ME 423: Engineering Design VII
Statically Stable Personal Urban Transportation Vehicle

Phase 1 Report

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I pledge my honor that I have abided by the Stevens Honor System

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Abstract

As modernization continues to expand and improve society, we can see that the rise of urban environments are increasing globally. These population dense environments will require transportation in and out, as well as within. Thus, it's important to provide society with methods of transportation that prove to be convenient and compatible in everyday life. Many companies have already jumped on the wagon to develop urban transportation vehicles through the development of the ride-share system that proliferates in cities like New York City and Los Angeles and personal transportation vehicles (PTVs). This upcoming means of transportation can be used in place of common day methods such as driving a car or taking public transportation. The drawbacks of current failing products are due to several factors such as safety, handling, or even portability. This senior design project will serve to develop and create a statically stable urban transportation vehicle by using various engineering systems to optimize performance for everyday commuters. In doing so the team will analyze a variety of automotive systems and principles such as braking systems and turning radius and its impact on steer. The vehicle will perform well in various urban conditions, providing riders of all ages with a safe, affordable, sustainable, and high performing experience.

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Project Description

Motivation

There is a growing need to use efficient and effective ways of transportation in urban environments. To get from place to place, people are mostly driving cars, taking public transportation, or walking. However, as society becomes more technologically advanced, solutions are constantly being developed to offer a smarter and dynamic way to get around. Electric personal transportation vehicles (PTVs), such as electric scooters, skateboards, and Segways are becoming an increasingly popular method for going from point A to point B. While appealing more so to a young demographic, older consumers are not entirely convinced that these devices are the answers to their transportation needs with concerns stemming mostly from potential safety risks.

Goals and Objectives

The goal for this project will be designing a safe and stable personal-urban-transportation vehicle that optimizes urban environments such as cities. Ideally, the device's design and features will attract a wider audience of consumers that were not satisfied by what is on the market today while also being a novel option for current users. It is the team's objective to have constructed and tested an alpha prototype by the Senior Innovation Expo in May 2021, depending on the university's reopening plans for the spring semester. Since the mechanical engineering senior design layout involves six major phases for the project, there will be several reports and presentations that will have to be completed throughout.

Potential Design and Analysis Issues

The concept of an electric scooter is not a foreign concept as all members of the group have had personal experiences regarding these vehicles through either the rideshare system that proliferates in urban environments or through other personal vehicles. However, when tasked to construct such a device, there are many concepts to consider. At several times in the design and analysis process, the group faced challenges in which additional research and problem solving was required.

The first major issue concerned itself with the urban environment that the PTV was to be designed for. Urban environments pose several practical challenges that the group's device was to overcome. This includes developing concepts that consider the uneven terrain that is common city streets such as potholes, curbs, and speed bumps. Without proper suspension from a suspension system the vehicle would be unidable in such environments as the curbs and bumps would cause great uncomfort to the user as well as compromise the safety of the ride. In addition to this, tires also provide the vehicle with natural suspension. However, while larger and wider wheels and tires allow for greater clearance of obstacles, the negative is that such components add considerably to the total weight of the vehicle. Weight is also a critical parameter as portability is key in urban environments specifically. As commuters often require vehicles that can be easily transported when not in use. For example, a commuter may also need to use the metro system in conjunction with the PTV. It is not practical to consider that a commuter is willing to carry an exceptionally heavy device through the metro system. Finding a balance between negatively correlated parameters such as tire size and total weight is key to the product's success.

Another major challenge was the implementation of safety devices and design language into concepts that are largely automotive. As the primary stakeholder of the group's PTV are adults ages 30 and over, safety is a leading priority. Safety mechanisms in automotive vehicles include suspension and steering, translating these mechanisms into a PTV posed several challenges. As stated previously, weight is a critical parameter, and the inclusion of the safety mechanisms often increases the weight and uses limited real estate on the body of the PTV. Static stability is one safety feature that the PTV is to include; however with the incorporation of static stability comes the increase in the total points of contact the PTV makes with the ground. This entails the inclusion of three or more wheels. As the inclusion of three wheels being a mandatory design restraint, the group then was tasked to find other ways of decreasing the total weight and improving portability. Other factors such as aesthetic value and turn radius are not to be compromised as well.

In addition to this, material selection also impacts the weight and safety of the vehicle. As the material of the chassis, deck, and steering system is all likely to be constructed out of the same material, this choice has heavy implications on the final product. Material properties such as modulus of elasticity, hardness, yield strength, heat conductivity, and corrosion resistance were all in consideration when selecting such material. As the PTV is to be used in rainy weather, corrosion resistance is a key necessary. At the same time, the yield strength, hardness, and modulus of elasticity all pertain to the maximum payload the vehicle can withstand.

Potential Prototyping and Experimentation Issues

The project will possibly present many prototyping and experimentation issues, largely due to the fact that the world is still in the midst of a global pandemic. It is currently unknown if students will be allowed to return to campus for the Spring 2021 semester. The senior design project will have to keep progressing until May 2021 so it will certainly be challenging to construct an alpha-prototype if team members cannot not physically meet and work hands on. Specifically the machine shops and 3D-printing labs will be barred from usage on campus if the current situation persists. Although the Design-Space Lab is accessible remotely with user submitted parts, collaborating remotely on a project that is largely graphical poses its own sets of problems. These include proper tolerancing and compatibility with respect to one another's parts and assemblies. With the ongoing pandemic, it will also be difficult to order and receive design parts on time due to potential huge delays in shipping and production. The team will combat this by ordering as soon as possible whenever final parts and materials are decided, preferably at the end of Phase 3. After the winter break, the team should have received their parts and can be immediately ready to start construction for Phase 4.

If it is deemed by the university that students cannot return for the spring, then a virtual alpha-prototype will most likely have to be created using highly detailed computer-aided draft(CAD) models and other software platforms. Programming and circuit modeling will have to be carried out to ensure the electrical functionality of the prototype which can pose to be a challenge. CAD simulations will have to be thoroughly performed if physical experimentation cannot occur. The team will also have to decide what types of experiments constitute proper testing of an electric PTV with consideration to factors like speed, weight, turning ability and durability. The team will have to confirm the safety and stability of their electric PTV design.

Literature Review

State-of-the-Art Analysis

As part of the ongoing investigation and research process of developing a statically-stable personal-transportation vehicle, discovering pre-existing products that share similar marketplaces is imperative to product success. By locating competing products, the group can take inspiration from these products as well as improve on areas where other companies may have compromised. The group has analyzed the following six urban-transportation devices that currently occupy the market or are expected to in the coming years and compiled then in Table 1 below. The color indicators represent product tiers with respect to price: *Red* refers to high-tier products, *Yellow* refers to mid-tier products, *blue* refers to low-tier products, and *grey* refers to products currently in development. Important specifications are listed in Table 1 as well. More detailed descriptions of each product can be found below as well. Other specifications of the products examined include the price, maximum operational time, operation size(when in use), and collapsibility. These parameters are critical for the group to consider as they coincide directly with customer needs. The group will also use these parameters to compare between generated concepts in the concept generation and combination phases.

Table 1: State of the Art Product Specifications

Product Name	Price(USD)	Max Run Distance(mi)	Weight (lbs)	Operational Size (*l* * *w* * *h*)	Collapsable
Relync R1	3300	18	55	43" x 21.6" x 35"	Yes
Stator LE	3995	20	90	68” x 16” x 46”	Yes
Comfy Go	1129	25	63	40″ x 21″ x 35″	Yes
Ninebot S	489.99	13.7	28	22.7”×11”×24.4”	No
fuRo CanguRo	N/A	N/A	141	~23” x _” x _”	Yes
Yamaha Tritown	N/A	20	88.2	44.9” x 24.4” x 4 4.9	No

Product 1: The Relync R1

Figure 1: Relync R1-Three Wheel Design

Straying from the transitional bipedal design of most electrical scooters, the Relync R1 boasts a three-wheel design for static stability as well as a collapsible seat with a backrest. In addition to this, this design is collapsible. As seen in the image above, the vehicle is able to transform into a luggage shape and is easily transported around by simply dragging it along as one would for luggage. The top speed of this device is estimated to be only 8 miles per hour. This specification is done on purpose as the target market of this device is for those who require aid in basic travel(for road, urban, and indoor use). For example, a potential buyer may be an individual who may have walking impediments or chronic pain(older demographic). Although this product coincides with our intended audience, this product has a much narrower demographic and it is priced at 2600 GBP(approx. 3300 USD). Other limiting specifications include its 18 miles per charge limit which limits the commuting distance for individuals(also may degrade over time). The dimensions of this scooter is 43" x 21.6" x 35” when in use; however, when the scooter is collapsed into its portable form-factor, the dimensions reduce to 23.6" x 21.6" x 11".

Product #2: Stator LE Scooter

Figure 2: Stator LE-Lowest center of Gravity

The Stator LE takes another approach to solving static instability by using large front and rear wheels in this bipedal design. As these tires have an 18-inch diameter and a width of 7.8 inches, this product can remain standing without a kickstand. These tires also allow for this scooter to handle more challenging road conditions. While this scooter does not utilize any sort of advanced suspension system, the shape and size of the tires alone compensate. Another defining characteristic of this product is its power and performance as it is capable of reaching speeds up to 30 miles per hour. While the performance is staggering, the drawbacks of such power come at the cost of weight and thus portability. The Stator LE weights 40.8 kilograms(90 pounds) making it among the heaviest bipedal scooters on the market. Other specifications include a choice of two battery sizes that correspond with 10 and 20-mile maximum travel distances respectively. The form factor for this device is 68” x 16” x 46” when in use; however, the handle-bar can be folded down to reduce the total height of the vehicle when not in use.

Product #3: Comfy Go Foldable Mobility Scooter

Figure 3: Comfy Go Foldable Scooter

The Comfy Go Foldable Mobility Scooter is an electric sitting scooter retailing at $1,129. This product emphasizes that the structure is stable and suitable for all age groups. However, as this company primarily produces products catered towards medically-disabled individuals, the product shares similar design language with such products. The scooter can travel approximately 25 miles on a full battery, depending on the ride factors, with a max speed of 12 mph. There are only three speed levels consisting of 3.75 mph, 7.5 mph, and 12 mph. The size of the product is 40″ x 21″ x 35″. The primary feature of this scooter is the ability to fold (advertised as in 5 seconds) which reduces the dimensions to 21.5″ x 14.5″ x 27″. The scooter weighs 63 lbs, including the battery, which makes it relatively lightweight for the consumer to carry around. Charge time for the battery takes between 5-8 hours. This vehicle differentiates itself from regular scooters by having a comfortable seat for the ride, as well as a separate children's seat. The foldability is most likely the most appealing feature since the entire product seems extremely compact considering there are two seats, an adjustable steering bar, and large headlight/taillights.

Product #4: Segway Ninebot S

Figure 4: Segway Ninebot S

The Segway Ninebot S is a safer take of the hoverboard due to the detachable knee control bar for greater support. It has a travel range of 13.7 miles with a max speed at 10 mph. The Ninebot S is lightweight at just 28 lbs and small in size to focus on convenient mobility. Its light and durable aircraft-grade magnesium alloy frame supports a payload of 220 lbs. One unique tech feature of this product is its Smart Battery Management System which reports real time status of voltage, current, temperature, usage, battery's status, and potential faults. The Ninebot S can also be controlled through a smartphone app where the segway can be locked, light colors can be adjusted, firmware can be updated, and remote control itself. Safety can be clearly seen as the most emphasized factor in this product. The design of tire texture allows for anti-skid and shock-absorption performances that increases stability during rides.

Product #5: fuRo CanguRo

Figure 5: fuRo CanguRo

The CanguRo by the fuRo company takes a very unique approach in designing an urban transportation vehicle. Choosing to forego the traditional scooter form-factor, this chinese robotics company chose to create this tripedal design that has the user straddle the device as one would a horse. This innovative design allows the front and rear wheels to sit in closer proximity without compromising stability or usability. This design decision also has implications for minimizing its size. As the width of this device is 600 millimeters, it measures to be almost equivalent to the width of a human's shoulders. This vehicle also is collapsible as well as the rear wheels are capable of collapsing inwards to save the user space when not in use. In addition to its design, the ConguRo also boasts lidar technology and is able to detect obstacles such as walls and curbs making it ideal for urban environments where such obstacles are prevalent. The drawbacks of this product is that its top speed reaches only 10km/h(6mi/h) which makes it among the slowest of the products analyzed and can hinder an individual's commuting experience. The weight of the CanguRo is also 64kg(141 lbs) making it among the heaviest to carry. Portability may not be as difficult as it appears as this vehicle has self parking capabilities and can follow the user even when not in use through the use of its lidar capabilities. While currently still a concept, live demonstrations have revealed that such a form factor in combination with the additional functionality and multimedia capabilities, show promising performance in urban environments.

Product #6: YAMAHA TRITOWN

Figure 6: Yamaha Tritown

The Tritown by motor company Yamaha utilizes biomimicry to maximize its performance by initiating how animal skeletal structures contort and shift when undergoing sharp and nimble movements. This flexible frame enables this vehicle to make sharp and precise movements despite its tripedal design without compromising the stability that having three wheels provides. Yamaha accomplishes this feat by engineering the frame of this vehicle to have adaptive capabilities. In use, the vehicle’s frame can be seen physically shifting during the cornering when the user leans to one side. The weight of this vehicle is 40kg(88.2 lbs) and has an estimated cruising range of 20 miles. These promising specifications are also complemented with a high top speed of 15 miles per hour. Although this design boasts many advantages, a large disadvantage of this product is its lack of collapsibility which calls into question the portability of this vehicle as it’s dimensions are 44.9” x 24.4” x 4 4.9”.

