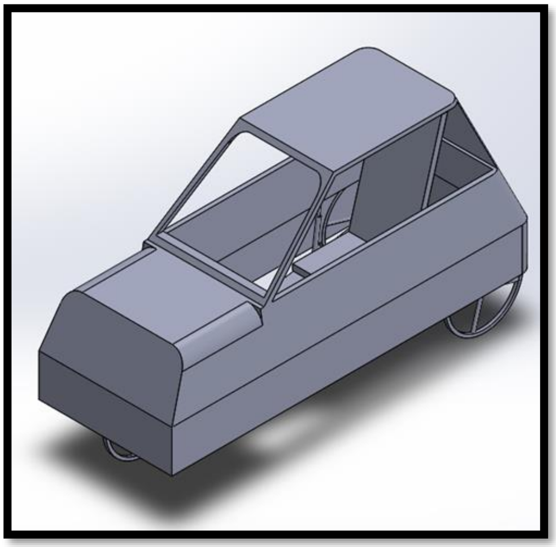


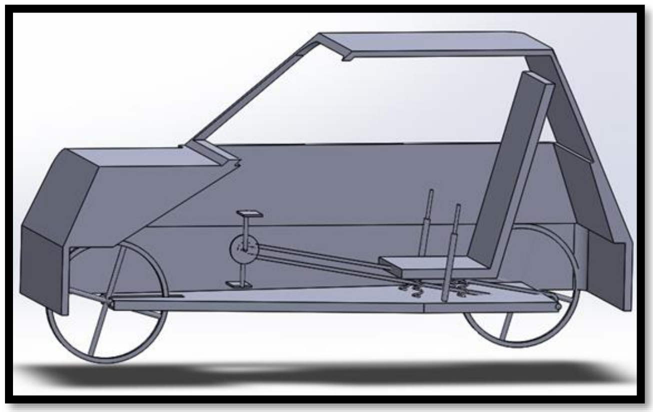




Concept 1 utilizes a bicycle style frame (has centered tubes that create the chassis), seat spring style suspension, sprocket and chain drivetrain, paddle steering, a canopy style enclosure, and two wheels in the back and one in the front. The drivetrain is a sprocket and chain design. This means that 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.

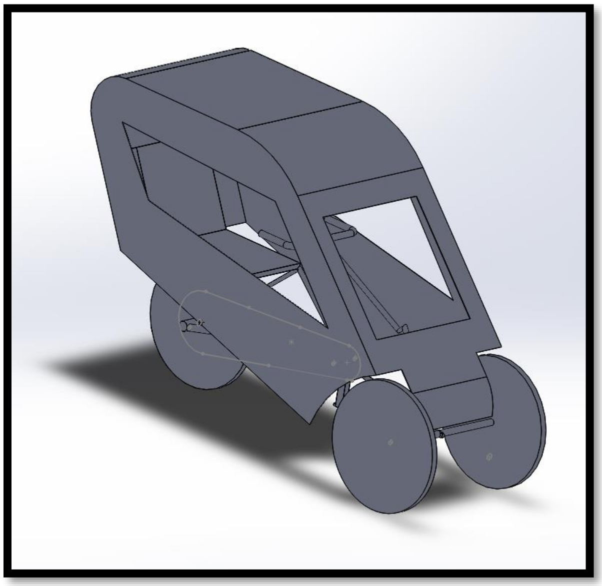
Concept 2:

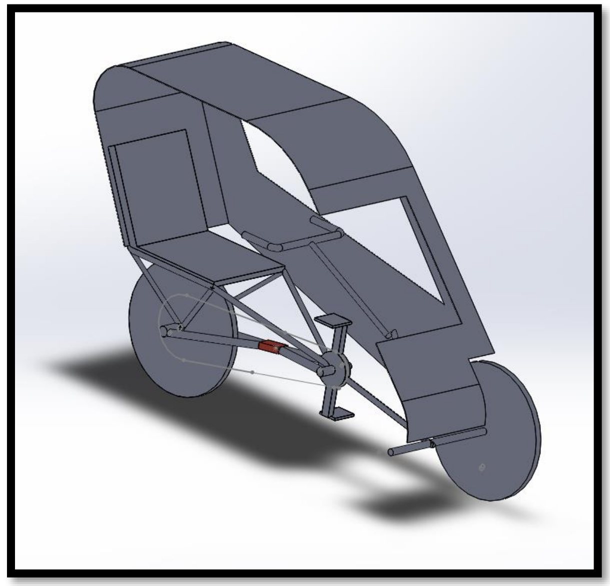


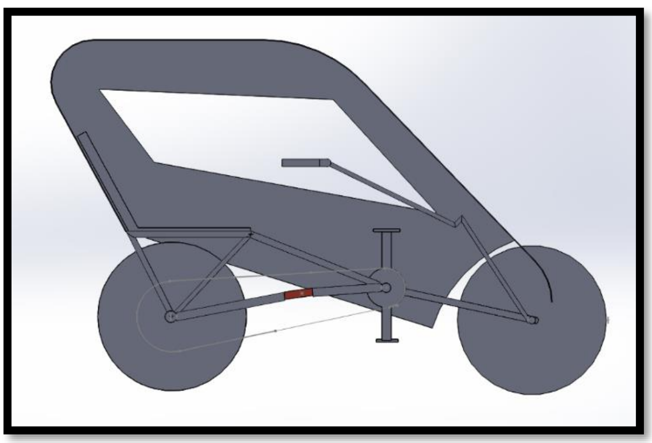


Concept 2 is comprised of a “go-kart” style frame, a spring seat and torsion bar suspension systems, a pulley and belt drivetrain, paddle style steering system, and what is referred to as a “beetle” style enclosure. The drivetrain is comprised of a belt and pulley system; the operator will rotate one 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 drivetrain, 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 drivetrain 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

Drivetrain

Design Alternatives and Selection

The drivetrain alternatives were chain and sprocket, belt and pulley, and drive shaft design. The selection of the chain and sprocket drivetrain system were based on the criteria of durability, ease of shifting gears, availability of standard components, and maintenance.

		Chain and Sprocket		Belt and Pulley		Direct Shaft	
	Weight	Rating	Weighted Rating	Rating	Weighted Rating	Rating	Weighted Rating
Durability	0.3	3	0.9	3	0.9	4	1.2
Gear Ratio	0.4	4	1.6	3	1.2	1	0.4
Standard Component Availability	0.2	4	0.8	3	0.6	2	0.4
Maintenance	0.1	1	0.1	2	0.2	3	0.3
TOTAL	1.00	-	3.4	-	2.9	-	2.3

0- Infeasible
1- Unsatisfactory
2- Poor
3- Acceptable
4- Good

After the chain and sprocket style drivetrain was chosen there was a need to understand the power output of a human being. To accomplish this a test was conducted using 4 different people: all males, aged 18-22, varying sizes from 61kg to 115kg and 167cm to 188cm. Two of the participants were roughly the same size of 178cm and 75kg, but to add variation one of these men ran three miles prior to the experiment to give the impression of fatigue from riding. All participants were told to ride a stationary recumbent bicycle in a fitness gym. This particular stationary recumbent bicycle had a set resistance level that could be selected from 1 to 20 and a monitor that outputted the watts and rpm generated by the rider. These participants were instructed to pedal at a comfortable pace while at level 10 resistance; this was meant to mimic the constant pedaling scenario of the rider. The energy and rpm output were then recorded for each rider. With this recording the torque generated could be calculated. The lever arm of the pedal was also measured and used to calculate the force output of the riders. To mimic the scenario of hard pedaling (pedaling uphill or trying to gain speed quickly) the stationary bike was set to the highest level, level 20, and the participants were asked to pedal as hard as they could for one minute and the rpm and energy output was collected.

	Comfort						Max Push							
User	RPM	RPS	Rotation (Rads/Sec)	Watts	Torque (Nm)	Force (N)	RPM	RMS	Rad/s	Lever Arm (in)	Lever Arms (m)	Watts	Torque (Nm)	Force (N)
1	84	1.40	8.80	230	26.15	152.50	65	1.08	6.81	6.75	0.1715	656	96.37	562.11
2	57	0.95	5.97	143	23.96	139.73	62	1.03	6.49	6.75	0.1715	325	50.06	291.96
3	65	1.08	6.81	172	25.27	147.38	103	1.72	10.79	6.75	0.1715	1009	93.55	545.62
4	73	1.22	7.64	201	26.29	153.36	65	1.08	6.81	6.75	0.1715	656	96.37	562.11
Averages				186.5		148.24						661.5		490.45

After the human output was estimated it was required to understand the requirements to move the vehicle. To do this there were many assumptions that had to be made. It was decided that the vehicle would have 20” bicycle wheels and these wheels would have a constant rolling frictional force of 20.09N (16). This rolling friction is taken to be constant due to the limited range of speeds that the vehicle will be exposed to. Because of this assumption the energy absorbed by rolling friction is calculated by multiplying the 20.09N by the velocity of the vehicle for all scenarios. It is also assumed that the vehicle is a total of 182kg.

