Mechanical Engineering Capstone Project

μ-AV Connected/Linked Vehicles

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Rebecca Sasten, Devin Taing, Li-Ling Plume, Fletcher Kurita

Advisor: Dr. Tyler Folsom

Mentor: Dr. Jong Yoon

Sponsor: Dr. Tyler Folsom

University of Washington Bothell

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A. Design Strategy

A.1.1 Design Strategy – User Insights and Research, Consumer Journey Map

Our direct customer is the company Micro-AV. *We are tasked with developing a coupling system for two vehicles in order to show a proof of concept.* With this proof of concept, Micro-AV will be closer to the goal of platooning multiple vehicles for various purposes. This long term goal of platooning vehicles has been described in depth below along with other potential considerations in order to show the importance of developing this product.

Empathy Map

	Customer 1	Customer 2	Customer 3
Description	Bike share companies (like Lime)	Delivery companies (like Amazon, Uber Eats, etc.)	Personal use
Job	Provide affordable and reliable transportation.	Provide efficient and affordable small deliveries.	Buy e-trikes directly from Micro-AV.
Pains	Initial cost of switching to autonomous e-trikes, maintenance.	Initial costs of adding autonomous e-trikes to the delivery fleet, maintenance.	Initial cost of buying the e-trike, small cargo space, maintenance.
Gains	Increased usage since e-trikes can redistribute themselves to high-demand locations, less energy cost with platooning of e-trikes, include customers who can't ride bikes or scooters safely.	Energy cost savings of not operating large vehicles for small deliveries, less employees to pay, quicker turnaround times since modules can return for reloading before the entire route is complete.	Reduce individual carbon footprint, save money by not buying a large personal vehicle and paying for fuel/insurance, a convenient option for auto-drive.

Here, the Consumer Empathy Map outlines three types of customers who may use the Micro-AV Millipod. There are 3 types of customers (bike share companies, delivery companies, and personal use). The customers are people and companies who will be directly purchasing vehicles or services from Micro-AV, and their pains are primarily how their funds will be used, and the gains are how they will benefit from their purchase. Some of these customers, such as bike share companies and delivery companies will also have users that will pay to use these products. For example, the customers of the bike share company will be using the Millipod trikes to commute within the city, and the delivery company customers will be indirectly using the trikes to schedule their deliveries.

Customer Journey Map

The Customer Journey Map shows a potential process of a single customer deciding whether a Micro-AV Millipod is a worthwhile investment. This journey map follows a customer named Vlad, who is an analytical thinker and puts a lot of thought into his purchase decisions. His journey starts with seeing a couple ads for the Micro-AV Millipod trikes on multiple platforms. These commercials spark his interest, as he is looking for affordable, reliable, and accessible transportation through the city of Seattle, so he decides to explore the options of using a Micro-AV Millipod and compare the pros and cons with his needs. He spends considerable time exploring and comparing different options of using this mode of transportation, as well as doing cost analysis and reading customer reviews. After he is satisfied with the information he finds on the internet, he decides to test the vehicles for 2 weeks and take notes on his experience. Eventually he decides to purchase a Micro-AV Millipod trike directly from Micro-AV and use it as his every day mode of transportation throughout the city. He is satisfied with his purchase which leads him to recommend Micro-AV to his friends and family, and write a positive review on the Micro-AV website.

The Customer Journey Map is only meant to be a representation of a single future potential

Customer Journey Map Using the Micro-AV Millipod

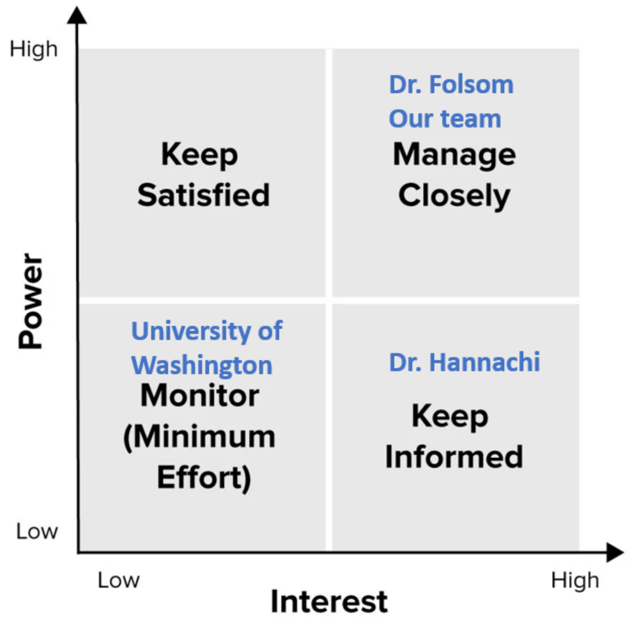
Overthinker Vlad
Vlad is an analytical thinker and makes purchase decisions about devices, products, and services by analyzing all aspects of the product before purchasing. He recently moved to downtown Seattle and is investigating the best way to commute around the city. His priorities are affordability, reliability, and accessibility.

Consider 1 week	**Explore** 1 month	**Compare** 1 month	**Test** 2 weeks	**Negotiate** 1 week	**Loyalty & Advocacy** Lifetime
Sees ad by a social media influencer promoting Micro-AV Millipod as convenient alternative to bicycle commuting. Sees billboards in the city by Lime promoting the use of their accessible Micro-AV Millipod e-trikes. Sees a commercial by Micro-AV promoting the Millipod as an energy efficient transportation option.	Explore the companies promoting the Micro-AV Millipod and how they are using them. Weigh personal pros and cons of using this vehicle with his lifestyle.	Comparing yearly cost of options such as owning a car, using rideshare, renting Micro-AV trikes from companies such as Lime, or buying a personal Micro-AV vehicle. Looks for other customer reviews on the product to ensure it will meet his expectations.	Plans to try the Micro-AV Millipod to determine if it meets his needs of accessibility, reliability, and affordability. Takes notes on experience and actual benefits.	Decide on what consumer avenue he wants to pursue (direct ownership or rent through a bike share company). If purchasing: -Contacts Micro-AV -Agrees on price (buys) -Starts using If renting: -Downloads app -Begins to use	Uses as his every-day mode of transportation. Recommend Micro-AV Millipod to friends/family. Leave a positive product review.

customer and does not encompass every individual experience. For example, a company such as Lime, Uber, or Amazon would have different priorities and therefore a different process of deciding whether to purchase Micro-AV Millipod trikes.

A.1.2 Design Strategy – User Insights and Research, Stakeholder Framing.

Stakeholders Map/Matrix of Power



The Stakeholders Matrix of Power shown above serves to outline the people or entities with interest in this project, and the level of interaction each will have in the process.

Dr. Folsom has high interest in this project because he is investing money into it in hopes of patenting a method of platooning between vehicles with our product. Since he is also the sponsor of this project, he has a high amount of influence in the project as well, which means he has a high level of interaction with the project and his needs must be managed closely. This management will be conducted through weekly meetings for updates and feedback on the design.

Our team has high interest in this project because it is an interesting mechanical problem to solve, is a requirement for graduation, and provides hands-on experience in our field. We also have a high influence on the project because we are in charge of conducting the project and making design decisions.

Dr. Yoon has high interest in the project because he wants his students to succeed and graduate. He also has some influence on the project because as the academic advisor, he is a resource for design suggestions.

Dr. Hannachi has high interest in this project because she wants her students to succeed in their capstone and continue on to graduation. However, she does not have much influence on the project so she must be kept informed but will not be as involved with decisions.

The University of Washington has some interest in the project because it is a requirement for engineering students to graduate, but they do not have much interest or influence on the project. They will be informed of our progress in the form of a capstone grade, which will result in graduation.

Other potential stakeholders are future customers or users of the product. The first implementation of this product would provide a proof of concept to show that two vehicles can be mechanically and electrically connected together. This proof of concept is necessary to further Micro-AV's goal of platooning multiple vehicles together for future use in multiple industries. The trikes that the product will connect will not exceed a maximum speed of 20 mph, if they are operated in bike lanes. If our product is successful, it will provide a good base for Micro-AV to expand and potentially patent more inventions and ideas. If the future products and inventions from Micro-AV were to become widespread throughout many cities and adopted for mass transit, regulatory entities such as the FTA [1] would need to be consulted to ensure adequate safety demonstration and smooth integration into the transportation system. In this case, years of small-scale application could serve as a safety demonstration. This is not something that is in the direct scope of our product, but it is important to consider for the future iterations of our product.

A.1.3 Design Strategy – User Insights and Research, User Scenarios and Personas.

When looking for a different way to travel around the city, there are many reasons why users would consider using Micro-AV Millipod trike, *which requires our product (coupling/decoupling system) to connect them*.

- Reduce carbon footprint by using a small, electrically powered e-trike
- Financial savings due to low energy cost and not needing to own a full size vehicle and pay for gas/etc.
- Convenience of autonomous driving
- Accessibility to people who either can't own a full size vehicle or ride a regular e-bike/scooter

Taking these motivations into consideration, 3 descriptions of future user scenarios are described in further detail below.

Scenario 1: Mackenzie (age 24) lives in the suburban area near the city. She has an older vehicle that she uses to commute to work, but since she doesn't like driving and her car is beginning to have issues, she is considering finding a new way to commute to the city. Her main objective is to save money, as she is looking to purchase a home in the next 5 years. She is also environmentally conscious, so she wants to reduce her carbon footprint as well. One option she has considered is taking the bus, but the route does not stop close to her work so she would have to walk the rest of the way. She also wants the flexibility to drive to other places in the city outside of the bus route.

If directly purchased a Micro-AV Millipod trike:
Pains:
- Initial cost of vehicle.
- Cost of insurance and repairs.
- Insecurity of new technology and lack of options in repair or choosing.
- Small vehicles have a lack of space for transporting goods.

Gains:
- Reduce carbon footprint.
- Long term saves money by not needing to buy a full-size vehicle and with reduced energy costs of the small e-trikes.
- Convenience of using autonomous driving.

If rented Micro-AV Millipod trike from bike-share company:
Pains:
- Lack of availability during peak hours.
- Small vehicles lack space for transporting goods.

Gains:
- Reduce carbon footprint.
- Save money.
- Convenience of using autonomous driving.

Mackenzie's general objective is to purchase a home, which means she must prioritize saving money. The timeline is 5 years (assuming she has some money saved already), which is estimated to understand it is a goal she is looking to achieve quickly. This is an important thing to note because the gains in this scenario mention long term financial savings, which may not benefit her goal since she is prioritizing a home purchase and needs to save money in the short term. The initial cost of a vehicle is a pain associated with any new vehicle purchase, but since she is prioritizing the short term financial savings, she will not buy a new vehicle.

However, she may still be interested in using a Micro-AV Millipod e-trike through a bike-share company because it allows her to realize the gains without the pain of the initial cost of the e-trike. Since Mackenzie is environmentally conscious, using an e-trike as transportation is appealing to her because it will help reduce her individual carbon footprint. Also, she does not have to drive anymore with the autonomous driving capabilities of the Millipod e-trikes. But a pain that concerns Mackenzie is potential unavailability of the e-vehicles during peak operating hours, as she does not want to be late to work if she cannot get a ride. If she decided to use this method of transportation, she would need to trust that the company supplying the Millipod trikes could keep up with their customers' demand.

If Mackenzie decided to rent an e-trike through a bike-share company, she could order one through an app and input her destination and the e-trike would arrive to pick her up and automatically drive her to work utilizing the bike lanes.

Scenario 2: Lime is a bike-share company that offers e-bike and e-scooter rentals in major cities. One of the problems they are experiencing is the abandonment of their e-bikes and e-scooters in random areas, as stated in many online articles. Their current solution is to pay people to pick them off the streets and charge them in their own homes, which heavily relies on people's willingness to do such tasks [2]. They are currently looking for other solutions to redistribute to high-demand areas, and to return their e-vehicles to charging stations.

Purchasing Micro-AV Millipod trikes:
Pains:

- Initial cost of purchasing fleet.
- Maintenance of more complex systems.

Gains:

- Increase usage by redistributing to high-demand areas.
- Automatically go to charging stations.
- Appeal to people who can not operate a normal e-bike or e-scooter.

Lime's main objective is to increase the use of their environmentally friendly transportation method. They are currently paying people to pick their e-vehicles up off the street, charge them, and replace them in high-demand areas. When making a decision about adopting a new solution, they must compare the pains and gains of their existing solution to the new solution. The main drawback of switching to Micro-AV Millipod trikes would be the initial cost of purchasing the fleet, and the maintenance of the more complex systems. However, compared to the opportunity cost of their vehicles being left in areas they won't be used, and having to pay people to collect, charge, and redistribute the e-vehicles, this cost may not be significant. Additionally, the autonomous e-trikes would appeal to people who can not operate a normal e-bike or e-scooter, opening up a new customer type for Lime.

If Lime adopted the Millipod e-trike into their fleet, they would expect customers to be able to conveniently use their phone to order a ride that would pick them up and automatically take them to their destination utilizing bike lanes.

Scenario 3: Uber is a company that offers small delivery services through the UberEats app. One of the problems they are experiencing is a driver shortage, which is leaving customers frustrated with canceled orders [3]. A solution to this problem may be autonomous deliveries by Micro-AV autonomous e-trikes.

Purchasing Micro-AV Millipod e-trikes:
Pains:

- Initial cost and maintenance of fleet.

Gains:

- Solution to driver shortage.
- Save money by not having to pay delivery drivers.
- Reliability.
- Reduce carbon footprint.