Commercial Applications

While there are several existing PTV products on the market, many of the existing electric scooter companies have target audiences narrowed to specific age ranges and implications. Through market research, the group has observed that the majority of PTV scooters target the younger demographic, specifically young adults and teenagers from ages 18-24. The second largest focus group are those with medical implications that prevent themselves from walking or commuting without aid. There seems to be a dearth in PTVs constructed for adults between the ages of 30-40. It is the mission of this project to generate a product that appeals to this target audience previously neglected in the market. This entails engineering a PTV that boasts greater safety options such as the static stability in which the project is centered upon without drawing association with medical-based PTVs as the primary use for this PTV is for commuting. Potential stakeholders in the product include the urban/city resident (primary stakeholder), the department of transportation, and other casual users. More detail on specific stakeholders can be found in the Appendix as Table A-1.

Customer Needs and Specifications

Essentially, the team has the prime objective of creating a design for an electric personal vehicle that is statically stable and safe. The device should offer society a fresh concept of getting around from place to place. Efficient urban transportation is what many city people desire whether it be for work, getting groceries, or daily explorations. Since there are already many different models and designs on the market today, the team aims to simply add another appealing option to fulfill a consumer's transportation needs.

The primary customers for the team's electric PTV are individuals who live in cities that require a reliable vehicle that has high emphasis on safety. They will use the device for general traveling to their workplaces, stores, or when they are just simply out and about. Common errands or daily commuting can be done easily and more efficiently with an electric PTV. The team hopes their vehicle can be an appealing and viable option for the ones seeking such a device. Although it may not be as convenient as if one was living in a city, the secondary market would be any general consumer looking to purchase an electric PTV for hobbying or recreational use. The setting may well be in a suburban or rural area and not as convenient, but any desire for a unique ride experience can be fulfilled through the purchase of an electric PTV. A city commuter relying on safe transportation will definitely have different needs compared to a recreational hobbyist. The team will prioritize people living in large cities as the project description specifically states the design should satisfy urban transportation needs.

With the potential customers identified, it is important to also realize who the stakeholders will be in this project. The purchasing consumers will undoubtedly be the number one stakeholder as their interest ultimately determines the overall success of the project, conceptually and financially. However, the rise of electric PTVs have recently led to new laws and rules being in place to regulate what types of vehicles are allowed and how they can be operated on public streets. This means that the Department of Transportation and any relevant government officials at the state or city level are stakeholders. The team will do the necessary research to ensure their design abides to the current rules and regulations in order to not have any legal issues come up after the product could be theoretically mass produced. Having riders be safe is a primary goal for the project so the team will aim to do so both physically and legally. Another type of stakeholder to consider are the people who will not be riding electric PTVs but still have daily interactions with the technology. The team will greatly consider how their concept will try not to be a nuisance to perhaps regular passerbys or police officers. As with any vehicle, the developers cannot account or strictly dictate how one individual decides to operate the product. It is the hope that consumers will properly use the device and abide by the set rules as to not be distracting or harmful to the public. A formal table describing the project stakeholders can be found in the Appendix as Table A-1.

In order to properly gauge what a customer needs from their electric PTV, the team had two forms of information gathering. First, the team created a Google Forms survey that can be sent to all the available contacts each member could reach. By doing so, the team could get a greater range of diverse opinions on the topic. Some questions that were asked included “What are your likes and dislikes of electric PTVs?”, “How much are you willing to budget for a new PTV?”, “What features would you like to see in an electric PTV?”, and “What aspects do you prioritize in your ride experience?”. The form collected age and gender data in order to know which demographics were being reached with the survey. Since the team is designing with the older consumer in mind, the form was also able to receive information on the public’s thoughts of why older adults do not tend to use such devices. With the link sent out, it was hoped that each person who filled out the form could pass along the link to people they knew as well. After giving a week for potential contacts to fill the form and reach others, the team had obtained 24 survey responses.

The team organized the findings to visually display what kind of demographics and information has been received. The age demographic of the survey responses consisted of 83.3% 18-24 year olds, 4.2% 25-30 year olds, and 12.5% 41-50 year olds. It was unfortunate to not have a greater diversity age wise for the answers since the goal is to develop a design appealing to all consumers. However, the few responses the team did get from the 41-50 year olds were very insightful and helped the team gain a better understanding of why older adults strayed away from using electric PTVs as a form of transportation. As seen below in Figure 7, scooters were the most popular for an electronic device while the traditional bike was preferred for the non-electric method. These results helped the team realize what form and shape their designs should resemble and take from during concept generation. It was also interesting to note that customers preferred sitting to standing with the outcome being 58.3% - 41.7%. Another factor to consider was what the selling price point of the final product should be around. The popular answer among the customers was that they were willing to spend between $400-$500 on a quality electric PTV (Figure 8). Compared to the products reviewed in the state-of-the-art review, this price can still be seen as “low tier” for what devices are highly regarded for their functionality and features. Without considering the budget allocated for senior design projects and potential material/manufacturing costs later, the team had a tentative plan to market their product under $1,000 anyways. Although useful, the team decided additional information was needed to cover more aspects of the needs and wants a customer looks for in an electric PTV.

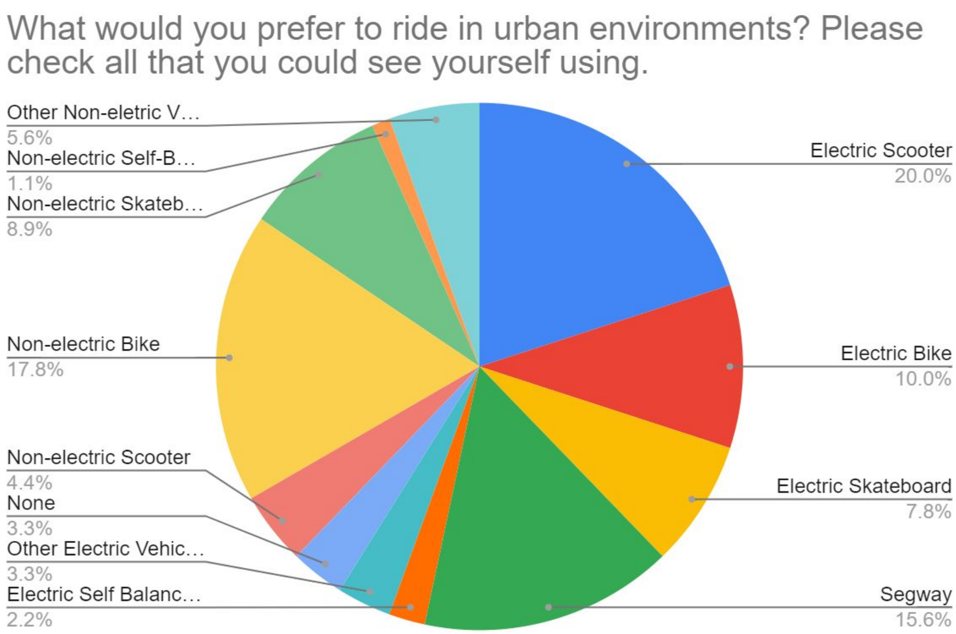

Figure 7: Customer Preferability of Electric and Non-electric PTVs

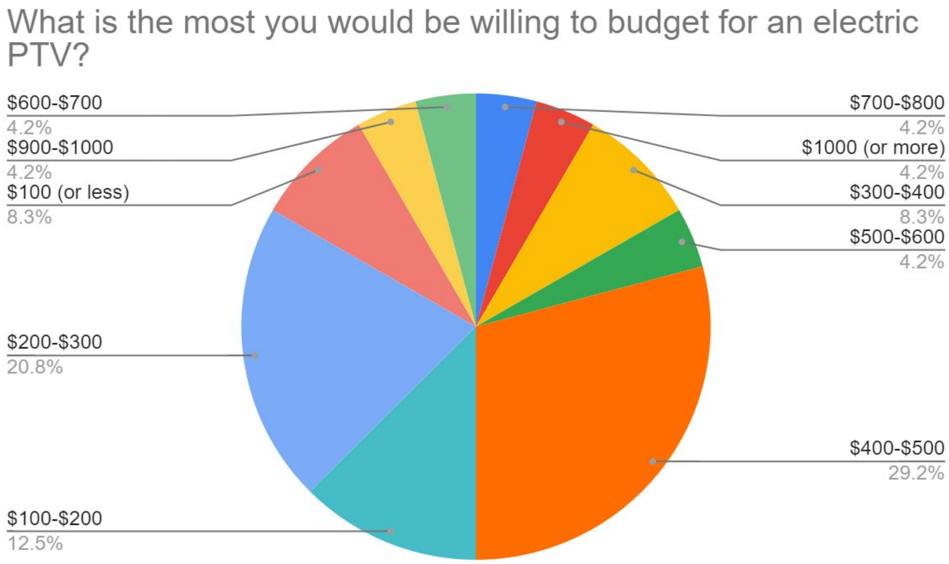

Figure 8: Customer Spending Limits for Electric PTVs

The second method of gathering customer information was by each team member conducting a personal interview with five contacts. Whether in person, talking on the phone, or through a video call, customer interviews were carried out to obtain very detailed answers to the online survey questions as well as some new ones the team prepared. Being able to directly talk to the person resulted in insightful and in depth answers the team would not have been able to get through the online form. The team determined enough information was gathered to formulate a satisfying list of customer needs.

The team identified several useful bits of information from the online surveys and in depth interviews. All this data was compiled into a Google spreadsheet where the needs can be interpreted from the customer statements. The team organized the customers' thoughts to see what they truly meant when perhaps saying "I live in a storied apartment with no elevators". The interpretation for this statement would be that the electric PTV should be relatively lightweight for easy carrying when not for actual ride usage. It might also be advantageous to have some sort of grip, straps, or convertible design to fit the lifestyle of someone living in a small space going in and out frequently. The team carried out this process for many statements which has resulted in the list of customer needs below.

Table 2: List of Customer Needs

No.	Need	Importance (1-5)
1	The PTV is lightweight	4
2	The PTV is electric	5
3	The PTV is easily storable	3
4	The PTV has storage space/component on it	2
5	The PTV is relatively affordable	3
6	The PTV is safe	5
7	The PTV has security measures	3
8	The PTV has an technological interface	2
9	The PTV has multimedia functions	1
10	The PTV is stable during rides	5
11	The PTV is comfortable	3
12	The PTV can endure weather/environmental effects	2
13	The PTV has a long battery life	4
14	The PTV is quickly chargeable	3
15	The PTV controls ride speed effectively	4
16	The PTV is visually appealing	3
17	The PTV uses environmentally friendly materials	2
18	The PTV is durable	4
19	The PTV is easily portable to carry around	4
20	The PTV is simple enough to start and use	4

With a decent list of customer needs, the team was ready to apply measurable metrics to these requirements. The technical side of the interpretation meant that the team had to determine how vehicle properties or features relate to the broader characteristics of coming from the customers. The PTV able to control ride speed efficiently was translated into finding maximum speed and acceleration the vehicle can undergo. The PTV being easily storable depends on the total weight and the minimum collapsible size if the design allows folding. The entire list of these metrics and the units they will be eventually determined to be can be found below as Table 3.

Table 3: List of Technical Metrics

Metric No.	Need No.	Metric	Importance	Units
1	15	Max Speed	3	mph
2	15	Max Acceleration	3	ft/s^2
3	10	Height of COG	4	inches
4	10	Tire Width	2	inches
5	10	Turn Radius	4	Ang, Degree
6	10	Turn Resistance	4	lbs*ft
7	14,20	Deploy Time	3	seconds
8	1,19	Total Weight	5	lbs
9	3,19	Minimum Collapsible Size	4	ft^3
10	4	Addition Storage Capacity	1	in^3
11	6,10	Maximum Obstacle Traversal	4	inches
12	6,10	Support Polygon Area	4	in^2
13	18	# of Moving Parts	3	Qty
14	13,14	Maximum Run Time	4	hours
15	11	Resistance to Phone Mountability	1	psi
16	12	Corrosion Resistance/Weatherproofing	2	mm/year
17	11	User Height Accessibility	2	inches
18	2,8,9,16,20	User Friendly / Simple Interface	2	subj
19	12,18	Product Life Expectancy	3	years
20	1	Braking Time From Max Speed	4	seconds
21	5,16,17	Total # of Components	4	Qty
22	6,7	Surface Area for Securing	3	in^2

The customer needs and technical requirements were transferred onto a quality function deployment (QFD) table to better observe the importance of each desire and relation to the engineering characteristics. Strong, moderate, weak, or no relationships were applied on the body of the table to judge the connections between one need and another technical metric. Each technical requirement was also determined to have a direction of improvement in order to maximize, minimize, or target that area. For example, the team would like to minimize the size the device takes up while in a collapsible form for easier storage capabilities. However, as a device that will be used frequently and for longer periods of time, the vehicle should maximize its run time to allow riders to travel further distances and have efficient charging ability. Plus and minus signs were also inserted in the table to judge if there are positive or negative correlations between metrics. The team's entire QFD Table can be found in the Appendix as Figure A-1.