There are two scenarios that were engineered to: riding on a flat surface at a speed of 8.9m/s and riding up a 10° incline. The first scenario will dictate the maximum gear ratio required and the latter dictates the minimum gear ratio.

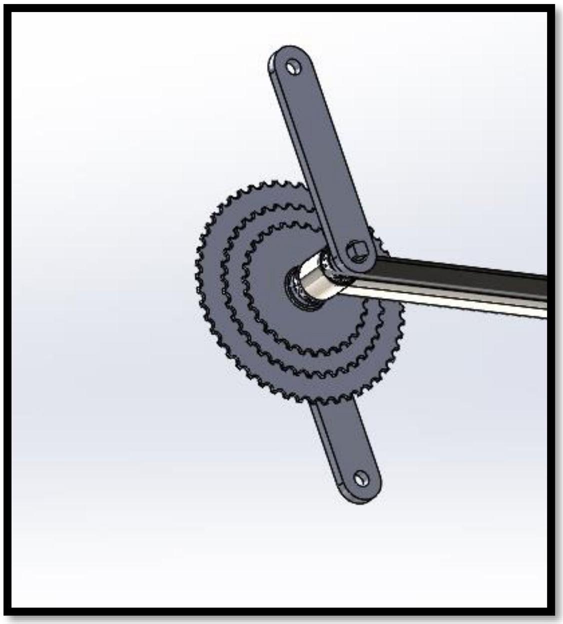
When riding on flat ground the only forms of energy are through rolling friction, air friction, and the energy produced by the rider. When the human output power is greater than or equal to the energy consumed in rolling friction and air friction the rider is able to ride at this speed. With the assumptions outlined previously the energy consumed by the friction is 308.055W, well below the maximum human output of 661W. This calculation verifies that the average rider can produce the output power required to ride at 8.9 m/s. To calculate the gear ratio, it was required to understand the rotational speed of the wheel and the rotational speed of the pedals.

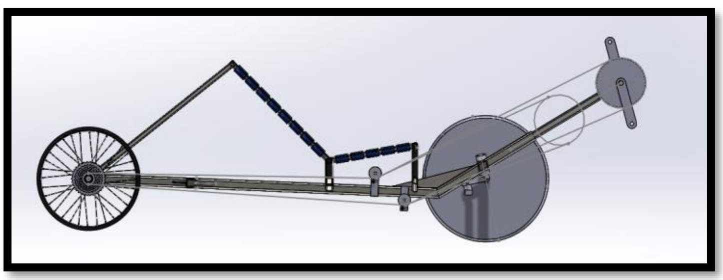
With the assumed diameter of the wheel and the speed of the vehicle the rotational speed of the wheel is calculated. The unknown variable is the rotational speed of the pedals. It was taken that a 75rpm rotational speed of the rider’s feet was reasonable. This assumption was verified by the experiment of four participants. With these two rotational speeds the gear ratio lower limit of the maximum gear ratio was determined to be 4.48.

The second scenario is riding up a 10° incline. This scenario differs from the previous in the fact that there is energy being stored in potential energy. The power being stored in potential energy is based on the velocity of the vehicle. To accomplish the calculations a minimum speed was assumed to be 1.79m/s. The method of calculating the energy consumed in air and rolling friction are the same as with the previous method with this new velocity. The power being stored in potential energy is calculated using the vertical velocity component of the vehicle, mass, and gravity. It was calculated that the power required by the rider would be 614W. Because this is below the 661W average rider peak power it is determined that this is an acceptable speed. The top limit of the lowest gear ratio was then calculated in the same way as the previous scenario with one exception. It was assumed that the rider’s pedal rpm is 60 rpm. This is validated through the experiment. In the experimental round where, the experiment participants were pedaling as hard as they could three out of the four participants pedaled near 60 rpm on the highest level and the other participant did not seem to have difficulty pedaling at the highest level of resistance. With these calculations the drivetrain required a range of gear ratios from 1.12 to 4.48.

The bearings of the wheels and pedals were chosen to be standard bicycle parts. Standard bicycle wheel bearings have a vast array of options. A very common and cost-effective bearing style for the wheel axle is cup and cone bearings where the ball bearings are free floating between a cup on the wheel hub and a threaded-on cone on the axle. This style bearing was chosen due to its common place and cost efficiency. One of the drawbacks of this style bearing is that it requires adding grease yearly.

Solid Model Assembly





Loading Conditions

All the Components will be from a manufacturer of bicycles. It is assumed that any purchased components under standard operating conditions are acceptable for standard loading conditions. The only component that is subjected to a different style of loading is the rear axle. A standard purchased axle is designed for a load of a standard bicycle. This vehicle will have far more loading on the rear wheel due to its size and weight.

Application of Industry Codes, Specifications, and Standards

Standard bicycle components were used to design the drivetrain. For example, the sprockets are all ½" pitch, which is seen on all modern bicycles. The components also had to be compatible with each other. The rear hub had to be able to accept the cassette as there are to different styles of rear cassettes and different sizes of cassettes as well.

Component and Material Selections

The material selection is based on standard bicycle components. This decision is based on the ease of manufacturing, availability for replacement parts, and the ability to have a bicycle mechanic do future maintenance on the vehicle.

For the gearing and power transmission it was decided to have all parts selected from the same company. This was decided to simplify the component compatibility; components from one bicycle company will often not be compatible with another bicycle component company. The company that was chosen was Shimano. This company was chosen by their reputation to create high quality components and a large variety of components.

To select components for the drivetrain it was first mandatory to decide the gearing style. Bicycles can have multiple sprockets at the pedals, known as chain rings, and at the wheel, known as cogs. With the large gear ratio range that was deemed necessary it was decided that a 24-gear ratio system was necessary (3 chainrings and 8 cogs). The rear cassette selected is a Shimano Claris 8-speec cassette CS-HG50-8 11-34. This cassette has 8 cogs ranging from 11 teeth to 34 teeth (11-13-15-18-21-24-28-34) and requires a HG 8-speed chain (16). The front chainring set is a Shimano FC-A073 Tourney Triple Crankset. This crankset has three chainrings of 30, 39, and 50 teeth (16). This set up would give a gear ratio range of 0.88 to 4.55 which encompasses the required gear ratio of 1.12 to 4.48.

With the chain ring and cog set chosen it was necessary to select a wheel and hub, bottom bracket, front derailleur, and rear derailleur. The wheel was already assumed to be a 20” bicycle wheel. The selection of the wheel was selected based on the hub; different hubs could only accept certain cog sets. This hub had to accept an 8 cog Shimano cassette. The only Shimano hubs that accepted this type of cassette is referred to as a free hub. This style of hub has the cogs slide over a component of the wheel and allows the bearings to be more centered along the shaft, lessening bearing load and stress in the axle.

There are also many versions of bearings used on the pedals, known as the bottom bracket. An older, cost effective style of bottom bracket with wider manufacturing tolerances is the square taper bottom bracket. This style has enclosed bearings that thread into the frame and a square axle that connects to the pedals through a square hole (17). The square taper bottom bracket is used on older and less expensive bicycles; this made it a good fit for our vehicle as it was well known, cost expensive, and readily available (17). The other styles that are available are targeted toward racing and higher end bicycles and did not meet our needs for this project. The selected bottom bracket is the Shimano BB-UN26 Square Taper Bottom Bracket (16). This style of bottom bracket is simple and rugged.

The front derailleur is selected based on the span of the chain ring sizes. In this design it was determined that the chain ring would have a small chainring 30 tooth and a large 50 tooth chainring or a 20-tooth difference. Therefore, the front derailleur would have to be big enough to contain the chain while on the smaller chain ring and not impede the chain from shifting to the higher chain ring (18). The front derailleur selected was a Shimano Claris FD-R2030-F (16). This derailleur is able to shift up to 3 chainring with the largest chainring being 50 teeth and a total capacity of 20 teeth (16). The capacity of the front derailleur is the maximum difference in teeth between the largest and smallest chainring (20). For this design a capacity of 20 teeth is required, which the Claris FD-R2030-F meets.