Ubers main objective of the UberEats app is to satisfy their customers with quick, affordable, and reliable deliveries. However, their driver shortage problem is preventing them from doing so by forcing them to cancel orders when there is no driver to accept. They also charge high delivery fees so they can pay their drivers, which means their services are not accessible to people looking to save money. If they adopted the Millipod e-trikes, they could offer autonomous deliveries at reduced costs which would be affordable for more people. They also would not have to cancel orders due to a driver shortage because the drivers would not be required to run deliveries, which would result in increased reliability of their brand.

If UberEats adopted the Millipod e-trikes, they would expect their customers to be able to order from an app, and have an e-trike autonomously deliver their order quickly and reliably.

While these potential customer considerations are much further down the line than the development of our product at hand (the coupling/decoupling system to interconnect two trikes), it is important to consider the impact our product may have on transportation if proven to be successful.

A.1.4 Design Strategy – User Insights and Research, User Insight Report

The sponsor wishes to have a physical connection between the two autonomous recumbent tricycles in order to have a modular vehicle system. This would allow for transportation in smaller, more efficient vehicles, and more modules may be added as necessary for transporting more people or goods. One of the benefits of a physical connection between two vehicles is increased fuel efficiency, but the closer the vehicles are coupled the bumpier the ride will be. Therefore, an effective spring/damping system must be designed to lessen this effect. Another key requirement is the desired capability for the vehicles to couple and decouple while in motion. Since there are a lot of variables influencing the position of the two vehicles being controlled autonomously, the coupling process may not be super precise. There are many different coupling mechanisms to be used between two vehicles, but this problem requires one that functions under loose tolerances.

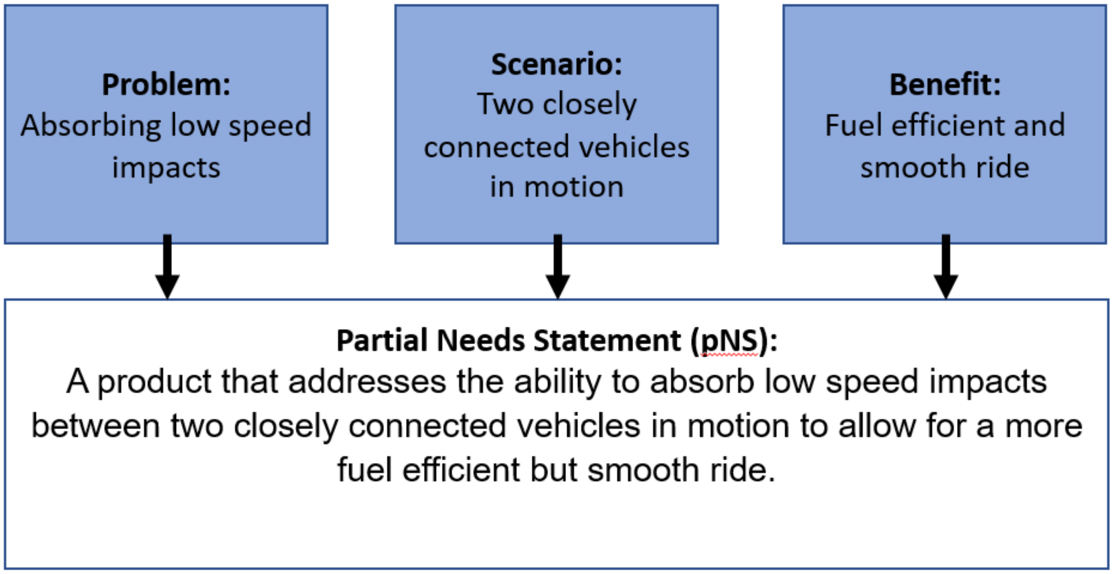
Other important design factors are the space constraints, mounting scheme, and height adjustability specific to the geometry of the two trikes. The sponsor mentioned that there will be a mount on the front of the trikes for Lidar/Sonar, and the front arm of both trikes are adjustable to accommodate riders of different heights. Also, the rear end of both trikes have different luggage carriers to hold the electronics.

The key learning from discussions with the sponsor was the problems associated with physically connecting the two vehicles. It is important to be aware of potential issues and constraints so that the final product will be compatible with the vehicles being used to test it.
The solution would lead to the ability to physically connect two vehicles without causing a bumpy ride. The benefits of this connection are better fuel efficiency and the ability to synchronize a transportation route for more time efficiency.

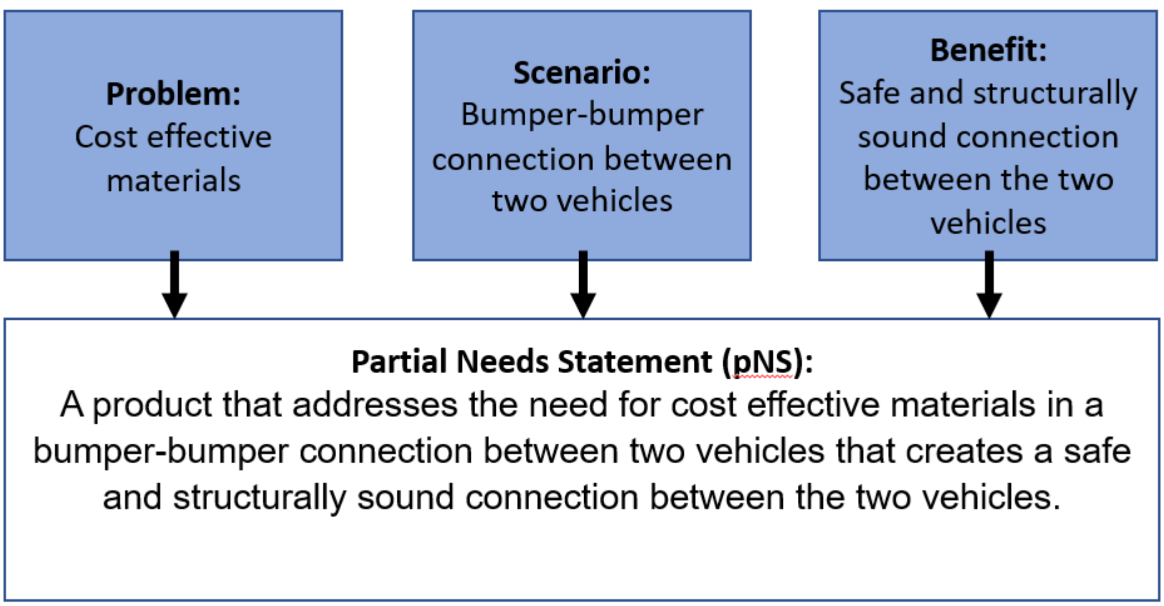
A.2.1. Design Strategy – Problem Understanding and Framing, Product Assumptions Outline

The benefits the sponsor would like to experience from the solution are better fuel efficiency, a smooth and safe ride, and the ability to synchronize a transportation route for more time efficiency. To address fuel efficiency, the vehicles must be connected as closely as possible. But to prevent a bumpy ride, the connection must have an effective spring/damper system within it to absorb the low speed impacts due to differences in the vehicles speed and position. This connection must also be manufactured from adequate materials to ensure it is safe and does not fail under the tension, compression, and shear stresses it experiences. And to address the ability to synchronize a transportation route for time efficiency, the vehicles must be able to couple/decouple while in motion so that the string of coupled vehicles does not have to stop to pick up and drop off passengers. Three partial needs statements for these benefits are as follows:

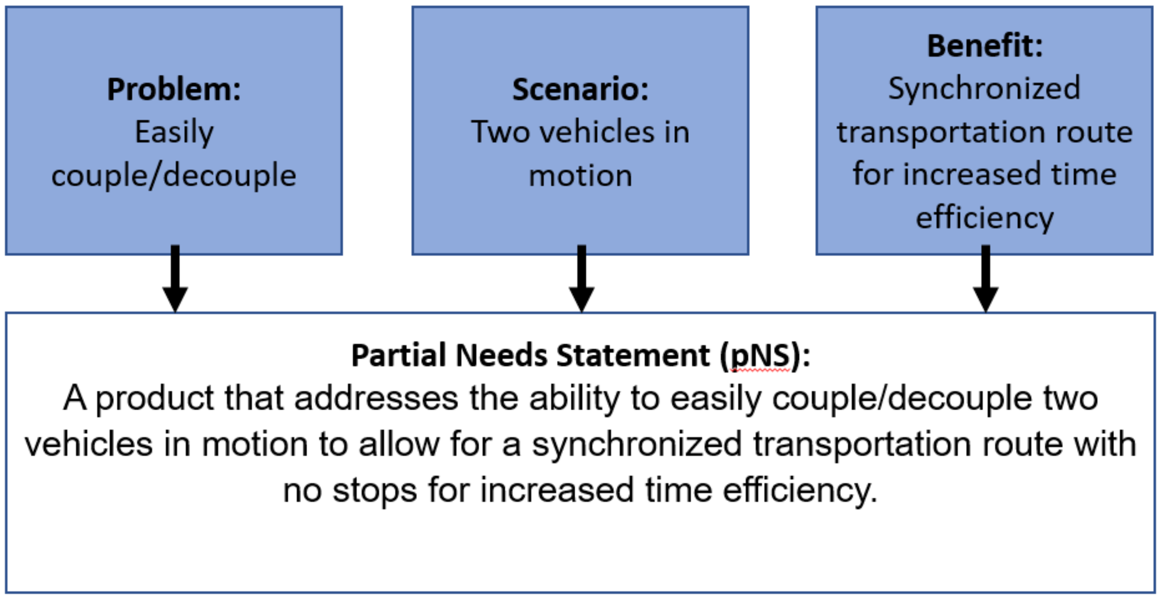
Partial Needs Statement 1



Partial Needs Statement 2



Partial Needs Statement 3



A.2.2. Design Strategy--Functionality (tasks and associated outcomes)

In the section below, the functional requirements of each of the needs statements are provided. The objective of this section is to identify the requirements of the product to alleviate pains felt by potential users.

List of functional requirements for PNS #1:
- Must have a safe low impact collision when docking.
- Must be able to absorb impacts from worst case scenario velocity differentials.

List of functional requirements for PNS #2:
- Must create a mechanically and electrically sound connection between two vehicles
- Materials must withstand stresses introduced from coupling and velocity differences while driving.
- Materials must be low-cost.

List of functional requirements for PNS #3:
- Trike coupling/decoupling systems must be able to dock/undock at a safe rate for passengers.
- Trike coupling/decoupling systems must be able to attach and detach from the fleet quickly and safely for user convenience.
- Must be able to have a safe low impact collision when docking.
- Must have a reasonable gathering range to accommodate error in the control system.

How will we know if our product is successful?
The product will be considered successful if the system can demonstrate reliable and automatic coupling and decoupling as well as the ability to remain coupled and provide a smooth ride. The goal is to use a prototype on the Micro-AV autonomous trikes to demonstrate the coupling capabilities. Proof of concept for physical coupling capabilities will be a large step towards the development of modular vehicle systems. This proof of concept would also be a large step towards Micro-AV attracting partners to commercialize the product.

A.2.3. Design Strategy--High-level Constraints on the Usability of the Product

In this section the high-level constraints for each of the needs statements are provided. The objective of this section is to identify constraints of the product to alleviate user pains.

High-level constraints for PNS #1:
- Vehicle speed differences must not exceed 5-10 mph in order for the product (coupling/decoupling mechanism) to be able to function properly

- Product must be able to absorb shock from the impact of collision for optimal user experience

High-level constraints for PNS #2:
- The total cost of the product must not exceed the budget amount of $1,360 ($400 provided by sponsor and $960 provided by the school)
- Product materials must withstand operation of 10 hours per day for 10 years (assuming 4-8 couples per hour)

High-level constraints for PNS #3:
- The product must be able to couple and decouple at a safe speed, providing a low impact collision when docking, for the user so that there is no user discomfort
- The product must be able to quickly attach and detach for optimal user convenience
- The product must have a reasonable gathering range to accommodate any errors in the alignment of the coupling process

Combining all of these high-level constraints together, we can determine our final needs statement for the product:

The product is a fully automatic coupling and decoupling system that will interlock two vehicles while in motion, absorb low speed impacts from the collision of coupling, and retain the bumper-bumper mechanical and electrical connections to allow for a modular vehicle.

A.2.4. Design Strategy--Final Needs Statement and User Outcomes

Final Needs Statement
The product is a fully automatic coupling and decoupling system that will interlock two vehicles while in motion, absorb low speed impacts from the collision of coupling, and retain the bumper-bumper mechanical and electrical connections to allow for a modular vehicle.

What does our client want from the product?
Our client wants a coupling mechanism that can automatically couple and decouple two vehicles, and maintain bumper-bumper connection while driving. The client also wishes for an electrical connection to be established between the two vehicles.

What are our customers' pain points?
Our customers' current main pain point is inability to attract partners to commercialize their product. This is due to a lack of a working prototype to prove their concept of the modular vehicles.

How can our product solve these pain points?
Our product can solve these pain points by demonstrating the automatic connection between two small vehicles to form a modular vehicle. Once the prototype of the coupling mechanism is proven to be effective, Micro-AV will gain funding and support from partners that will help them commercialize their Millipod vehicles for bike-sharing or small delivery purposes.

A.2.5. Design Strategy--Hypothesis Statement

Our direct clients, Micro-AV, require a proof of concept for physical coupling mechanisms between vehicles as a crucial component of the proposed system of modular vehicles being developed by Micro-AV. The solution will satisfy the requests of the client if it can serve as a proof of concept for an physical system that can automatically couple and decouple with specified control signals, as well as stay coupled under dynamic loads as provided by the operating conditions designated by the client. If this system which is built is compatible with the provided vehicles to test and passes simulation conditions as defined by the project requirements, this project will be successful.