Numerical design specifications will be determined in Phase 2. It is tough for the team to decide what certain values they should apply to the technical metrics when a final concept has not been selected yet. The team will have to also conduct more research on vehicle properties to decide what specifications ensure the electric PTV stays safe and stable during operation. For example, the team can already acknowledge their electric PTV will have a max speed less than 25 mph based off of the usual product speeds already on the market as well as traffic laws for PTVs. With a proper idea of customer needs for an electric PTV, the team was able to start concept generation.

Concept Generation

To further understand and visualize the outcome of this project, the team began to generate a number (1-2 concepts per teammate) of preliminary concepts in the form of hand sketches and 3D models which met the customer requirements gathered from the various customer survey/questionnaire responses and interviews. Altogether, a total of 7 initial concepts were developed. In sum, a total of 11 concepts were generated during this phase of the project. Utilizing the information garnered from the technical and state-of-the-art analysis, the group generated the following concepts.

Concept 1

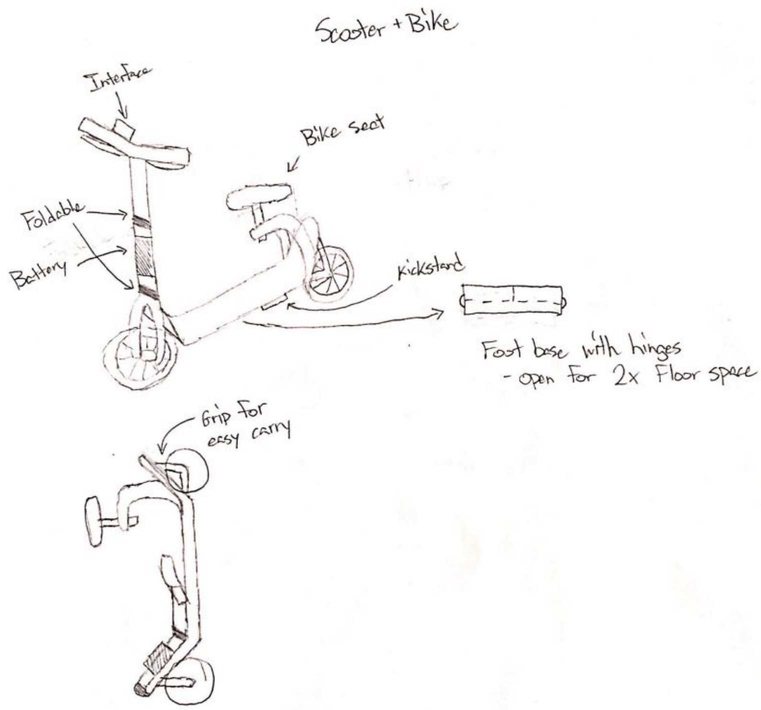

Figure 9: Concept 1

Concept 1 is a combined scooter and bike design which can be folded at multiple sections to ensure storage and portability (Figure 9). The handlebar stem, where a battery is mounted, can be collapsed and folded so that it can rest flush along the deck of the device. In this collapsed stage, the user would be able to carry the device around using the conveniently placed grip found near the rear wheel. The handlebars contain a throttle, handbrakes, and an interface which displays information that the user can interact with during their commute. The concept allows the rider to remain in a seated position and provides an option of expanding the deck space for more foot room by opening the hinged platform underneath the deck. The design is 2 wheeled so the necessity of a kickstand is present in order for the device to be statically stable.

Concept 2

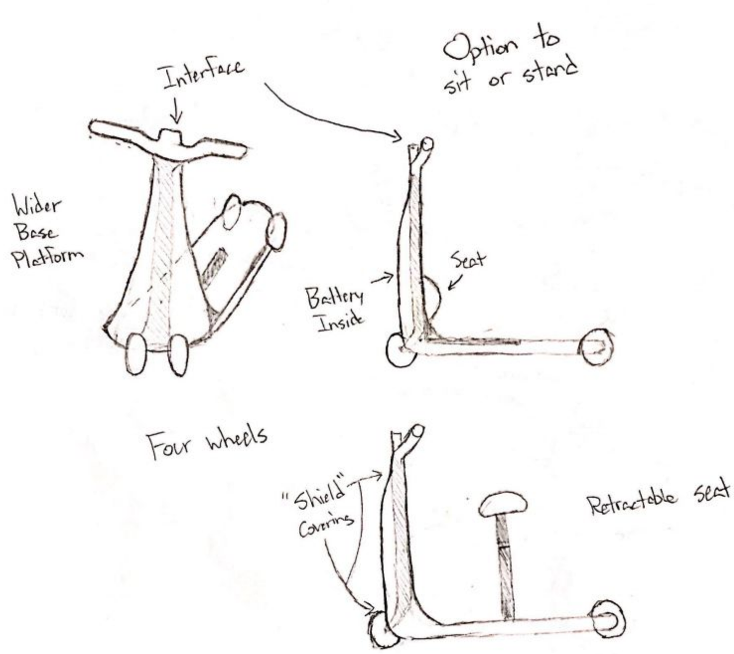

Figure 10: Concept 2

Concept 2 is a scooter design which operates on four wheels, seen in Figure 10. Similarly to concept 1, a battery can be found mounted on the handlebar stem, which is protected inside a shield covering. The covering serves as a way to protect the electrical components (motors, battery, sensors) as well as the rider during their commute. The shield also houses the retractable seat which allows the rider to operate the vehicle in either a sedentary or standing position, depending on their preference. The handlebars control the directional movement of the device and include a throttle, hand brakes, and interface. One downside of this concept is the inability to fold the handlebar stem onto the deck, which may pose an issue for storage or portability.

Concept 3

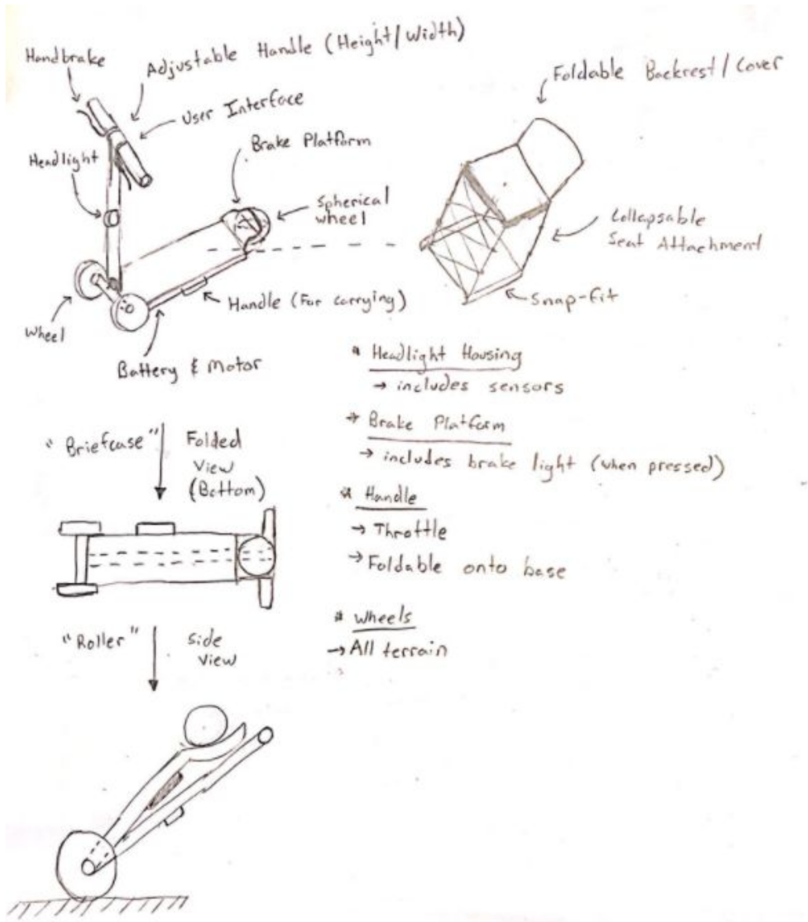

Figure 11: Concept 3

Concept 3 is a three wheeled scooter design and operates using bipedal front wheels and a sphere caster for the rear wheel (Figure 11). The purpose of the sphere caster gives the rider of the device more capability of handling sharper turns. The adjustable handlebar and handlebar stem allows any user of any height to ride it. On the handlebar, the throttle and braking system can be found, as well as an interface for the rider to interact with while they are on their commute. The headlight housing includes sensors needed for traffic detection. A handle can be found on the side of the deck which allows the concept to be held like a suitcase in its collapsed state. When the concept design is collapsed, it can also be rolled around similarly to rolling carry on bags seen in airports. This design also includes a collapsible seat attachment which can be snapped fitted onto the deck. In its collapsed state, the back of the seat attachment folds onto the seat and remains flush with the deck, permitting the rider to use the device in a standing or seated position.

Concept 4

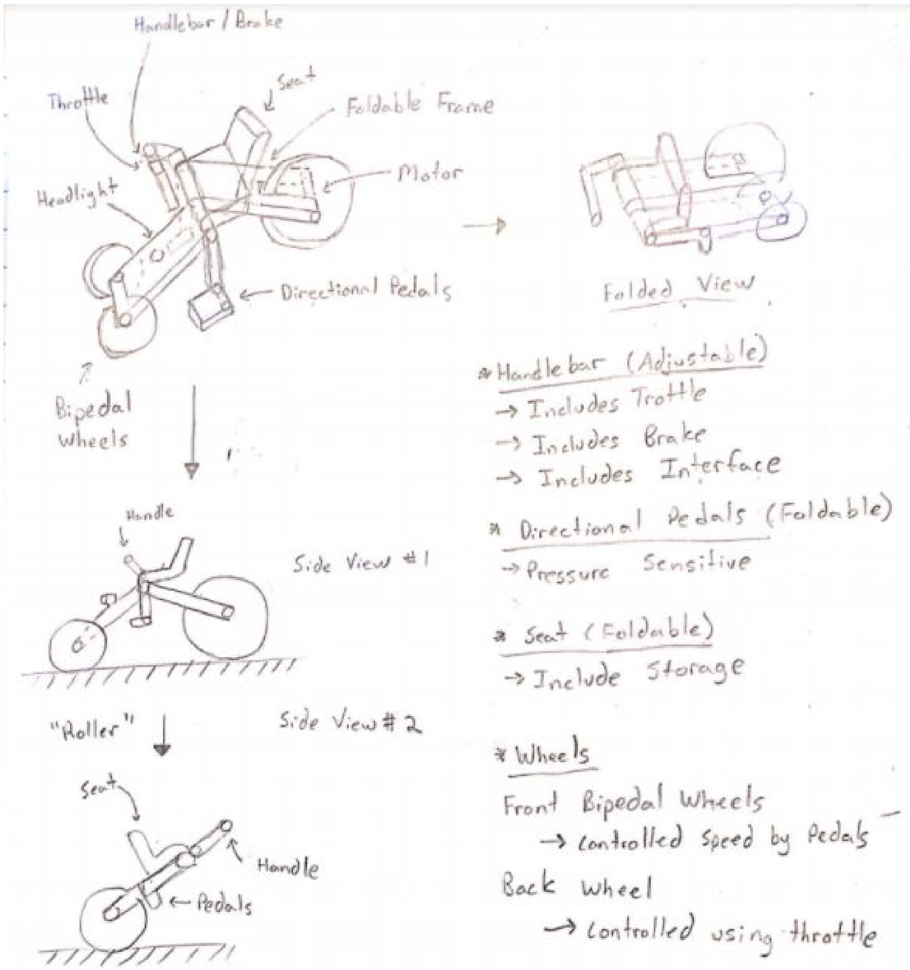

Figure 12: Concept 4

Concept 4 is another tripedal design and operates only in the seated position, like a motorcycle (Figure 12). However, the concept can be adjusted to any height by folding the main frame in or out. Directional pedals which coincide with the use of lean steering are the main methods of directional operation in this concept. The handlebar contains the throttle, brakes, and an interface, like the majority of the preceding concepts. The concept includes a large rear wheel to traverse over obstacles as well as sensors for traffic detection in the headlight housing. The seat contains a small compartment for minor storage, and can be folded down when the concept is in its collapsed state for portability functions. Parts that can be folded or are telescoped include the pedals, frame, handle, and seat. When the concept is collapsed, it can be rolled around in a "roller" mode much like concept 3.

