Metro-E Design Evolution

ME450 | Winter 2023 | Team 29

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Executive Summary

The electric bicycle market has experienced significant growth in recent years, as consumers seek sustainable and convenient transportation alternatives. However, many e-bikes still suffer from ergonomic and accessibility issues, which can discourage potential users. Our goal is to evolve an e-bike, Metro-E, developed by our project sponsor, Hans Erickson, that addresses these concerns, while maintaining safety and performance standards.

Requirement	Specification
Weight	Must be under 40 lbs with battery installed
Cost	Cost to produce (including battery) under $1100
Ergonomics	Upright seating geometry with balanced head-tube angle and reach under 8 inches. Average person can make 90^{o} turn within on a 5 ft sidewalk
Form-Factor and portability	Must fit within the size envelope of a standard 26-in wheeled bike & maximum stepover height of 20 in.
Safety	Can stop within 15 ft from 15 mph with a 150 lb rider (CPSC 16 CFR Part 1512.5 [5]) and can support a 250 lb rider.
Cargo Capability	Can support a case of beer (35 lbs) when the bike is tilted 45deg. Must be able to stand upright during loading.
Comfortability	Accommodates riders in the middle 90% of heights 5'1 - 5'11

This report presents the design and analysis of Metro-E, with a focus on ergonomics, accessibility, and safety. Our team utilized various computational and analytical methods, including Fusion 360 simulations and hand calculations, to evaluate critical components such as the frame, suspension, footrests, and braking system. The results of our analysis provided valuable insights into the e-bike's performance and allowed us to make informed design decisions, ensuring a comfortable and safe user experience. The final design proposed includes improved brakes, shorter wheelbase for increased maneuverability, a simple frame design guided by design for manufacturability, and a rigid cargo rack of improved strength. The design is also easily produced/serviced. With the exception of the welding of the frame, the bike can be assembled using simple tools such as a wrench, screwdriver, and allen key. The total projected cost of the bike is approximately $919. However, this estimate is derived from the cost to produce a prototype rather than the cost at scale.

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Introduction

Metro-E is a consumer product intended to replace golf-carts and other similar modes of short-distance transit, sponsored by Hans Erickson, Entrepreneur. The previous model, pictured below, was intended to serve an urban audience and is prohibitively expensive to manufacture. Current market competitors are either too-heavy to lift, or incapable of carrying cargo. We aim to provide a simple, reliable, lightweight frame design for the Metro-E that is easy to maintain, and highly comfortable to ride.

Figure [1]: Previous version of the Metro-E, or MEV1

Through our evolution of the Metro-E, we sought out to improve the frame, braking system, footpegs, seat, and cargo rack, as well as reduce cost. In this report, we outline the design journey that resulted in version 2 of Metro-E, or MEV2.

Stakeholder Analysis

We set out to identify our stakeholders by creating individual stakeholder maps. Upon collaboration, our group was able to determine our best stakeholder map, outlined below. This technique of stakeholder analysis worked well in refining primary stakeholders, as well as expanding each other's scope when thinking about tertiary stakeholders.

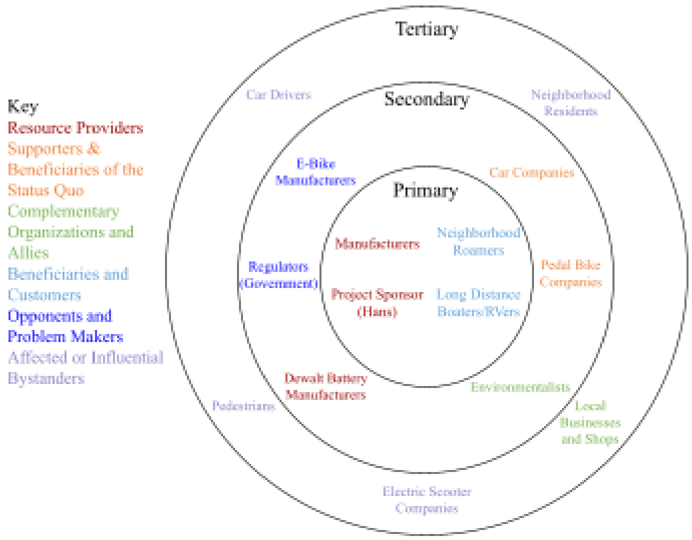


Figure [2]: Stakeholder Map and Key

We discussed with Hans the market he was trying to target to help identify the primary stakeholders. It is worth noting that Hans' target audience changed from urban transit to long distance boaters and RVers as well as people wishing to travel around their neighborhoods. These people have become the users, or beneficiaries and customers whose lives are directly impacted by the problem. The other primary stakeholders are Hans, as it is his business that he is running, and the manufacturers, the ones manufacturing the product.

We were able to determine our secondary stakeholders by thinking of those who are part of the problem context, but may not encounter the E-bike themselves. Reflecting on those that fit this description included some opponents and problem makers, supporters and beneficiaries of the status quo, and complimentary organizations we generalized as "environmentalists".

For the determination of tertiary stakeholders, we benefited from collaborating with each other about those outside the problem context, but may have the ability to impact the success or failure of the Metro-E. Doing so allowed our scope to be expanded, as we brought to light those that do not immediately come to mind. The majority of those in this category were affected or influential bystanders. In theory, this category could expand well beyond our stated stakeholders, however, and as we move along this semester we may identify stakeholders that become more relevant to our problem worth considering. Consideration of the stakeholders positively and negatively affected from the development of Metro-E are outlined below.

Table [1]: Stakeholder Impact Analysis

Stakeholder	Effect	Positive/Negative
Long Distance Boaters/RVers	The main users/customers that will benefit from a dinghy/RV-portable Ebike to travel.	Positive
Neighborhood Roamers	The main users/customers that will benefit from comfortable short-distance travel.	Positive
Hans Erickson (Sponsor)	Project sponsor that will benefit from a successful business.	Positive
Environmentalists	Groups that will appreciate a decreased dependency on cars and decongestion.	Positive
Local Businesses and Shops	Potential for increased shopping in tourist shops or local businesses.	Positive
Tool Battery Manufacturers	Because Dewalt batteries are an external material our product uses, they should see more business.	Positive
Pedal Bike Companies	Increased competition will lead to less business.	Negative
Ebike Companies	Increased competition will lead to less business.	Negative
Regulators (Government)	More regulation/infrastructure may be needed for Ebike travel.	Negative
Car Companies	Car companies have a history of lobbying against accessibility to car-alternative travel.	Negative
Pedestrians	Shared pathways present public safety issues with the bikes traveling at much higher speeds than pedestrians.	Negative
Car Drivers	Bikes present an additional obstacle for car drivers to navigate when bike and car spaces overlap.	Negative

Intellectual Property

Our project sponsor, Hans Erickson, had requested that we transfer over the intellectual property for this project, which required us all to sign student IP agreements, making Hans the owner of all intellectual property created in this course. Before this project was underway, we knew these conditions going into our project selection.

Design Process

During the semester, our team adhered to a systematic design process, which greatly influenced our actions and decision-making. We followed a structured approach, beginning with concept generation, where we created numerous concepts for each subfunction, such as the frame, seat, footrest, and battery security. To promote diversity in our ideas, we used individual brainstorming sessions, design heuristic cards, and morphological charts, ensuring that we considered a wide range of potential solutions. After generating an extensive list of concepts, we employed a multi-stage concept selection process. First, we eliminated concepts based on our intuition and sponsor's preferences. Next, we used our engineering knowledge to evaluate the feasibility of each concept and iteratively refined them. Finally, we employed Pugh charts to objectively compare the top concepts and selected the best fit for our Metro-E e-bike project.

The systematic design process facilitated a comprehensive frame redesign and the development of additional features. Our alpha design incorporated improvements such as a simplified construction using aluminum square tubing, a fixed-mounted storage rack, and updated geometry for nimble handling without compromising stability. We also performed stress simulations to ensure the safety and durability of our design. Throughout the project, we remained mindful of our target audience and the sponsor's requirements, allowing us to develop a product that caters to the needs of middle to old-age consumers in suburban settings. The systematic design process played a crucial role in guiding our actions, ensuring that we approached each stage with rigor, creativity, and attention to detail.

Information Sources

Throughout our project, we actively sought valuable input and expertise from external sources. We engaged with Fitmi!, a local professional bike-fitting service and custom bike builder in Ann Arbor, Michigan, and Human Electric Hybrids, a nearby e-bike shop specializing in bike geometry and user demands. Both establishments provided us with invaluable insights to inform our engineering project. Fitmi!, founded by Jessica Maxine Bratus, a cycling enthusiast with over 15 years of experience in bike fitting, offered essential guidance on optimizing the bike fit for our target demographic. Through consultations with Fitmi!, we gained insights into key ergonomic considerations, such as the ideal seat design, footrest placement, and frame geometry, to ensure a comfortable ride for our middle to old-age consumers.

In addition to Fitmi!, we consulted Human Electric Hybrids, a local e-bike shop with expertise in common user demands and sales trends to inform our featureset. Their knowledge in e-bike design and functionality enabled us to identify critical design elements, such as battery placement and securement, motor integration, and braking systems. Human Electric Hybrids also provided feedback on industry trends and user preferences, allowing us to incorporate features that cater to the specific needs of suburban commuters.

User Requirements and Engineering Specifications

As the electronics system is entirely frozen for this design cycle, we first selected our main areas of concern to be addressed; cost, weight, cargo capability, safety, comfort, and form-factor. From here we assigned functional metrics for each category based on stakeholder feedback. We consulted bike geometry experts to help us quantify stability and ergonomics in the design process. Metro-E was designed first and foremost for comfort, to enable more riders to choose personal electric transit over an alternative form of transportation. In the spirit of this, we have chosen to retain comfort as our first and foremost priority. Practicality follows close behind, which is where the previous design suffers the most. We hope to increase practicality and significantly lower manufacturing costs through strategic simplification of the frame.

In terms of the breadth of our requirement set, we actually chose to completely eliminate all performance requirements, as most of the components that contribute to those areas are frozen for this design process. Our task is to improve the existing design without any loss of functionality, and our set of requirements is simply a measure of that. There are a multitude of alternative products on the market, but none that serve this particular audience that necessitates both a substantial cargo capacity, as well as a low enough weight for practical portability. There are very few options on the market which entirely forgo a crankset that also keeps the bike form factor, all of which weigh over 100 lbs. Table 2 outlines our list of requirements and associated specifications for verification and validation.

Table [2]: Requirements and Specifications

Requirement	Specification	Verification	Validation
Weight	Must be under 40 lbs with battery installed	Measure weight in CAD	Weigh final build design
Cost	Cost to produce (including battery) under $1100	Bill of materials	Bill of materials
Ergonomics	Upright seating geometry with balanced head-tube angle and reach under 8 inches. Average person can make 90º turn within on a 5 ft sidewalk	Reference CAD model for geometry, comparison to similar market products for turning radius	Measure final build design for geometry, use of final build design for turning radius
Form-Factor and portability	Must fit within the size envelope of a standard 26-in wheeled bike & maximum stepover height of 20 in.	Measure CAD model	Measure final build design
Safety	Can stop within 15 ft from 15 mph with a 150 lb rider (CPSC 16 CFR Part 1512.5 [5]) and can support a 250 lb rider.	Hand calculations from brake specs and design geometry, frame/subsystem FEA for strength standards	Final design build stopping tests and weight loading tests.
Cargo Capability	Can support a case of beer (35 lbs) when the bike is tilted 45deg. Must be able to stand upright during loading.	FEA of cargo rack attachment with angled loading	Practical load tests on final build design
Comfortability	Accommodates riders in the middle 90% of heights 5'1 - 5'11	Wooden frame mock-up	Final build design

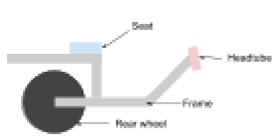
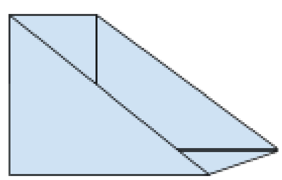
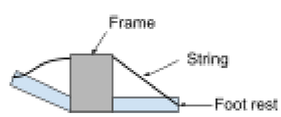
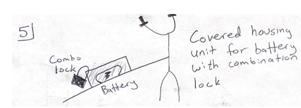
Our weight target was set by our project sponsor, as a ”reasonable” improvement over the existing bike’s weight of 43.8 lbs. While there are no universal lifting standards, OSHA recommends a maximum lifting weight of 55lbs for the general populous, and a 40lb maximum lift weight for those over 50 years old. Metro-E is aimed to be a sub-premium transport option, with a target MSRP of $2000, at the scale of production we expect to see, a 40-50% profit margin is appropriate for the sector. Most importantly is comfort, accessibility, and safety. The bike must be able to bring a 150 lb rider to a full stop from 15 mph for a class II ebike, per the standards of CPSC 16 CFR Part 1512.5 [5].

Design Phase

Concept Generation

In order to maximize project potential, generating a large number of concepts is necessary. Since metro-e is a combination of many subfunctions, we created concept categories for each individual target component (frame, seat, footrest, battery security). These categories were chosen based on the district characteristics that our project sponsor wanted evolution on. Although all of these components need to be compatible, the concept generation of each component can be thought of as separate. For example, the security lock for the battery shouldn't change the design of the seat and vice versa. An example for each of the subfunctions is shown below in Table 3.

Table [3]: Concepts for different subfunctions

Frame	seat	footrest	Battery Security
			

Initially, we held individual brainstorming sessions, which were divergent in nature. An idea like alternative energy led to ideas like regenerative braking, digital drive pedals, and solar power. We went from generating and sketching any ideas that came to mind to using the design heuristic cards. These concept generation sketches can be seen in Appendix B. This strategy allowed us to draw inspiration from the various prompts on the design heuristic cards. For example, card #76 states, 'Utilize an Opposite Surface', which led to the concept of foot pegs with whole foot support and top and bottoms fitting two different sized feet, shown in Figure 3.