The rear derailleur selection is based on the number of cogs and the capacity of the derailleur. The capacity of the rear derailleur is calculated differently from the front derailleur because the rear derailleur consumes the slack in the chain caused from shifting to different sized sprockets in the cassette and the chain ring (19). The required capacity of the rear derailleur is calculated through the maximum difference of the chain rings (20 teeth in this design) and the maximum difference in the cassette cogs (23 in this design). The capacity of the rear derailleur is the sum of these two differences (19). In this design the required capacity is 43 teeth (19). This means that the rear derailleur will need to be able to take up the slack in the chain when going from one extreme to the other. In this project it is required that the derailleur be able to shift through 8 cogs, have a capacity of 43 teeth, be able to have a small cog of 11 teeth, and be able to accept a large cog of 34 teeth. The rear derailleur that was selected was the Shimano RD-R2000-GS (16). This derailleur shifts through 8 rear cogs, accepts a small cog of 11 to 13 teeth, accepts a large cog of 28 to 34 teeth, and a total capacity of 43 teeth (16).

The chain selection is based on the cassette. Bicycle chain has a pitch of 12.7mm and has to have a inside width large enough for fit over the sprockets while having a small enough outside width so that it does not come into contact of neighboring sprockets. These dimensions vary between different manufacturers. Due to this, the chain selected should be based on customer recommendations. All the components selected prior to the chain selection determine what chain is to be purchased exactly. Shimano designates a HG 8-speed chain for all the previously selected components (16). This chain will be used in an effort to keep consistency with using the same manufacturer.

The axle on the rear, drive wheel is also something of concern. It is assumed that there is cyclical loading on this component. Because of this the safety factor of 6 was chosen. To calculate the stress in the axle a 3D model was generated in SolidWorks. It was estimated that the rear axle is subjected to bending moments as shown previously. A solid axle of 4130 steel will be used on the rear wheel.

One more component of the drivetrain that must be accounted for is the acceleration of the vehicle. To do this there are certain assumptions that have to be considered. It will be assumed that the vehicle is on flat land, the number of shifts that the rider will need to complete, and the amount of work that will be required to reach the top speed of 8.9m/s. The acceleration will be the change in velocity divided by the change in time. The change in velocity is deemed 0 to 8.9m/s. The process required is to find the change in time. Modeling this will be in two stages. The first stage will be calculating the time for the rider to reach this speed given constant wind force, constant rolling friction, and constant power output from the rider. The wind and friction forces are calculated the same way they were previously while calculating the gear ratios. The power from these forces is based on the velocity. The acceleration is assumed to be constant. With this in mind the average power consumed from the wind and rolling friction are considered half of the power consumed at the max speed of 8.9m/s. The human is estimated to output 500 Watts. The second stage is to consider for the time required for the rider to shift through all the gears. For each shift that the rider must complete 0.75 seconds will be added to the time to accelerate. It is assumed that the rider will need to shift 10 times from rest to top gear. With all this in mind the acceleration was estimated to be 0.314m/s with a total time difference of 28.5 seconds.

Suspension

Design Alternatives and Selection

The suspension was determined to be located in the seat. The options for suspension based on research were varying types of spring and dampener suspension systems, linear and torsion spring systems, and swinging suspension systems. When comparing these systems to the target audience and manufacturability one reigned supreme: the swinging suspension system. Applying this system to the seat of the rider allowed simplicity throughout the frame and steering components.

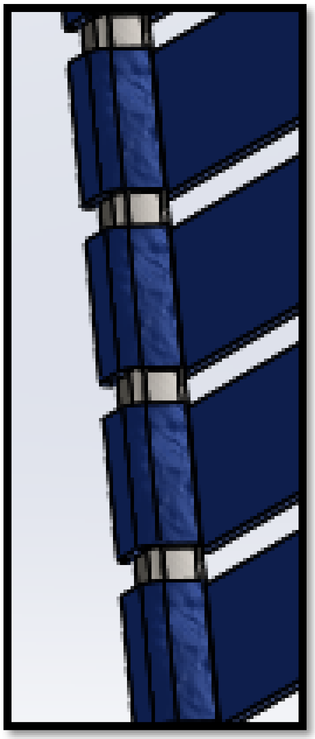
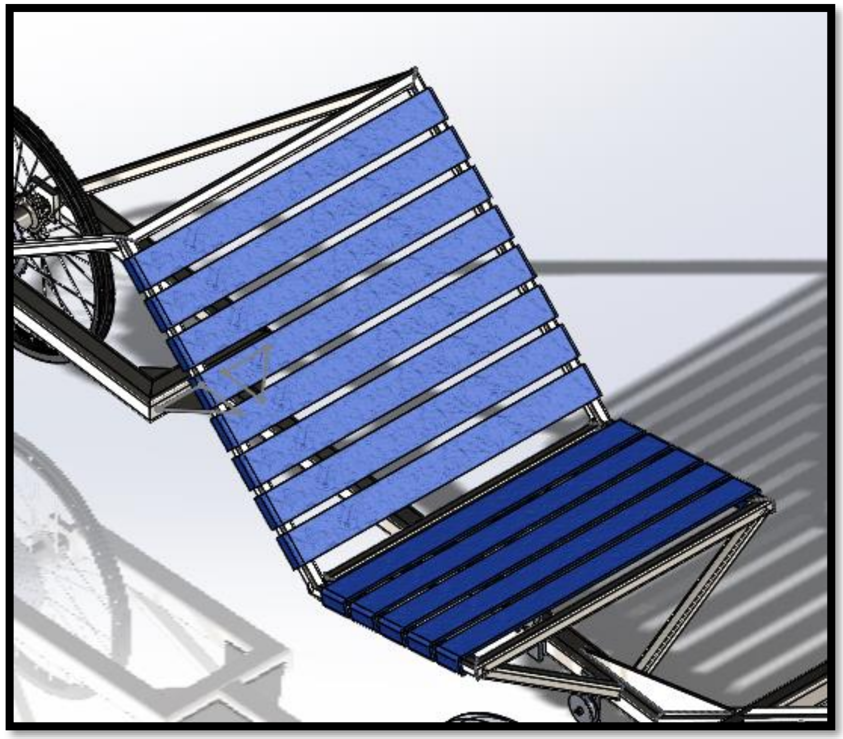
The end user cares most about reliability and cost when considering the suspension of the vehicle. They also care about the dampening effectiveness to a lesser degree. Because this vehicle is meant for road application the dampening effectiveness is desired for comfort over performance of the vehicle. The cost of the vehicle would grow not only as a result of the components added to the suspension system, but also as a result of frame complexity. When adding more complex suspension systems to the vehicle the frame will have to have added control arms or pivot points to allow for this motion. In an effort to keep the cost down the selection of the suspension system was chosen with these characteristics in mind.

Suspension Design Selection

		In-Seat Suspension		Shock and Damper		Torsion Bar	
Characteristics	Weights	Ranking	Weighted Rank	Ranking	Weighted Rank	Ranking	Weighted Rank
Reliability	0.35	4	1.4	3	1.05	4	1.4
Added manufacturing complexity	0.3	3	0.9	2	0.6	2	0.6
Material Cost	0.2	4	0.8	2	0.4	3	0.6
Dampening Effectiveness	0.15	1	0.15	4	0.6	2	0.3
	1		3.25		2.65		2.9

0: Unreasonable
1: Unsatisfactory
2: Poor
3: Acceptable
4: Good

Solid Model Assembly

Loading Conditions

It was determined that the loading conditions for this suspension system would be the load of the rider under impact. Impact was chosen due to the assumption of sudden jerking when going over bumps in the road. With the frame and steering components being rigidly fixed the absorption of motion would have to be considered in the seat. It is assumed that the seat only supports the rider and the force from pedaling is negligible to the loading.

It is also assumed that the bands will be manufactured to have a 15° angle in them from the thigh of the rider to the beam of the seat when loaded with the rider. This assumption is based on the expectation that the material the seat is assembled with will be installed taught. The angle of 15 degrees was chosen as a conservative slight angle. With these assumptions in place the loading condition is readily calculatable.

The load of the rider was assumed to be 1224N in weight (approximately 125kg). The load of the rider is assumed to be evenly distributed along their thighs into the bottom portion of the seat. With the angle of the material and the load of the rider the last assumption to be made is that the load is evenly distributed through the material of the seat, meaning there is no significant friction that would cause one side of the seat to be loaded differently from the other. The assumption of the all the weight of the rider being supported on the bottom of the seat is conservative because it is known some load will be loaded on the back of the seat. Due to the variable nature of how much load will be distributed to the bottom vs the back the load was concentrated to the smaller area.

With these assumptions the load calculated to be in the seat material would be 2364N.

Factors of Safety of Concern

The factor of safety that is applied is 12. This is applied to the working tensile strength of the material that will be used. With that being said the bottom of the seat will have to endure a force of 28400N.

Component and Material Selections

The material selection for this design was based on mold and mildew resistance, tensile strength, abrasion/UV resistance, elongation resistance, and flexibility with weights of 0.25, 0.30, 0.15, 0.15, and 0.15 respectively. These were chosen due to the customers desire for reliability and low maintenance. If a material does not meet a high enough tensile strength it will tear prematurely; this is not acceptable. This vehicle will be ridden and likely stored outside so if the material is susceptible to UV degradation the seat will fail prematurely. The rider should be confident that their clothing choice will not wear or rip the seat and cause it to fail while riding. The seat should not over elongate and call for tensioning or new material because that will lead to an excess maintenance.