Concept 5

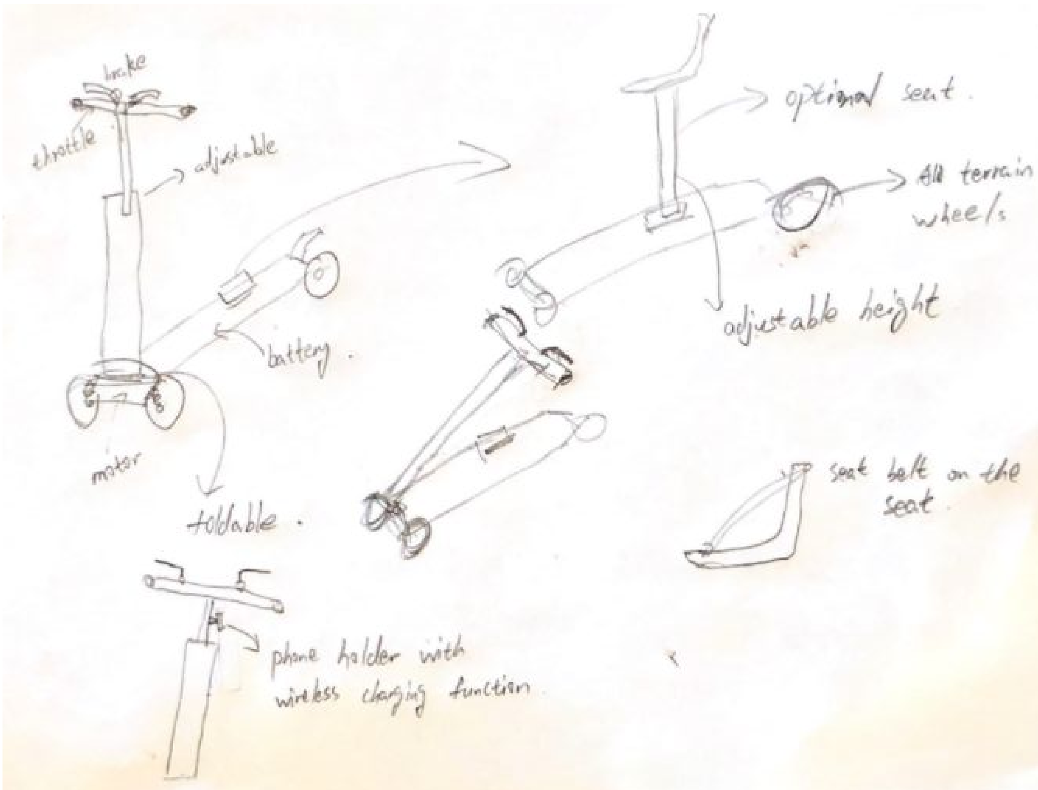

Figure 13: Concept 5

Concept 5 is a standing or seated scooter design which represents portable transportation vehicles in a more traditional sense (Figure 13). It is another tripedal concept which means that it is statically stable when not operated. It includes several features which shows the unique side of its design such as a seat which telescopes out from the deck, allowing users of any height to operate it. The handlebar stem is adjustable and can be folded back onto the deck to ensure easy storage capabilities post usage. The handlebar contains a throttle, brake, and a charging port for users to plug in their phones while it's in operation. The wheels are all terrain to ensure that small obstacles and slight weather changes pose no challenges during its daily operations.

Concept 6:

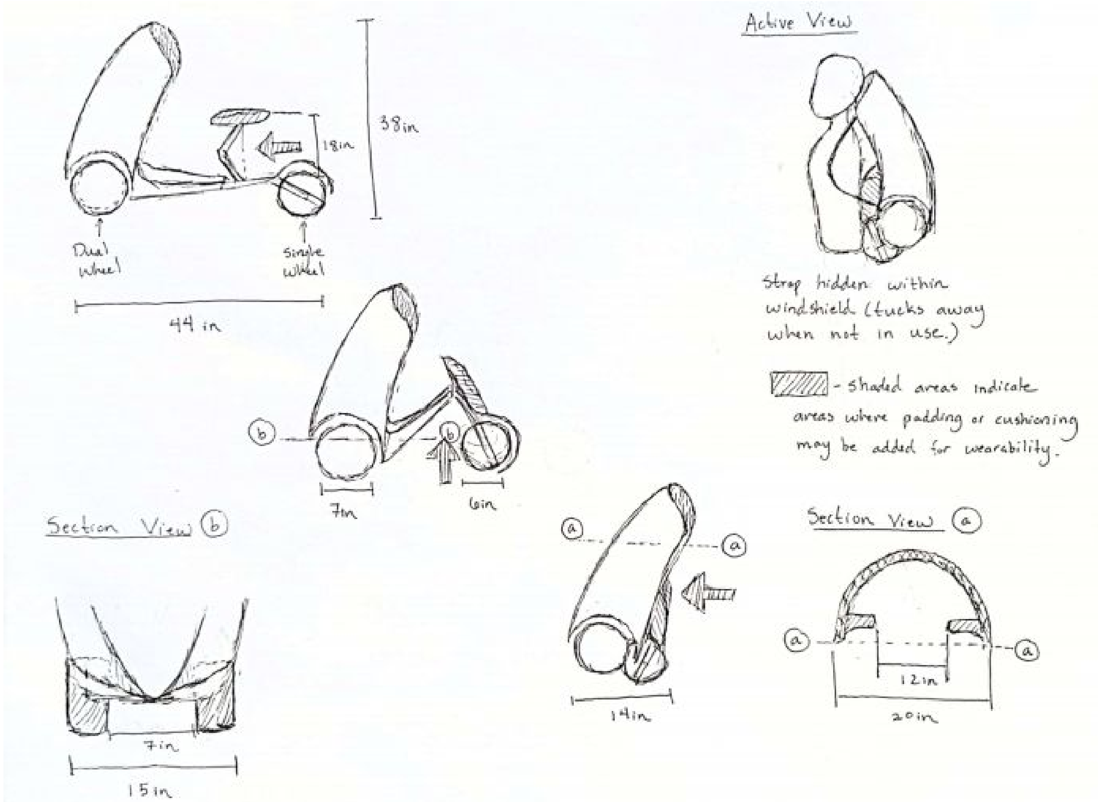

Figure 14: Concept 6

Concept 6 pertains to a tripedal-scooter design seen in Figure 14. Unique features that this concept includes is a tri-folding mechanism that enables the deck of the device to collapse and pivot in two areas. Notabile this collapsibility allows the deck to fold neatly into the shell/windshield of the vehicle. The vehicle can also be sedentary or standing as a retractable seat can be pulled to and from the deck. This degree of collapsibility allows the form-factor of the device to be reduced greatly when not in use which increases its portability and storability. When the vehicle is in its collapsed state, the user can use the attached backpack straps hidden in the shell of the design to carry the vehicle on the individual's back. The seat cushion acts as a backrest to the in addition to the existing padding song the shell and deck of the scooter for user comfort.

Concept 7

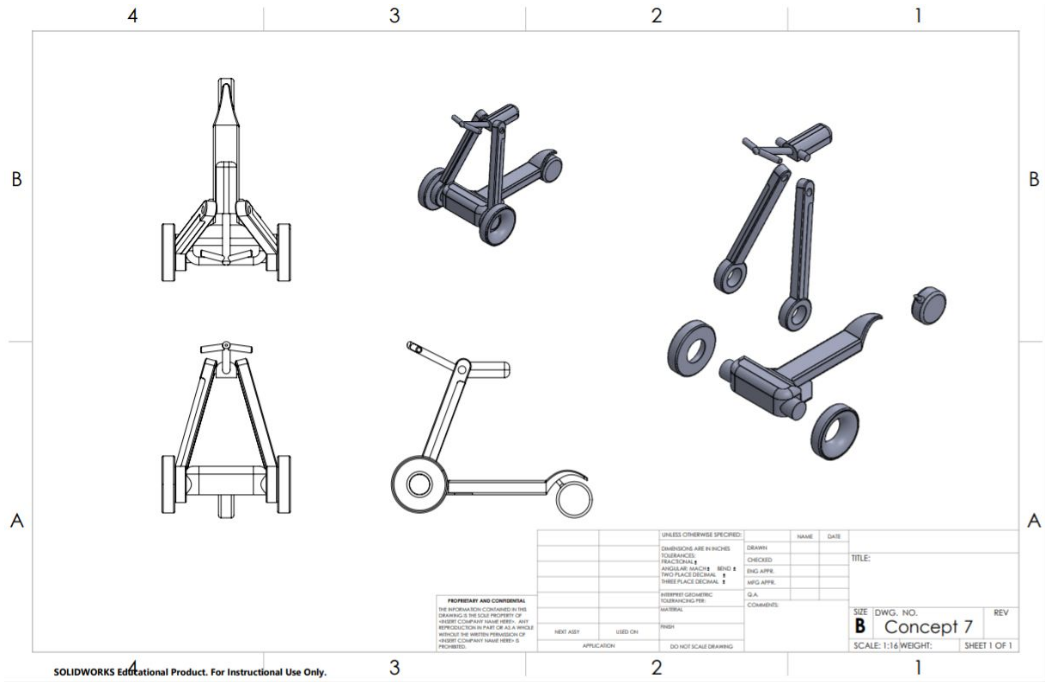

Figure 15: Concept 7

Concept 7 is a tripedal design that takes inspiration from concepts that combine the handle-bars with the seat of the vehicle (Figure 15). This feature can be seen as the most similar to the earlier fuRo canguRo (Figure 5). The person is to straddle the scooter versus completely sitting on a traditional seat. Footrests are present on both sides of the deck to provide this support. With the combination of the seat and handle, the design yields less parts which will improve the manufacturability of the device as well as reduce weight ideally. The rear wheel of the design is a caster wheel and the front two wheels hold the steer mechanism and drivetrain (the vehicle is Front-Wheel Drive). When not in use, the vehicle is able to fold on itself, as the handle and seat is fashioned with a hinge that connects it to the deck on both sides. With this mechanism, the scooter is able to be dragged like a luggage when not in use which increases the portability of the device.

Concept Combination

After reviewing these initial concepts and discussing the benefits and flaws of each design, the team developed 4 more concepts which served as "combination" concepts. These additional concepts identified areas of weaknesses of the initial designs and improved upon them using inspiration from other groupmates concepts and the state-of-the-art technology. These combination concepts can be seen below.

Concept Combination 1

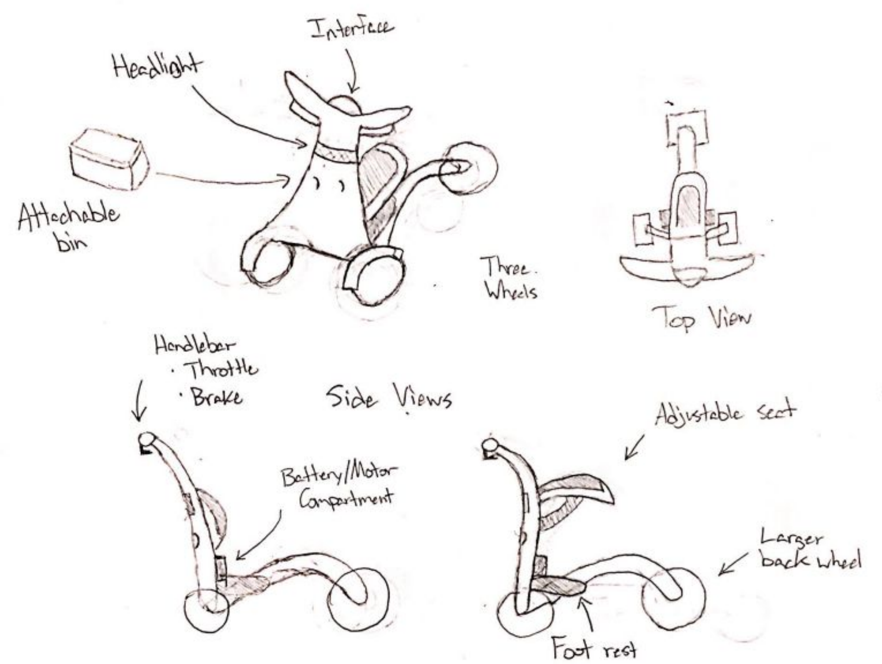

Figure 16: Concept Combination 1 Sketch

Concept Combination 1 references Concept 2 and adopts many similar features such as the shield which houses the batter and seat (Figure 16). It is a tripedal design and includes a larger back wheel for terrain mobility. This concept has the seat built into the shield portion and can be pulled out from the handlebar stem so that the rider can ride on the vehicle in a straddle position (similar to the seating position of Concept 7). The handlebars contain the brake, throttle and interface like many of the previous concepts. Footrests were added and installed at the base of the deck near the front wheels to ensure a comfortable ride for the user and an attachable bin component allows for additional storage space. The one downside of this concept is that the only collapsable part is the seat which means storage capability is low.