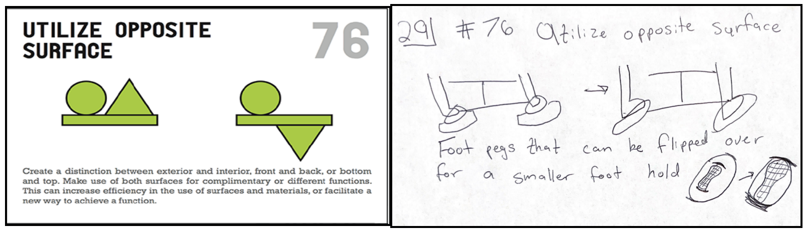


Figure [3]: Concept generation from design heuristic card #76

Another way to promote diversity in concept generation is to consider any concept, not just ones that seem feasible. For example, in order to make the battery less likely to be stolen, this proposes hiring security to watch over the battery as seen in Figure 4 below.

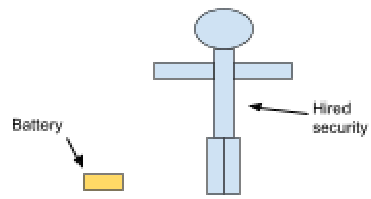


Figure [4]: Concept proposing hired security to watch over the battery

We also explored concepts that consider changing the transport device entirely. For example, the concept seen below proposes an electric wheelchair design as opposed to the classic bike design.

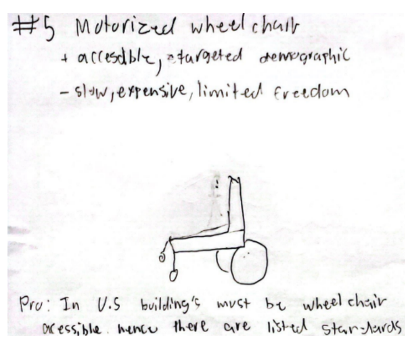


Figure [5]: motorized wheelchair concept

After the initial concept generation, we encouraged additional diverse concepts by organizing all of our individually found concepts into the sub function categories. This allowed us to see which categories needed more concepts. From this we noticed that we had less concepts regarding seat design. In order to increase the number of concepts for something we were struggling with, we developed more concepts by combining existing ideas. This can be seen in Table 5, where our team used a morphological chart to create a large number of seat designs from individual seat design ideas. Implementing the morphological chart in our concept generation phase allowed for concepts with unexpecting pairings of features, but some promising results. Additional examples of morphological charts in our concept generation phase can be found in Appendix B

Table [4]: Concept generation of seat using a morphological chart

Characteristic	Concept			
Shape	Flat	Contoured	Traditional bicycle	Desk style
Seat padding	Air	Foam	Stretch material	Plastic
Edge profile				

In this chart, each concept for a characteristic can be combined with the concepts from the other characteristics, resulting in 64 different seat designs.

Concept Selection
After generating a large number of concepts, these concepts must be narrowed down. For the first round of concept selection, our team went through each concept category and removed the bulk of the concepts due to “gut feelings” and sponsored pre-selected features. For example, Our second round of concept selection used our engineering knowledge to estimate how easily each concept could hit the requirement and specifications. This was an iterative process that allowed us to modify and evolve concepts before we eliminated them. For the third round of concept selection, we scored the top concepts using pugh charts to find the best fit for Metro-e. Concepts, along with elimination explanation, are shown in Appendix A.

The selection of our frame concept consists of 4 different designs and using steel as the material for the best scored design. The frame design needs Strength is also a concern, yet since the riding is low impact (no cyclical loads and smooth terrain) we weighted it lower. Our first concept was to keep the current frame design but remove the current slider mechanism. This has the benefit of increasing the strength and manufacturability, but still is an over complicated design that would be difficult to steer. The Foldable frame concept would be our most portable option, but with the trade off of complicated manufacturing and lower strength. The recumbent style frame would be both strong and portable, but since this project is intended for ages 55 + years, the recumbent frame would not be easy enough to ride. The Vframe design offers a large decrease in weight and manufacturing difficulty yet doesn't offer the same strength as other options. Using steel allows for an increase in strength with a decrease in manufacturing difficulty, but results in an increase in weight, which not only affects the portability, but also the rideability. This is summarized in the pugh chart in table 5.

Criteria	**Weight**	**Frame w/o Slider**	**Foldable Frame**	**V Frame**	**Steel V Frame**	**Recumbent Style Frame**
Strength	2	2	1	2	3	2
Portability	3	1	4	3	2	3
Cost	3	2	1	3	4	2
Rideabilit y	3	1	2	3	2	1
Total		16	23	31	30	22

Table [5]: Pugh chart selection for the frame concept

The V frame design will hit the specification for weight and manufacturability. It also has a decreased wheelbase and slack which will contribute to decreasing the turn radius. There could be issues with the angle from the seat to the footpegs being too steep forcing the rider to stand, so seat and peg placement will be important. The initial idea that came to mind for this project was a frame similar to classic cruiser bicycles. This initial idea is similar to our current concept with a low stepover height and a shortened wheelbase; however, due to the complication of manufacturing bent tubes, our chosen concept has a unique V shaped geometry. It is difficult to avoid fixation on an initial concept, but by generating a large number of concepts and using an unbiased and consistent selection process, this is avoided.

In addition to the frame Metro-e needs revision to the battery securement, foot pegs, brakes, storage rack, and seat. As later discussed, the frame will be made from square tubing, this will prevent the rotation of the current storage rack, additionally, we will include strap loops to hold down large cargo. Our initial seat design was foam and contoured. This had to be eliminated due to the new specification of no water absorption. We are currently planning on using a contoured seat with curved edges made from plastic. This will allow us to easily iterate and test the seat to find a comfortable design. For the battery securement, we have developed a concept that will lock a piece in front of the battery to prevent the battery from removal (slides forward to remove). This concept to be further developed is shown below in Figure 6.

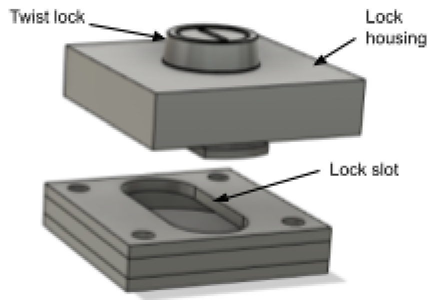


Figure [6]: Slide stop concept chosen for battery security

This design uses twist locks which can be found on McMaster-Carr or hardware stores. This design also allows for the width and height of the lock to be changed based on the location and height of the battery. There may be issues with the shape making good contact with the battery, so iteration and concept development will be necessary.

The current rim brakes are insufficient in stopping the bike. Due to the low cost, low maintenance, and high stopping power, hydraulic disc brakes will be the best. The disk brakes do not integrate with the current rear hub, which is a design parameter we cannot change, therefore we will need to keep rim brakes on the rear. The footrest we have chosen are pegs that are attached to the frame with a pin allowing for the ability to between the vertical position and horizontal position. Pugh charts for choosing the footrest and battery securement are shown in Appendix C.

Concept Description (Alpha Design)

After narrowing down our design criteria and selecting the concepts we would like to move forward with, we proceeded to generate an alpha design. As metro-E is an ongoing process, there are a number of concepts that are mandatory carryover, such as the seating-style, step-through geometry, and integrated rear cargo rack. To accomplish our goal of making a comfortable, suburban commuter for middle to old-age consumers, we have opted to focus the majority of our resources into a comprehensive frame redesign, with additional added features, as needed.

In our current alpha design, we have eliminated the frame-fold, consolidated the whole bike into one stock for production, decreased the size, and updated the geometry to allow for more nimble handling, without sacrificing stability. We have done this by increasing the headtube angle from 63 degrees to 68 degrees, reducing the natural stability of the bike. It is of note that the alpha design is heavily restricted in terms of overall geometry, and required features for the new iteration. With such a wide range of improvements, the depth of engineering analysis for some subsystems will have to be neglected to achieve a suitable deliverable at the end of the semester, hence the rather easy-to-validate requirements above.

In our alpha design for DR2, we have chosen to omit seating options pending a complete overhaul due to shareholder requirements. We have simplified the bike to use a single, 1.5x2.5”, 0.09 inch thick aluminum square tubing to greatly simplify construction. We have replaced the storage rack with a fixed-mounted solution, following industry trends for cargo-ebikes, and we have updated the geometry of the bike for a nimbler ride, without compromising stability. While the presented design has entirely fixed suspension, the bike is designed to easily accept suspension with minimal frame redesign, and full carryover of the existing rear-wheel suspension

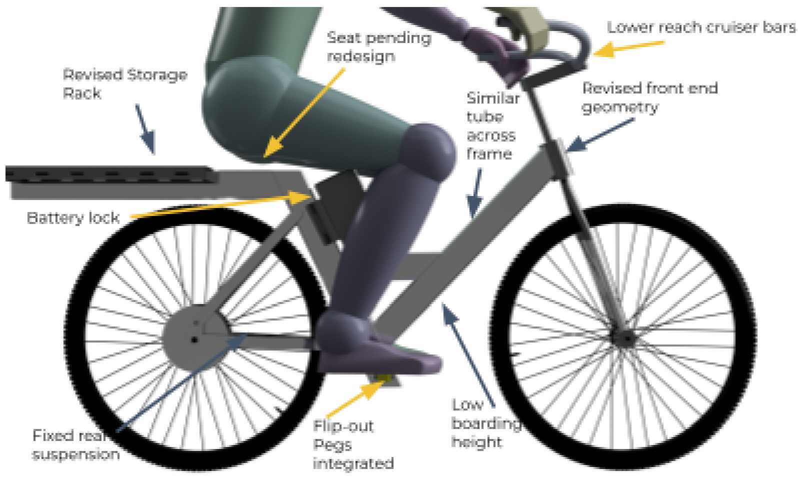


Figure [7]: Alpha design of Metro-E V3

In order to find the points in the frame design, we ran a simulation with the forces applied to the frame as seen in Figure 8. For this simulation, we assumed the rider to be 250 lbs , which is the 95th percentile among bike riders in the United States [18]. We also assumed that the force is a constant, applied at the wheel axis. Since there is no pedaling motion, there is no cyclical loading and the constant force assumption can be made, with allocations made for simulation of road vibrations and shock load to be made before DR3.

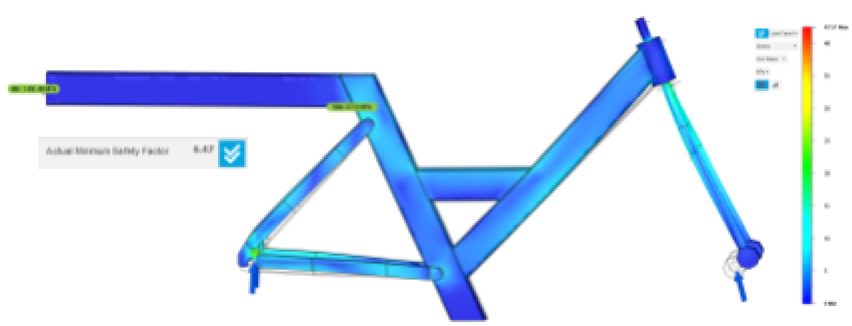


Figure [8]: Stress simulation for alpha design

From this simulation, we can see that the highest stress will be at the connection between the frame and the seat stay. The simulation found this maximum stress to be 42.51 MPa with a minimum safety factor 6.47, which is more than sufficient.

Engineering Analysis

For our project, we used various engineering analyses that consisted of theoretical and physical models.

FEA Analysis

Because our iterative design for our bike took place on CAD, finite element analysis was a fluid transition to implement. Our analytical approach saved us time and prevented us from waiting to perform analysis on our final design.

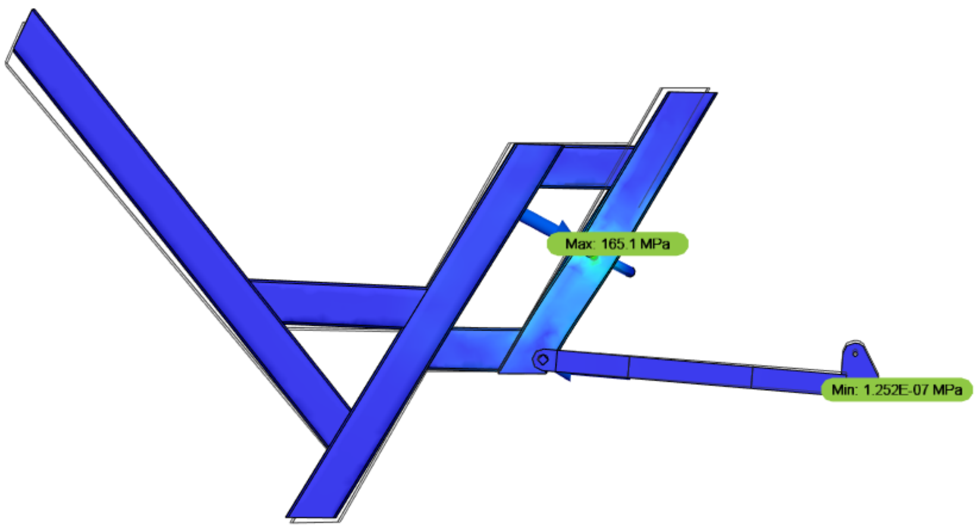


Figure 9: Frame Analysis in Fusion 360

Our first analysis of the bike was the frame design. The analysis on the frame ties to the accessibility requirement. Because the frame geometry is such a critical part of the design for bicycles, we needed to make sure that the frame could withstand a sufficient amount of force. Because our E-bike is unique in the aspect of no pedaling function, our analysis came from applying a singular force of 3 kN in the downward direction, placed where the seat lies. This was the simplest method that still satisfied our test to determine the strength of the frame. The approach to the FEA was rigorous, as the model used represented the exact geometry and of the final design and consists of the exact dimensions and materials of the final product. The results showed a stress of 165 MPa centralized. We were able to proceed with our frame design because the forces were able to withstand the applied force without fracturing.