To look at the possibility of different types of webbings three common webbing materials were selected to be analyzed: Nylon, Polyester, and Polypropylene. After ranking these materials against each other in the following table Polyester webbing was selected as the prime material to be used for the webbing material of the seat. Polyester and Polypropylene are more resistant to mold and mildew when compared to Nylon even though Nylon is resistant when compared to other cloth and mesh (20). Nylon and Polyester have greater tensile strength when compared to polypropylene (21). Nylon is stretches more than polyester as Nylon absorbs water where Polyester and Polypropylene do not (20) (22). This stretch in Nylon gives it more flexibility and "retracts a good percentage of its stretch", but also lends it to have elongation over time (23). Nylon webbing will elongate about 10% while Polyester webbing will only elongate roughly 3% (23). Nylon is less resistant to "pilin, which causes the fabric to fray at the seams" when compared to Polyester (20). These frayed ends would lend to tearing with the friction of a rider. Nylon and Polypropylene are susceptible to UV degradation where Polyester is not (20) (23). This degradation causes discoloring as well as some strength diminishes.

Material Selection

		Material #1		Material #2		Material #3	
		Nylon Webbing		Polyester Webbing		Polypropylene	
Characteristics	Weights	Ranking	Weighted Rank	Ranking	Weighted Rank	Ranking	Weighted Rank
Mold and Mildew Resistance	0.25	2	0.5	3	0.75	3	0.75
Tensile Strength	0.3	4	1.2	4	1.2	2	0.6
Abrasion/UV Resistance	0.15	2	0.3	3	0.45	1	0.15
Elongation Resistance	0.15	1	0.15	3	0.45	2	0.3
Flexibility	0.15	3	0.45	2	0.3	2	0.3
	1		2.6		3.15		2.1

0: Infeasible
1: Unsatisfactory
2: Poor
3: Acceptable
4: Good

From this comparison Polyester was chosen as the optimum material. The webbing for the seat will be purchased from a vendor, StrapWorks. The exact material will be solid color utility webbing 2" in thickness with a maximum working load of 8900N and a breaking load of 26700N (26). With these numbers the bottom of the seat will need no less than 4 bands of webbing.

Fabrication and Assembly

Drivetrain

Rear Wheel

Wheel and hub must be spoked together. This is done by first lacing the wheel (ie. getting the spokes and nipples in place). During this process the spokes must be routed correctly, and this wheel was laced in a standard “cross three” configuration. With this wheel there are 36 spokes, 18 spokes per side; each side has 9 spokes oriented clockwise and 9 oriented counterclockwise. Cross three configuration is called such because each spoke overlaps 3 spokes that are in the opposite direction. After the lacing of the wheel is completed the spokes must be tensioned. This is done in such a fashion that the spokes have the same tension throughout, the rim is true about the axle, and the spokes are impacted to help them hold their new location.

After the rear wheel is assembled a rim cover must be put into place. The purpose of this is to cover and smooth the holes in the rim that can puncture the inner tube of the tire. After this is put into place the tire and inner tube is assembled onto the wheel. Once this is completed the tire is inflated to the recommended specification.

Once the wheel is assembled the sprockets must be attached. The Shimano 8 speed cassette has grooves that only align with the Shimano hub one way. These cogs are slid into location and the locking nut is torqued down. Specialty tools are required to achieve this as the hub will rotate with respect to the wheel. A special wrench is used to hold the cassette stationary while a Shimano specific socket torques down this locking nut.

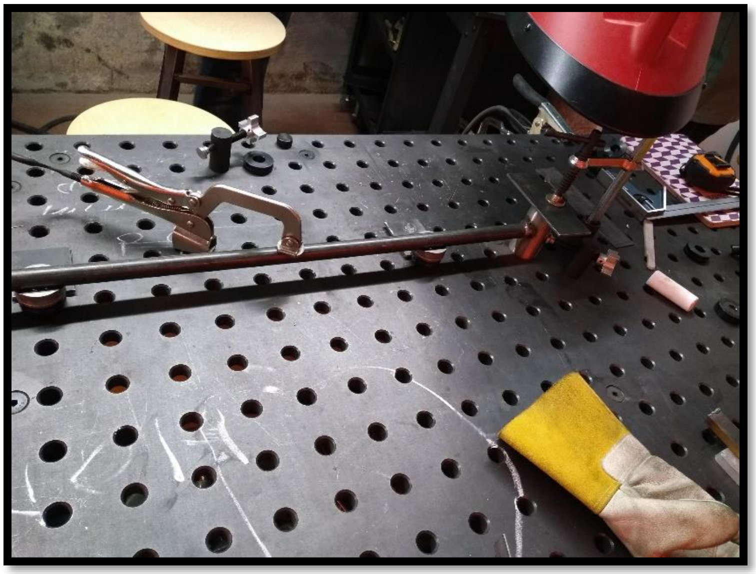
In order to attach the now assembled wheel to the frame, dropouts must be attached. Dropouts are steel pieces that have cut outs for the rear wheel axle, this is a standard bicycle part. MIG welding was the preferred method of attaching these parts. To keep the dropouts in line with each other a scribe mark was made across the two while they were aligned next to each other.

This scribe mark was used to locate the dropout on the frame during welding. The dropouts were held in location using a 90° magnetic block and were visually lined up with the scribe mark. This was to prevent the pull of the weld during the process. The process was mirrored on the other side. Finally, after the dropouts are welded into location the rear wheel can be attached to the frame.

Rear Derailleur

The rear derailleur is attached to the frame at the dropouts. The dropout must be welded to the frame. This is the location that the derailleur and the rear wheel are attached to the frame. To hold the axle of the rear wheel parallel to the ground when riding the dropout must be held in place during welding. This was done in two steps. One, to mark the dropouts to align the slots across the frame. Two, hold the dropouts perpendicular to the ground with a 90° block. After this, a bead of weld was used to fix the parts to the frame using a MIG welder. The rear derailleur is then bolted to the dropouts.

The rear derailleur cable is the connection between the rider's operation and the mechanism. This cable goes from the shifter handle mounted on the steering system, down to the kingpins, and down the frame to the rear derailleur. The cable is enclosed in a cable cover until it reaches the rear derailleur. This cover keeps the tension in the cable over curves and bends. The cable is fixed to the frame using zip ties. Once the cable is routed it is attached to the derailleur by means of a pinching bolt. After the chain is routed through the system, described in detail below, the rear derailleur is tuned using the three set screws to ensure the rider can achieve all gear ratios when shifting. The first two screws ensure that the chain does not exceed the length of the cassette and fall off. The third set screw adjusts the tilt of the derailleur with respect to the frame; its purpose is to allow control of the derailleur sprocket location to ensure that they do not come into contact with the cassette.



Bottom Bracket

The bottom bracket has a shell that is welded onto the extension rod of frame. This shell is welded with a MIG welder and centered of the extension rod. Once the welding is done on the shell the bottom bracket is torqued into place using a specialized bit for Shimano bottom brackets.

Front Derailleur

The front derailleur is attached to a stem on the bottom bracket shell. This stem is a 1 3/8" in OD steel tube and is welded in a similar fashion to the bottom bracket shell to extension weld set up. This weld is a continuous MIG weld around the base. The extension had to be shaped to fit up against the bottom bracket shell. To accomplish this the extension pipe was cut using a hole saw and a drill press.

Once the extension rod is in place the front derailleur is clamped around the extension and adjusted to be parallel with the crank set and located to access the highest gear and lowest gear. There are two set screws on the front derailleur. One adjusts the amount the derailleur is able to retract to the smallest gear and the other adjusts the amount the derailleur is able to extend to the largest gear. The torsion spring in the derailleur body hold the derailleur at the most retracted point. The tension in the shifting cable pulls the body so that it extracts. As one shifts the tension increases and the rider can shift between the front, three gears.

The shifting cable has to have a stationary point to pull on the derailleur from. To accomplish this a connection piece was welded onto the extension. This was a small piece of metal with an opening large enough for the cable to pass through and small enough to catch the cable cover. This piece of metal was MIG welded onto the extension pipe directly below the derailleur.

The shifting cable was routed from the handle bar, where the shifting handle is connected, down to the kingpin to the center bar of the frame and routed to the front derailleur from there. From the center of the frame to the derailleur enough slack must be given to allow the pedal lengths the ability to be adjusted. The shifting cable had to be covered from the shifting handle to the piece of metal on the extension in order to maintain tension around curves. After this point the cable extends past the cover and connects by pinch bolt on the derailleur. The cable must be connected and rest in tension in order for shifting to be possible.