Concept Combination 2

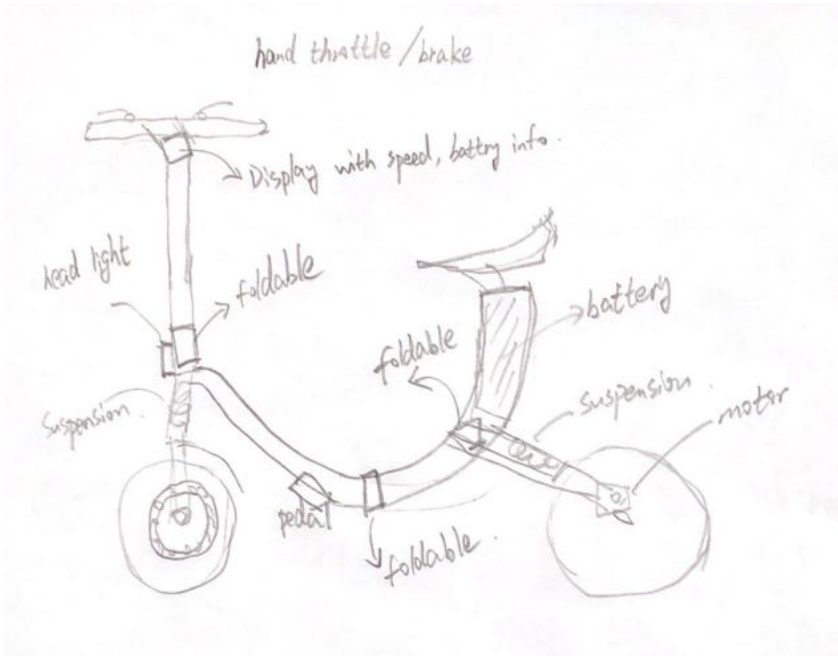

Figure 17: Concept Combination 2 Sketch

Concept Combination 2 is a modified design with two wheels and includes more foldable components (Figure 17). Similar to Concept 5, the throttle and brake systems are all placed on the handlebar. The handlebar also houses a display interface that presents the rider with commuting information and a port for phone charging. The motor can be found between the two front wheels, while another independent motor is used for the rear wheel so that more power can be delivered to the vehicle. A new suspension system is added and an advanced brake system will be used to bring the vehicle's obstacle traversal capabilities up. A seat is directly installed on the main body part and the pedal is added to satisfy customer needs for ride comfort and ergonomics.

Concept Combination 3

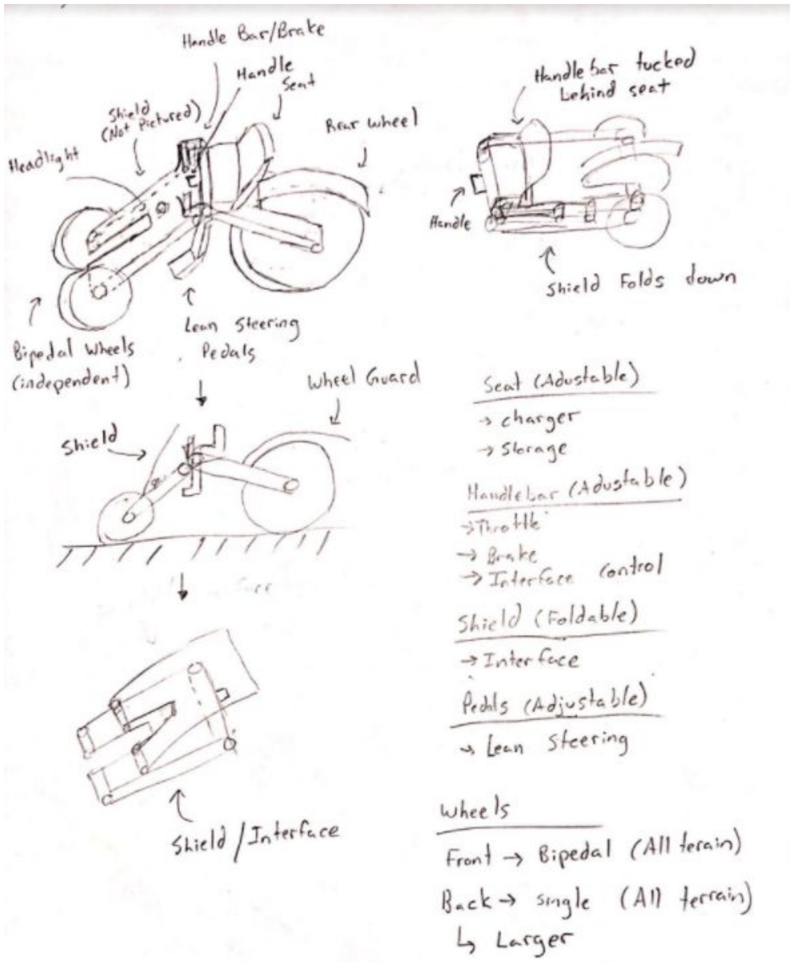

Figure 18: Concept Combination 3 Sketch

Concept Combination 3 serves as an updated rendition of Concept 4, holding on the main aspect of a folding frame (Figure 18). A rear wheel guard as well as a front windshield is added to protect the vehicle and rider from any loose debris brought up off the ground. Compared to the initial concept, this sketch shows the two front wheels on their own independent axis which allows each wheel to operate at different speeds which enables them to operate well with lean steering. The front shield also serves as the rider's interface display (heads up display) which the rider interacts with using controls found on the dual handles. Like the design of Concept 4, this concept can also be folded into a collapsible roller mode which provides users with an easy portability function important for larger and heavier concepts.

Concept Combination 4

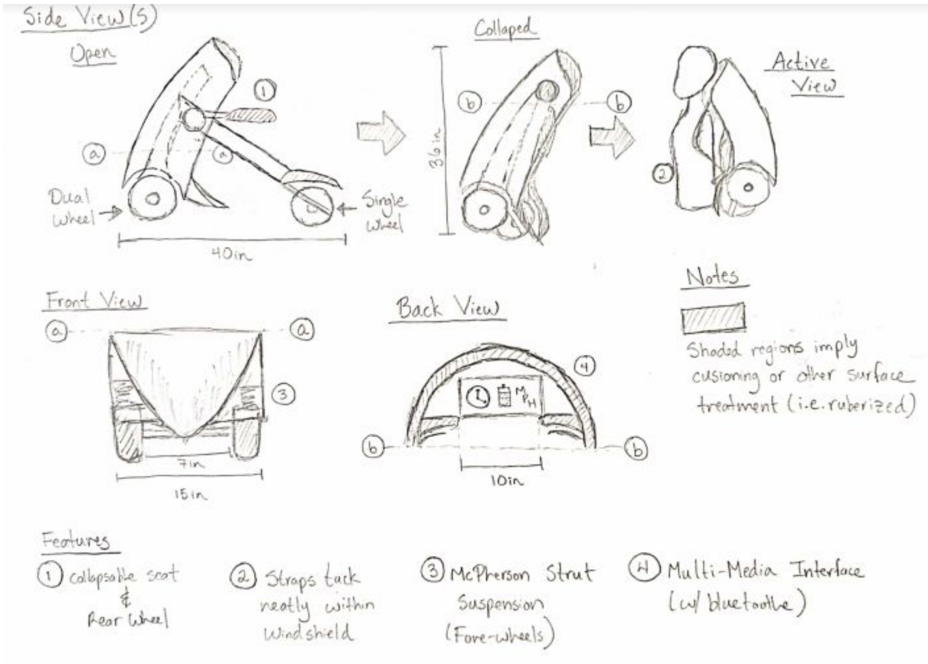

Figure 19: Concept Combination 4

Concept Combination 4 is a revised version of Concept 6 and is seen as Figure 19. Where the weaknesses of the original concept were the total weight of the device(as the vehicle was meant to be carried on the person's back), the total number of components, and the lack of interface and safety features. In redesigning the concept, the deck of the scooter was removed entirely in place of an angled support rod that is able to slide and lock into place with respect to the shell. The seat also mirrors this functionality. This change allows the total weight of the vehicle to decrease as well as reduce the number times one needed to collapse the vehicle to carry it. Now, the concept is a simple bi-hinge design that maintains the benefits and features of the old concept while improving upon the negative aspects of the design. Monoshock suspensions and multimedia displays were also added.

Use of Concept Metrics

When comparing various concepts to one another, it is important to compare certain aspects with one another using metrics. These metrics serve to provide measured data which shows the benefits and drawbacks of using certain designs. These metrics were gathered from the interpreted customer needs taken from the various interviews and statements found in the public survey/questionnaire sent out. The needs were first ranked in terms of importance and then metrics which related to those needs were incorporated for later use. Table 3, from the Customer

Needs and Specifications section, showed the list of metrics which were translated from the customer needs statements.

Since our team has only recently finalized our concept selection, we are in the progress phase of applying metric data to the final concepts that were selected. Some metrics remained the same such as maximum speed which was capped at a limit of 25 mph, as it is the speed limit in most high traffic urban areas. Other metrics such as those relating to handling include turn radius, which vary throughout each concept. Concept Combination 3 is strictly a lean steering only vehicle which may prove to have a very wide turn radius, causing potential issues with sharp corner handling compared to other concepts. In order to optimize concept metrics, it will be important to study the technologies in the state of the art document and technical analysis so that proper designs can be implemented to improve initial metrics. The team will look to complete the metrics soon since the final selection phase for the combination concepts are underway.

Concept Selection

After the team had drawn up all of its initial concepts (concepts 1 through 7) and created combination concepts (concepts 8-11), it was finally time to take a look at scoring and selecting which designs would advance to the following stages of the project. Narrowing down the concepts proved to be a long process as scoring was involved in all portions of the concept selection process, including the initial concept generation stage. The concepts were scored using two different scoring methods, an initial “plus, zero, minus” scoring table (Table 4) and a final “weighted ranking” scoring table (Table 5).

The first scoring table utilized 3 rating criterias, a plus, zero, and minus. A plus means a concept goes above the required need listed, while a zero means it’s neutral and just meets the requirements. As the trend applies, a minus would mean that none of the requirements are met by the concept or it performs the requirement at a below satisfactory rate. In order to get the best results for this first table, each teammate graded each concept and the total pluses, zeros and minus were calculated to determine which concepts held advantage in certain categories. The average of all the pluses, zeros and minuses were taken as well to give the team an overall picture of which concepts needed more improvement. This scoring method was used for the initial seven concepts as well as the four combination concepts developed later in the project.

Table 4: Two Phases of Initial Concept Screening

	Concept 1				Concept 2				Concept 3				Concept 4				Concept 5				Concept 6				Concept 7			
Vote	A	J	K	D	A	J	K	D	A	J	K	D	A	J	K	D	A	J	K	D	A	J	K	D	A	J	K	D
Low cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Speed control	0	0	0	0	0	0	0	0	+	+	+	+	0	+	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Visually appealing	-	0	0	0	0	+	0	0	0	0	0	0	+	+	-	+	+	+	-	0	0	+	0	0	0	0	0	0
Ease of handling	0	0	+	0	+	+	+	+	+	+	+	+	0	+	0	0	0	+	0	0	+	0	-	-	+	0	0	+
Portable	+	+	0	+	0	0	0	0	+	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	0	+	0	0
Universal comfort	0	+	0	+	0	+	0	+	0	+	0	+	0	0	0	0	+	+	0	+	0	+	+	+	0	-	-	-
Storage Component	-	-	-	-	-	-	-	-	0	+	0	0	0	+	0	0	-	0	0	0	-	-	0	0	-	-	0	0
Stabilization features / safety	-	-	-	-	0	0	0	0	+	0	0	0	0	-	-	0	0	-	-	-	0	0	0	0	0	0	0	0
Repairability	0	0	0	0	0	0	0	0	0	0	-	0	0	0	-	0	0	0	-	0	0	0	-	-	0	0	0	0
Long range for daily commuters /battery life	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	+	+	0	0	0	0
Multimedia	0	+	-	-	0	+	0	0	0	+	+	+	0	0	0	0	-	-	0	0	-	-	0	0	-	-	0	0
Weatherproofing	-	-	0	-	0	0	0	0	-	0	-	-	-	0	0	0	0	0	+	0	0	0	0	0	0	0	0	0
Usability through interface / accessibility	+	+	0	+	+	+	+	+	+	+	+	+	0	+	+	0	-	-	0	0	-	0	0	0	-	-	0	0
Environmentally friendly materials and performance output	0	0	0	0	+	0	0	0	0	0	0	0	0	0	0	0	+	0	0	+	0	0	0	0	0	0	0	0
"Find my..." feature/insurance/security	-	-	0	0	0	-	0	-	-	-	0	0	0	-	0	-	0	-	0	0	0	-	0	0	0	-	0	+
SUMS (+)	2	4	1	3	3	5	2	3	5	7	5	6	2	6	2	2	4	4	2	3	2	3	2	2	1	1	0	2
SUMS (0)	8	7	11	8	11	8	12	10	8	7	8	8	12	7	10	12	8	7	10	11	10	9	10	10	11	9	13	12
SUM (-)	5	4	3	4	1	2	1	2	2	1	2	1	1	2	3	-	3	4	3	1	3	3	3	3	3	5	1	1