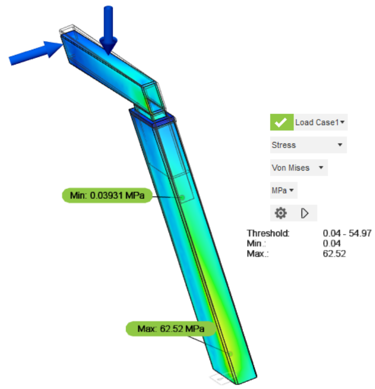


Figure 10: Cargo Rack Analysis in Fusion360

Our team performed an FEA analysis of the cargo rack in order to look into the strength and the ability of it to hold the weight of 35 lbs when tilted 45 degrees. In Figure 10, a vertical load was applied at a much larger value, 200 lbs, than the desired capacity. A horizontal moment was added to simulate when the bike is at a 45 degree angle. This simulation resulted in a max stress of 62.52 MPa, which is well under the yield strength of our material, 276 MPa for Aluminum 6061. Not only did this simulation potentially save us time and money by not testing on the actual manufactured bike, but this test would've also required testing to failure, something we do not want to do on our final product.

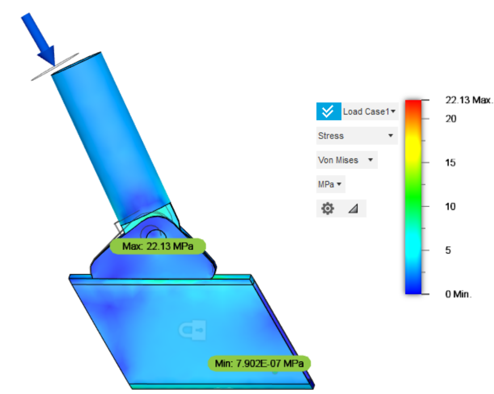


Figure 11: Suspension Component Analysis in Fusion360

In Figure 11, the component shown is located under the suspension, and the stresses were analyzed in Fusion 360 to see if a 3D printed part made of Nylon-6 is able to withstand the compression forces associated with the suspension. With the spring rate known and a fixed geometry, we were able to determine that the max stress, shown in the figure as 22.13 MPa, does not surpass the strength of Nylon-6. This test allowed us to save time by running a simulation in Fusion360 instead of testing the actual manufactured bike. Furthermore, a physical test may run until failure, something we want to avoid with limited resources and a short timeline. Future analysis work could include developing dynamic FEA simulations for the critical components above. Dynamic simulations are more rigorous, but are also more complex and time consuming to set up.

Computational Analysis

Our team performed computational analysis on the bike to give us an idea of the properties and characteristics before going through with the actual manufacturing process, outlined below.

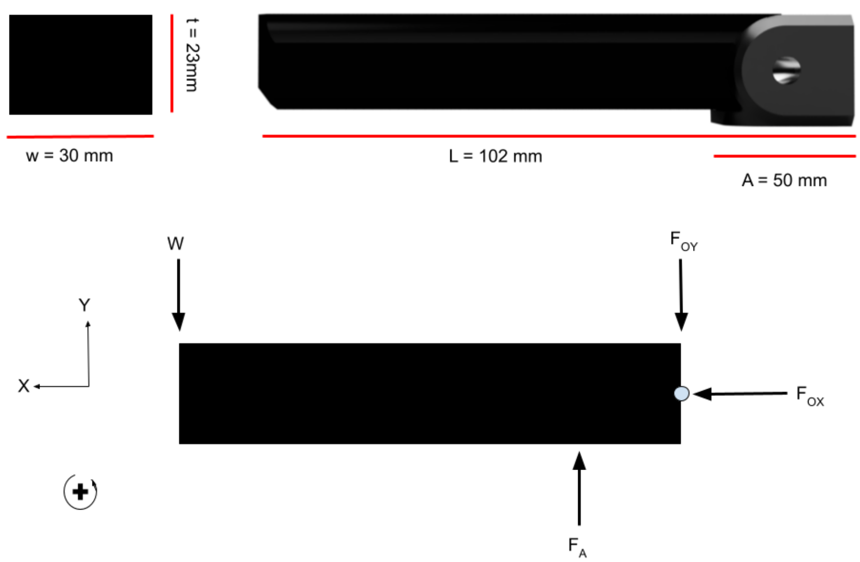


Figure 12: Diagram of the Footpegs

The computational analysis of the footrests, or footpegs, was done using hand calculations for both the structure and the pin joint. The equations can be seen in Appendix D. Our use of the calculations were justified by the fact that they did not take much time, and took no resources, while still giving us reliable results that we can compare to the listed strength of the material to understand if they will withstand the rider's weight. The details of the calculations include that the rider is assumed to put all of their weight of 250 lbs on one end of the foot pegs, which would be a worst case scenario. The results of this test showed that the point above the support of the footpegs would be the maximum stress of 21.86 MPa of stress. Compared to the yield strength of the proposed footpeg material, Nylon-6, which is 40-100 MPa, we are well under the point where the footpegs would fail [24]. In order to account for the stress at the pin joint, the area was underestimated (to maximize stress) and the stress was found from the force at the joint. This stress was found to be less than that at point A, above the support.

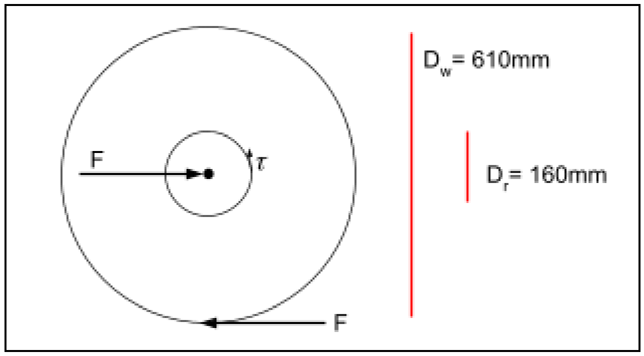


Figure 13: Diagram of the Bicycle Wheel

For the engineering analysis of the braking distance, we performed hand calculations on the friction applied to the front wheel, shown in Figure 13. This analysis related to the braking distance allowed us to save time and money before going through with the production of the bike, and saved us the risk of creating a bike that is unsafe due to a too large stopping distance. The calculations can be seen in more detail in Appendix D. The end goal was to find the required clamping force on the brake that results in the bike stopping within 15 feet with a rider of 150 lbs. Since only the front brake will be disc, we performed this calculation assuming there is no rear brake. After assuming a coefficient of friction of 0.3, which is a relatively low estimate, the required clamping force was found to be 1425 N. Per manufacturer specifications, all Shimano hydraulic disk braking systems are tuned to a 100-1 force ratio from the tip of the lever. Per CPSC 16 CFR Part 1512.5 [5], the lower bound for expected grip strength is 50N, which multiplied by 100 already puts us well above our safety margin for sufficient braking power.

Figure 14: Wooden bike frame design

Another engineering analysis consisted of constructing a mockup of our frame design out of wood to analyze the ergonomics of the design. The construction above was chosen as it was a simple and cheap way to test how the dimensions of the bike felt. The cost for this test was under $10, and took less than an hour to complete. The analysis consisted of qualitative determination of the comfort of the bike based on the placement of the foot pegs and seats, and stepover height. Performing this test instead of waiting until the final bike was manufactured saved us the potential disaster of designing a bike that turned out to not be comfortable ergonomically. We also did not want to spend resources on an ergonomic specialist. We assumed that the wooden bike frame would suffice and give us a good idea of the placement of a body on the bike. The results of this verification can be seen in the verification and validation section

Final Design Description

Our final e-bike design, named Metro-E V2, is a short distance transport solution tailored to middle-aged to older suburban commuters seeking a comfortable, efficient, and versatile mode of transportation. The design incorporates the engineering conclusions derived from our analysis and consultations with Fitmi! and Human Electric Hybrids, ensuring that the e-bike meets the specific needs of our target audience while offering superior ergonomics, performance, and adaptability.

Figure 15: Final build design

Key design features and specifications include:

- Rear suspension carried over from the original Metro-E V1 design, offering a smooth and comfortable ride on various terrains.
- A 26-inch fork for ease of acquisition and compatibility with disc brakes.
- Front disc brakes installed on a 24-inch wheel, providing reliable and efficient stopping power.
- An underslung battery to lower the center of gravity, enhancing stability and handling.
- A 2.6" lower seat height compared to Metro-E V1, accommodating a wider range of rider heights and improving overall comfort.
- A detachable cargo rack and seatback that can be easily removed or adjusted using a telescoping rod.
- Rectangular tubing for the cargo rack to prevent rotation and ensure stability when carrying loads.

Our final design is supported by detailed CAD drawings and engineering schematics that outline the dimensions and assembly of each component. Furthermore, a virtual prototype has been developed to simulate the e-bike's performance and verify the effectiveness of our design solution. Based on the evidence gathered, we are confident that our final design meets the specified requirements and will function as intended.

Despite our efforts to address every aspect of the design, we encountered some open issues during the development process:

- The 48V electronics and 60V battery requirements could not be validated through rolling tests due to budgetary and time constraints. Future iterations should prioritize troubleshooting and verifying compatibility.
- The front brake caliper was shipped with an incorrect hose side and excessively long hosing, requiring adjustments before installation.
- Internal wiring was not considered in the design, leading to potential aesthetic and functional concerns.
- The kickstand height is suboptimal, necessitating further optimization for ease of use and stability.
- The backrest is a placeholder for evaluation purposes, as developing an entirely new seat was beyond our engineering capacity during the scope of the class.

Regarding manufacturing, our design relies on materials such as aluminum for the frame and high-quality plastics for the battery casing, ensuring a balance between weight, strength, and cost. The manufacturing process would involve extrusion and welding for the frame, injection molding for the plastic components, and assembly of the e-bike components. Broad issues to consider include quality control, sourcing of materials, and scalability of production.

Manufacturing Plan

First and foremost, our goal with our project was to decrease cost and increase usability for the existing Metro-E platform, both of which were affected by the manufacturing process. Metro-E V1 consisted of 6 different stock types, mixed between round, square, and rectangular stocks of various thicknesses, which was not considered in the final manufacturing cost of the design. We had chosen to vastly simplify the construction of the bike, with the frame predominantly being made out of the same feedstock, with only the cargo rack and headtube necessitating unique stock. As we were expecting low to medium scale production of MEV2 (Metro-E V2), we had to consider the available stock length intervals and ensure we were not left with a significant amount of unusable excess stock. The semi-final design fitted on an 6 foot length of 1.5x2-0.125" rectangular tubing with only 3% excess as shown below:

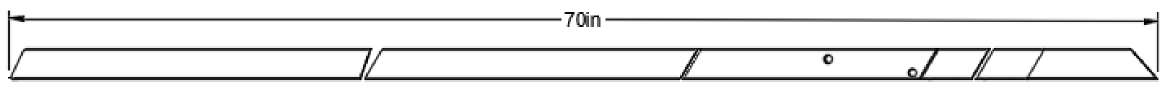


Figure 16: Cut layout for MEV2

Furthermore, the previous design necessitated the use of hole-saws for pre-weld fitting of nearly every joint, which we had completely eliminated with the use of a single, rectangular stock. This meant the entire bike could be prepared with nothing but a hand-drill, a Miter-saw, and standard hold-down fittings for welding. Metro E V2 did not require precise layup, with both cut and weld tolerances of plus/minus 0.125 inches. As the bike did not have any power transfer mechanism outside of the motor, the only critical tolerances we had were interfaces between the axles and frame, the position of the suspension pivots, and the headset cut angle. The frame was intended to be built out from the center, starting with the main frame V and working outward to ensure proper pre-weld fitment.

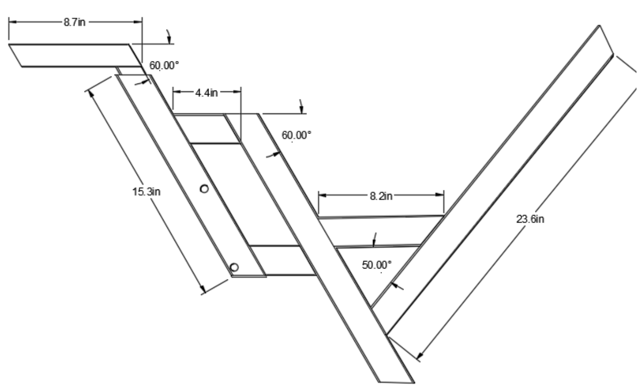


Figure 17: Mechanical layout of MEV2

The entire bike had been manufactured in two flips on the welding table (reduced from 8 for MEV1). First, the bike was laid out with tack welds from the center in, as outlined before, until the main frame was complete. Then, the frame could be flipped on the table, small adjustments could be made with a rubber mallet to correct for warping, and the other side of the frame could be tacked and welded into the final place. This process was then repeated for the other side. From there, the head-tube could be welded in-place. To create a precise clearance for the cylindrical headtube, we had piloted the hole with a 3D printed jig used in tandem with a standard 1.5” hole saw with extended pilot drill as shown below:

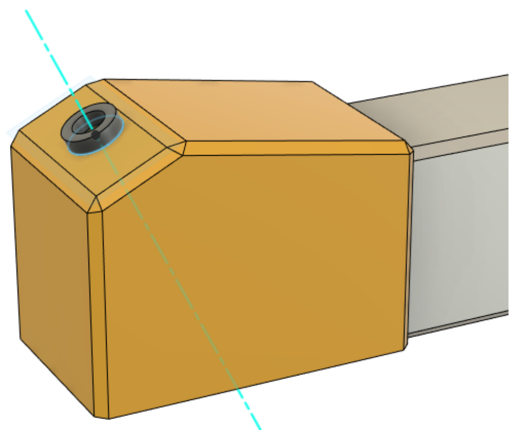


Figure 18: 3D printed headset pilot-hole jig

Operationally, we had expected MEV2 to perform similarly to MEV1, with less natural stability, and similar carrying capacity and ride performance. Where we had expected the performance to differ the most had lied in the handling and braking performance of the bike. MEV1 had suffered from having its highest natural stability occur at a perfectly upright position. This posed a problem when the rider tried to initiate a turn, the bike would “fight” the rider, and gradually lose more and more stability as the turning angle progressed. To combat this, we had increased the headset angle to decrease natural stability, but had lowered the heat height by 3 inches, as this linearly affected the stability at all turning angles the bike would experience. The result should have been a consistent (and more importantly) predictable ride experience. Finally, the addition of hydraulic disk brakes on the front axle should have massively increased both braking performance and rider ease, as the hydraulic brakes did not experience line losses as the mechanically operated rim brake calipers did.