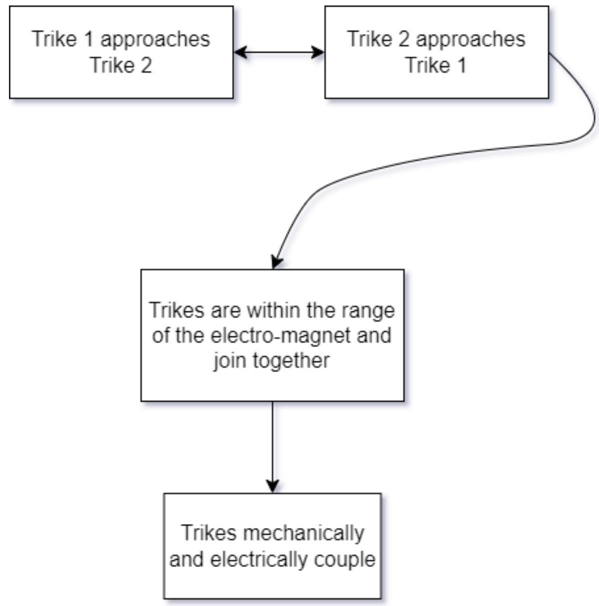
The hypothesis is that physically connected vehicles outperform platooning vehicles in fuel efficient, autonomous, synchronized travel. This is due to the physical couple and damping system correcting for errors in the control system of the vehicles. Additionally, vehicles traveling in platooning formation still suffer from some amount of aerodynamic drag, that of which is minimized when following distance between vehicles is minimized. The most practical way to safely achieve this minimized following distance is through physically coupling them.

A.2.6 Design Strategy--Possible Inventions and Business Model

Below are listed possible inventions for the coupling and decoupling product. Each possible invention has been ruled out of our consideration for various reasons due to assumptions and constraints required from the final product.

Invention #1:
Utilizing an electro-magnet system to couple and decouple the trikes when within an acceptable range.

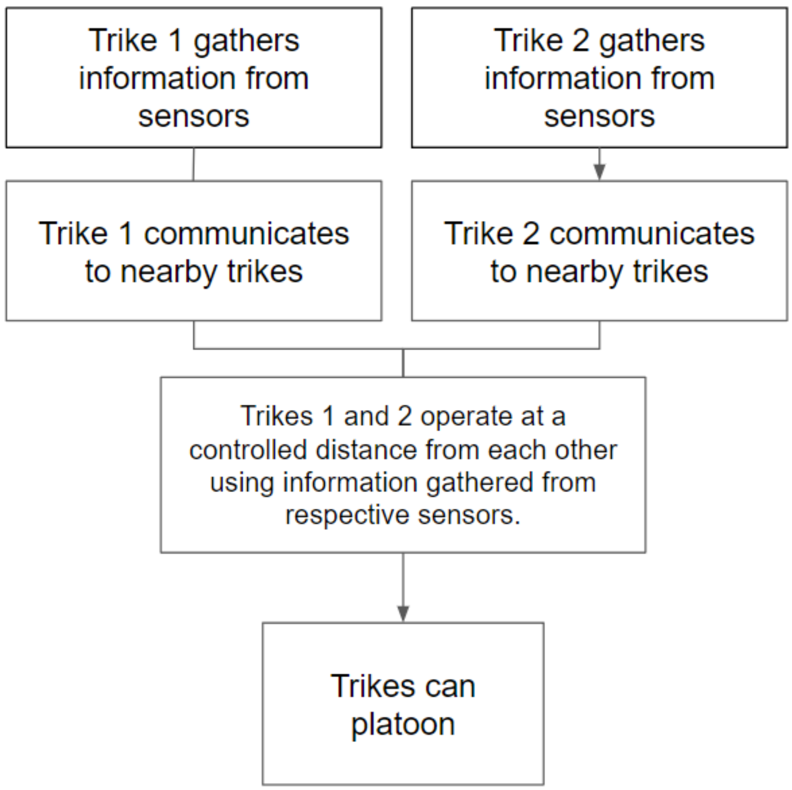
Systems Level Sketch Invention 1



Invention 1 was not feasible because it would be difficult to control the collision between the two trikes if using magnets to couple. It would be hard to dampen the forces from the collision to an acceptable level for user comfort. Invention 1 would also require very strong magnets which would be both very heavy and costly.

Invention #2:
Platooning enabled by wireless information transfer which can be used to inform vehicles to control distance between one another. Utilizing WiFi or other forms of wireless communication between vehicles, signals containing information vital to road operation would be collected using proximity sensors, GPS, lidar, or other similar mechanisms. This information would be transmitted between all vehicles within a specific range, allowing their driving to be informed and synchronized to the point of platooning.

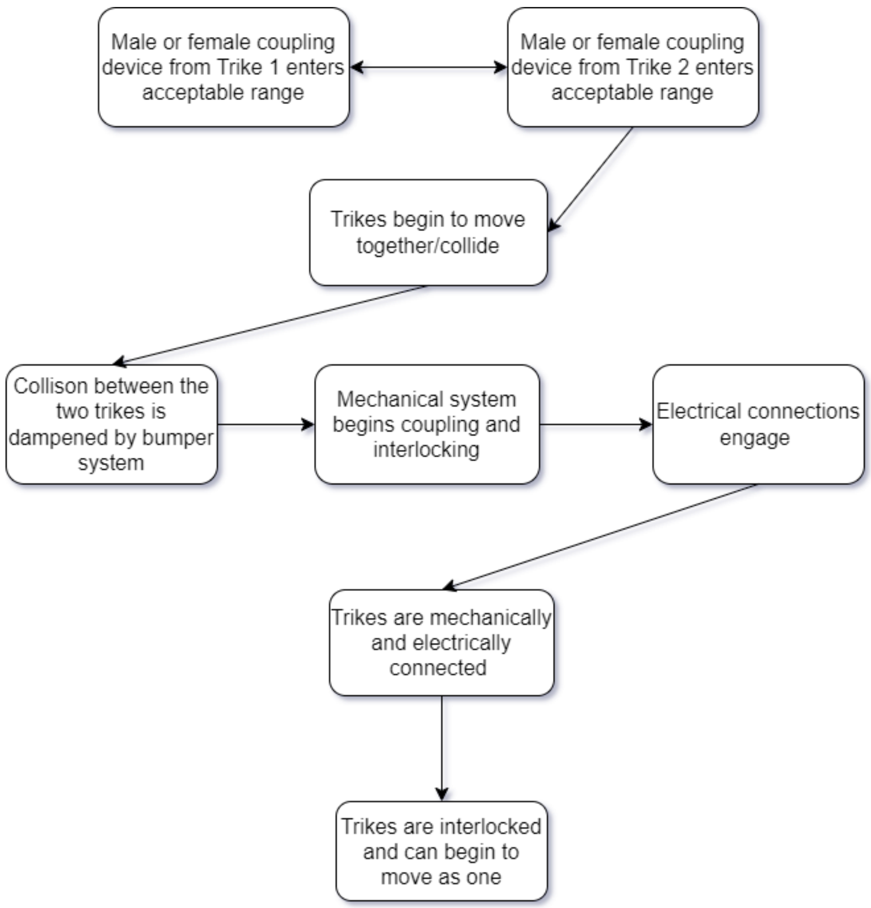
Systems Level Sketch Invention 2



Invention 2 is not considered to be desirable due to the fact that platooning is not as energy efficient. Without physical systems to couple, this system is limited by how close vehicles can safely operate to each other, which will ultimately limit the amount of energy usage reduced.

Invention #3:
Utilizing interchangeable male and female coupling parts in a system alongside a dampening device (such as a bumper) in order to couple and decouple two trikes both mechanically and electrically.

Systems Level Sketch Invention 3



Invention 3 is feasible and provides all the necessary components desired for our product. Invention 3 provides the scope of a product that is a fully automatic coupling and decoupling system that will interlock two vehicles while in motion, absorb low speed impacts from the collision of coupling, and retain the bumper-bumper mechanical and electrical connections to allow for a modular vehicle.

Lean Canvas

PROBLEM
Top 3 problems

- Current public transportation has inefficiencies in time, energy, and cost
- Burning fossil fuels creates a large carbon footprint and pollution
- Public transportation makes frequent stops
- Last mile problem - final leg of transportation systems becomes signifcantly less efficient in high capacity, urbanized areas

SOLUTION
Top 3 features

-Small,autonomous,lightweight electric vehicles specialized for urban travel under 25mph
-Physical coupling of EVs traveling in same direction to reduce fuel consumption and drag
-Dedicated pathways similar to bike lanes

KEY METRICS
Key activities you measure

Environmental:
-travel times
-local emission data
Product:
-amount of units sold or distributed
-usage/energy consumption compared to other transportation methods

UNIQUE VALUE PROPOSITION
Single, clear, compelling message that states why you are different and worth buying

A solution to transportation inefficienies which address traffic and the last-mile problem featuring faster commutes and environmentally conscious fuel

UNFAIR ADVANTAGE
Can't be easily copied or bought

-Underdeveloped sector primarily in R&D phase
-physical coupling system will be a complex assembly of electromechanical parts, with unique parts like sensors

CHANNELS
Path to customers

-Mobile applications, possibly an additional segment to existing transportation apps (Transit, Uber, etc.)
-Contracts with government

CUSTOMER SEGMENTS
Target customers

-Urban commuters
-Government entities handling public transportation

Archetypes:

-Rising megacities
-Established megacities
-Car-dominated mature cities
-Mature advanced cities

COST STRUCTURE
Customer Acquisition Costs
Distributing Costs
Hosting
People, etc.

Costs:
-materials
-production
-testing
-product development (prototyping, R&D)
-app develoment
-marketing

REVENUE STREAMS
Revenue Model
Lifetime Value
Revenue
Gross Margin

-selling units to government/companies
-renting units to government/companies
-charging per use

A.2.6.1 Design Strategy--Final Invention

The physical coupling solution was chosen because it allows for a modular vehicle such as the Millipod to operate with increased fuel efficiency, synchronization, and enhanced autonomous capability. This solution will be deployed on the e-trikes as well as the Millipods. This physical coupling solution will play a significant role in fulfilling the visions of improving fuel economy and reducing environmental footprints.

These Millipods will then be used by both urban commuters directly as well as public and private entities who would distribute products or services. Important marketing factors such as scale and configuration can be assessed based on research pertaining to the four urban city archetypes: rising megacities, established megacities, car-dominated mature cities, and mature advanced cities. The scope and scale of the deployed products would adjust according to specific city needs based on this criteria.

To reach these desired customers, outreach will coordinate with government and private entities to deploy products. A mode of flowing demand from urban commuters to such entities that is heavily in consideration is through the use of mobile applications, either new or existing, to "book" or "order" such services or products. This could function in a way similar to Lime scooters or Uber. Supportive capabilities could also be added to apps like Transit which detail public transportation. Revenue could be earned through different avenues, primarily selling the units themselves and possibly renting them out.

A.2.7 Design Strategy – Product Planning Roadmap

The main features of the product for the scope which will be worked within will be the bumper, physical coupling system, and electrical connection.

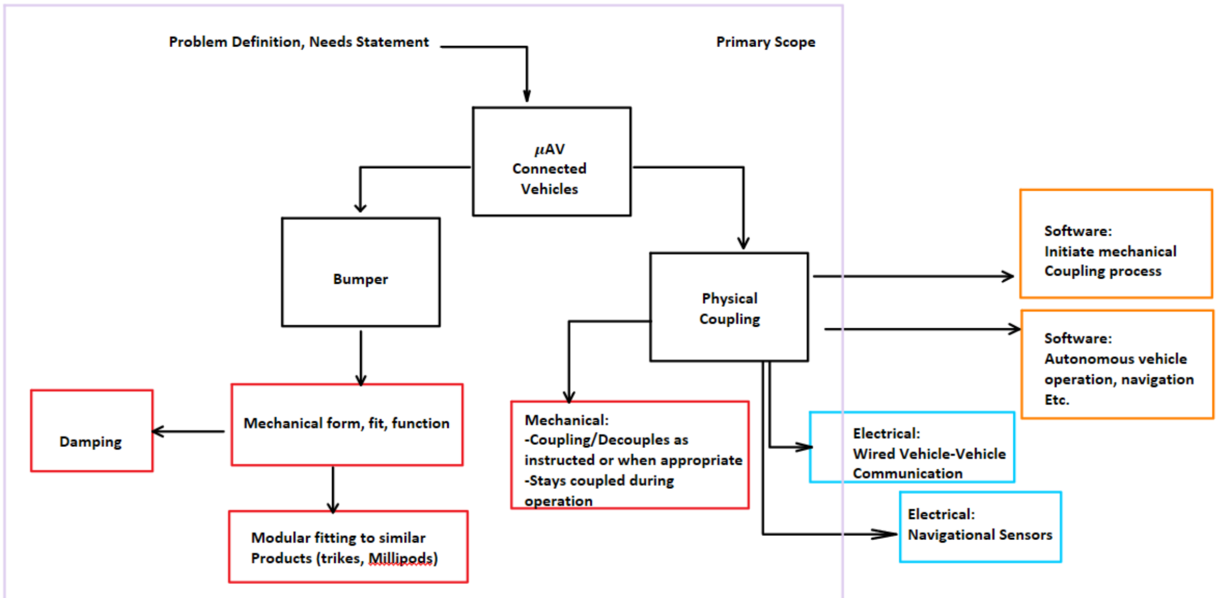
The main function of the bumper will be to damp the forces from collisions. The fit of this bumper will be intended to be modularly compatible with different µAVs. The form of the bumper will accommodate the physical coupling system. Within the scope of this project, the bumper is to be designed to house the physical coupling system strictly. However, for future product development occurring outside of the project scope, the bumper will also implement sensors that will provide positional information and proximity to other vehicles. This comprises the bumper's planned functionality.