CONCEPT COMBINATION

	Combination 1				AVG	Combination 2				AVG	Combination 3				AVG	Combination 4				AVG
Vote	A	J	K	D		A	J	K	D		A	J	K	D		A	J	K	D	
Cost ($)	0	-	0	0	**-1**	0	-	0	+	**0**	0	+	0	+	**2**	+	+	+	+	**4**
MaxSpeed (mph)	+	+	+	+	**4**	+	+	+	0	**3**	+	+	+	0	**3**	+	+	+	0	**3**
Ease of handling (Turn Radius)	+	+	+	+	**4**	+	+	0	0	**2**	0	+	-	0	**0**	+	0	+	+	**3**
Ergonomics (Adjustibility Range) (User height min-max)	+	+	0	0	**2**	0	0	-	0	**-1**	+	0	0	0	**1**	-	0	-	0	**-2**
Vehicle Minimum Storage Volume (ft^3)	0	0	-	+	**0**	-	-	0	-	**-3**	+	+	+	0	**3**	+	+	-	-	**0**
Addition Storage Capacity (in^3)	+	0	+	+	**3**	0	+	0	0	**1**	-	-	-	0	**-3**	-	-	0	0	**-2**
Stabilization (Obstacle Traversal) (height)	+	+	+	+	**4**	+	+	+	+	**4**	+	+	+	+	**4**	+	0	+	0	**2**
Safety (support polygon)	+	0	+	+	**3**	0	0	+	+	**2**	+	0	+	+	**3**	0	-	-	0	**-2**
Maintenence (number of Parts)	0	0	0	-	**-1**	0	0	0	0	**0**	0	0	0	-	**-1**	0	0	0	+	**1**
Run-Time (Watts/hr)	0	0	0	0	**0**	0	0	0	0	**0**	0	0	0	0	**0**	0	0	0	0	**0**
Phone Mountability (force needed to hold/remove)	0	+	+	0	**2**	0	+	+	+	**3**	+	+	+	+	**4**	0	+	+	0	**2**
Weatherproofing (submergent depth)	-	-	0	0	**-2**	0	+	0	0	**1**	+	-	+	0	**1**	-	0	-	-	**-3**
Deployment time (seconds)																				
Sustainable	0	0	0	0	**0**	0	0	0	0	**0**	0	0	0	+	**1**	0	0	0	0	**0**
Power Output	0	0	0	0	**0**	0	0	0	0	**0**	0	0	0	0	**0**	0	0	0	0	**0**
Security	-	0	0	0	**-1**	0	0	+	0	**1**	0	0	0	0	**0**	-	-	0	-	**-3**
SUMS (+)	7	7	8	7		7	10	8	8		9	10	9	8		6	5	5	4	
SUMS (0)	8	9	9	10		10	6	10	10		9	7	8	10		8	11	10	12	
SUM (-)	4	3	2	2		1	2	1	1		1	2	2	1		5	3	4	3	
AVERAGE (+)	7.25					8.25					9					5				
AVERAGE (0)	9					9					8.5					10.25				
AVERAGE (-)	2.75					1.25					1.5					3.75				

The second scoring table only served to rate the four combination concepts. Each metric is listed in the selection criteria and is rated on a scale from one to ten. The weights of each metric is listed as well so that a weighted score can be calculated. After all the individual weighted scores are calculated, they are summed. From this table, rankings would be determined from the final score summations which showed the team which design(s) they would move forward with. As the second scoring table shows, the “Backpack Vehicle (Concept Combination 4)” came first in the selection, followed by the “Shield Vehicle (Concept Combination 1)” “Leaning Tri-Wheel (Concept Combination 3)” and “Sitting Scooter (Concept Combination 2).”

However, the margin of selection is very close between the top 3 combination concepts so the team will likely proceed with the top 3 concepts and continue to have detailed discussions until a final concept is agreed upon. In the end, whatever concept is chosen will still have room for improvement. The team noticed that the scores were close because some concepts excelled in areas that others didn't and vise versa, ultimately teetering the scores. Certain features that excel in another concept will most likely be merged into the final concepts so that all lacking areas are covered.

Table 5: Weighted Ranking Scoring Table

Scoring(1-10)	100.00%	Shield Vehicle		Leaning Triwheel		Backpack Vehicle		Sitting Scooter	
Selection Criteria	**Weight**	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score	Rating	Weighted Score
Max Speed (UNIVERSAL RATING)	5.00%	5	0.25	5	0.25	5	0.25	5	0.25
Max Acceleration	5.00%	3	0.15	3	0.15	4	0.2	5	0.1
Height of COG	2.00%	4	0.08	6	0.12	2	0.04	4	0.08
Tire Width (NO RATING)	0.00%	-	-	-	-	-	-	-	-
Turn Radius	8.00%	5	0.4	2	0.16	6	0.48	6	0.48
Turn Resistance (NO RATING)	0.00%	-	-	-	-	-	-	-	-
Deploy Time	4.00%	7	0.28	3	0.12	6	0.24	5	0.2
Total weight	6.00%	3	0.18	1	0.06	8	0.48	6	0.36
Storing Capability	6.00%	2	0.12	6	0.36	6	0.36	5	0.3
Addition Storage Capacity	1.00%	5	0.05	2	0.02	2	0.02	2	0.02
Maximum Obstacle Traversal	10.00%	6	0.6	7	0.7	4	0.4	4	0.4
Support Polygon Area	12.00%	7	0.84	8	0.96	6	0.72	4	0.48
Number of Moving Parts(Repairability)	3.00%	5	0.15	8	0.24	4	0.12	6	0.18
Maximum Run Time (UNIVERSAL RATING)	6.00%	5	0.3	5	0.3	5	0.3	5	0.3
Resistance to Phone Mountability (UNIVERSAL RATING)	2.00%	5	0.1	5	0.1	5	0.1	5	0.1
Corrosion Resistance(Weatherproofing)	5.00%	6	0.3	6	0.3	6	0.3	2	0.1
Accessibility (User Height)	5.00%	4	0.2	6	0.3	2	0.1	4	0.2
User Friendly / Simple Interface (UNIVERSAL RATING)	3.00%	5	0.15	5	0.15	5	0.15	5	0.15
Product Life Expectancy	7.00%	5	0.35	3	0.21	5	0.35	5	0.35
Braking Time (From max speed)	5.00%	5	0.25	4	0.2	5	0.25	6	0.3
Total Components/ Parts	3.00%	4	0.12	3	0.09	5	0.15	4	0.12
Security (locking surface area)	2.00%	3	0.06	3	0.06	3	0.06	5	0.1
Total Score			4.93		4.85		5.07		4.57
Ranking			**2**		**3**		**1**		**4**

Technical Analysis

As a prerequisite for Phase 2 of the project, the group conducted a technical analysis on the automotive and dynamic properties required to form an understanding for the project at hand. As the project places heavy emphasis on static stability and safety in order to reach an older audience, physics and systems pertaining to this 'product need' were considered. In addition to this, modern technologies in automotive systems such as caster wheels, braking systems, and suspension systems are also discussed below. The group will utilize this information to make conscious and educated design decisions that will lead to the success of the project. From this analysis the group is able to elucidate the physics governing your design and what analysis are you likely to perform next phase

Vehicle Dynamics

To initiate the group's understanding of urban-transport vehicles, a basic understanding of vehicle dynamics is required. A main focal point in vehicle dynamics are the tires, specifically the tire-ground interface. The weight of the vehicle is bolstered by the tires which then contribute to a normal force that governs the frictional force experienced by the tires. In a simplified case where wind resistance and other losses are negligible, the frictional force can be utilized to determine other parameters of vehicles such as maximum acceleration as seen in the table below.

Table 6: Acceleration of Different Drivetrain

Front-Wheel Drive	Rear-Wheel Drive	All-Wheel Drive
$a_{FWD} = \frac{g \cdot a_2 \cdot \mu}{\mu \cdot h + L}$	$a_{RWD} = \frac{g \cdot a_1 \cdot \mu}{L - \mu \cdot h}$	$a_{AWD} = \mu \cdot g$

a_1 = Horizontal Distance from Center for Gravity to Front Wheel
a_2 = Horizontal Distance from Center for Gravity to Rear Wheel
g = Gravitational Constant
μ = Static-Coefficient of Friction of Ground
L = Length of Vehicle
h = Height of Center of Gravity
m = Mass of Vehicle

When assessing vehicle dynamics the vehicle drivetrain is important to consider. The vehicle drivetrain pertains to if the vehicle is all-wheel drive (AWD), rear-wheel drive (RWD) or front-wheel drive (FWD). The difference between AWD, FWD, and RWD is the maximum slope angle in which the vehicle can clear. Typically, AWD is the best for clearing slopes followed by RWD and then FWD. As the vehicle travels upwards the slope, the center of gravity of the vehicle shifts towards the rear of the vehicle putting more reaction force on the rear tires/wheel. The Center of Gravity is defined as the point from which the weight of a body or system may be considered to act. In uniform gravity, it is the same as the center of mass. This explains why RWD is typically better for clearing steep slopes as more reaction force allows for the tires to utilize the increased frictional force to propel it up the slope. The maximum angle of inclination in which a vehicle can clear is dependent on the drive train as seen in Table 7 below. The equations below were derived using dynamic properties of moment and force balance equations of a vehicle on an incline of angle(θ). As seen in the table, the slope angle depends upon other parameters such as vehicle dimensions, height, and mass. By understanding this concept, the group can have a better understanding on how changing vehicle dimensions will affect the slope in which the vehicle is able to clear.

Table 7: Slope angle of Vehicle with Respect to Drivetrain

Front-Wheel Drive	$F_{FWD} = \frac{\mu(m \cdot g \cdot cos(\theta) \cdot a_2 - m \cdot g \cdot sin(\theta) \cdot h}{L \cdot g \cdot m}$
Rear-Wheel Drive	$F_{RWD} = \frac{\mu(m \cdot g \cdot cos(\theta) \cdot a_2 + m \cdot g \cdot sin(\theta) \cdot h}{L \cdot g \cdot m}$
All-Wheel Drive	$F_{RWD} = F_{FWD} + F_{RWD}$

As static stability is a major focal point of our project, an understanding of what governs static stability is important. The support polygon is defined as the "horizontal area over which the center of mass must lie to achieve static stability." In a simplified case, this region is roughly correlated to the area under the vehicle in regards to the points of contact it makes with the ground. Thus tripedal vehicles give an advantage over bipedal ones due to this definition.

Suspension Systems

Suspension systems in vehicles serve many purposes such as supporting the weight of the vehicle, maintaining accurate tire contact with the ground for better vehicle control, and absorbing any shock as a result of driving over rough surfaces. Without suspension systems not only will the ride of the vehicle be very rough, but the handling and control of the vehicle also will be heavily impacted. Suspension systems come in many different forms but all tend to have some sort of dampening system to absorb shock(torsion springs and coil springs) and links for connectivity with the vehicle's axles and other wheels(anti-roll bars/sway bars). Several different types of suspension systems have been used throughout the years; however, the most popular suspension systems include the MacPherson Strut Suspension Systems(MSSS) and Double Wishbone Suspension Systems(DWSS). The most commonly used system in scooters is a mono-shock suspension that is under the same design family as the MacPherson Strut.

MacPherson Strut Suspensions are typically preferred in commercial vehicles especially the more budget models as one of the main advantages of the MSSS is that it is cheap to construct and maintain. Along with this, the MSSS is also compact in design so volume and weight constraints are more easily met. MSSS also operates using only one control arm and strut with a coil spring used as the dampener. Its main disadvantage is that it lacks advanced handling capabilities because the camber angle will change with suspension travel so "the contact area of the tire will be minimized to one side or the other side when you are taking har corners."Double Wishbone Suspension Systems(DWSS) are another popular system; however, they are becoming less popular over time. This is due to its costly design and relative complexity when compared with the much simpler MacPherson suspension system. Ball-joints in this system will also wear out a lot faster in this design while also being less fuel-efficient than a MacPherson system. What this system provides though is better handling as it consists of two arms instead of one. This allows the wheels to produce negative camber for stability while turning.

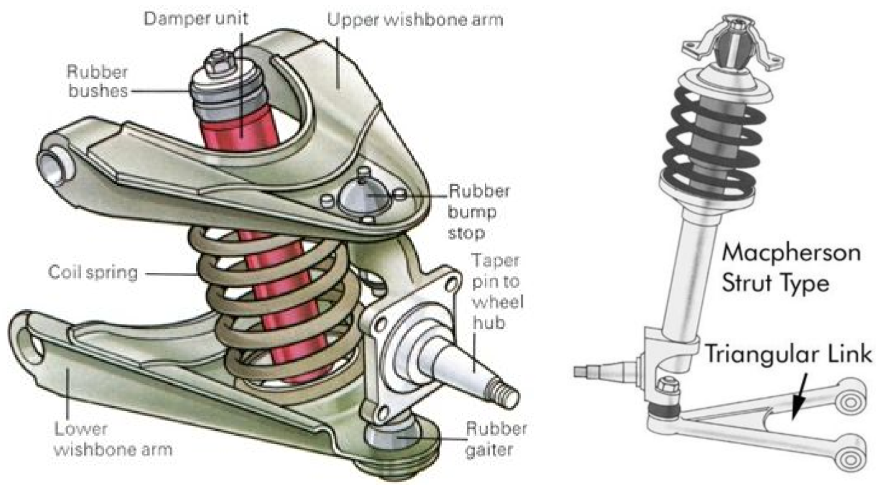

Figure 20 : Double Wishbone Suspension System(Left)
MacPherson Strut Suspension System(Right)

Braking Systems

Braking systems are another integral part of designing a vehicle. A few of the primary functions of the braking system are as follows: The braking system must decelerate a vehicle in a controlled and repeatable fashion and when appropriate cause the vehicle to stop. The braking system should permit the vehicle to maintain a constant speed when traveling downhill. The braking system must hold the vehicle stationary when on a flat or on an inclined plane. There are several types of braking systems that are implemented in vehicles. To list a few there are disk brakes that use clamping forces and friction to apply force on the brake disk and hydraulic braking systems that use braking fluids to transfer pressure from the controlling mechanism to generate the braking motion. There are disadvantages to both types of braking systems listed above. Disk brakes are subject to overheating as braking over high speeds can cause the disk to overheat and shatter depending on the material of the brake disk. Hydraulic brakes can be difficult to repair and maintain as fluids are more difficult to contain than solid mechanisms. There are many more factors that contribute to proper brake design, this includes breaking efficiency or the amount of effort or force required by the user to initiate the braking motion of the vehicle. (Smith 434)

The braking efficiency of the vehicle can be defined with the following equation:

$$\eta_{braking} = \frac{V^2}{3D}$$

Where the variables are defined as:

V = Initial Velocity of the vehicle
D = Stopping distance from which brakes were engaged

Lean Steering (Counter Steering)

When it comes to steering around corners for a vehicle that isn't as stable laterally, such as a motorcycle, it is important to lean into turns in order to steer in the right direction. The term lean steering, also or commonly referred to as counter steering is the method riders take in leaning in a turn. As a result of leaning the vehicle, a rider and their vehicle is able to shift their center of mass to a lower position which allows them to control their vehicle despite it no longer being in an upright position.