Verification and Validation Approach

In order to determine how well our design solutions succeed in their intent, verification and validation steps were used, highlighted below.

Comfortability Verification

Question/specification	**Test method**
Is the bike comfortable?	Construct a bike frame out of wood to test dimensions with physical boarding of the bike.

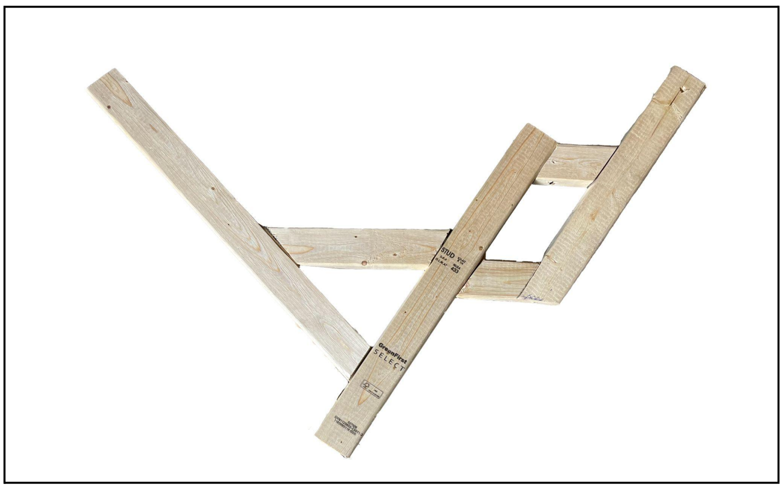


Figure 19: Wooden bike frame design

The construction above was chosen as it was a simple and cheap way to test how the dimensions of the bike felt. The cost for this test was under $10, and took less than an hour to complete. It allowed us to test the feel and comfortability of where our foot rests on the foot pegs, where our butt rests, and the stepover height. Performing this test instead of waiting until the final bike was manufactured saved us the potential disaster of designing a bike that turned out to not be comfortable ergonomically. We also did not want to spend resources on an ergonomic specialist. We assumed that the wooden bike frame would suffice and give us a good idea of the placement of a body on the bike.

The results of our test indicated that the dimensions of the bike turned out to fit a person within the 5'4 - 6'1 height range well, after tests of various human heights. The stepover height was also found to be suitable. Despite the stepover height being 6" higher than the previous iteration of the bike, the new stepover height of 14" is well under ASTM maximum stepover height [13]. This verification process showed us that the bike frame will fit our intended audience and give us confidence going through with the final frame manufacture. Our primary stakeholder has expressed positivity towards the results of the test, as he has confidence in the verification as well. Ideally we would test comfortability by allowing individuals of different body types to test the actual bike frame and seat. However the wooden frame was a cheap, and sufficient verification method for us to carry out early in our design process. For the validation of the frame design that deals with the comfortability of the bike in regards to the customers, we would like to wait until the final product is manufactured to receive real world feedback. Comfort is an important aspect of the bike since it directly impacts the consumer's experience with the bike.

Weight Verification

Question/specification	**Test method**
Will the bike be < 40 lbs net weight with battery?	Measure weight in CAD

Figure 20: Bike design in Fusion360

For the verification of the weight of the bike, we measured the weight in CAD, with correct material and dimensions input. Our justification is that it was a quick test, our CAD design was already produced in Fusion360, and has relatively good accuracy without having to weigh the final product. Our results showed that the estimated weight of 36.8 lbs is within the specification, and 2.2 lbs lighter than the previous model of Metro-E. In order to validate our design, our plan is to weigh the actual build design on a physical scale. Some more light weight components such as the break and electrical components were not included. However CAD was able to provide the team with a reference to how much weight we were adding onto the bike throughout the design process. Additionally, the team was able to weigh the final design prototype and found it to be 38.7. Light weight is an important factor for both consumers and our sponsor. Lower weight means easier transportation for consumers. Additionally it makes transportation costs lower for our sponsor increasing profitability.

Frame Verification

Question/specification	**Test method**
Will the bike be able to support a rider of 250 lbs?	FEA simulation using Fusion360

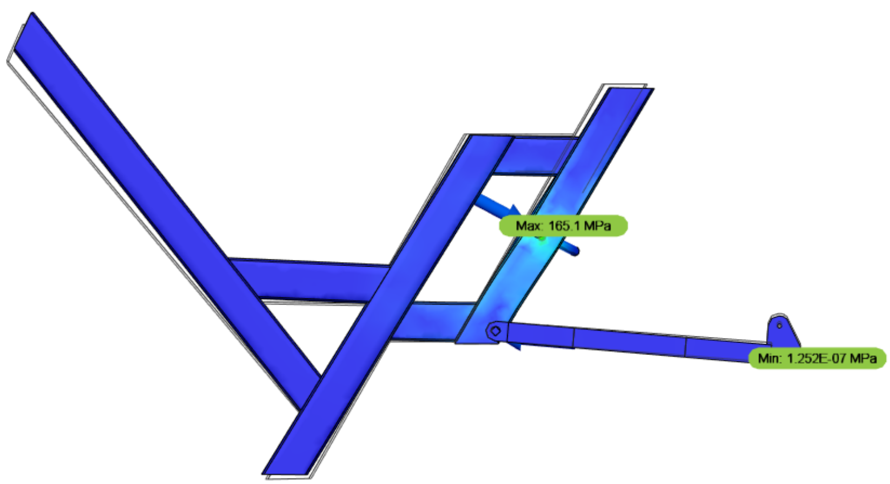


Figure 21: Frame Diagram

The analysis on the frame ties to the accessibility requirement. Because the frame geometry is such a critical part of the design for bicycles, we needed to make sure that the frame could withstand a sufficient amount of force. Our ebike is unique though, in terms that there is no pedaling, so our analysis came from applying a singular force of 3 kN in the downward direction, placed where the seat lies. This was the simplest method that still satisfied our test to determine the strength of the frame. The approach to the FEA was rigorous, as the model used represented the exact geometry and of the final design and consists of the exact dimensions and materials of the final product. The results showed a stress of 165 MPa centralized. We were able to proceed with our frame design because the forces were able to withstand the applied force without fracturing. Validation will occur by placing one of the team members on the bike with the additional weight of the to reach 250lb, while also loading the cargo rack to the maximum 35lb.A more rigorous verification method would be to do a dynamic FEA analysis with impact loaded and then use the stresses acquired from that model to do a cyclic loading analysis. This FEA model would be much more costly and time consuming. Over time cyclical loading can lead to crack propagation, eventually causing failure at rider weights much lower than what would cause failure loading statically. This phenomenon is why we chose high safety factors and worst case scenario situations.

Suspension Component Verification

Question/specification	**Test method**
Can the suspension frame-mount be made of Nylon-6? (Safety)	FEA simulation using Fusion360

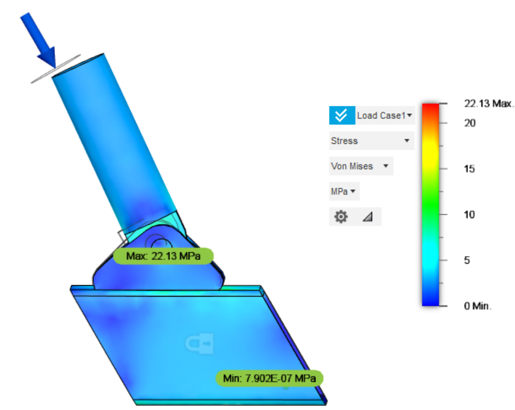


Figure 22: Cargo Rack and attachment under stress

In Figure 22, the component shown is located under the suspension, and the stresses were analyzed in Fusion 360 to see if a 3D printed part made of Nylon-6 is able to withstand the compression forces associated with the suspension. With the spring rate known and a fixed geometry, we were able to determine that the max stress, shown in the figure as 22.13 MPa, does not surpass the strength of Nylon-6. This test allowed us to save time by running a simulation in Fusion360 instead of testing the actual manufactured bike. Furthermore, a physical test may run until failure, something we want to avoid with limited resources and a short timeline. Ideally, we would do a cyclical loading test until the nylon insert failed. The load applied by the test would be found from the dynamic FEA model where the rider impacts the ground off a ledge the height of a typical curb 6in. The reason physical testing would be preferable is to ensure the quality of the manufacturing of the nylon part. 3D printed parts can have largely different material properties based on the quality of manufacturing. The safety of the nylon insert will be validated by placing one of the team members on the bike with the additional weight of the to reach 250lb, while also loading the cargo rack to the maximum 35lb. They will then ride the bike at the maximum total weight that the suspension should be able to support, and test the suspension by going off a 20 in drop.

Cargo Rack Verification

Question/specification	**Test method**
Will the cargo rack hold and secure a case of beer?	FEA simulation using Fusion360

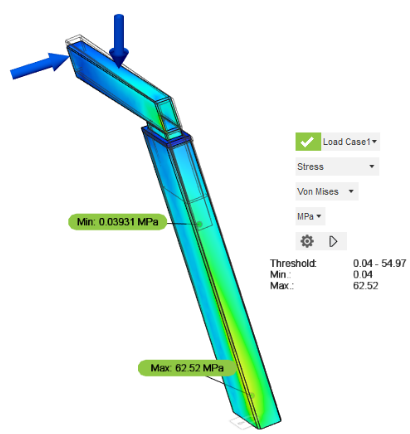


Figure 23: Cargo Rack and attachment under stress

Our analytical approach to verify the loading capacity of the cargo was chosen because of the ease of implementing the test on our already existing CAD design in Fusion360.

Our team performed an FEA analysis of the cargo rack in order to look into the strength of it and the ability to hold the specificied weight of 35 lb when tilted 45 degrees. In Figure 23, a vertical load was applied at a much larger value, 200 lbs, than the desired capacity. A horizontal moment was added to simulate when the bike is at a 45 degree angle. This simulation resulted in a max stress of 62.52 MPa, which is well under the yield strength of our material, 276 MPa for

Aluminum 6061. Not only did this simulation potentially save us time and money by not testing on the actual manufactured bike, but this test would've also required testing to failure, something we do not want to do on our final product. We understand that FEA in general is limited by the fact that you are simulating a load on a model and not testing the actual product. We are confident in these result despite knowing the limitations of FEA analysis since applied load is over 5x greater than what the bike will be rated to be able to hold, there are no stress concentrations developed in the nylon material, and where a stress concentration does exist it is less than a 1/4 of the yield stress for the aluminum stock we have selected. So although FEA is not a perfect replacement for physical testing and results are approximate, FEA still provides us with values well within our design limits and provides sufficient reason that stresses will not concentrate in the more vulnerable nylon part of the cargo rack's design. In order to validate the cargo rack we will load the cargo rack with 35lb and ride it around, and lean the bike at a 45 degree angle while loaded to see if the cargo rack holds. Additionally after manufacturing the cargo rack we were able to statically load over 100 lb onto the cargo rack with no issues.This validates the durability of the cargo rack and matches with FEA analysis. The durability of the cargo rack will allow potential consumers with more utility and use cases.

Footrest Weight Verification

Question/specification	**Test method**
Will footrests hold the necessary weight?	FBD to find moments and max stress.

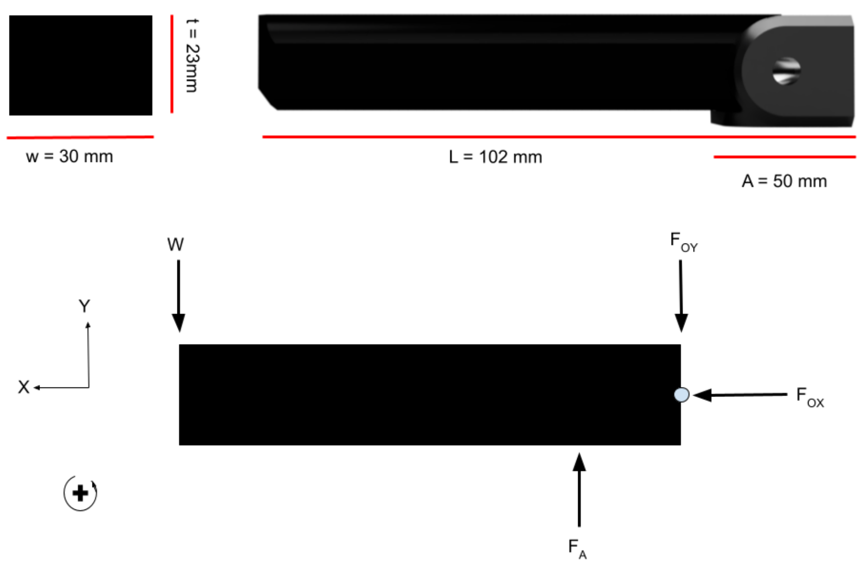


Figure 24: Footrest Diagram

For the verification of the footrests, we performed analytical calculations to determine their strength. Knowing the theoretical value of the weight that the footrests, or footpegs can hold, will prove to be beneficial to determine if additional reinforcement is needed. We chose to verify if the footpegs can hold the necessary weight via hand calculations due to our confidence in being able to simulate the forcing. Also, doing so allows us to save time and resources by waiting to manufacture the foot pegs with a 3D printer using Nylon6 until we know the weight capacity of the footpegs from free body diagram analysis and inputting the materials properties. The main con of testing the footpeg loading capacity is wasting materials by going in not knowing if it will fracture. As previously stated in the engineering analysis, the results showed that the point above the support of the footpegs would be the maximum stress of 21.86 MPa of stress, which is under the yield strength of the proposed foot peg material, Nylon-6, which is 40-100 MPa [24]. In order to account for the stress at the pin joint, the area was underestimated (to maximize stress) and the stress was found from the force at the joint. This stress was found to be less than that at point A, above the support. Since it is likely some riders will place all their weight on the footpegs at some point, we will have a teammate with additional weight added to reach a 250lb stand on the footpegs in order to validate the footpegs. The foot peg requirement is an important safety measure. During operation of the bike, riders need a means of shifting their weight from side to side during turns. Foot pegs allow the rider to support themselves while they change their center of gravity. Failure could lead to crashing or instability.