The physical coupling system is to couple and decouple the vehicles when appropriate. When coupled, the vehicles are to stay coupled during operation until the system is otherwise instructed. Two different structures must be designed, one female connection and one male connection, to accommodate front and back linking between multiple vehicles. Due to the current stage of maturity of the vehicles utilizing the coupling system, proximity sensors will be not implemented into the design but planned for. As a result, the design of the coupling system will utilize a purely physical coupling initiation. Digital components will not be required at this point in development.

In mechanically developing the two systems, teams can be assigned between bumper and couplers. The bumper must first be engineered to absorb a certain amount of shock in specific instances to protect the rest of the vehicle. The couplers will then be developed, using the bumper as a housing of sorts. This comprises the scope of development for this project. At the end of this project, a bumper system that houses a primarily mechanical coupling system will be built and attached to the provided vehicles that would provide a proof of concept.

For future product development, electrical and software systems will be introduced into the coupling systems. Electrical proximity sensors that can identify distance between vehicles and verify coupling and alignment will be important to allowing autonomous operation. Additionally, within the couplers, wired connections enabling vehicle to vehicle communication will be pursued. Lastly, software must be further developed to enable autonomous vehicle operation and navigation. This would include a fully autonomous coupling and decoupling process as well.

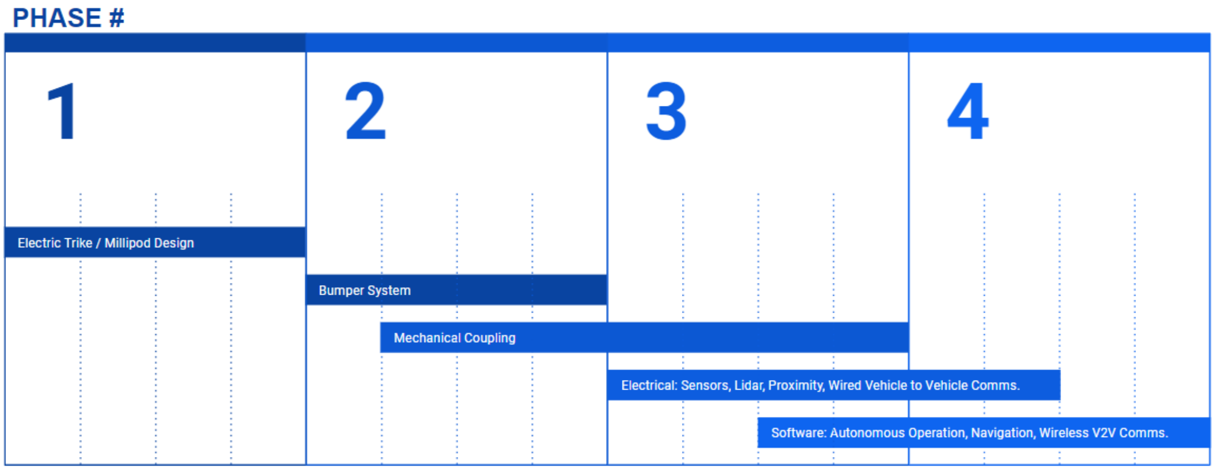
Product Roadmap



This project will be supported by four primary functional roles: Project Manager (Devin Taing), Outreach (Li-Ling Plume), Lead Mechanical Engineer (Rebecca Sasten), and Technical Lead((Vladimir Roca). The project manager will be responsible for managing the budget and coordinating the timeline of all technical tasks. Outreach will be responsible for managing and flowing information from all communication external to the team. The lead mechanical engineer will be the subject matter expert for technical research and development. This also includes ensuring the compatibility and integration between different systems i.e. bumper and coupling. The technical lead will be responsible for testing, prototyping, and physical production needs. This includes generating test methods as well as executing them, and generating reports to communicate. It should be noted that all of the roles will be intermixing with one another and that these are assignments of responsibility, not activity.

Technical responsibilities will also be primarily group-based, but generally owners of responsibility will be divided in terms of research and knowledge ownership, while design decisions will be made collectively. Subject matter ownership can be split up between bumper design, front coupling design, back coupling design, and operating condition requirements.

Product Development Timeline

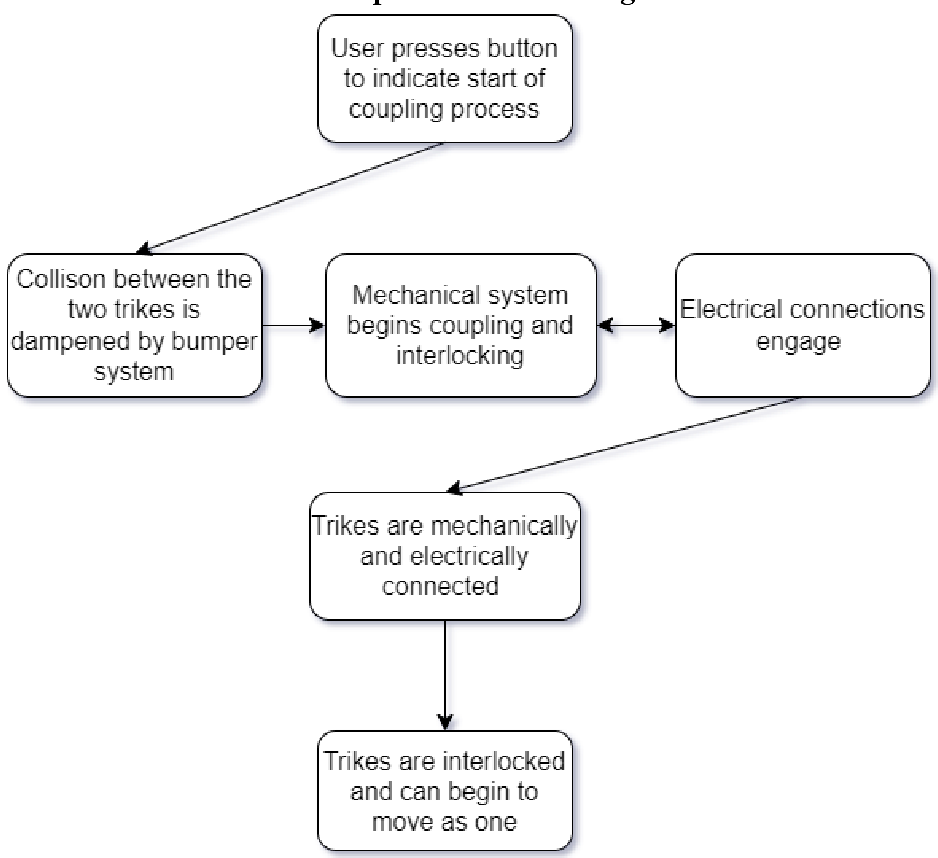


B. Experience Design

B.1 Experience Design – Human Interface Design, User Workflow

This project consists of developing a mechanical system/product that can couple and decouple two trikes. These trikes will ideally be used in a platoon composing the Millipod, however this will be in later iterations of the product. The product must be able to couple two trikes front-to-back and back-to-front, therefore being interchangeable. This product will consist of a male and female part which will interlock once within an acceptable coupling range. The product will be able to couple while the trikes are in motion. There will be adequate shock absorption from the collision caused by coupling through the use of bumpers along the front and rear of the trikes. For the first product, the user will press a button to indicate that they are ready for coupling. Once the button is pressed the product will begin to couple and will mechanically interlock. After mechanical interlocking, the electrical connections will engage. The utilization of the user pressing a button to indicate the start of coupling is only necessary for this scope of this project and will be replaced by a signal from the vehicle control system in later iterations. The user will optimally experience seamless coupling and decoupling with adequate shock absorption.

User Experience Flow Diagram



B.2 Experience Design – Human Interface Design, Environmental analysis

Various assumptions that must be made for the product to be operational are listed below along with design constraints resulting from human interface with the product.

Product Requirements:

1. The product must operate on flat road conditions with minimal turns when coupling and decoupling.
2. The maximum speed differential between the two trikes during coupling must be within a range of 0-5 mph, with a maximum of 10 mph between the two trikes.
3. The product must dampen/absorb the shock associated with the coupling process.
4. The maximum speed the product must withstand when coupled is 40 mph.
    a. If the trikes housing the product operate within a bike lane the top speed will be reduced to 20 mph.

Product Expectations:

1. The product will be expected to couple and decouple 4-8 times per hour.
2. The product will be expected to operate 10 hours a day.
3. The product will have an adequate tolerance range in the X, Y, and Z direction in order to assist the coupling process.

Expectations of User's Interface/Experience:

1. The product will be mounted to the front and back end of the trike. The front end of the product will be mounted on the existing foot pedals of the trike and the user footrest will be relocated out of the way of the coupling/decoupling process.
2. The user will press a button to indicate when it is safe to start the process of coupling or decoupling. As aforementioned, this will be replaced by a signal from the vehicle control system in later iterations of the product.
3. The user will not experience any jolting with coupling that may cause discomfort.
4. The user's extremities will not be at risk of getting caught in any of the coupling and decoupling processes.

B.3 Experience Design – Human Interface Design, Cultural factors mapping

The design is primarily for city and suburban use. We analyzed both the United states and internationally to see how certain cultural factors will affect the design of our coupling system. Here are the 5 cultural characteristics:
Learned: We learn culture from family, peers, institutions and media.
Shared: When we share culture it allows us to act in a societal way and predict how others will act/react.

Symbols: Must have a group of people agree on the meaning of a symbol to use. (language for example)
Integrated: Holism, as one culture is not defined by a singular thing but is interconnected to multiple different parts that make it whole.
Dynamics: Most cultures are in contact with other cultures and this causes us to share ideas and adapt to changes in society.
These characteristics will directly affect how effective we are in designing something that is human centered. Although it is hard to measure the characteristics of culture depending on the country, we can generalize the idea to give us a better understanding on how it affects our design. When designing a product within the US, the dynamics and integrated portions of the characteristics is a higher factor since the United States is a melting pot of multiple cultures. This causes us to take into higher consideration how those factors will affect the coupling design. The most important characteristic that is equally affected internationally, is Symbols.
A vehicle/trike can symbolize multiple things, this depends on how together as a group, a village, city, state, or country views something and agrees upon that something. Since language is a symbol in which we can agree on the meaning of something, language is our main factor. When we say vehicle/trike we think of a transportation device first and then other factors follow along.
So when designing a vehicle/trike that transports people or things, we must automatically try to fulfill the idea of the word vehicle/trike. This is important if the desire is to have better adaptations for all different cultures.
Next we must take into consideration what the expectations of what a vehicle/trike is. Traditionally a vehicle/trike is thought to be a transportation device that you must operate at all times. When designing something new that breaks the norm of what was thought previously, we must take into consideration how we are adding value to the symbol of the word "vehicle/trike" and how that will affect the culture within that environment.
The impact within each human interaction will be affected by how we redefined the word vehicle/trike. Since autonomous vehicles coupling in platoons is a new idea of transportation we will aim to add value and create a design that can be accepted by many different cultures.
Internationally the micro-Av will be of benefit depending on the transportation system that each country operates under. Questions such as, what type of terrain is there? Is there service? And much more is critical. Accessibility would vary depending on the country so when designing the micro-Av coupling system we must take into consideration different terrains to give every human the same experience when using the micro-Av. This means we must try to design to still operate under the worst terrain possible, depending on our target environment . This helps later for all cultures to experience the same thing which then can provide similar issues or positive results.
Each industry will also vary since certain cities even within the united states are highly populated so addition and transition of a new transportation would not easily be welcome to the public. When thinking of the dynamics of culture, it will depend on how the transition happens. New York for example is a dense city and the transition would be critical since it is a fast paced

environment. Even if humans were open to the benefits of the micro-Av, the transition would factor higher how they would communicate about the new transportation system with the micro-Av. In contrast, other cities that are not dense, if they applied the micro-Av as a part of their transportation system, they would share the benefits to one another, eventually if accepted by the people of one location it will be known as a part of their culture on how they transport themselves or items.
Since the environment changes per culture, it can be concluded that each design must first view the environment and in line see how culturally it would be accepted by the group of individuals in different regions of the world.

B.4 Experience Design – Human Interface Design, Information Architecture and Hierarchy

Using the user experience flow diagram and information gathered in B.2. A list of inputs and outputs can be created to ensure that the design is human-centered at all stages of the workflow.

User presses button to indicate start the coupling process:

Human-centered inputs user/device:
- Visual representation of the button
- Location of button
- Force required to press the button.

Human-centered outputs user/device:
- Visually able to distinguish between other buttons or surfaces.
- Location is accessible for better performance.
- Pressing a button that does not take too much force but enough to recognize the switch.

Collision between the two trikes are damped by bumper system:

Human-centered inputs user/device:
- Force and speed of impact
- Distance of trikes

Human-centered outputs user/device:
- No shock felt to passenger or items during collision

Mechanical system begins coupling and interlocking:

Human-centered inputs user/device:
- External/internal forces and vibration due to terrain

Human-centered outputs user/device:
- Passenger would not likely notice the trikes are coupling

Electrical connection engages:

Human-centered inputs user/device:
- Mechanical switch triggers electrical response.