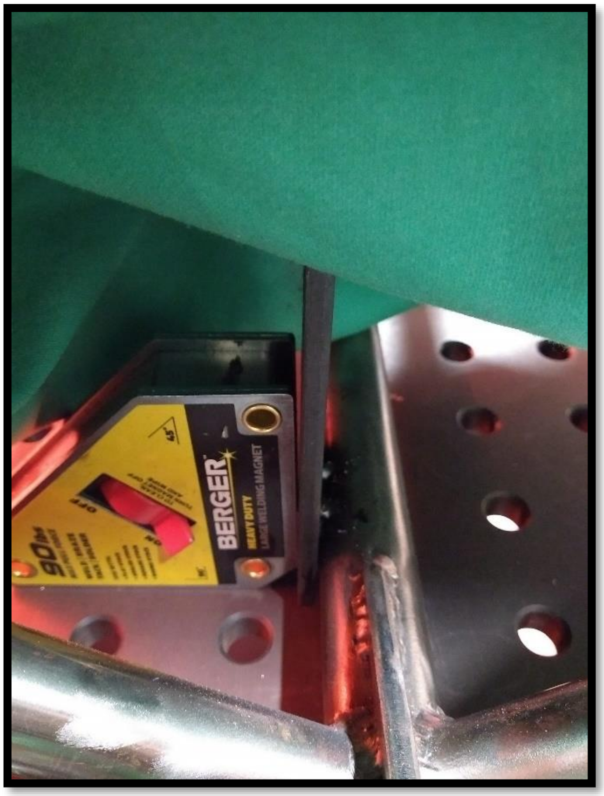
Front Pedals and Chainrings

The chainring and crank arms are connected to the bottom bracket through bolting. This bolt along with the square tapered axle fixes the crank arms to the bottom bracket. The pedals are then assembled to the crank arms. These pedals are threaded into the crank arms. The pedals have a left-hand and right-hand side that changes the direction of the threads, this is considered when attaching the pedals.

Chain

The chain is longer than a standard bicycle chain and to accomplish this, four bicycle chains had to be connected using master links. This method is the simplest way to connect chain and the tension inherently in the system insures that the links do not come undone. Once the four chains are connected the crank set must be locked into location. The chain routing has to be done after this.

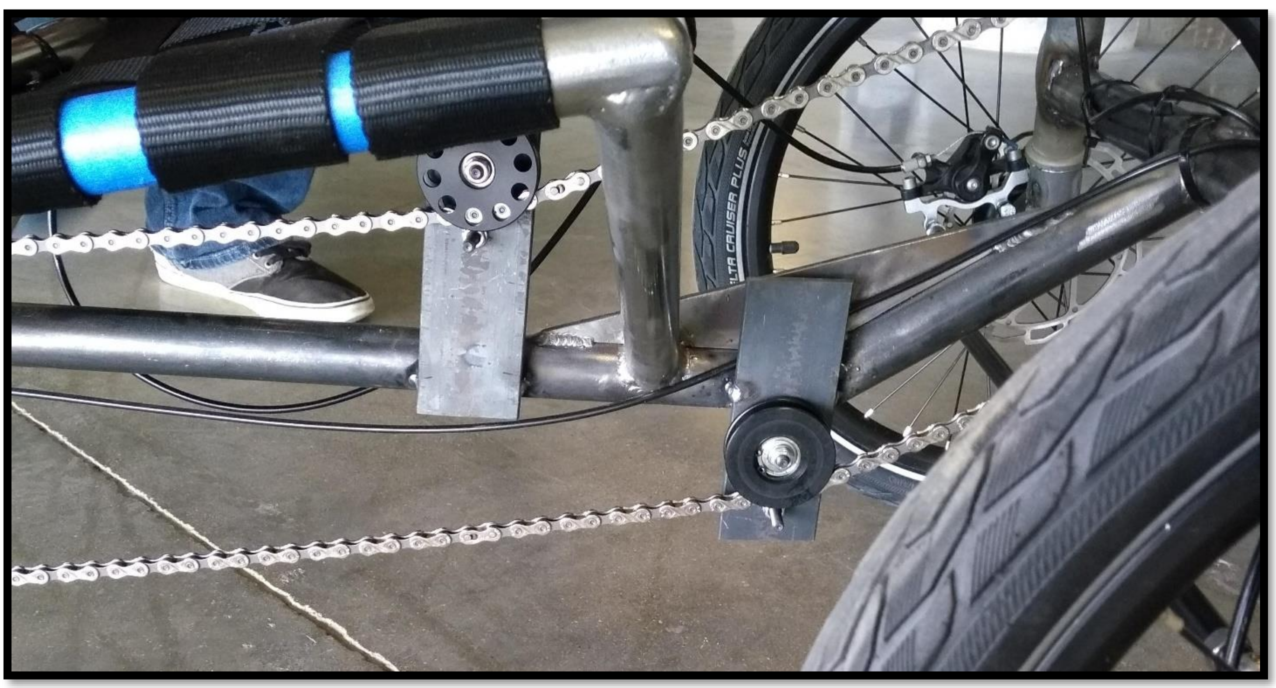
The two pieces of the chain routing that remain to be installed are the idler pullies. The purpose of these pullies is to guide the chain around the bottom of the seat and frame to prevent rubbing on the tension side and excessive slack on the non-tensioned side of the chain. These pulleys are attached to plates that are attached plates that are attached to the frame. These plates are carbon steel with 8mm holes drilled in the location of the pullies and one outside the outer diameter of the pullies. The pullies are attached to the plates with 6mm bolts. The bolt goes through the plate with washers on both sides of the plate. A bolt is threaded onto the bolt to secure it to the plate. Then, a washer, a pulley, and a washer are put onto the bolt and torqued down with a nut to secure the pulley. A bolt is attached at the other hole in a similar fashion to prevent the chain from falling off the pulleys.



Once the plates are shaped and drilled, they are attached to the frame. To do this the frame is put onto a welding table. The plates are held with a 90° magnetic block and tack welded to the round pipe. After this the pulleys are bolted as previously described.

The chain is then routed through the rear derailleur, around the cassette, through the tension side pulley, through the front derailleur, and through the non-tension pulley side. The chain is pulled to the correct tension and the chain is broken. This is done with a standard bicycle chain breaker to remove links. Once the excess links are removed, the two ends of the chain are attached using the chain breaker again.

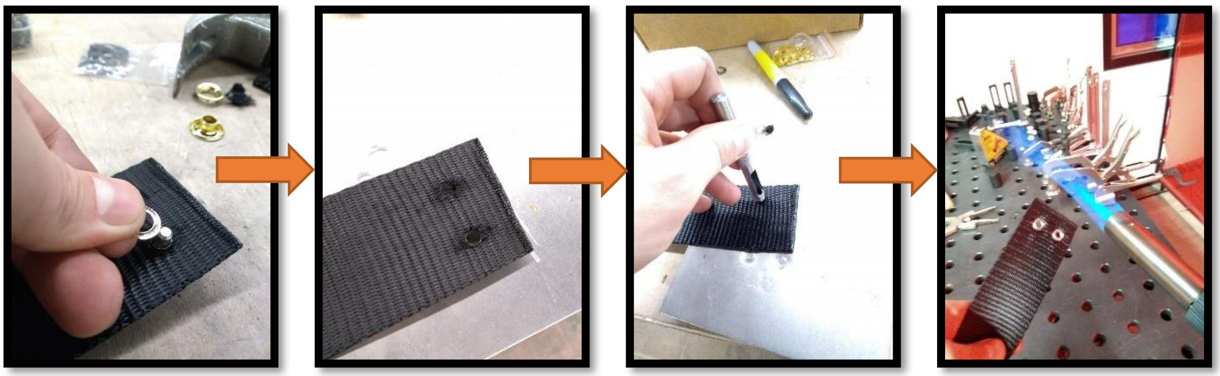
After riding the vehicle, it was notice that there was rubbing on the frame by the chain when on the smallest cog in the cassette. To remedy this the frame was filed to smooth the location of rubbing and allow the chain to slide over this surface without taking on damage.



Suspension

The shorter suspension straps are measured to length by wrapping them around one tube of the seat, pulled along seat, and wrapped around the other end of the seat. Once these pieces are cut to length they need to be treated with a blow torch to prevent fraying at the ends. Next, a punch is used to create two holes on both ends of the bands. These holes are then grommeted using ¼” grommets and the associated tooling. After this, the gromet locations are heated with the blow torch to prevent fraying. Once this is done the bands are held in place on the seat and locations are marked at the grommets. These holes are then drilled with a 3/16” drill bit. This generates the guide hole for the self-drilling screws. The self-drilling screws go through the opening in the grommets and into the frame to secure the band to the seat.