Braking Verification

Question/specification	Test method
Will the braking distance be less than 15 feet?	Computational analysis

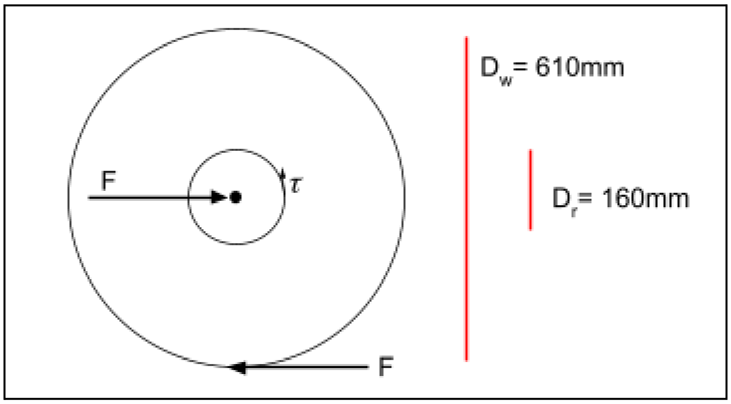


Figure 25: Diagram of the Bike Wheel

For the testing of the braking distance, we performed hand calculations on the friction applied to the front wheel, shown in figure 25. This test related to the braking distance allowed us to save time and money before going through with the production of the bike, and saved us the risk of creating a bike that is unsafe due to a too large stopping distance. The calculations can be seen in more detail in Appendix D. The end goal was to find the required clamping force on the brake that results in the bike stopping within 15 feet with a rider of 150 lbs. After assuming a coefficient of friction of 0.3, which is a relatively low estimate, the required clamping force was found to be 1425 N. To contextualize this result, we referenced a study that showed that a hand force of 100N correlated to an average clamping force of 5040 N [23]. For validation of our actual bike, our plan is to test the braking distance with a 150 lb rider and simulate a test that follows Code of Federal Regulations Standard 15.12.5 [15].

After performing our verification and validations, our stakeholders should be confident that our design will meet the requirements and specifications. Of course, there are limits to the accuracy of the methods and tests above, but we are confident that our verifications set us up well going forward. Due to the nature of our project, many of the validation methods will come after the production of MEV2, and may be out of our project timeline due to the limited scope of this course. The braking requirement is a critical safety component since the severity of a collision increases with speed. Additionally an increased ability to stop can prevent potential crashes from occurring.

Discussion

Problem Definition

If more time and resources were available to collect data and better define the problem for our project, we would explore several key questions further. These questions include:

1. What are the specific needs and preferences of the target user group in terms of comfort, accessibility, and cargo capacity?
2. How do different design features affect the overall user experience, and how can we prioritize or balance these aspects?
3. What other successful cargo e-bike designs are available in the market and what aspects can be incorporated into our design to improve usability and user satisfaction?

To answer these questions, we would use various methods such as surveys, interviews, and focus groups with potential users, as well as studying market trends and analyzing competitor products to gain insights into the design features that best suit the target audience.

Design Critique

The strengths of our design include its focus on comfort, accessibility, and safety, and its ability to maintain these aspects while significantly reducing weight and manufacturing costs. However, there are still areas where our design can be improved:

Frame: Our frame design could potentially be further optimized for weight reduction without compromising its durability or structural integrity. This could be achieved through the use of advanced materials or more innovative design techniques.

Seat: Although we aimed for an upright seating geometry, further ergonomic analysis and testing could lead to improved comfort for a wider range of users.

Battery Security: While our current design meets the safety requirements, future iterations could benefit from enhanced battery security features to prevent unauthorized access or theft.

In hindsight, we could have invested more time in exploring alternative frame materials and manufacturing methods that could lead to further weight reduction and cost savings. Additionally, conducting more in-depth ergonomic assessments and user tests could have informed our design process more effectively.

Future modifications to improve the design could include the adoption of advanced frame materials or manufacturing techniques, a more comprehensive ergonomic assessment, and additional security features for the battery system. These modifications could be realized through continued research, testing, and collaboration with experts in the respective fields.

Risks

During the design process, we encountered several challenges, including balancing weight reduction and cost savings with comfort, safety, and accessibility requirements. To address these risks, we focused on simplifying the frame design while consulting with bike geometry experts to maintain desired performance characteristics. We also considered regulatory standards and used them as guidelines to ensure the safety of our final design.

The risks associated with the end-user of our final design include potential dissatisfaction with the comfort or ergonomics of the bike, which could be mitigated through further user testing and ergonomic assessments. Additionally, potential theft or unauthorized access to the battery system could be addressed by implementing enhanced security features in future iterations of the design. Overall, by acknowledging these risks and addressing them proactively, we have minimized their adverse effects on our final design and ensured a more successful product outcome.

Reflection

Throughout the course of our project, our perspectives have evolved as we strived to develop a product that addresses the needs of a diverse range of users and contributes to making the world work better. The Metro-E e-bike directly impacts public health, safety, and welfare by offering a comfortable, accessible, and safe personal transportation option. By encouraging the use of e-bikes instead of traditional vehicles, we can reduce traffic congestion, air pollution, and greenhouse gas emissions, leading to a healthier and more sustainable urban environment.The global demand for affordable, efficient, and eco-friendly transportation solutions is on the rise, and our design holds significant potential in this context. The Metro-E e-bike, with its emphasis on comfort, practicality, and affordability, can cater to users across various regions, cultures, and economic backgrounds.

It is important to consider the social and economic impacts associated with the manufacture, use, and disposal of our design. By promoting environmentally friendly transportation, we contribute to cleaner surroundings and improved public health. However, we must also be mindful of potential negative consequences, such as labor exploitation or the use of unsustainable materials in the manufacturing process. We must take appropriate measures to mitigate these negative impacts.

Our design can have positive economic implications, such as providing an affordable transportation alternative, stimulating local businesses, and creating job opportunities in manufacturing, sales, and maintenance. Nonetheless, it is crucial to assess the long-term economic consequences associated with the life cycle of the e-bike, ensuring that it remains a sustainable and cost-effective solution for end-users.

To evaluate the potential societal impacts of our design, we employed various tools like stakeholder and ecosystem maps, life cycle costing, and user surveys. These tools enabled us to better comprehend the needs of our target audience, the environmental and economic implications of our design, and the broader context in which our product will exist.

In summary, our project aimed to address various factors related to public health, safety, welfare, global context, and societal impacts. By reflecting on our initial perspectives and considering the potential outcomes of our design choices, we developed a product that contributes to a better world for a diverse range of users, while remaining relatable and grounded in the realities of today's society.

Inclusion and Equity

The best way we achieved diverse viewpoints is to spitball many ideas. This allowed a lot of out of the box ideas that could be considered, even the seemingly "bad" ideas. Some stakeholders that were not directly part of the project we were able to talk to, for example pedal bike companies. Due to the scope of the class, there were some stakeholders we weren't able to talk to**,** but were able to try to put ourselves in their mindframe to help generate diverse ideas from the concerns that they may have. Having diverse viewpoints is important to ensure that there are lots of ideas that can be selected, ensuring the best and most inclusive design.

For Metro-E, our project sponsor acts as a primary stakeholder and has the most decision making power as to what concepts are used. As the designing engineers we also had a large amount of decision making power, yet would get approval from our sponsor for design changes. Although the end users didn't have any direct say over what they wanted for our design, some of our design criteria was focused on safety and comfort. This caused us to create our design based on what would be best for the end users. This included testing from non group members and the consideration of many different sized end users.

When there were clashing ideas or concepts among the team members, we were able to use discussion techniques to determine which idea would be best to inform the project. This includes pros and cons list, pugh charts, and morphological charts. The result of this wasn't always a simple selection of an idea, but sometimes a combination of the ideas. As stakeholders, end users were a large part of Metro-E. This required us to set aside ideas that we would think are good if it impeded the ability to be a leisure device. Our sponsor held the key power for this design and had the ultimate say in whether or not our ideas would be used on Metro-E.

Our group was entirely male. We were the same age and going for the same degree. The problem with this is that the design process could result in a design that works best for males. In order to combat this lack of diversity, we had to get outside viewpoints from other genders on what may work for them. A big part of our version of Metro-E includes lowering of seat height. This allows for smaller riders such as women to be able to ride more comfortably. Our group has diversity in areas where they are from. This allowed us to consider how this could be used in both rural and urban areas. Our group also has a diversity in experiences, some having experience working on bikes which allowed for more insight into the project.

Our sponsor was also male, but brought in the perspective of someone that is older. Typically we would want to design something that's fast and fun, but this provided us with a more in depth look at leisure riding. Although we were all from different areas, our entire group and sponsor were from michigan which could cause the project to be most suitable for michigan type areas. For a different cultural perspective, our sponsor ports boats in locations around the world, which is where he saw the need for an E-bike that could be used at places like marinas, and should be easily transportable and used for leisure with cargo capabilities.

Our experience shaped our perspective on the project. Throughout the project, our experience has shown us that there are many factors that go into the safety of the bike. There is braking distance, stability, suspension strength, footpeg strength, and many points of frame strength. Safety is very important but, assuming the end user doesn't have any safety issues, wont cross their mind. Additionally, our group is not able to see this project make it through testing, production, and marketplace release, and therefore lack perspective compared to the end user who would be using the final product.

Ethics

A large ethical dilemma that was faced was deciding what height range we should aim for hitting. This is an ethical dilemma because it can cause one gender to be able to use the product more easily than another. Since the previous prototype only allowed for tall riders, we aimed at lowering the seat height for more gender inclusivity. Another large ethical dilemma is the socio-economic state of our end users. This product has an end price goal of $2000. Since this is expensive, it could cause an issue in the marketplace where only more well off individuals are able to purchase this item. In order to combat this, we aimed to lower the cost as much as we can to allow for more socioeconomic diversity. Another ethical dilemma is the extent of our safety testing. Due to time constraints we were not able to perform comprehensive safety tests which could result in the product having safety issues with longer term use. If this product was released to the public as is, it would be unethical as further testing is required.

Personal ethics drive one's professional ethics to a great degree. However, being part of a company or university means you're a representative of that institution. As such, it is one's responsibility to reflect on how their actions may affect the larger institution around them. In a professional setting you may want to forgo the more colorful aspects of your personality in order to provide a cohesive work environment. It is not to say that one's personal ethics don’t matter. However, if an ethical issue is not relevant to your position at the institution or you are not the one bearing responsibility for a given action, it may not be your place to address it in a manner that specifically advocates for your worldview. In ethical dilemmas where the potential for harm is severe it may be worth allowing your personal ethics to override your profession ethics. Although you may negatively impact the team around you, there is no moral obligation to be complicit in doing harm to others. Of course not all circumstances are so extreme, and human organizations are dependent on cooperation to be effective. This means that to some extent it is customary to adopt the ethics of the team in which you work with as a means of optimizing productivity.

Recommendations

Based on our experiences in the project, we present the following recommendations for our sponsor. These recommendations address both system-level and detailed-level aspects of the design, aiming to improve the overall quality and effectiveness of the final product.

1. Frame Material and Manufacturing Techniques: We recommend exploring alternative frame materials and manufacturing methods, such as advanced composite materials or 3D printing, to further reduce the weight of the frame without compromising its durability or structural integrity. This could lead to an even lighter and more cost-effective bike design.
2. Ergonomic Assessment and User Testing: To ensure optimal comfort and accessibility for a wide range of users, we recommend conducting comprehensive ergonomic assessments and user testing with a diverse group of potential riders. This will help identify areas where the bike's design could be improved and tailored to better meet the needs of the target audience.
3. Enhanced Battery Security: We recommend incorporating additional security features into the battery system, such as advanced locking mechanisms or smart access controls, to prevent unauthorized access or theft. This will provide increased peace of mind for the end-users and enhance the overall value of the product.
4. Improved Cargo Capacity: To better cater to the target audience that requires substantial cargo capacity, we recommend investigating options for increasing the bike's cargo-carrying capabilities. This could involve optimizing the frame design or suspension profile to accommodate larger cargo loads or integrating modular storage solutions that can be easily added or removed as needed.
5. Regenerative Braking System: To improve energy efficiency and extend battery life, we recommend considering the implementation of a regenerative braking system. This system would capture and store energy generated during braking, which could then be used to power the bike, reducing the overall energy consumption and providing additional range.
6. Continuous Market Research and Analysis: To stay ahead of the competition and ensure the product remains relevant and appealing to the target audience, we recommend conducting ongoing market research and analysis to identify emerging trends, competitor products, and customer preferences. This information will be invaluable for informing future design iterations and ensuring the product continues to meet the needs of the market, or ensure there is a market for the product at all.