Human-centered outputs user/device:
- Electrical message is sent to connect within the coupling system.
- Coupling system is an external device, no electrical wires are exposed to passengers.

Trike is mechanically and electrically connected:

Human-centered inputs user/device:
- Mechanically closed
- Electrically closed

Human-centered outputs user/device:
- Coupling device understands it is electrically and mechanically connected.
- Passenger would not notice anything happening when system is being coupled

Trikes are interlock and can begin to move as one:

Human-centered inputs user/device:
- Ready to move

Human-centered outputs user/device:
- Passengers would not notice anything happening when the coupling system is completely coupled.

B.5 Experience Design – Human Interface Design, Analog Interface Design

Since the end product of the coupling device will be fully autonomous, there would be no analog interface for humans to interact with. However, for the purposes of this project, some steps in the coupling and decoupling of the mechanism will require intervention in the form of pressing a button. For this design, the electrical connection will be made after the physical connection is secure by using an actuator controlled by a switch or button. In future iterations of the design, this switch will be replaced by a signal from the vehicle's control system.

If the Millipod system is used to transport people in the future, the design of the vehicle pods must be comfortable for the user to sit in, as well as easy to get in and out of. For the scope of this project, the only comfort feature that will be added is foot rests on the front of the Micro-AV trikes so the user can comfortably ride in them without having to hold their feet up. The foot rests will be installed on adjustable pegs to accommodate different rider heights and allow for ease of adjustment before riding.

B.6 Experience Design – Human Interface Design, Graphic User Interface Design

There is no graphic user interface involved with the coupling device. However, the graphic user interface for the entire Millipod system will most likely be in the form of an app users may download on their smartphone, similar to rideshare or food delivery apps. If the Millipod is used to transport goods to people's homes, this app would have features allowing the user to select items, schedule deliveries, and track their shipments. In the future, the Millipod technology may be adopted into the larger transportation system, in which case this app would allow users to schedule their route and notify them when their vehicle pod will arrive.

B.7 Experience Design – Human Interface Design, Best Use Practices Report

There are multiple failure modes that are possible for this project. This includes mechanical and electrical failures. For mechanical failures, the coupling system may not maintain physical connections, causing the components to yield or break under the stress of operation. This would result in the coupling mechanism to detach from itself or from the mounting at an undesired time.

Another possible point of failure may be inaccuracy during coupling. As a result of this inaccuracy, the vehicles to be coupled may not make the necessary contact to physically connect them, thus not completing project requirements.

Lastly, electrical failures could occur. Any event which would dampen or disrupt the electrical signals carrying either information or energy between vehicles. Electrical connections may be disrupted through physical means, such as insufficient mechanical methods of maintaining coupled status, or the introduction of other substances which would interfere such as moisture or dust.

The desired end-product in which this coupling mechanism will be applied intends to be fully automatic. As a result, the user would not need to directly interface with the coupling mechanism which this project's scope focuses on. As such, best use guidelines would not be necessary for the rider. Instead, failure would be prevented by ensuring proper maintenance protocols are established once the design of the product is finalized. Maintenance would be primarily analog, checking for the health of the mechanisms throughout its operational life.

Once the design life is finalized, the frequency of maintenance checks on the coupling system can be determined in combining financial and engineering considerations. Depending on the frequency of maintenance checks on the coupling system, different types of maintenances checks may be deployed, but all will ultimately check for things such as: a) health of moving parts, b) health of impact dampers, c) health of overall structures and housings, and d) verification of electrical connection pins. The methods used to evaluate these indicators of system performance is yet to be fully determined.

System Maintenance Plan

Component	Health Indicator	Test Method	Frequency
Moving Parts	Full, smooth movement within designed range of motion, no squeaking	Undetermined	Undetermined
Impact Dampers	No signs of wear and damage such as cracks, rust	Undetermined	Undetermined
Structures / Housing	Absence of audible/visible signs of damage or wear such as cracks, rust	Undetermined	Undetermined
Electrical Connection Pins	Transfer of current/ power/information when in contact	Undetermined	Undetermined

B.8 Experience Design – Human Interface Design, the Summary Document, in essence a Usability Requirements Documentation.

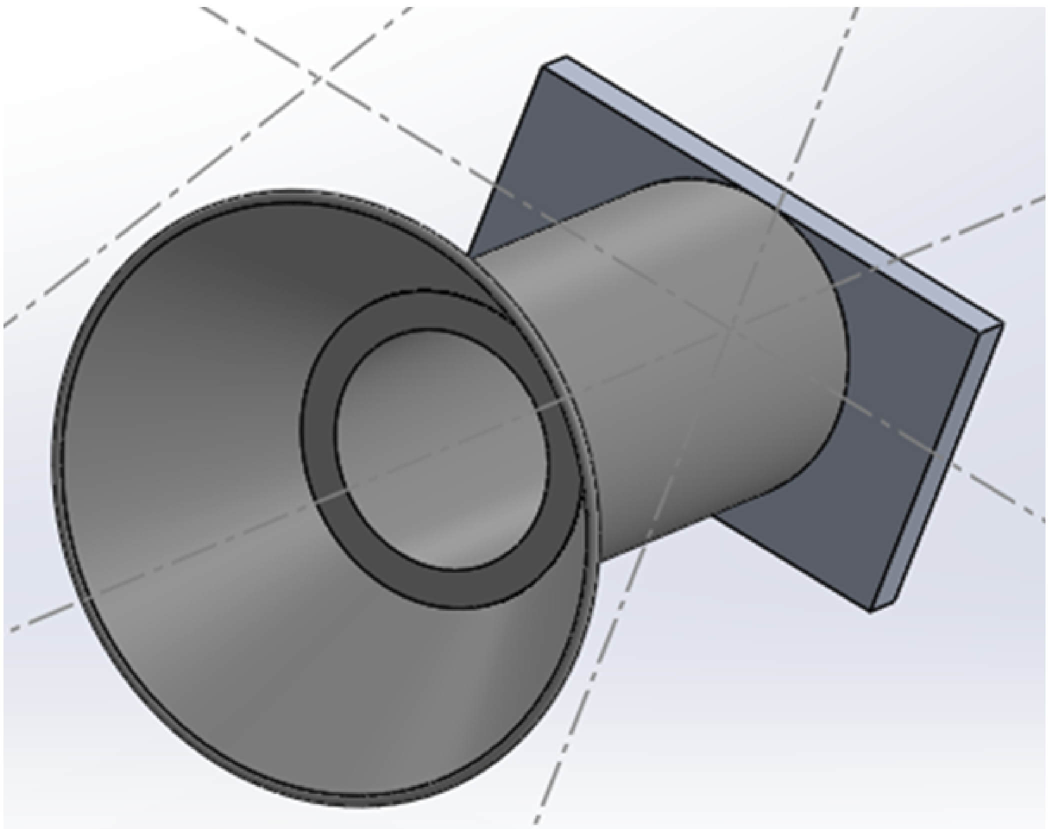
The requirements of the coupling system will not be driven heavily by aesthetic considerations. As a result, the considerations of form will not be weighing heavily into the design of the coupling system. Instead, the function of the system will be a much more prominent design driver. In addition to the function of the system, the comfort of the riders will be of much higher importance. In terms of aesthetic possibilities, as long as the coupling system generally fits with the visuals of the existing system it is being integrated into. Another possible consideration visually is to have the material of the system be one which can be painted over to have greater flexibility visually.

C. Requirement Documentation

C.1.1 Design Decisions and Rationale

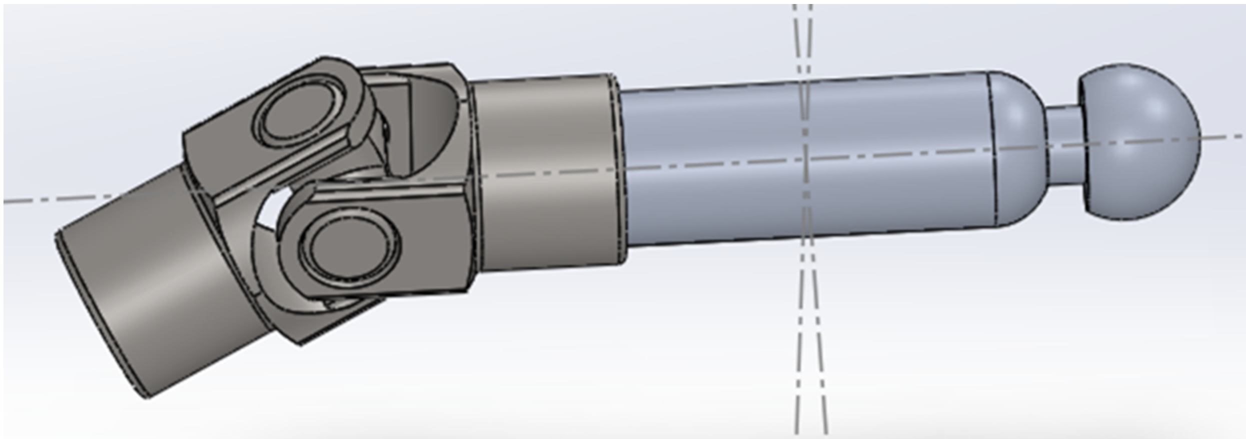
Given the chosen design, the final product will likely be machined and manufactured in house. The final product will consist of two male and female counterparts. The order in which the male and female counterparts will be built is yet to be determined, they may also be built simultaneously.

Female Counterpart



There will be two main components to manufacture for the female counterpart. The funnel of the female counterpart will be made of a tin funnel that can be cut down to size and attached to the rest of the female assembly. The base of the female counterpart will be made of a solid aluminum block. The slots and openings within the block will be machined with the 3-Axis CNC Milling Machine in addition to the CNC. The two pieces will then be welded together. The locking mechanism within the female counterpart can either be machined in house or purchased from an online supplier.

Male Counterpart

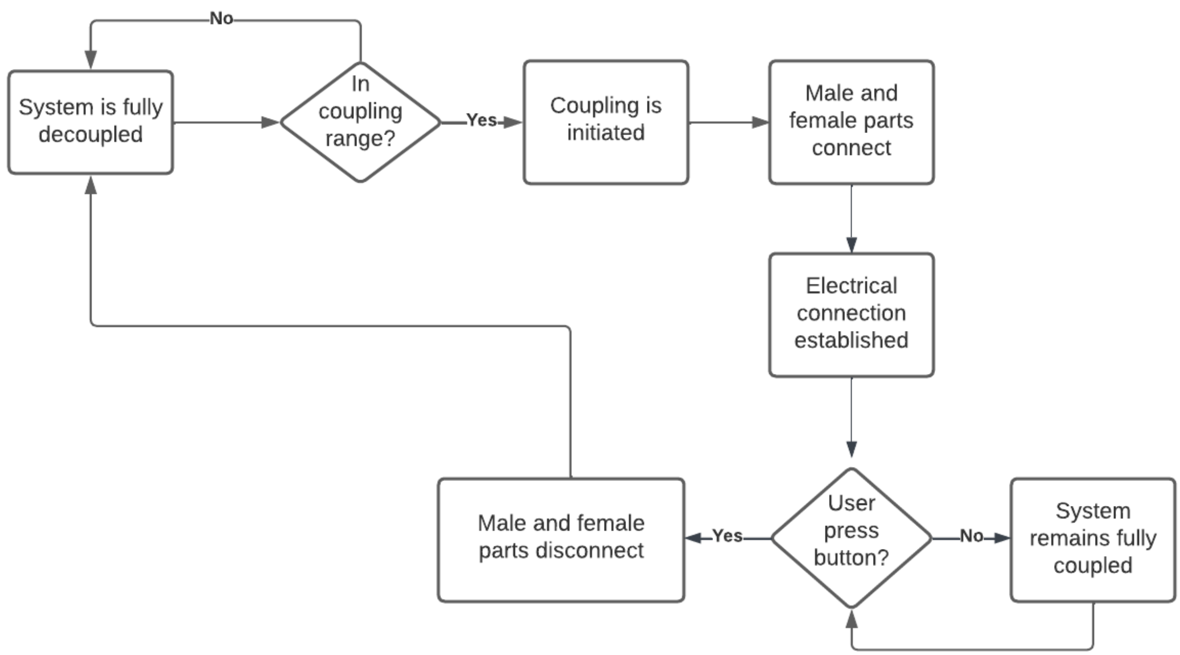


The male counterpart will consist of a main shaft, universal joint, and dampening system. The main shaft will likely be machined out of round aluminum stock that will be turned to size and shape on the lathe. Additional details on the shaft can also be machined in house with the 3-Axis Mill and CNC machine. The shaft will be TIG welded to a universal joint. This universal joint will be purchased according to spec and size from a supplier online. The dampening system will consist of a casing and spring welded to the back end of the universal joint. The casing will need to either be purchased online as hollow stock material (tubular or rectangular) or machined in house. The spring will be purchased online and will sit inside the casing.

The final product will be an automatic coupling and decoupling system consisting of a male and female counterpart as depicted above. The final product for testing purposes will consist of two complete sets of male and female counterparts mounted onto two trikes, the male counterpart will be mounted onto the front of the trike and the female will be mounted to the rear of the trike. There will be a simple mechatronic system consisting of a button that the user can press to initiate coupling or decoupling. When both counterparts are mechanically interlocked, there will also be three electrical connections that will accompany the system to provide electrical connections (two data connections and one ground connection).

C.1.2 Tier 1 Schematics (block diagram)

Level 1 Roadmap of Major Elements



There are a couple major elements in this design, which will be explained below:

Mounting
The mounting scheme does not appear in the schematic shown above because it does not play a significant role in the function of the coupler, as its only purpose is to provide an attachment between the coupler parts and the trikes.