After attaching all the shorter bands to the seat, the longer bands need to be created and attached. The longer bands are cut to length by wrapping them around the horizontal tube of the seat (either on the bottom or the top), weaved through the existing bands, behind the horizontal bar at the back of the seat bottom and around the other end of the seat. Once the length is established the band is cut and attached in the same way as the previous banding.



Testing and Proof of Design

Drivetrain

The drivetrain will require three tests. These tests will verify that the rider can reach all gears, that the gear ratios allow the rider to reach a speed of 8.9m/s on flat land, and can hold up to 32km of travel.

Title	Purpose	Method	Results
Gear Availability	To ensure the derailleurs are shifting properly and to all gears.	Shift through all gears while pedaling stationary and shifting through gear ratios during ride.	Passed: all gear ratios were achieved
Lowest Gear Ratio	To ensure that the lowest gear ratio is low enough so that the rider can go over terrain.	Ride the trike up a 10° minimum hill.	Passed: a rider went up a 26° incline during testing
Highest Gear Ratio	To ensure that the highest gear ratio allows rider to pedal at 8.9m/s.	Rider pedals on flat ground and must reach 8.9m/s on bike odometer.	Passed: the rider passed 8.9m/s while riding on flat land
Endurance	To test that the components hold up to reasonable usage.	A rider rode 20km on streets and 4km on smooth land.	Passed: no noticeable signs of wear or damage.

The drivetrain allowed the vehicle to achieve 8.9m/s on flat land when starting from rest, scale a 10° incline, and shift through all 24 gears. All tests were run on the same day. After the drivetrain was assembled there was a test to shift through all gear ratios. There were adjustments made to the derailleurs per manufacture instruction until this was achieved. Then, during a test ride after all essential aspects to ride are assembled a test rider will shift through all gear ratios. This is not a test of speed therefore it can be running while riding downhill. Because all the gear ratios were achieved during this test it was a success. Next, all essential aspects to ride were assembled and a test rider rode as fast as they can on flat ground. A bicycle speedometer was attached to the vehicle and the rider recorded the max speed that they achieved, this was 10.5m/s. Because the vehicle traveled at a speed greater than 8.9m/s this test was a success. To verify longevity of the drivetrain a sum total of 24km were ridden with the vehicle. A test rider rode the vehicle and recorded the distance that was traveled. This distance was be measured using an odometer designed for bicycles. Because no damage or failures were observed during or after the ride this test was a success. The vehicle was ridden around Evanston, Avondale, and East Walnut Hills.

Suspension

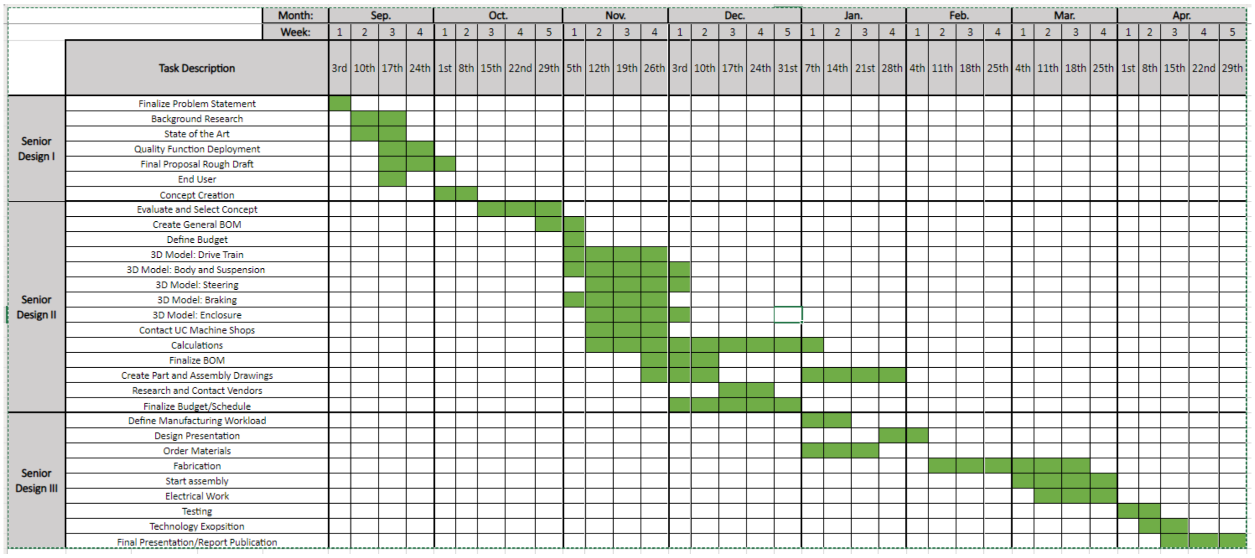
To test the suspension there will be two simple tests: endurance and impact. To test the longevity of the suspension a sum total of 24km were ridden with the vehicle. A test rider rode the vehicle and record the distance that was traveled. This distance was be measured using an odometer designed for bicycles. The vehicle was ridden around Evanston, Avondale, and East Walnut Hills. Because damage at the grommets of the bands were observed after the endurance test the impact test was not ran for safety reasons.

Title	Purpose	Method	Results
Endurance	To test that the components hold up to reasonable usage.	A rider rode 20km on streets and 4km on smooth land.	Failed: fraying was spotted at the grommets.
Impact	To ensure that the seat can support the impact of the rider.	A 125 kg rider will drop their body roughly 25cm to the bottom of the seat.	N/A: Test was not ran due to damage

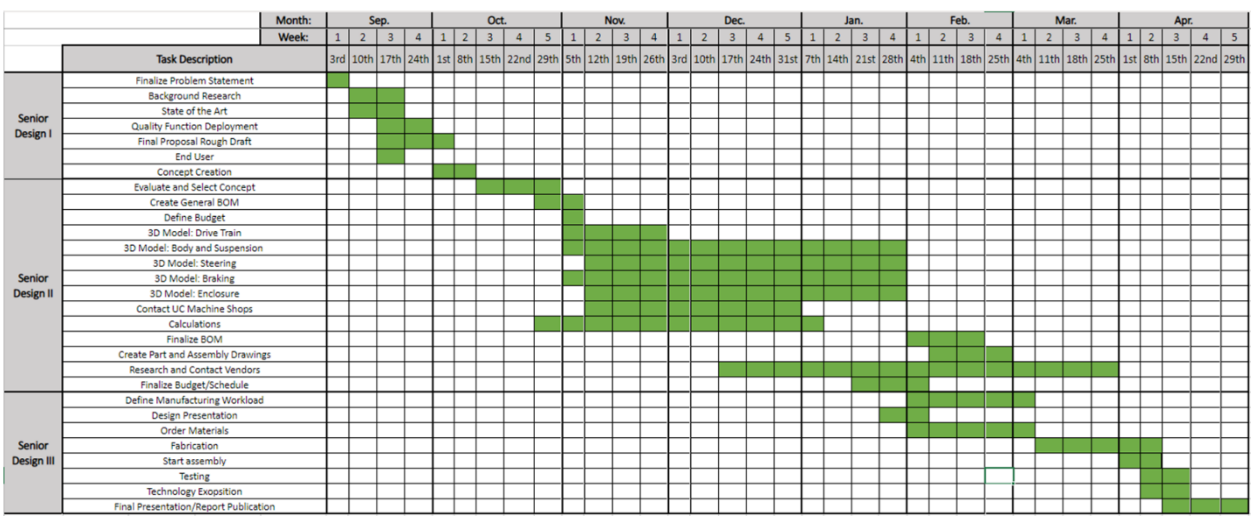
Project Management

Schedule Discussion

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 unforeseen, miscellaneous hardware and small part.

Budget Discussion

With the planned fabrication of the systems the budget is broken down as follows.

Planned Budget

Sub-System:	Item:	Value ($):
Suspension	Banding	60
	Hardware	10
Drive Train	Rear Wheel	85
	Cranks	50
	Hardware	175

Actual Budget

Subassembly	Item Name	Vendor Name	Cost (USD)
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	$ 22.50
Drivetrain	Crankset	Universal Cycles	$ 58.84
Drivetrain	Chain	Amazon	$ 35.98
Drivetrain	Idler Sprocket	Amazon	$ 16.95
Drivetrain	Idler Pulley	Amazon	$ 13.95
Drivetrain	Bottom Bracket	Amazon	$ 12.95
Drivetrain	Dropout	Paragon Machine Works	$ 20.50
Drivetrain	Dropout Connection	Paragon Machine Works	$ 20.50
Drivetrain	Bottom Bracket Shell	Frame Builder Supply	$ 12.28
Drive Train	Wire covers	Spun Bicycles	$ 30.00
Drivetrain	Shifters	Amazon	$ 30.90
DriveTrain	Chain	Amazon	$ 53.92
DriveTrain	Chain Breaker	Amazon	$ 6.99
		TOTAL	$ 445.22

Subassembly	Item Name	Vendor Name	Cost (USD)
Suspension	Bands	Strap Works	$ 73.99
Suspension	Screws	McMaster-Carr	$ 17.58
Suspension	Grommet Tool	Amazon	$ 10.00
		TOTAL	101.57

The suspension budget went over by 30$ and this is mostly due to under estimated cost of self-drilling screws as well as shipping costs. The drivetrain budget is 135$ over budget; this is due to a couple of reasons. The cost of shipping was much higher than originally expected, which lead to roughly 50$ in shipping throughout the project. Another hurdle was that vendors did not supply the parts that were priced in the early days of budgeting when trying to purchase them weeks later. This was seen in sale prices ending, parts not being able to be shipped, and parts being discontinued from manufacturing. The rear wheel is a large portion of the budget discrepancy. The wheel was originally planned to be purchased as a singular purchase from Germany, but it was apparent that this company did not ship to the United States when purchasing. This forced the purchase to be of the components and the rear wheel had to be assembled (both more expensive and more time consuming).