Conclusion

In conclusion, the Metro-E project is aimed at providing a consumer product to replace golf-carts and other modes of short-distance transit. The main objective is to offer a reliable, lightweight and easy to maintain frame design that is highly comfortable to ride. The project is currently in the prototype phase with several design challenges being addressed including low-speed stability, complicated welding fixtures, and subjective comfort levels. The project team has consulted with various standards organizations to ensure the product meets the required regulations and standards. The stakeholders affected by the Metro-E project have been analyzed and their impact on the project has been assessed. As we have begun the design phase, we have implemented various strategies of concept generation and used Pugh charts and stakeholder engagement for concept selection. Along the way, requirements and specifications have been iterated to reflect new information, mainly presented by our project sponsor. We have developed alpha designs for the bike frame, battery securement, foot pegs, and storage rack, and have created a bill of materials that we hope is suitable to proceed with. The interactive design process will likely continue beyond our team's semester long project, however we have settled on a final build design. Some of which is carried over from the previous interaction of Metro-E. The final design features an improved bike frame, new foot pegs, and storage rack similar to the alpha design. It also features a lightweight front fork and mounting area for rear brakes. We believe that this design will improve upon the previous iteration, and fulfill the design problem of creating a functional, comfortable, and safe ebike that is reasonably cheap to manufacture, convenient for storage, and lightweight enough to transport.

Acknowledgments

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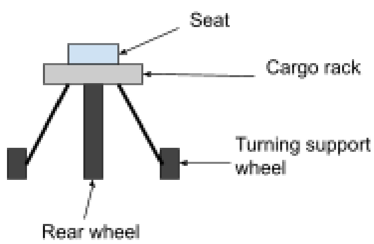
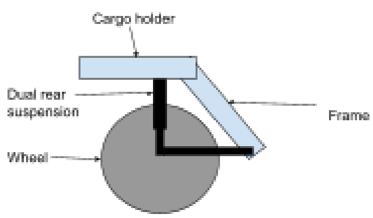
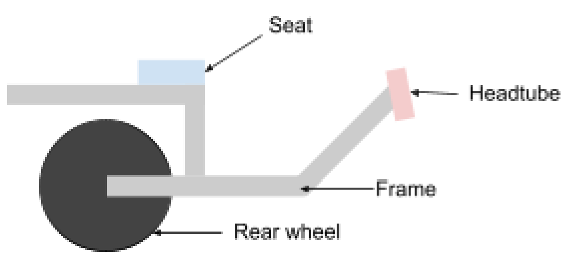
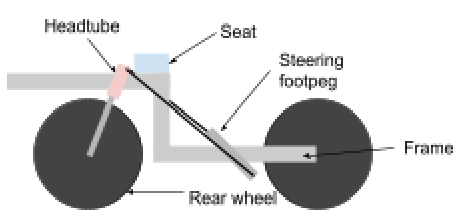
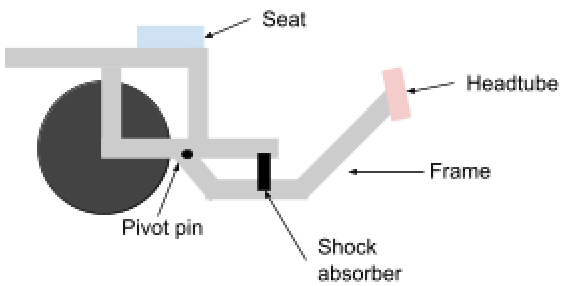
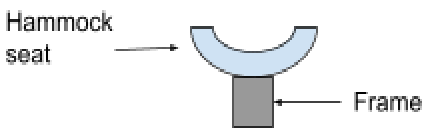
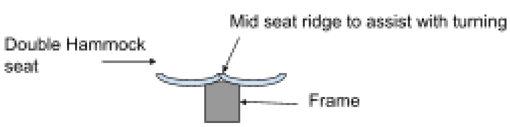
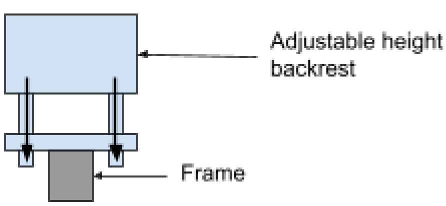
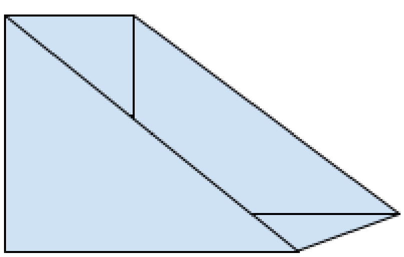
Appendix A - Concepts selection process examples

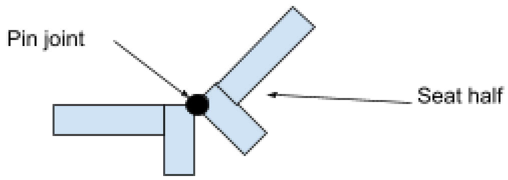
Frame:

Concept	Reason for elimination or selection
	Eliminated due to the added manufacturing complication, and the width requirement.
	Eliminated due to the added weight and cost of the two large shocks.
	Eliminated due to gut feeling about stress on the frame
	Eliminated due to the difficulty of riding a bike with rear turning wheels, which will drive away the target consumer.

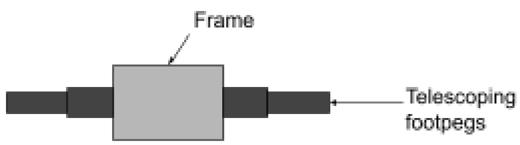
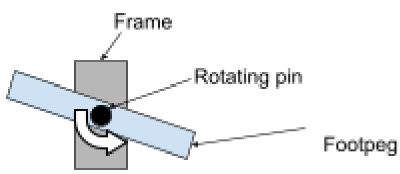
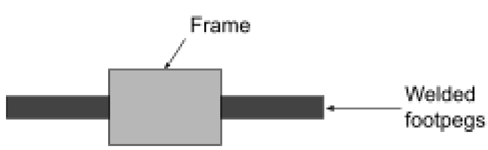
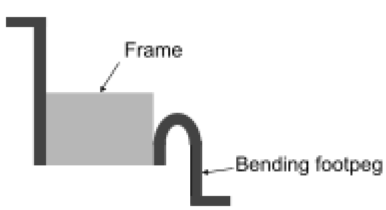
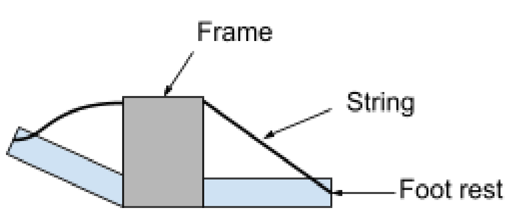
	Eliminated due to the difficulty of

Seat:

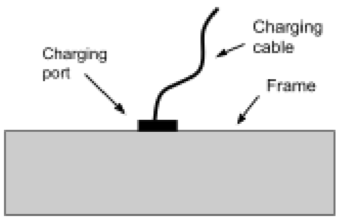
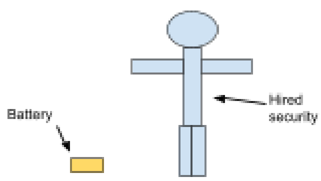
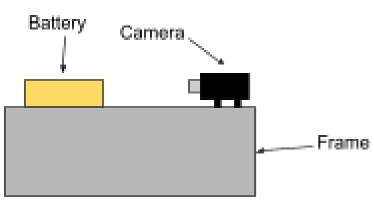
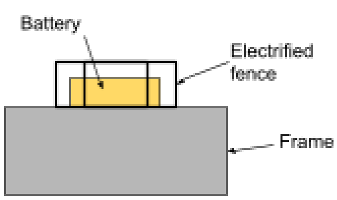
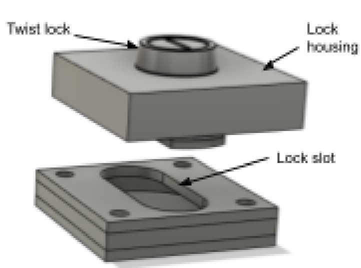
Concept	Reason for elimination or selection
	Eliminated due to current models lack of security
	Eliminated due to gut feeling about comfort
	Eliminated due to sponsor need for simplicity
	Eliminated due to difficulty of mount/dismount

	Still in consideration, pending compatibility with chosen seat design

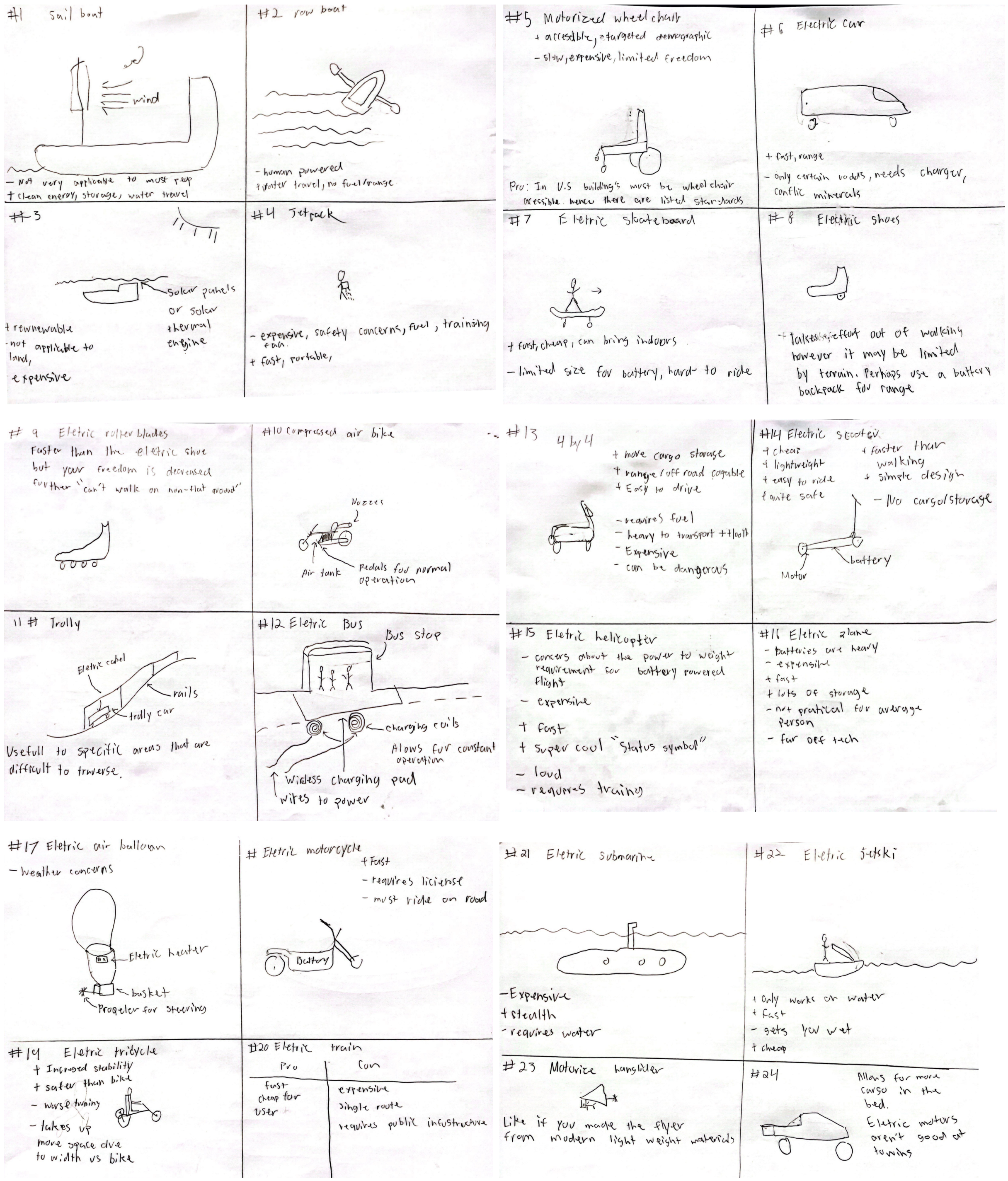
Foot rest:

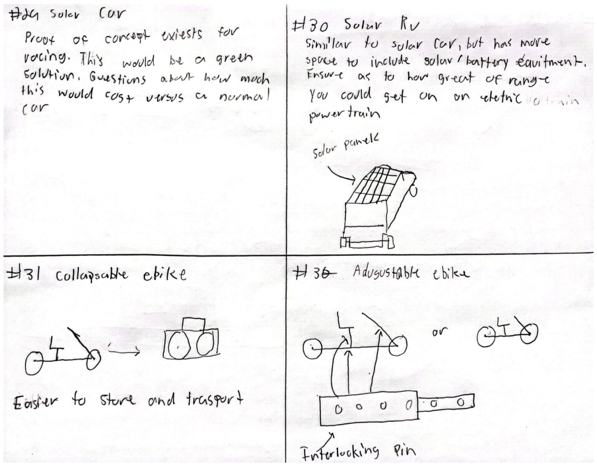
Concept	Reason for elimination or selection
	Eliminated due to odd shaped footrest and difficulty of manufacturing
	Eliminated due to Gut feeling about sturdiness
	Selected for consideration due to simplicity
	Eliminated due to the difficulty of finding a material that will be able to bend easily, frequently, and remain sturdy
	Eliminated due to string durability and difficulty