Male Counterpart
The male counterpart will attach to the front of the trike and will serve as a connection point between the two trikes. This element is also responsible for accommodating the motion between two trikes and providing damping from low speed impacts. Within this element, there are several different parts that work together to fulfill those requirements.

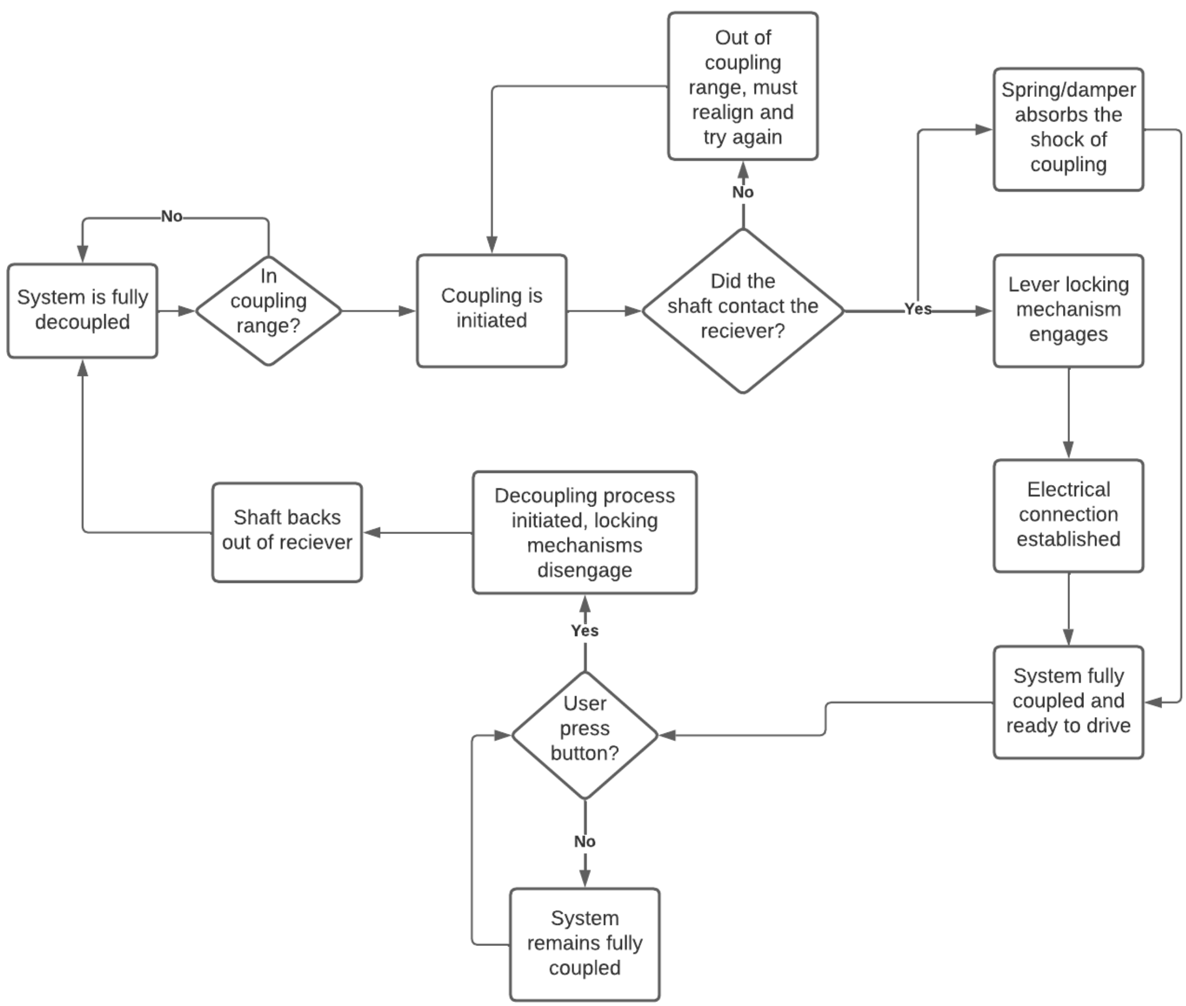
Female Counterpart
The female counterpart will attach to the back of the trike and will work to lock the male part in place. This element is also responsible for accommodating for positional differences between the parts as the trikes are coupling.

Electrical Connection

The sponsor also wishes to have a 3 wire electrical connection established between the two trikes. For the scope of this project, this connection only serves the purpose of physically demonstrating the connection of the wires. However, in future iterations of the project an electrical connection will be important for inter-trike communications.

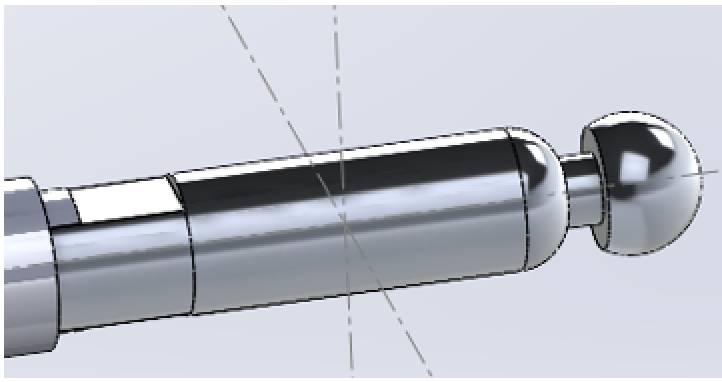
C.1.3 Tier 2 Schematics for each element (block diagram)

Level 2 Roadmap of Individual Pieces within Elements



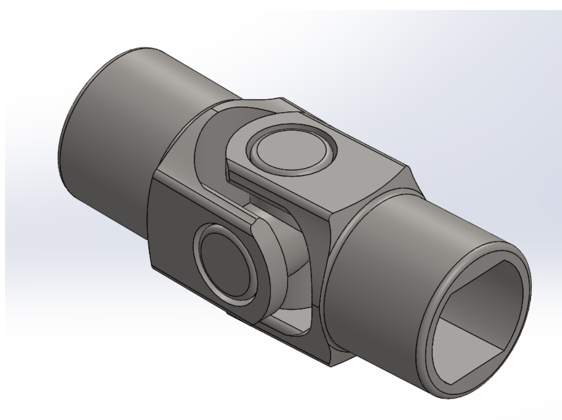
The design consists of a couple major elements that will be mounted to either end of the trikes. The male part will attach to the front of the trike and consists of a shaft, universal joint, and damping system. The female part will attach to the rear of the trike and consists of a funneled receiver, and lever locking mechanism driven by motors. There will be a mounting scheme designed to attach the coupler parts onto the trikes. There will also be wired electrical connection between the two trikes with a high signal, low signal, and ground. The coupling will happen purely mechanically (with the trikes being driven manually by remote control). The decoupling will use a simple mechatronic system and be initiated by the user pressing a button. The individual pieces of each element are described and shown below.

Shaft (male part)



The unique shape of this part allows it to enter the hole in the receiver and also provides a secure surface for the lever locking mechanism to rest. The curved ball shape at the front of the shaft allows the lever to be pushed onto the shaft and drop into the groove behind it.

Universal Joint (male part)



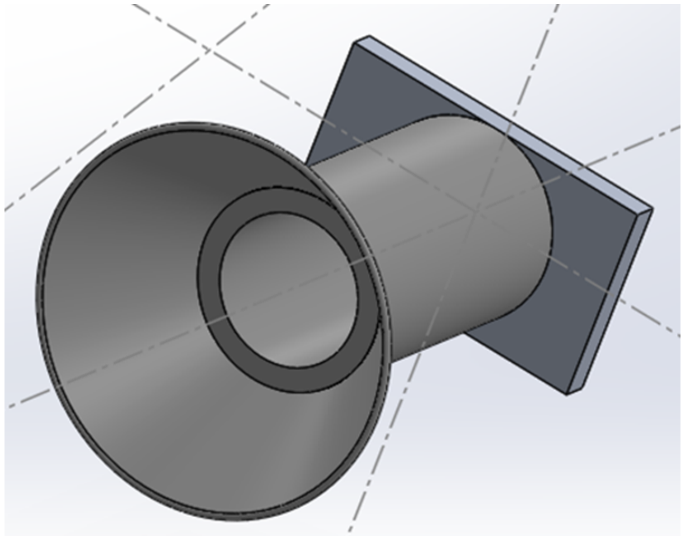
A universal joint is used to accommodate for 90 degrees of motion in every plane (pitch, yaw, roll). This type of joint was chosen to imitate the McHitch design and can be purchased assembled with the yokes or separately.

Spring/Damper (male part)

The spring/damper will be responsible for absorbing forces introduced to the system by low speed collisions due to coupling or potential speed differences while the vehicles are driving.

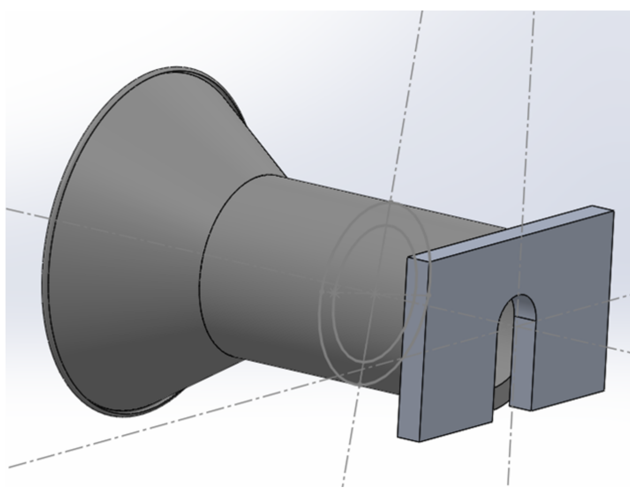
An important consideration for selecting a system for this application is the potential for tension in the spring.

Receiver (female part)



The receiver has a funneled shape at the entrance to accommodate for errors in the alignment of the two vehicles before coupling. This will allow for the shaft to be a few inches to the left, right, top, or bottom of the receiving hole and still couple successfully.

Lever Locking Mechanism (female part)



The lever will be attached to the back of the receiver and will sit in the slot of the shaft while the trikes are coupled, similar to the McHitch design. A motor will be engaged, using a rack and pinion gear to aid in lifting the lever to allow decoupling. The motor will be activated by the user pressing a button, but in future iterations of the design this could be replaced by a signal from the vehicle's control system.

Electrical Connection

The sponsor also wishes for an electrical connection to be established between the vehicles through the coupler. This electrical connection will consist of 3 wires, one for high signal, one for low signal, and one for ground.

C.1.4 Tier 3 Schematics (concrete connections between blocks)

The design consists of multiple parts individually but collectively depend on one another. Here, the relationship between certain parts in detail to describe the interaction between them will be covered. The brief conceptual actions between each part will play on one another and how that will act collectively, so it must begin at the starting point. The main objective is to couple two dynamic systems so all parts will contribute to this action being completed. Below is the first relationship with the male part and female part (overall part). This should be looked at from the big picture and brought down to the specifics.

The male shaft will insert itself through the female part through a funnel which will cover the direction guidance factor for precise coupling and minimize disturbance caused by external factors. These factors are things such as overall bumps, vehicles not fully aligned, and etc. These factors are the forces acting of the male shaft from all directions and will be maximize during the beginning of insertion and once male shaft has fully insert it itself those external forces being applied from all directions will be negligibly small, and so focus can be directed on the linear motion of forward and backwards, working with a 2D problem rather than a 3D. To take care of the peak forces being applied to the male shaft and female part during the beginning of the interaction since they will be rigid parts additional material for the female part may be needed. Additional material selections will be worked through after main parts are built but ideally the funnel should consist of possibly additional material that would take care of vibrations and minimize direct contact of parts as it would eventually damage the funnel and male head shaft destroy its purpose. Additional material will also minimize notice of coupling interaction when the user is activating the action.

Next there will be a focus on how the male and female part connect to one another and the purpose of why each part is shaped differently. As noticed before the male shaft head is rounded to push the lever mechanism to the groove which is after the head that will cause it to act and hold on the groove that the male shaft has. These are the final forces acting between the male and female parts that cause no high amount of forces acting on one another, once lever has dropped in place to hold on to the groove. To not allow all direct forces of forward and backward to be on the groove of the male shaft an additional pin mechanism is added to take care of the forces of forward and backward. Since it is understood that the groove has a max measurement that is based on the diameter of the shaft, the high load will likely bend the lever that holds on the groove and for that reason an additional location is needed to take care of this issue. Having the pin will take care of the stress concentration being only applied to the lever and groove of the male shaft which is limited by the diameter of the shaft. Having a pin go through the male shaft gives of more space to allow the forces to act evenly and if failure was to happen that it would not snap if it was only on the male shaft groove and lever but for the male shaft to elongate and there to be visible failure so repair can be conducted and no spontaneous slip or snap of the groove.

The reason for selecting a motor based pin mechanism is to also take into consideration that the vehicle is autonomous and this will allow for easier interaction between locking mechanism and brain of vehicles but also if implications where to happen, any failures can be determined where motor itself is having instead of a purely mechanical mechanism that would have no interaction of its performance and notice of its failure. Additionally the U-joint and Yokes are to take into consideration the vehicle's motion of pitch for bumps and yaw for turns. Roll is not a major topic of consideration due to the fact that the vehicle should be on a road. The U-joint being mounted to the male shaft was due to the idea of having a steady female part, because the male part was already under a lot of motion and to apply motions to different places in this scenario causes more disturbances and increase the external forces that affect the male shaft and female part already.