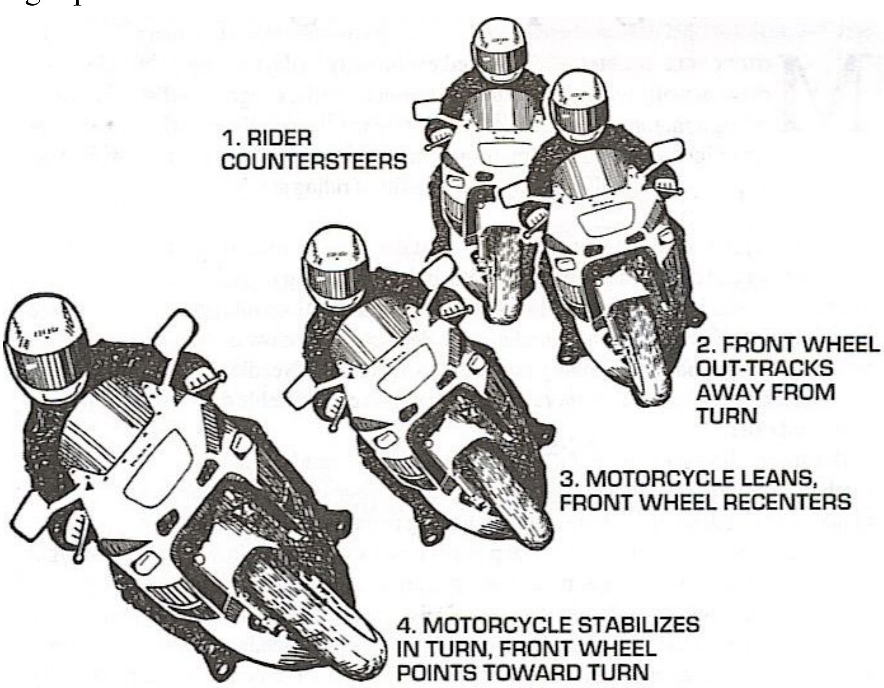

Figure 21: Motorist Countersteering

Newton's Laws enable the rider to remain in a steady position during the turn as the frictional force from the tire traction interacts opposite with the gravity and centrifugal force from the cornering. Due to a motorcycle's tendency to only remain upright in the moving position, the need for counter steering is required in order to handle the vehicle. At slow speeds, counter steering is less effective because of the lack of tire traction against the road to support the counter steer. However, at high speeds, one will notice that cornering using the method of countersteering is far more natural because of the higher tire traction with the road.

The advantage of counter steering is that it provides the rider with no need to use handlebar steering especially at higher speeds. However, if it were to be applied at lower speeds, design changes would need to be made to the device so that the center of mass remains balanced at all turns. This would allow the rider to theoretically be enacting forces and acting physically equivalent to that of a bike cornering at high speeds. Application of additional technologies such as a gyroscopic mechanism that keeps the vehicle in a balanced state and a suspension system to counteract certain forces in a turn would all need to be applied into the design to make counter steering a useful method in an everyday commute scenario.

Caster Wheels

A caster wheel allows the object which rolls to move in any direction due to the construction of its design. Unlike normal wheels which typically rotate on a single axis, caster technology enables the wheel to move on its axis as well as swivel on another. This gives the wheel the ability to have more directional variety over the surface which it rolls on. The distance at which the pin holding the secondary axis and the center of the wheel is called the swivel offset. This offset measurement is important as it determines the necessary forces needed to overcome friction to turn the wheel. When studying caster wheels, one has to understand that there are important factors which improve the performance of the wheel. Factors such as wheel radius, wheel shape, bearing material, and wheel material all affect the way the wheel operates.

Lower loads applied on caster wheels don't serve a beneficial purpose compared to regular wheels. They begin to show their benefits when holding heavier loads because of the ability to utilize torque and twisting force to its advantage.

$$\text{Torque} = \text{Radius (arm)} \times \text{Force (applied)}$$

Using the simplest form of the torque equation, one can see that increasing the distance from which a force is applied gives mechanical advantage to the device. When a caster wheel is incorporated in a design, it serves as a hypothetical "nut" which can be tightened by applying an opposite force, that being pulling or pushing force. A visual understanding of this concept can be noticed on a shopping cart, a common application for caster wheels. Despite the amount of groceries in the cart, you may notice that it is easier to turn the cart from the caster wheel side. This is thanks to the idea of torque. The force applied perpendicular to the contact of the caster wheels lets the consumer use torque to their advantage and move a heavy cart without much difficulty.

Frictional Resistance must also be taken into consideration as it is a parameter that affects the performance of a wheel. Wheels can often be used on various surfaces so the need to mind wheel material that is optimal for certain environments is important. In these cases, understanding the coefficient of friction and the force needed to overcome the friction is needed to properly roll the wheel. Comparing and calculating these frictional forces is required on both the surfaces which the wheels are rolling on and the material which the wheels are made of.

Heads Up Displays

Heads up displays are a technology that have been around since the 1950's but haven't been used in vehicles until recently. Prior, you could find this technology on fighter jets which displayed various kinds of information such as speed and altitude on the windshield for the pilot to see. Head up displays, as the name implies, are simply displays which are typically projected onto a transparent surface such as a window or windshield that provide information to users without the worry of distractions. Since these systems are typically integrated into a vehicle, the need for distracting secondary technology such as a GPS or phone is eliminated.

The technology uses transparent phosphors which are placed onto a transparent surface so when a laser interacts with it, information is projected. Information that gets sent to the head up display is usually collected from the vehicle's current performance or from surrounding environments (temperature, road shape, etc). As technology advances. We will see that more and more complex information will be available on heads up displays. Current technologies are starting to feature aspects such as infrared cameras and internet accessible applications. These applications will provide users with safer and efficient rides.

Project Plan

Deliverables

The overall project will be conducted in six major phases according to the senior design curriculum in mechanical engineering. The design of the team's electric PTV will be continually worked on for the remainder of the Fall 2020 semester. With the submission of this report on 10/6 and the presentation on 10/8, Phase 1 involving introduction of the project and conceptual designs will be completed. Phase 2 will begin with the group finalizing the design and providing a thorough technical analysis. The deliverables for Phase 2 are another presentation as well as creating a website designated to the product. The Fall semester will end with Phase 3 where engineering designs of the concept are introduced and preparation for construction of the alpha prototype will take place. Phase 3 will also ask for a formal report and presentation where some kind of alpha prototype demo will be required. Depending on the university's reopening plans for the Spring 2021 semester, it is the team's hope to begin constructing and testing the alpha prototype for Phase 4. Along with testing, a product fabrication plan will be created for the Phase 4 report and presentation. Phase 5 involves providing a complete final design and potential beta prototype fabrication. The team will carry out the Phase 5 presentation and update the project website. The entire project will have been concluded in Phase 6 after attending and presenting at the Innovation Expo in early May 2021. The team will prepare for this event as well as write up the Phase 6 final report and perform the last presentation during class time.

Schedule

For this project, the team decided to use Airtable for their project planning needs. A Gantt chart was started on the online service where tasks, status, members, and deadlines could be easily added and seen from the user friendly interface. After inputting the necessary information, a block diagram can be visually seen, attached to the Appendix as Figure A-2, to represent the project's status at any given time interval. As the project progresses throughout the semester, the Gantt chart will constantly be updated to reflect the current status of weekly tasks. Having this Gantt chart allows the team to stay organized and make sure milestones are completed for the six phases.

	Task	Category	Status	Team Member	Start date	End date
1	Meeting Details (Dates, Attendanc...	Progress Report 1	Complete	Alvin La	9/3/2020	9/24/2020
2	Project Description & Main Goals	Progress Report 1	Complete	Alvin La	9/3/2020	9/24/2020
	Completed Task List	Progress Report 1	Complete	Jing Bao, Alvin La	9/3/2020	9/24/2020
4	In-Progress Tasks	Progress Report 1	Complete	Jing Bao, Alvin La, Kevin Yan	9/3/2020	9/24/2020
5	To-Be-Completed Tasks	Progress Report 1	Complete	Jing Bao, Alvin La, Kevin Yan	9/3/2020	9/24/2020
6	Interview Customers / Send Surveys	General Phase 1	Complete	Jing Bao, Alvin La, Kevin Yan, dongrui lu	9/10/2020	9/17/2020
7	Customer Needs into Metrics and ...	General Phase 1	Complete	Jing Bao, Alvin La, Kevin Yan, dongrui lu	9/16/2020	9/22/2020
8	Project Name	General Phase 1	Complete	Jing Bao, Alvin La, Kevin Yan, dongrui lu	9/3/2020	9/16/2020
9	Concept Generation and Selection	General Phase 1	Complete	Jing Bao, Alvin La, Kevin Yan, dongrui lu	9/10/2020	9/24/2020
10	Discuss Project with Advisor	General Phase 1	Complete	Jing Bao, Alvin La, Kevin Yan, dongrui lu	9/3/2020	9/3/2020
11	Determine Project Objectives	General Phase 1	Complete	Jing Bao, Alvin La, Kevin Yan, dongrui lu	9/3/2020	9/10/2020
12	State of the Art Review	General Phase 1	Complete	Kevin Yan, Alvin La	9/9/2020	9/17/2020
13	Initial Concept Design Decision	General Phase 1	Complete	Jing Bao, Alvin La, Kevin Yan, dongrui lu	9/24/2020	9/30/2020
14	Itemized Budget List	General Phase 1	Complete	Jing Bao, Kevin Yan	9/24/2020	10/6/2020
15	QFD Table	General Phase 1	Complete	Alvin La	9/28/2020	9/29/2020
16	Project Statement/Description	Phase 1 Final Report	Complete	Alvin La, Kevin Yan	9/29/2020	10/6/2020
17	Literature Review	Phase 1 Final Report	Complete	Kevin Yan, Alvin La	9/29/2020	10/6/2020
18	Needs, Metrics, Specs	Phase 1 Final Report	Complete	Alvin La	9/29/2020	10/6/2020
19	Concept Generation/Selection	Phase 1 Final Report	Complete	Jing Bao, dongrui lu	9/29/2020	10/6/2020
20	Technical Analysis	Phase 1 Final Report	Complete	Jing Bao, Kevin Yan	9/29/2020	10/6/2020
21	Project Plan	Phase 1 Final Report	Complete	Alvin La, dongrui lu	9/29/2020	10/6/2020
22	Phase 1 Presentation	Phase 1 Final Presen...	In progress	Jing Bao, Alvin La, Kevin Yan, dongrui lu	10/6/2020	10/8/2020

Figure 22: Project Plan Task List for Phase 1

Budget

The total budget of the project is $700 and the team needs to decide which suitable material should be used. Based on findings from the technical analysis, the team was able to substantiate several parts required for the construction of the PTV. For universal components such as wheels and batteries, it is easy to find a relevant price. However for the material of the main part, the team still needs to do some simulation to find the most cost effective material. For prototyping, the group is likely to use 3D printing to make enclosures for electrical components as this technique allows for the fast and cost-effective creation of complex parts. In the final product, the design will use a metal that is consistent with most PTV products. The group considers an aluminum alloy as a leading material due to its low weight and relative high hardness. The parts range from 2.95 to up to 180 dollars. The most expensive components being the motor and bike wheels (tires and drivetrain hardware included) as these are the critical components for the PTV to function. The budget list is subject to change over time as more components are added to maximize the budget usage. A tabulation of all parts and component specifications is seen below in Table 8.