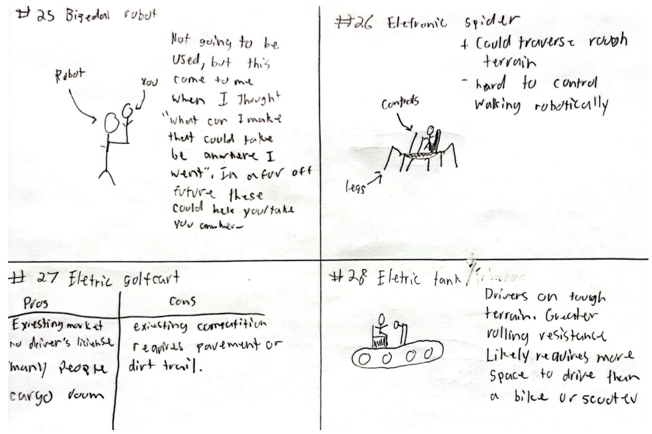
Battery security:

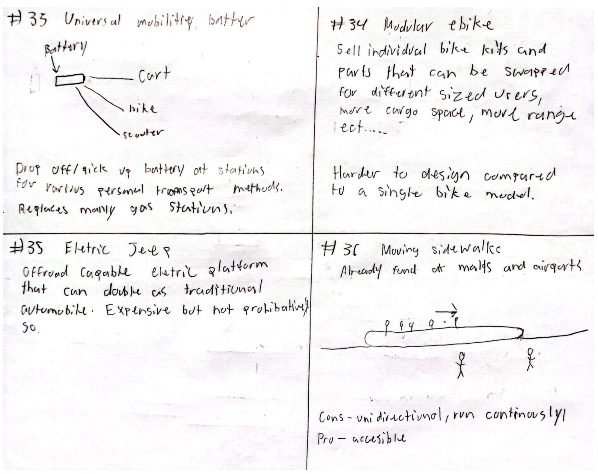
Concept	Reason for elimination or selection
	Selected for consideration due to difficulty of battery removal
	Eliminated due to cost and difficulty of hired security
	Eliminated due to cost of camera
	Eliminated due to a gut feeling about legal and safety issues
	Selected for consideration due to access to McMaster-Carr twist locks

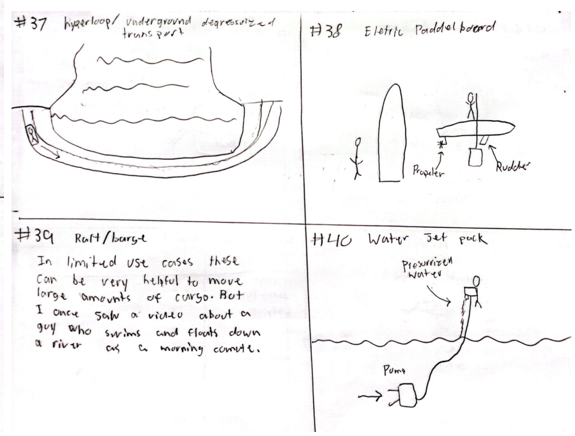
Appendix B - Sketch concepts

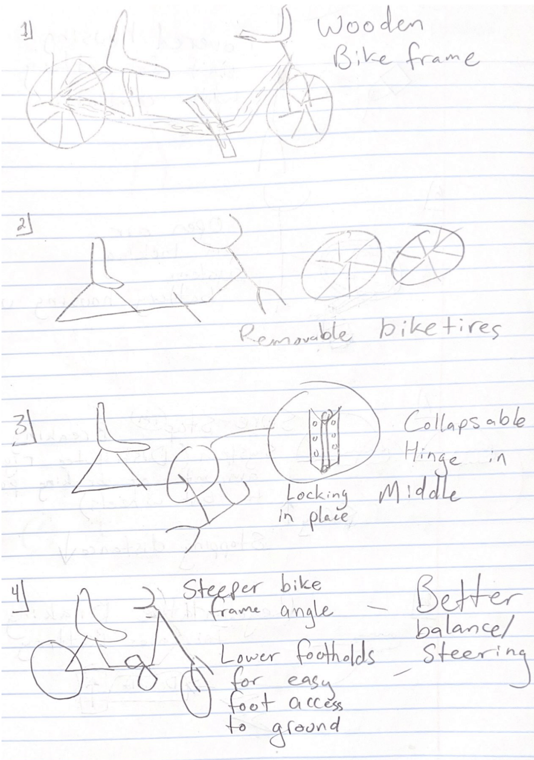


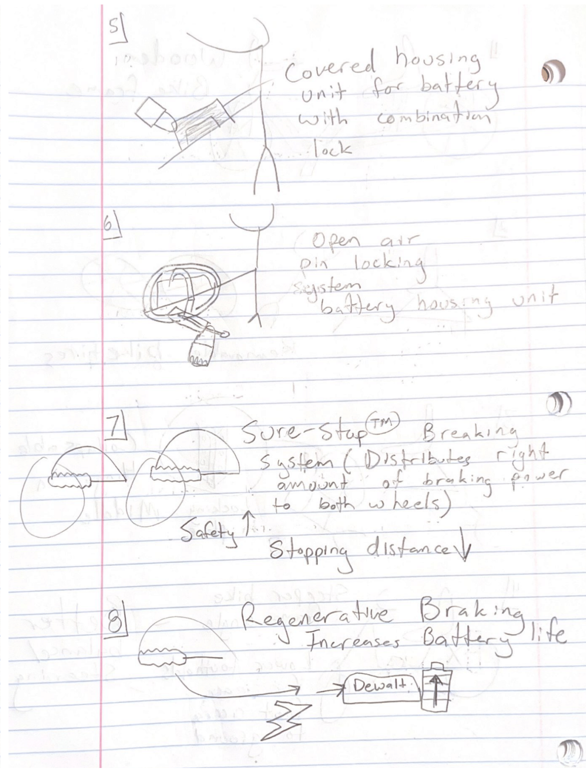

#29 Solar Car
Proof of concept exists for racing. This would be a green solution. Questions about how much this would cost versus a normal car
#30 Solar RV
Similar to solar car, but has more space to include solar / battery equipment. Ensure as to how great of range you could get on an eletric power train
Solar panels
#31 collapsable ebike
Easier to store and trasport
#30 Adugustable ebike
or
Interlocking Pin

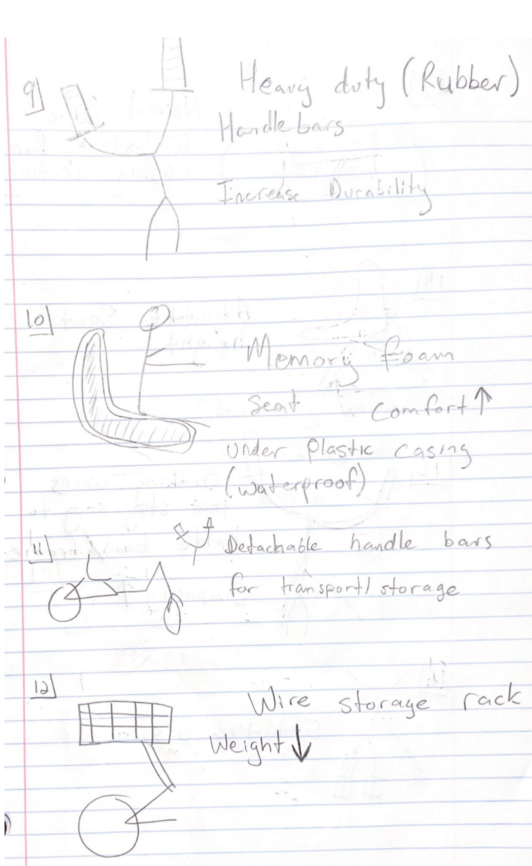

#25 Bipedal robot
Robot
You
Not going to be used, but this came to me when I thought "what can I make that could take be anywhere I went". In a far off future these could help you take you anywhere
#26 Eletronic spider
+ Could traverse rough terrain
- hard to control walking robotically
Controls
Legs
#27 Eletric golfcart
Pros
Existing market
no driver's license
many people
cargo room
Cons
existing competition
requires pavement or dirt trail.
#28 Eletric tank
Drivers on tough terrain. Greater rolling resistance
Likely requires more space to drive than a bike or scooter

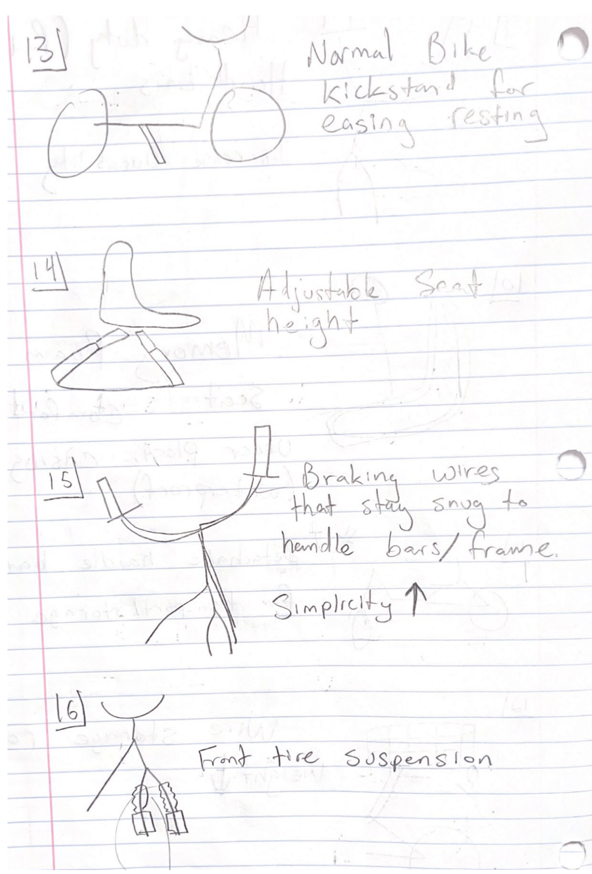

#35 Universal mobility batter
Battery
Cart
bike
scooter
Drop off/pick up battery at stations for various personal transport methods. Replaces many gas stations.
#34 Modular ebike
Sell individual bike kits and parts that can be swapped for different sized users, more cargo space, more range iect.....
Harder to design compared to a single bike model.
#35 Eletric Jeep
Offroad capable eletric platform that can double as traditional automobile. Expensive but not prohibitively so.
#36 Moving sidewalks
Already found at malls and airports
Cons - unidirectional, run continously
Pro - accesible

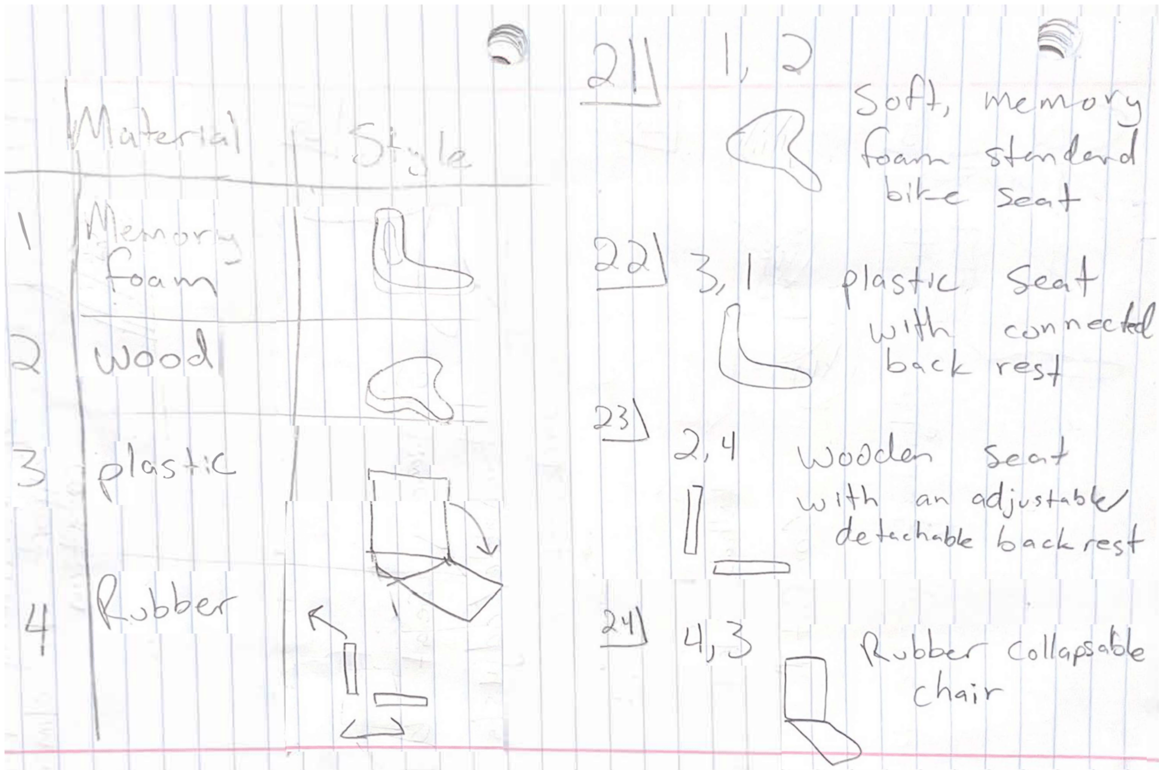

#37 hyperloop/ underground depressurized transport
#38 Eletric Paddelboard
Propeller
Rudder
#39 Raft/barge
In limited use cases these can be very helpful to move large amounts of cargo. But I once saw a video about a guy who swims and floats down a river as a morning commute.
#40 Water Jet pack
Pressurized water
Pump