Lastly the spring damper system will be attached to male part due to the following reasons. Since two vehicles are connecting to one another it can be assumed the vehicle behind will be trying to add speed to get closer to the vehicle in front to attach itself to. Since the vehicle behind is moving forward, and there needs to be a smooth and not noticeable coupling interaction, the part being on the male shaft is ideal since to increase life of the spring/damper system.

To conclude these are major interactions to no another and reason behind the design that is present here. Further analysis will determine the exact measurements of parts to create a suitable coupling design to suffice to any two dynamic systems operating on a road.

C.2 Estimation of cost of goods

Listed below is the Cost of Goods Chart pertaining to the materials necessary for the final product. This is currently a rough draft of what our chart/bill of materials will look like in the future. It currently cannot be determined exactly what is needed to order as the design for the final product is not yet complete or close to being complete, ordering will be conducted for materials once the design has progressed more. More research on materials and alloy compositions needs to be done before any items can be purchased.

Cost of Goods Chart

Description	Name of Product	Product Part Number	Direct Link	Quantity	Unit Price	Total Price	Order Status
aterial for female cou	6061 Sheet Aluminum	N/A	/fBhC3ARIsAC	N/A	N/A	N/A	Not Started
rial for female counte	6061 Block Aluminum	N/A	https://them	N/A	N/A	N/A	Not Started
al Joint for male cour	uminum Universal Joi	N/A	https://www	N/A	N/A	N/A	Not Started
		N/A		N/A	N/A	N/A	Not Started
		N/A		N/A	N/A	N/A	Not Started
		N/A		N/A	N/A	N/A	Not Started
		N/A		N/A	N/A	N/A	Not Started

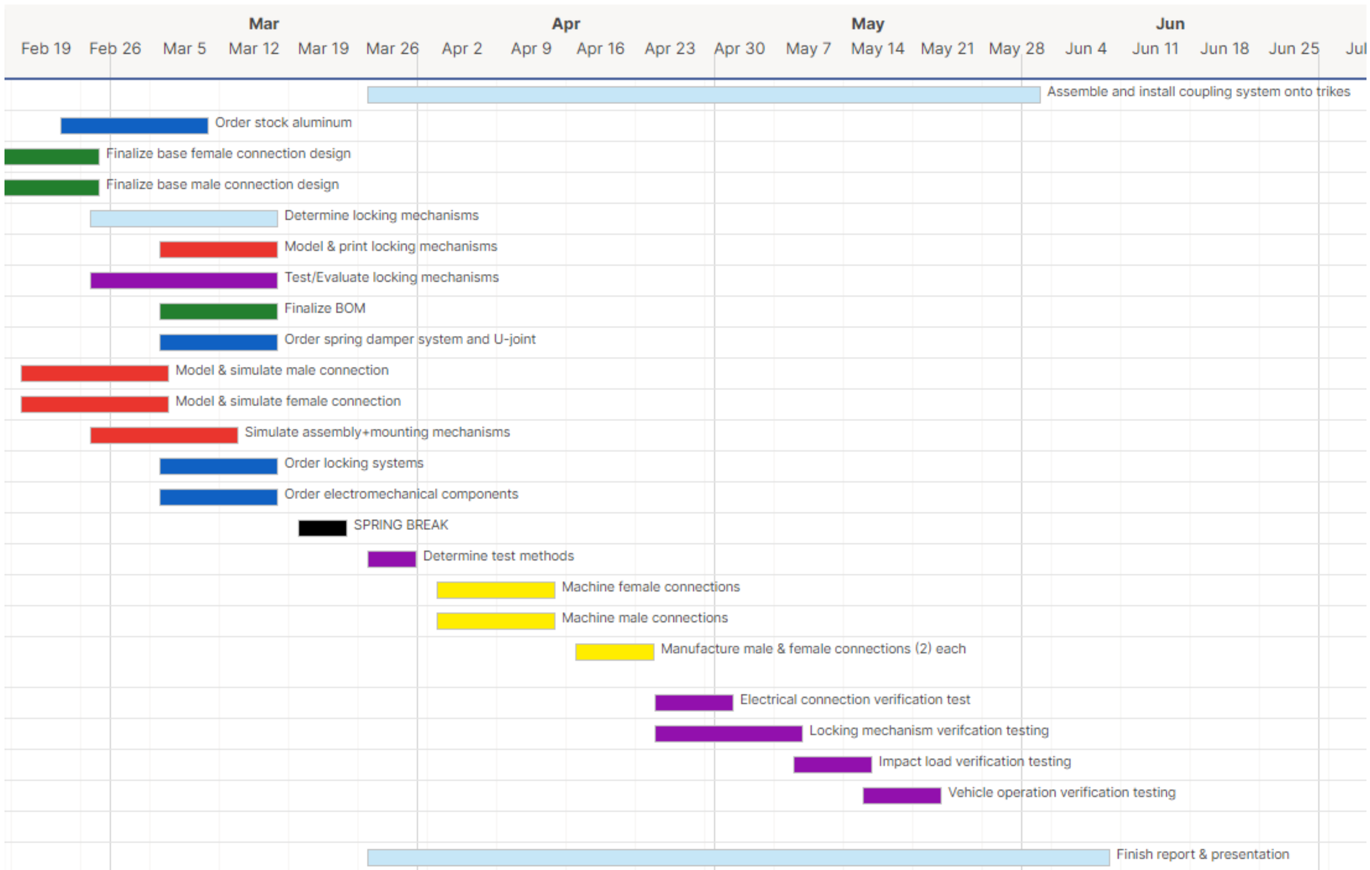
Link to access:
https://docs.google.com/spreadsheets/d/1FNnuN2hvXIVhPkbXcQaQ7vHTFL8sz9O7/edit?usp=share_link&ouid=105278363206855465252&rtpof=true&sd=true

The items currently in the list are placeholders. Some items not listed in the spreadsheet above include materials for making or purchasing a locking mechanism for the male and female counterparts. There is no listing currently for plans to purchase the spring and tube for the damping system as greater specifications for those items still need to be determined. Additionally, support for mounting the male and female counterparts onto the trikes will be needed as well. This may consist of metal brackets. Additionally, items will need to be purchased for the simple mechatronics system controlling the engagement of the coupling/decoupling.

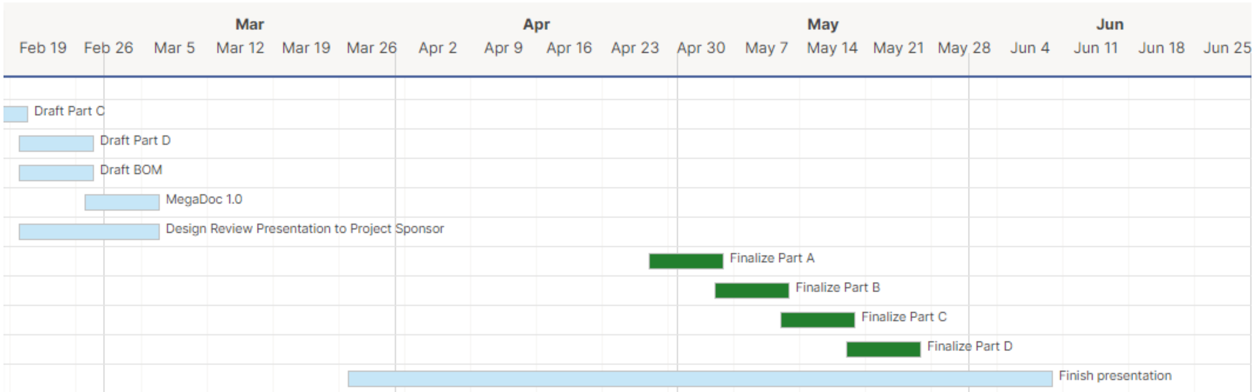
In addition to the raw cost of goods, the cost of machining and manufacturing in house into the budget, such as cost of supplies to weld, must be factored in.

C.3 Schedule

Technical GANTT Chart



Documentation GANTT Chart



Technical Tasks & Deadlines

Assemble and install coupling system onto trikes	03/27/23	06/02/23
Order stock aluminum	02/24/23	03/10/23
Finalize base female connection design	02/13/23	02/27/23
Finalize base male connection design	02/13/23	02/27/23
Determine locking mechanisms	02/27/23	03/17/23
Model & print locking mechanisms	03/06/23	03/17/23
Test/Evaluate locking mechanisms	02/27/23	03/17/23
Finalize BOM	03/06/23	03/17/23
Order spring damper system and U-joint	03/06/23	03/17/23
Model & simulate male connection	02/20/23	03/06/23
Model & simulate female connection	02/20/23	03/06/23
Simulate assembly+mounting mechanisms	02/27/23	03/13/23
Order locking systems	03/06/23	03/17/23
Order electromechanical components	03/06/23	03/17/23
SPRING BREAK	03/20/23	03/24/23
Determine test methods	03/27/23	03/31/23
Machine female connections	04/03/23	04/14/23
Machine male connections	04/03/23	04/14/23
Manufacture male & female connections (2) each	04/17/23	04/24/23
Electrical connection verification test	04/25/23	05/02/23
Locking mechanism verifcation testing	04/25/23	05/09/23
Impact load verification testing	05/09/23	05/16/23
Vehicle operation verification testing	05/16/23	05/23/23

Documentation Tasks & Deadlines

Finish report & presentation	03/27/23	06/09/23
Draft Part A	01/09/23	01/16/23
Draft Part B	01/30/23	02/06/23
Draft Part C	02/13/23	02/20/23
Draft Part D	02/20/23	02/27/23
Draft BOM	02/20/23	02/27/23
MegaDoc 1.0	02/27/23	03/06/23
Design Review Presentation to Project Sponsor	02/20/23	03/06/23
Finalize Part A	04/28/23	05/05/23
Finalize Part B	05/05/23	05/12/23
Finalize Part C	05/12/23	05/19/23
Finalize Part D	05/19/23	05/26/23
Finish presentation	03/27/23	06/09/23

Above are table-formatted and GANTT-visualized objectives and due dates for the two primary objectives of the project: Technically satisfy the requirements of the sponsor and provide a report and presentation of the result. For the report and presentation, this timeline is heavily guided by deadlines for the due date of each section of the report.

The design portion is still a heavily variable factor in terms of timeline, to which the build phase relies entirely upon.To lessen the time restraint burdens on the build phase, materials to purchase will be determined, sourced, and ordered as soon as possible for each individual design component. The rest of the build and test phase will follow the roadmap of design functionality as it is confirmed.

D. Concept Development [Demonstrating the solution]

D.1 Concept Development – Technology mapping, risk analysis and feasibility plan

Risk & Resources Component-Level Breakdown

Risk Level (1-5)	Component	Resources required
5	Male & Female Components	- 6061 sheet, block, aluminum - 6061 aluminum rod - Universal joint - Spring

5	Locking mechanism	Items tentative:
		- Lever lock:
		    - Servo motor
		    - Sheet metal (for lever)
		- Pin motor

4	Mounting	- Sheet/block metal - Servo motor
2	Electrical Connection	- Conductive plates / pins - Wires

The table above details the assessment of risks associated with each major component of the product. Risk is scaled from 1-5, with 1 being the lowest risk and 5 being the highest. Each occurring risk level will be discussed.

<u>Key Mechanism Designs</u>

Risk Level 5 – Male & female components, locking mechanism

The primary design drivers and core of the project are encompassed in the design of the male and female components working in tandem with the locking mechanism(s) as selected. These two components ranked the highest in risk level due to providing the core function of the product in coupling the products. As such, the design of all other components will hinge on the design of these two components.

The resources required for these two components as listed above will need to be ordered as soon as possible. To reduce risk of not having material, rods, blocks, and sheets of metal may be ordered before the design is finalized as long as there is an approximate minimum amount determined. The ordered metal can then be machined as appropriate to the design.

However, the motors, universal joints, and springs will require a greater amount of precision before ordering due to their function being more precise. These sub-components carry a greater amount of risk due to their specific nature, and may cause complications in receiving parts on time if they are not specified on time. To reduce the possibility of this risk affecting other aspects of the design, the specifications of other components can be run in parallel.

Testing methods can be determined in parallel with design and while parts are in delivery. For locking mechanisms, the scaled versions can be 3D-printed and tested for fit or interference issues before they are ordered.

Risk Level 4 – Mounting

Mounting similarly is of high risk, but slightly less so due to taking less priority design-wise compared to the coupling mechanisms. While design wise, the mounting is still reliant on the coupling mechanisms, the geometry and material for which the female and male components would connect to mounting has been determined at this point. With this knowledge, separate research, design, and build can be run in parallel with the coupling components to reduce the risk of running out of time.

Notable design concerns are still in progress, but the sheet metal that would be required to form the mounting structures could possibly be ordered along with the materials required for the male and female components. An appropriate thickness of the sheet aluminum would have to be verified before doing so. Whether or not a servo motor would be required for the mounting to meet the requirements of the project is still being determined. This poses a risk to the project's timeliness.

Risk Level 2 – Electrical connection

The electrical connections are of low risk to the project's goals in terms of technical execution and timeliness. They can be ordered at any time relative to the project as soon as the male component has been specified and are not especially complicated to integrate compared to the other components. As a best practice, they should be ordered around the time that the shaft is ordered to reduce risks to the project timeline considering possible supply chain complications.

Development of Test Methods

Test methods shall begin to be developed in parallel with the development of the designs themselves, although not taking priority. The development of test methods will then take priority as the designs are finalized. At the moment, no additional instrumentation is expected to be required, although this could be a source of risk if not thoroughly researched. As such, personnel can be dedicated to the development of test methods for each key component based on the customer's requirements in parallel to design.