Table 8: Tentative Product Part Budgeting

Component	Component Description and Function within Project	Unit Cost(USD)	Quantity	Total Cost(USD)
E-Scooter Wheels(Front)	Front aluminum alloy electric scooter wheel with 12-1/2x3.00 tire and tube, 160mm disc brake rotor, two wheel bearings, axle, and mounting hardware. Provides steer and braking for the scooter	59.95	2	119.9
E-Scooter Wheels(Rear)	Rear wire spoke electric scooter wheel with 12-1/2x2-1/2 tire and tube. 80 tooth chain sprocket with freewheel, band brake, axle, axle spacers, and mounting hardware.	49.95	1	49.95
ABS Fillament	For Alpha/Beta Protoyping (Makes up comlex furfaces such as sheilding, elctrical eonclosures, etc.	11.30 per lb	5	56.5
Cast Aluminum	Aluminum is esimated to be the main material governing the body and deck of the scooter for its weight and price.	0.33 per lb	20 lbs	7.26
Bike Battery (12-Volt 12-Ah)	Power Source for Vehicle	39.95	1	39.95
Disk Brake Caliper with Pads	Disc brake caliper with brake pads. Universal fit caliper compatible with most electric scooters. Attaches to Wheel Assmbly	17.95	2	35.9
Pull Break Switch and Spring	The spring is designed to go between the plunger and any part of the braking system which will pull on the spring when the brake is engaged. The spring takes up any over-pull that the braking system exerts on the switch to prevent pulling too hard on the brake switch's plunger.	2.95	2	5.9
Inline Charging Port	Provides means for batery to be charged	3.49	1	3.49
Inline Charging Plug	Provides means for batery to be charged	4.49	1	4.49
Motor (24-48Volt)	Powers Drivetrain from electricity drawn from the battery(electric)	(50-180)	1	50
Suspension/Shock Absorber	Suspension srings with mounts for front and rear wheels. Impacts handling and comfort of the vehicle	14.95	3	44.85
Upholstered Seat with Suspension	Seating platform for user in sedentary position	19.95	1	19.95
Total				438.14

Conclusion

The project is currently on track to meet the goal of designing a statically stable and safe design for an electric PTV. A literature review was completed for many products currently on the market and allowed the team to see what features and styles could inspire their designs. The team has gained insightful information of what customers are looking for in an electric PTV through the online survey and several in-depth interviews. After observing current types of electric PTVs and understanding the customer needs, the team was able to generate seven individual concepts before combining them into four to undergo a final scoring matrix. It was decided the top two concepts, “Shield Vehicle” and “Backpack Vehicle”, were the selected designs but will have to be further evaluated in order to come up with a true final design where prototyping could begin. The team also performed a technical analysis on systems and mechanisms that will potentially be used in their selected concept. In terms of project planning, the Gantt chart will be constantly updated to reflect current progress on milestones and the project’s budget will continue to be evaluated until it is time to order parts. With this report and upcoming presentation, Phase 1 has concluded and the team will begin working for Phase 2.

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Appendix

Table A-1: Stakeholder List

Primary Stakeholder

Who is the stakeholder?	● Everyday City Commuter
What are they doing (or failing to do)?	● Commuting for work ● General traveling needs
When are they doing it?	● At the beginning and end of their workdays ● For common day errands (post office, groceries, etc.)
Where are they doing it?	● Urban Environments (cities, towns, etc.)
Why are they doing it?	● To get from point A to point B quicker and easier ● Need another form of safe and reliable transportation
How are they doing it?	● Will be using electric PTVs on the streets, either sitting or standing
What is the current solution?	● Walking, public transportation, driving

Secondary Stakeholder

Who is the stakeholder?	● Consumer for Recreational Use/ Hobbyist
What are they doing (or failing to do)?	● Getting around places without using the common method
When are they doing it?	● Whenever necessary (ex. Going to the store, simply out and about)
Where are they doing it?	● Suburban or rural areas
Why are they doing it?	● Want an easier way to get around besides the conventional methods like walking or driving
How are they doing it?	● Will be using electric PTVs on the streets, either sitting or standing
What is the current solution?	● Walking, public transportation, driving

Secondary Stakeholder

Who is the stakeholder?	• Department of Transportation/ Government officials at state or city level
What are they doing (or failing to do)?	• In charge of the laws concerning transportation/traffic
When are they doing it?	• Are constantly passing laws to keep up with the technological era • Every time a new device is introduced to the public
Where are they doing it?	• In their government offices or at city hall
Why are they doing it?	• To keep all citizens safe on the road
How are they doing it?	• By implementing and updating transportation/traffic laws
What is the current solution?	• Some cities have passed specific laws to regulate the use of electric PTVs by the public

Secondary Stakeholder

Who is the stakeholder?	• The Regular Passerby
What are they doing (or failing to do)?	• Minding their own business to get to their desired destination with no issues
When are they doing it?	• Any time when they are out and about their days
Where are they doing it?	• Can be anywhere • For this project, they will be on the sidewalks or also on the streets
Why are they doing it?	• To get to their intended place using the quickest method
How are they doing it?	• Walking, driving in cars
What is the current solution?	• Electric PTVs should not be a nuisance to the regular passerby. The device will aim to cause little to no distractions or disruptions to the people around the rider.

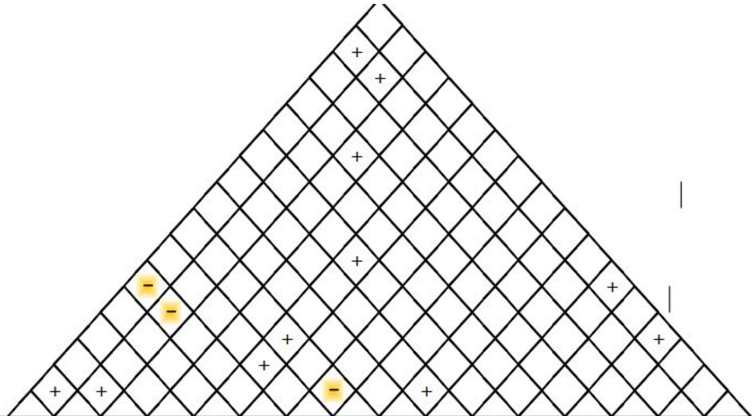
Table A-2: List of Customer Questions Asked

What do you prefer to ride in urban environments (densely populated areas such as cities)? If you were in a large city like NYC, how would you usually get around places?
Do you own any personal transportation electric vehicles? Are any of them electric? If not, why not?
What do you LIKE and DISLIKE about ELECTRIC personal transportation vehicles?
What would you look for in your ride experience? (Ex. Speed, Mobility, Stability, etc)
Would you prefer to be standing or sitting while riding a personal transportation vehicle?
How much are you willing to budget for an electric personal vehicle?
What issues have you had with personal transportation electric vehicles? Did you find any faults with one particular device?
What features would you like to see in new personal transportation electric vehicles? Ex. Touchable interface, long battery life, etc.
Why do you think the older audiences don't use personal transportation electric vehicles as much?

Correlations	
Positive	+
Negative	−
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

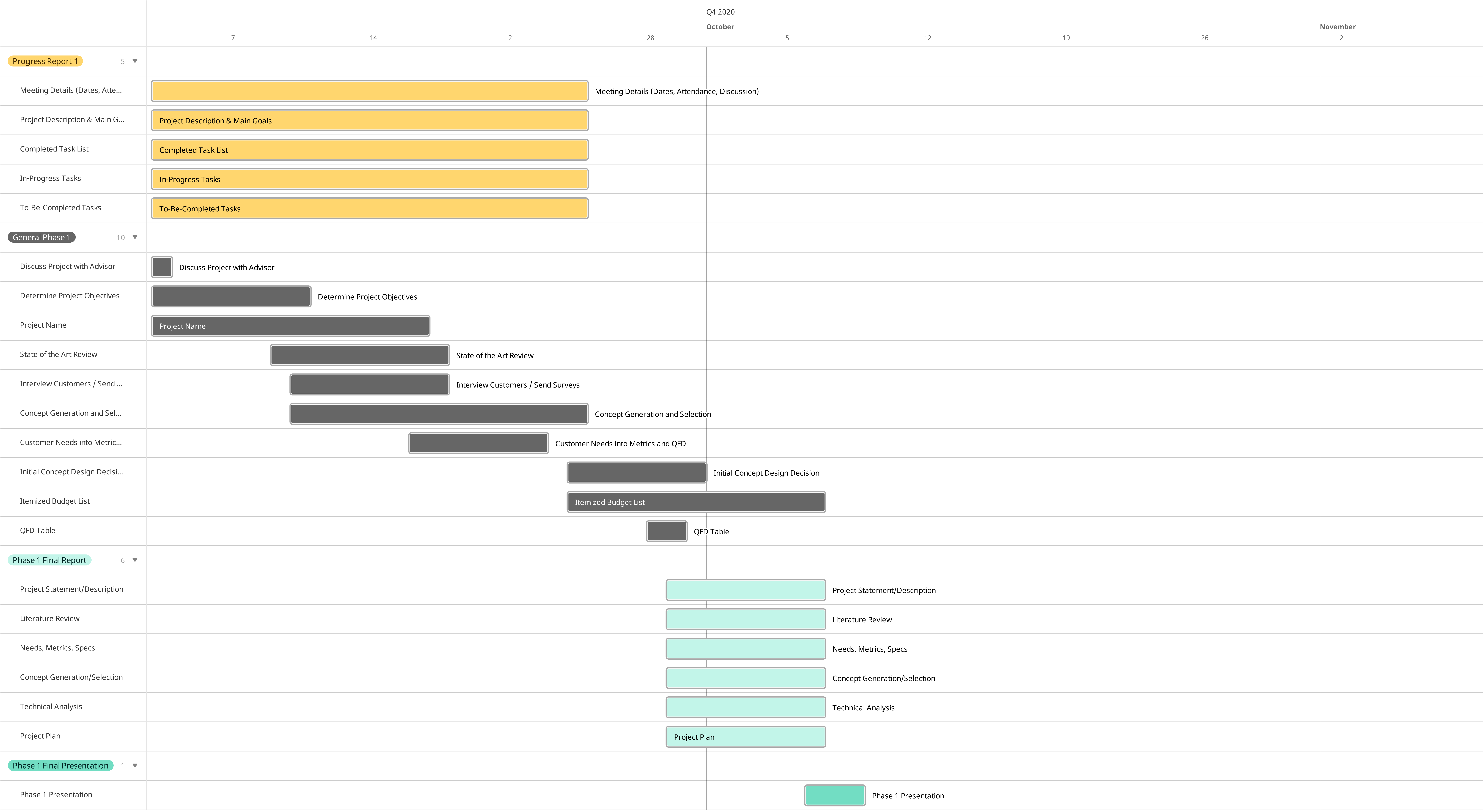
Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



Row #	Weight Chart	Relative Weight	Customer Importance	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
				Direction of Improvement	◇	◇	◇	▼	▼	◇	▼	▲	▲	▲	◇	▲	◇	▲	▼	◇
				Technical Requirements / Customer Requirements	Max Speed	Max Acceleration	Height of COG	Turn Radius	Deploy Time	Total Weight	Minimum Collapsible size	Additional Storage Capacity	Maximum Obstacle Traversal	Support Polygon Area	Number of Moving Parts	Maximum Run Time	User Height Accessibility	Product Life Expectancy	Braking Time	Total Components
1		6%	4	Lightweight	●	●		●	○	●					▽	▽				○
2		8%	5	Electric	○	○									○	○		○	○	○
3		5%	3	Easily Storable					●		●	○								
4		3%	2	Extra Storage Component							○	●								
5		5%	3	Affordable							▽	▽			●	○		●		●
6		8%	5	Safe	●	●		○		○			●	○			●		●	
7		5%	3	Security Measures												▽		○		
8		3%	2	Tech Interface					○							○				
9		2%	1	Multimedia Functions												▽				
10		8%	5	Ride Stability	○	○	●	○		○			●	●			●		○	
11		5%	3	Comfortable			○						○	▽			○			
12		3%	2	Endures Weather/Environment									○					○		
13		6%	4	Long Battery Life	▽	▽			▽						○	●		▽		
14		5%	3	Efficient Chargability											▽	○				
15		6%	4	Controllable Ride Speed	●	●				○				○			▽		●	
16		5%	3	Visually Appealing						▽	○	▽			▽			▽		○
17		3%	2	Environmentally Friendly Materials											▽			○		○
18		6%	4	Durable						▽			▽		●			●		
19		6%	4	Easy to carry around					○	●	○	▽			▽					▽
20		6%	4	Simplicity for usage			▽		▽		○	▽			○		○		▽	
				Technical Priorities	228.79	228.79	87.879	100	98.485	183.33	104.55	62.121	165.15	113.64	178.79	125.76	174.24	160.61	174.24	110.61
				Relative Weight	10%	10%	4%	4%	4%	8%	5%	3%	7%	5%	8%	5%	8%	7%	8%	5%
				Weight Chart																

Figure A-1: Quality Function Deployment Table

Figure A-2: Gantt Chart


Q4 2020
October
November
7
14
21
28
5
12
19
26
2
Progress Report 1
5
Meeting Details (Dates, Atte...
Meeting Details (Dates, Attendance, Discussion)
Project Description & Main G...
Project Description & Main Goals
Completed Task List
Completed Task List
In-Progress Tasks
In-Progress Tasks
To-Be-Completed Tasks
To-Be-Completed Tasks
General Phase 1
10
Discuss Project with Advisor
Discuss Project with Advisor
Determine Project Objectives
Determine Project Objectives
Project Name
Project Name
State of the Art Review
State of the Art Review
Interview Customers / Send ...
Interview Customers / Send Surveys
Concept Generation and Sel...
Concept Generation and Selection
Customer Needs into Metric...
Customer Needs into Metrics and QFD
Initial Concept Design Decisi...
Initial Concept Design Decision
Itemized Budget List
Itemized Budget List
QFD Table
QFD Table
Phase 1 Final Report
6
Project Statement/Description
Project Statement/Description
Literature Review
Literature Review
Needs, Metrics, Specs
Needs, Metrics, Specs
Concept Generation/Selection
Concept Generation/Selection
Technical Analysis
Technical Analysis
Project Plan
Project Plan
Phase 1 Final Presentation
1
Phase 1 Presentation
Phase 1 Presentation