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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**

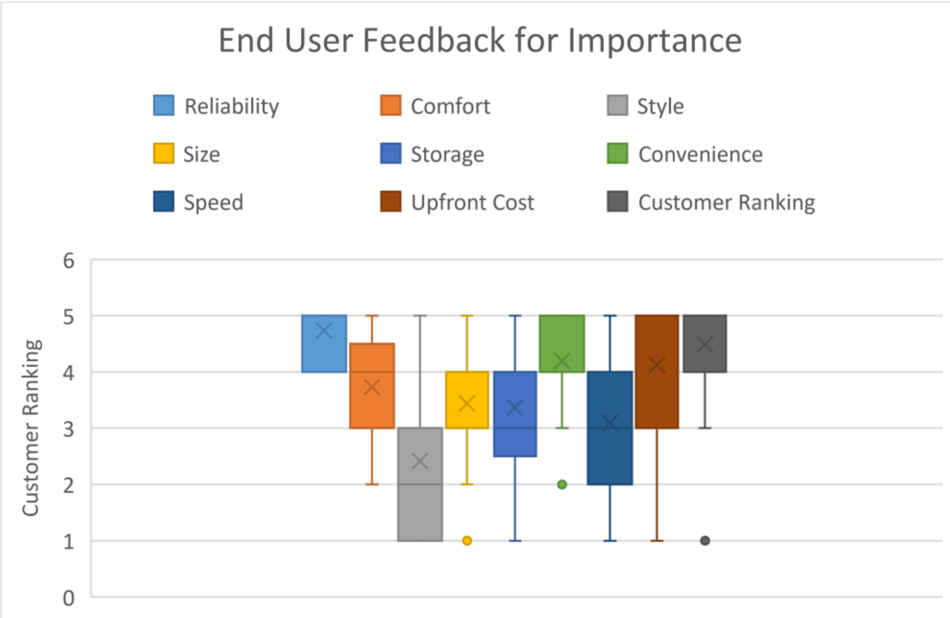
Reliability	1	2	3	4	5
Comfort	1	2	3	4	5
Style	1	2	3	4	5
Size	1	2	3	4	5
Storage	1	2	3	4	5
Convenience	1	2	3	4	5
Speed	1	2	3	4	5
Upfront Cost	1	2	3	4	5
Maintenance	1	2	3	4	5

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

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

Equations/Calculations

Minimum Greatest Gear Ratio

$$\omega_w = 60 * \frac{v_{max}}{\pi * D_w} = 60 * \frac{8.9}{3.1415 * 0.508} = 336rpm$$

v_{max}: maximum velocity on dry land (designed to 8.9m/s)

D_w: wheel diameter

ω_w: rotational speed of wheel while traveling at 8.9m/s

$$G_{r,greatest} = \frac{\omega_w}{\omega_h} = \frac{336\ rpm}{75.0\ rpm} = 4.48$$

ω_h: rotational speed of a human being pedaling

$G_{r,\ greatest}$: minimum greatest gear ratio

Verification that these speeds can be pedaled on flat surface

$$\dot{W}_{human} \geq \dot{W}_{required} \therefore 600 \geq \dot{W}_{required}$$

$\dot{W}_{human}$: Power output by human (determined to be 660W)

$\dot{W}_{required}$: Power output required to ride at 8.9m/s

$$\dot{W}_{required} = \dot{W}_{rolling} + \dot{W}_{wind}$$

$\dot{W}_{wind}$: Power consumed through wind friction

$\dot{W}_{rolling}$: Power consumed through rolling friction

$$\dot{W}_{wind} = v_{max} * F_{wind} = 8.94m/s * 14.4N = 128W$$

F_{wind}: force from wind (assumed a constant 14.4N)

$$\dot{W}_{rolling} = v_{max} * F_{rolling} = 8.94m/s * 20.1N = 180W$$

$F_{rolling}$: force from rolling friction (assumed a constant 20.09 N)

Rolling Friction Information (24)

Conditions	Rolling Resistance Coefficients	Mass of Vehicle (kg)	Weight of Vehicle (N)	Rolling Friction per Wheel (N)	Rolling Friction For Vehicle (N)
Bicycle Tire on Concrete	0.002	182	1785.42	3.57084	10.71
Bicycle Tire on Wooden Track	0.001	182	1785.42	1.78542	5.36
Bicycle Tire on Asphalt Road	0.004	182	1785.42	7.14168	21.43
Bicycle Tire on rough paved road	0.008	182	1785.42	14.28336	42.85
*Assume Constant Rolling Restance Coeffients with respect to velociy				Average:	20.09

$$F_{rolling} = c * F_g = c * m * g$$

c: Rolling resistance coefficient

F_g: force from gravity

m: mass of the vehicle and the rider together (182kg)

g: acceleration from gravity (9.81m/s^2)

$$\dot{W}_{required} = \dot{W}_{rolling} + \dot{W}_{wind} = 128W + 180W = 308W$$

$$\dot{W}_{human} \geq \dot{W}_{required} \therefore 660W \geq 308W$$

Maximum Lowest Gear Ratio

Energy to climb a 10° incline at 1.79m/s

$$\dot{W}_{required,incline} = \dot{W}_{rolling,incline} + \dot{W}_{wind,incline} + \dot{W}_{gravity,incline}$$

$\dot{W}_{wind,incline}$: Power consumed through wind friction

$\dot{W}_{rolling,incline}$: Power consumed through rolling friction

$\dot{W}_{gravity,incline}$: Power consumed through rolling friction

$$\dot{W}_{gravity,incline} = \frac{mgh}{t} = mgv_v = mgv * \sin(\theta) = 182kg * \frac{9.81m}{s^2} * \frac{1.79m}{s} * \sin(10°) = 553W$$

m: mass of vehicle and rider (assumed 182kg maximum)

g: acceleration due to gravity ($9.81m/s^2$)

v_v: vertical velocity

v: velocity of vehicle going up incline (1.79m/s)

θ: degree of inclination (10°)

$$\dot{W}_{wind,incline} = v * F_{wind} = 1.79m/s * 14.4N = 25.7W$$

F_{wind}: force from wind (assumed a constant 14.4N)

$$\dot{W}_{rolling,incline} = v * F_{rolling} = 1.79m/s * 20.1N = 35.9W$$

$F_{rolling}$: force from rolling friction (assumed a constant 20.09 N)

$$\dot{W}_{required,incline} = \dot{W}_{rolling,incline} + \dot{W}_{wind,incline} + \dot{W}_{gravity,incline} = 553W + 25.7W + 35.9W = 614W$$

Verification that this can be achieved

$$\dot{W}_{human} \geq \dot{W}_{required} \therefore 660W \geq 614W$$

Rotational speed of the wheel

$$\omega_w = 60 * \frac{v}{\pi * D_w} = 60 * \frac{\frac{1.79m}{s}}{3.1415 * 0.508m} = 67.2rpm$$