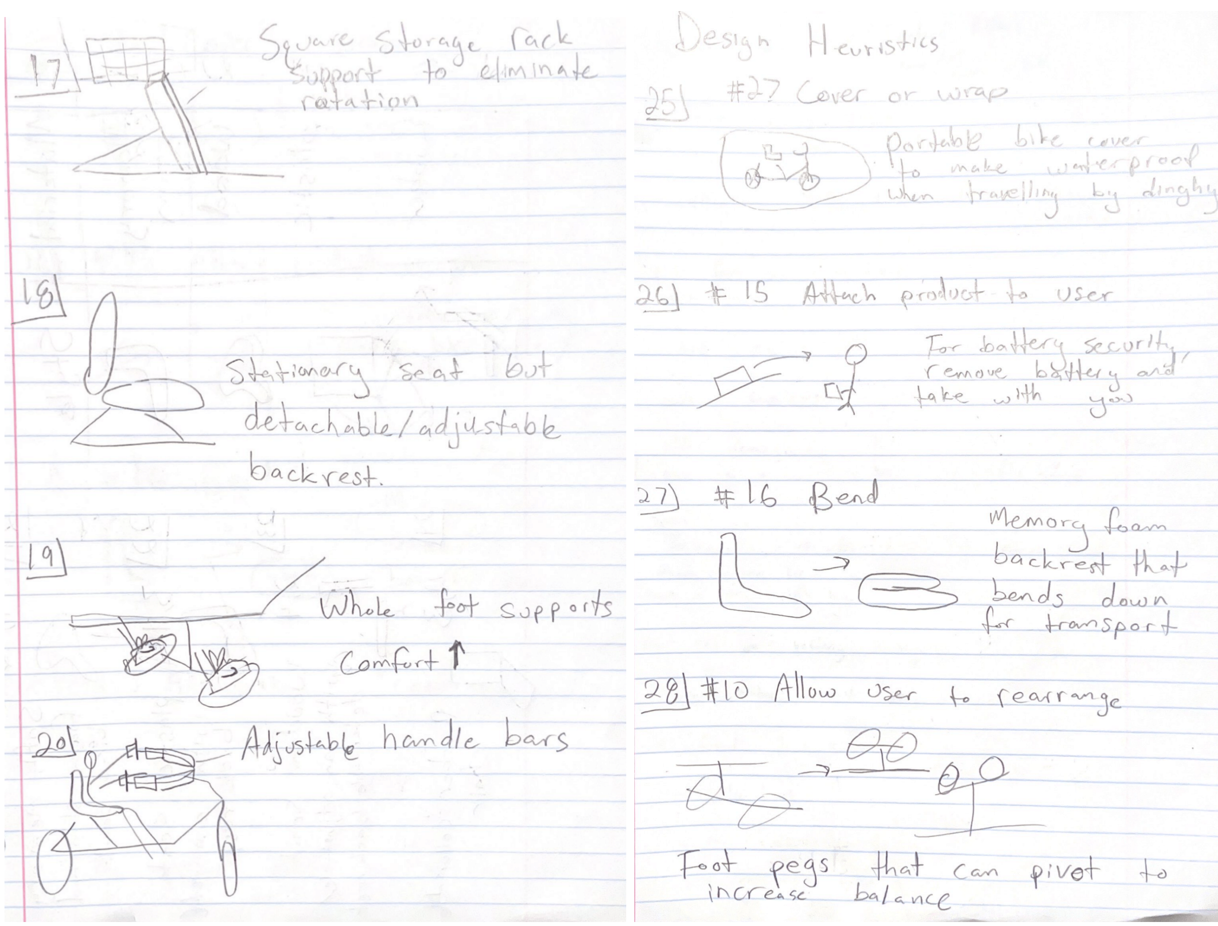

1] Wooden Bike frame
2] Removable bike tires
3] Collapsable Hinge in Middle
Locking in place
4] Steeper bike frame angle – Better balance/steering
Lower footholds for easy foot access to ground


5] Covered housing unit for battery with combination lock
6] Open air pin locking system battery housing unit
7] Sure-Stop(TM) Breaking System (Distributes right amount of braking power to both wheels)
Safety ↑
Stopping distance ↓
8] Regenerative Braking Increases Battery life
Dewalt

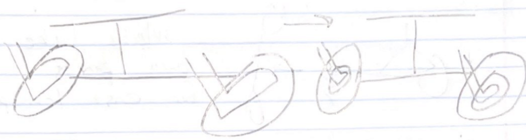

9] Heavy duty (Rubber) Handle bars
Increase Durability
10] Memory foam Seat Comfort ↑
Under plastic casing (waterproof)
11] Detachable handle bars for transport/storage
12] Wire storage rack
Weight ↓


13] Normal Bike kickstand for easing resting
14] Adjustable Seat height
15] Braking wires that stay snug to handle bars/frame.
Simplicity ↑
16] Front tire suspension


Material
Style
1 Memory foam
2 wood
3 plastic
4 Rubber
21) 1, 2
Soft, memory foam standard bike seat
22) 3, 1
plastic seat with connected back rest
23) 2, 4
Wooden seat with an adjustable/ detachable backrest
24) 4, 3
Rubber Collapsable chair

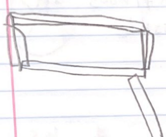

17
Square storage rack support to eliminate rotation
18
Stationary seat but detachable/adjustable backrest.
19
Whole foot supports
Comfort ↑
20
Adjustable handle bars
Design Heuristics
25) #27 Cover or wrap
Portable bike cover to make waterproof when travelling by dinghy
26) #15 Attach product to user
For battery security, remove battery and take with you
27) #16 Bend
Memory foam backrest that bends down for transport
28) #10 Allow user to rearrange
Foot pegs that can pivot to increase balance

29] #76 Utilize opposite surface



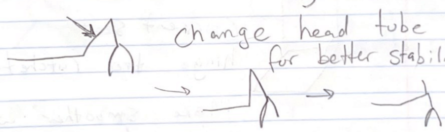
Foot pegs that can be flipped over for a smaller foot hold

30] #9 Allow user to customize



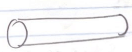
Back storage rack has lips that can be put up or down to either contain or support.

31] #20 Change Geometry



change head tube angle for better stability

32] #37 Hollow out



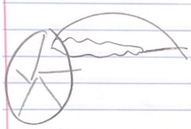
Hollow everything that can, weight↓ cost↓?

#74 Used recycled materials

37)

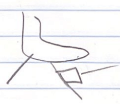
Could make tires out of recycled rubber

38) #70 use different energy source



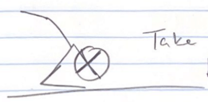
Use smart braking powered by battery

39) #7 align components around center



place battery under seat (less exposed).

40) #53 reduce material



Take out a support in back of frame.

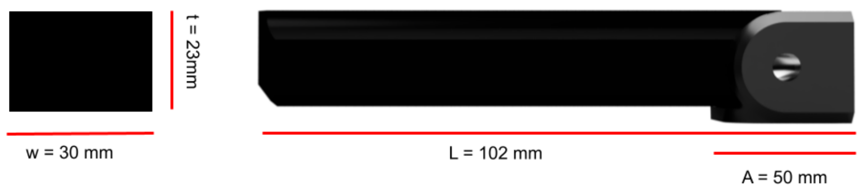
Appendix C - Pugh Charts

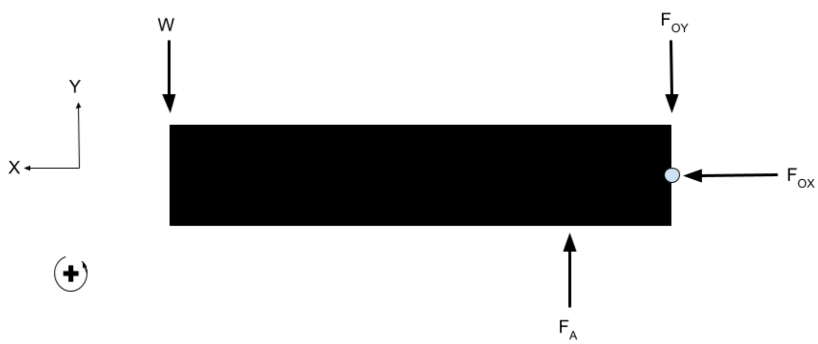
Criteria	**Weight**	**Covered w combo**	**In frame Integration**	**Slide stop**	**Smaller battery**
Ease of access to user	4	2	0	3	1
Hard to Steal	4	3	4	2	2
Durability	2	2	3	3	3
Weather protection	1	3	3	0	0
Cost	3	2	1	3	3
Total	N/A	33	28	35	27

Criteria	**Weight**	**Flip-out**	**Whole foot support**	**Welded**
Foldability	2	2	2	0
Cost	3	3	2	3
Weight	2	2	1	2
Durability	3	3	2	3
Comfort	2	2	3	2
Total		30	24	26

Appendix D - Engineering Analysis Calculations

Footrest stress:





The second moment of area of the cross section is

$$I = \frac{wt^3}{12}$$

The furthest distance from the neutral axis is

$$y = \frac{t}{2}$$

The force F_A can be found by taking the moment about point O to be zero

$$M_o = 0 = W * L - F_A * A$$

$$F_A = \frac{W*L}{A}$$

The force F_{OY} can be found by setting the vertical forces to zero

$$F_A - W - F_{OY} = 0$$

$$F_{OY} = F_A - W$$

The moment throughout the footrest is found through two sections

From 0 to A: $M = F_{OY} * x$

From A to L: $M = F_{OY} * x - F_{A}(x - A)$

Max moment at A

$M_{max} = F_{OY} * A = (\frac{W*L}{A} - W) * A = W * L - W * A$

The maximum stress in the cross section is

$\sigma_{max} = \frac{M_{max}*y}{I} = \frac{(L-A)*W*6}{wt^2} = 21.86MPa$

For the pin, the surface area is:

$SA = 2 * \pi * r * w$

Where r is the radius of the pin

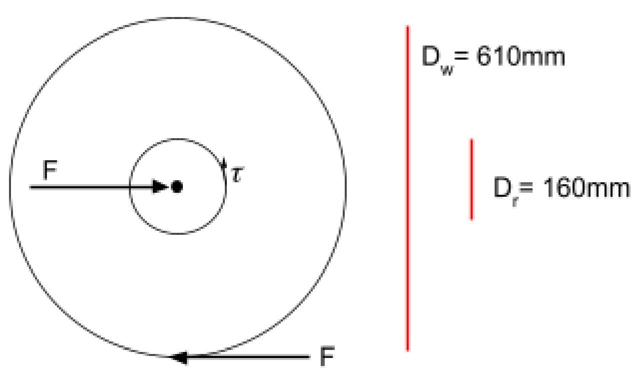
The force at the pin is F_{OY}

By underestimating, the force is spread across only the top eighth of the pin joint: $\frac{SA}{8}$

The stress in the area around the pin is estimated to be

$\sigma_{p} = \frac{F_{OY}}{\frac{SA}{8}}$ = 16 MPa which is less than that of point A

Stopping distance:



The force on the bike to cause an acceleration is

$$F = M * a$$

The torque on the wheel to cause the same acceleration is

$$\tau - F * R_w = I * \frac{a}{R_w}$$

Where τ is the torque from the brake rotor and R_w is the radius of the wheel. This torque can be found from the the frictional force F_f and the radius of the rotor R_r

$$\tau = F_f * R_r$$

Since there are two sides to the rotor, the frictional force can be related to clamp force by

$$F_f = 2 * \mu * F_c$$

The moment of inertia of the wheel is

$$I = (M_{rim} + M_{tire}) * R_w^2 + \frac{M_{spoke} * R_w^2}{3} \approx 0.11\, kg\, m^2$$

The necessary acceleration to stop is

$$V_f^2 = V_i^2 + 2ad$$

$$a = \frac{(V_f^2 - V_i^2)}{2d}$$

Combining the above equation results in

$$F_C = \frac{(V_f^2 - V_i^2)*(R_w * M + \frac{I}{R_w})}{4 * d * \mu * R_r} = 1425\, N$$

With the constants being

d = 4.572 m, V_i = 6.71 m/s, V_f = 0 m/s, M = 88.45 kg, R_w = 0.31, R_r = 0.16 m, μ = .3

Build Design Bill of Material

Section of Assembly	Part Name	Quantity	Cost per part	Total Cost for Parts
1	24 in wheel	1	$81.98	$81.98
1	Front Wheel Fork	1	$72.99	$72.99
1	headset in wheel	1	$5.70	$5.70
1	Handel Mount to Fork	1	$6.96	$6.96
1	Handlebars	1	$29.83	$29.83
1	Fork Headset	1	$29.94	$29.94
1	Disc brake rotor	1	$75.99	$75.99
1	Disc brake	1	$5.98	$5.98
2	Front bar to fork	1	$22.56	$22.56
2	Middle of V Frame	1	$8.42	$8.42
2	Rear of V	1	$13.16	$13.16
2	Suspension Linkage	1	$16.55	$16.55
2	Cargo Strut	2	$4.47	$8.93
2	Cargo Strut ReR (1)	1	$9.70	$9.70
2	Cargo nylon insert	1	$1.20	$1.20
2	Foot Pegs	2	$2.60	$5.20
2	Rack	1	$15.16	$15.16

2	Nylon plug Suspension linkage	1	$0.10	$0.10
2	Kickstand	1	$21.99	$21.99
3	Rear Wheel	1	$81.98	$81.98
3	Bike Shock	1	$11.99	$11.99
3	Chainstay tube	1	$51.10	$51.10
3	Suspension triangle	2	$3.63	$7.25
4	Seat cloth	2	$1.24	$2.49
4	Bar 5 bottom bar for seats	2	$2.13	$4.25
4	Horizontal seat bars	8	$1.53	$12.21
4	Outside seat cross bars	4	$2.13	$8.50
5	Controller	1	$39.59	$39.59
5	Wiring	1	$15.00	$15.00
5	Electronic Dash	1	$43.10	$43.10
5	Battery mount	1	$12.98	$12.98
5	Battery pin	1	$12.00	$12.00
5	Pin housing	1	$0.50	$0.50
5	FLEXVOLT® Batteries. 60V MAX	1	$169.00	$169.00
6	3/8-16 x 5 Bolt	5	$2.18	$10.89
6	3/8-16 Stainless Steel Hex Nut	5	$0.38	$1.90
6	5/8 Hitch Pin	1	$2.28	$2.28
Total Cost				$919.37