D_w: wheel diameter

ω_w: rotational speed of wheel while traveling at 8.9m/s

$$G_{r,lowest} = \frac{\omega_w}{\omega_h} = \frac{67.2\ rpm}{60\ rpm} = 1.12$$

ω_h: rotational speed of a human being pedaling

$G_{r,\ lowest}$: maximum lowest gear ratio

Loading on axle of rear wheel

Governing Equation for Bending Stress

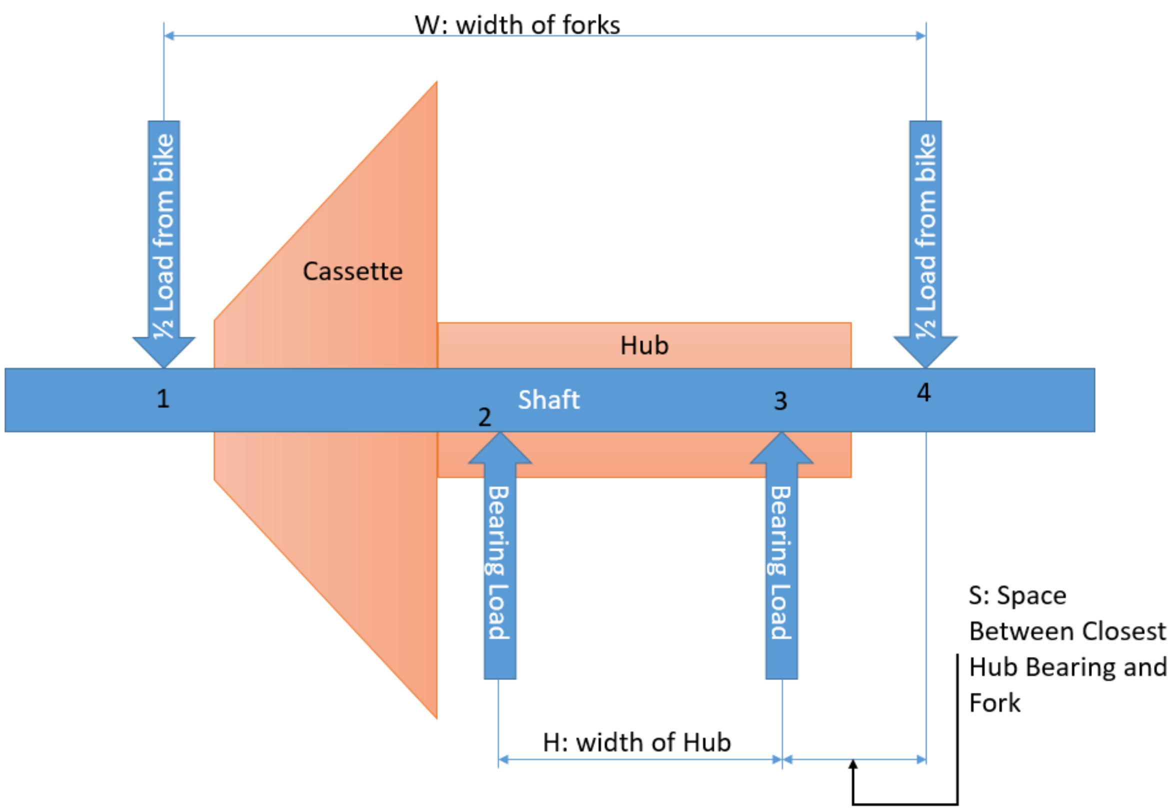
$$\sigma_B = \frac{M}{S}$$

M: max bending moment (Nm)

S: Section Modulus (m^3)

σ_B: max bending Stress (Pa)

Estimated Loading scenario (25)



W=135mm

H=88mm

S=22.5mm

Load from bike=630N

Seat Stress Calculation

Bending Moment

$$M = F * x$$

M: Bending Moment

F: Force

x: Displacement

Bending Stress

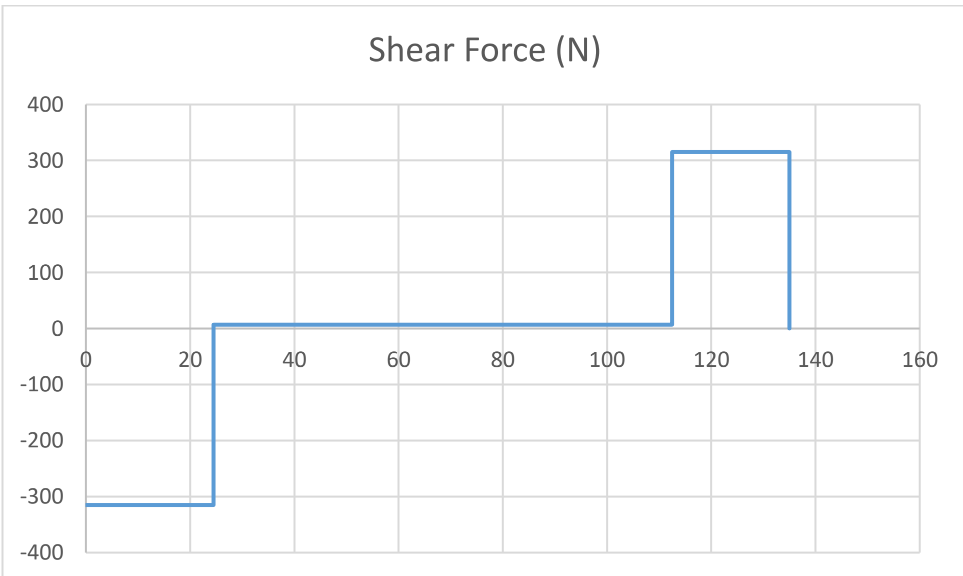
$$\sigma_B = \frac{M * y}{I}$$

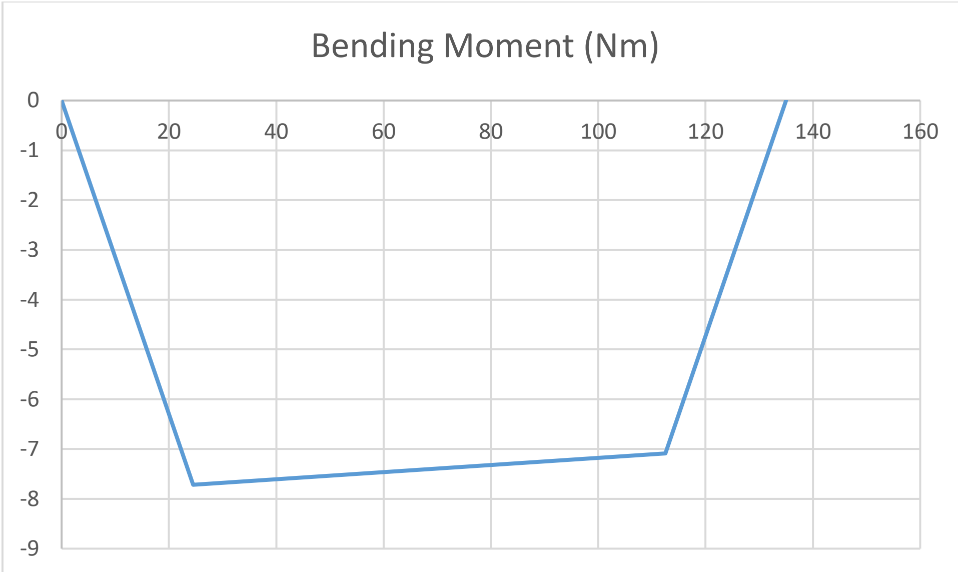
σ_B: Bending Stress

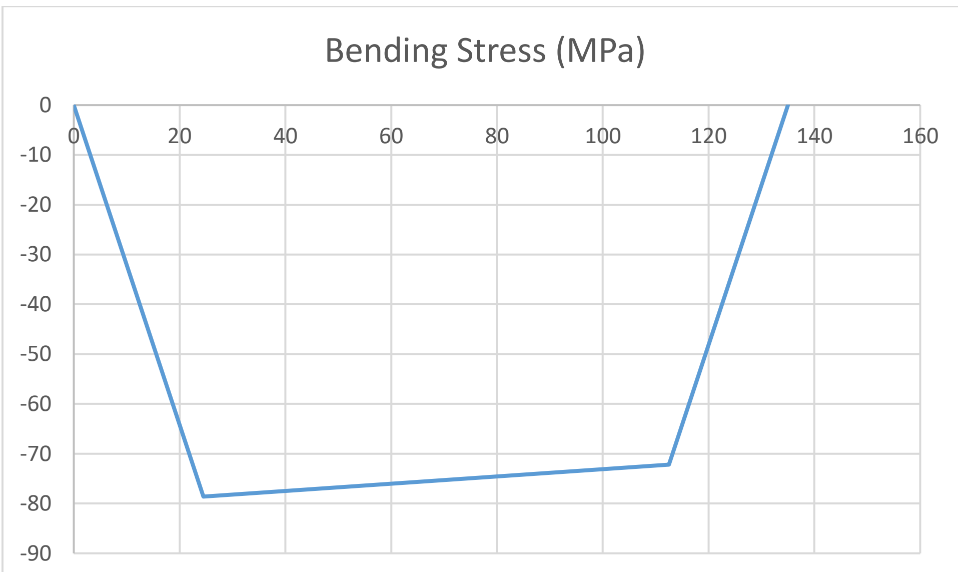
M: Moment

y: Maximum displacement from neutral axis

I: Moment of Inertia about neutral axis




Bending Moment (Nm)
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
0
20
40
60
80
100
120
140
160


Bending Stress (MPa)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
0
20
40
60
80
100
120
140
160