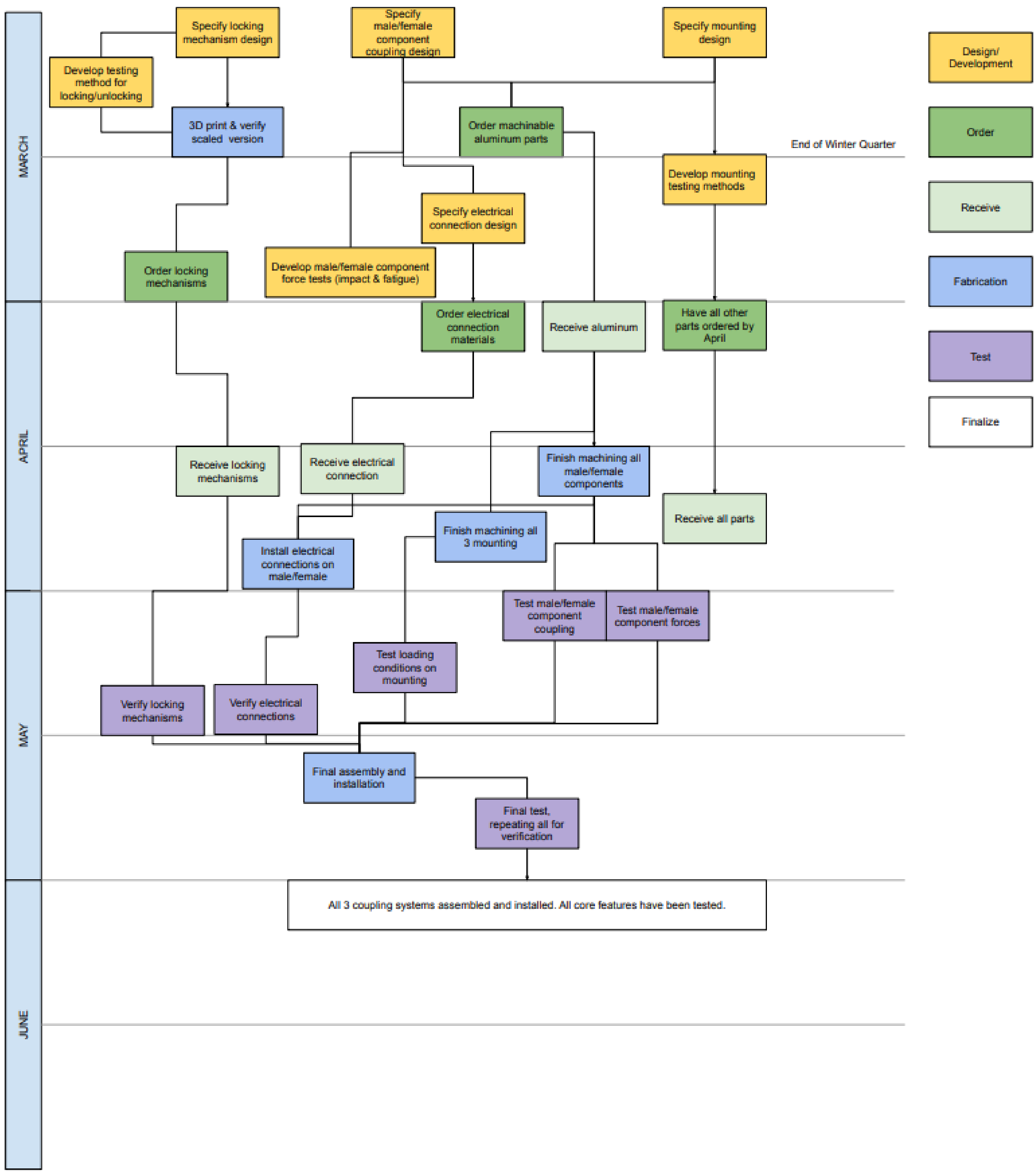
Many of the customer's requirements are not strict constraints which require precise value outputs. Instead, the majority of the test methods will be verifying that the system functions as designed.

Feasibility Timeline

On the following page is a feasibility timeline of the build phase which details the order of which items are completed and the latest day in which they can be completed in order to complete the project on schedule. Many specific objectives will be run in parallel. The highest threats in the timeline can be found by relating the above defined risk and resources component-level breakdown to the critical path respective to each component.

Foreseeable risks in the project can be found in having late deliveries, behind-schedule designs, and components which do not perform as designed. For the latter, specific steps can be taken to reduce this risk based on the type of component. For example, the locking mechanisms can be 3D printed initially to quickly verify fit and function before electromechanical systems are ordered. To determine the ability of a component to withstand loads, simulations can be utilized. To reduce risk of material availability, safety stock can be considered and orders shall be placed early. Coordinating with the sponsor to expedite authorization processes will also be vital.

Feasibility Timeline



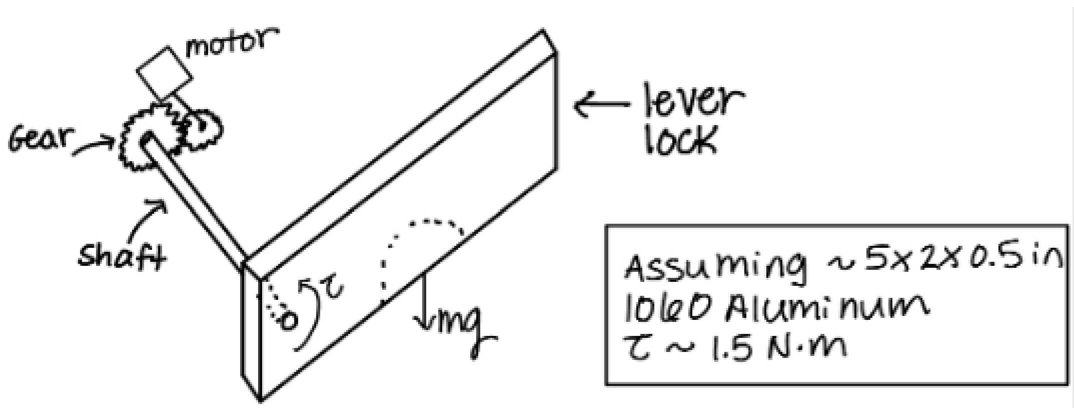
D.2 Design Strategy – Technology mapping, Component Technology Research

D.2.1 Concept Development, Concept Risk Identification & Mitigation - EE/Circuit Models

There will be very minimal electrical components and circuits within the final product as it is a mostly mechanical system. The electrical components and circuits involved in the product will be centered around controlling the locking mechanism for the male and female counterparts. There will also be an IR Remote and Receiver to initiate coupling and decoupling.

An Arduino will control the locking mechanism shown below by controlling a servo motor attached to a gear system that will rotate the lever lock in and out of a locking position. When the lever lock is engaged in a locking position, the male counterpart will be fully engaged with the female counterpart.

Locking Mechanism



The IR Remote and Receiver to initiate coupling and decoupling will also be connected to the Arduino. The IR Remote will be able to be pressed by the user in order to initiate decoupling and it will generate a unique hexa-demical code which will be sent in a module format over IR to the receiver. This system will be used purely for decoupling as the coupling process will be semi-automated.

Major identified risks associated with the electronic and circuit components of the final product include components (such as the Arduino) overheating and loss of communication between the IR Remote and Receiver. In order to mitigate these risks it will be important to test the coupling and decoupling capabilities of the final product before the user enters and rides the trikes with the final product attached.

If there is any electrical or circuit failure, it will be imperative to replace or fix these components as soon as possible in order to prevent any further failure of the system.

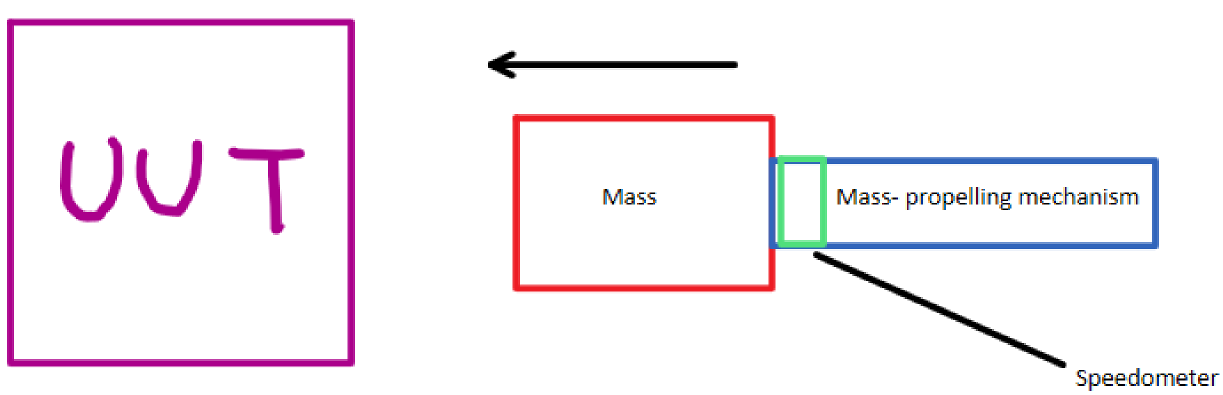
D2.2 Concept Development, Concept Risk Identification & Mitigation - Mechanical Models
Design, develop and at least schedule to evaluate models of appropriate complexity validating key mechanical functions independent of the whole system, that address the risks you have identified above.

The key mechanical functions of the system will be absorbing impact forces, linking vehicles together, and engaging locking mechanisms. These are three functions that can be independently validated.

To verify that the force dampening systems are meeting required specifications, a test can be created. This test would propel a mass towards the system. Tests would be performed on both male and female ends individually. To determine the force, the acceleration and mass will need to be known values. The mass can be controlled by measuring the weight of the object and choosing it accordingly to match the required conditions of the system. The acceleration can be determined by using a speedometer on the moving mass as it is impacting the stationary unit under test. This speed differential can be used as acceleration. By controlling these two parameters, the force of impact can be controlled to simulate operating requirements. This test after the products have been fabricated and will require the actual products rather than scaled models. The mass may be propelled by a linear actuator or spring-loaded mechanism of sorts.

The outputs of the test will include the condition of the unit under test after impact. Markers can be placed to mark before and after positions of key features of the system to verify that no significant deflection occurs due to the impact. This impact will be repeated some amount of times to match the project requirements.

Damper Test



For engaging locking mechanisms, scaled models will be 3D printed. Both male and female connections can be manually pushed together to verify that the locking mechanism will engage when they are meant to. The primary output of this test will be visual feedback, requiring only physical confirmation. As such, it is unlikely that any instrumentation will be necessary. As seen in the feasibility timeline, this verification will be sought to be done by mid-March or the end of winter quarter.

Finally, the testing method to ensure that the system stays coupled between vehicles will require the µAV trike team's project to be far along enough to where it can operate in a relatively complicated manner to simulate general conditions of operation. Once the coupling systems are mounted and properly installed into the trikes, one trike will pull the other for some amount of time according to project requirements. This operation will include speeding up, slowing down, turning, and possibly moving up and down hills. This is to verify that the system can stay coupled with various operating conditions.

D.2.3 Concept Development, Concept Risk Identification & Mitigation - Firmware and Software Models

Per information from Dr. Folsom, this section currently is not in the scope of the Micro-AV Connected Vehicles product.

D.2.4 Concept Development, Concept Risk Identification & Mitigation - Human Interaction Models

Per information from Dr. Folsom, this section currently is not in the scope of the Micro-AV Connected Vehicles product.

D.2.5 Concept Development, Concept Risk Identification & Mitigation - System interface modeling, testing and risk analysis

Three sets of male and female counterparts will be developed for the final product of the project. There will be a set of male and female counterparts allocated to each of the two trikes and ideally another set for concept development. If time does not permit to be able to complete three sets of couplers, the third concept development set will be 3D-printed on a scale model. The sets will be machined in-house of aluminum alloy or similar material. If it is not possible to machine the sets, they can be 3D printed, however there will be a great decrease in structure and strength and this is not an ideal outcome.

In order to develop the three sets of male and female counterparts, there must be time allocated for prototyping and proving that the system functions as designed. Before the sets made of aluminum alloy are machined, a 3D printed scale model of the final product solution will be printed and tested for functionality. If the 3D printed scale is not able to couple and decouple as intended, the design will be altered in order to accommodate any potential problems. Once the 3D printed scale model is able to couple and decouple as intended, the sets of male and female counterparts will be machined out of the desired material and made to scale. It will be easier to machine all necessary parts for the three sets at once versus manufacturing them in waves due to the time constraint of the project.

As soon as the first set has been machined and verified for functionality, it will be mounted to one of the trikes. Ideally, all components for the three sets will be machined at once by a designated individual and the sets will be assembled and mounted simultaneously by other teammates in order to optimize efficiency. Additionally, the mounting system for the sets will need to be assembled along with the damper and controls. The controls will be assembled from blank PCR boards and soldered together for the required function.

After everything has been machined, manufactured, and assembled, the final stage of testing will be to test the couplers with a mock collision between the two trikes to mimic coupling and decoupling. If the product is able to couple and decouple as desired, the final product will be successful. If the product is not able to complete these aforementioned tasks, revisions will need to be made until the product is able to successfully perform if time permits.

The biggest risk associated with the aforementioned processes revolve around time. There may not be adequate time to machine all parts in-house under the time constraints provided. There is limited access to machining tools at University of Washington Bothell so it will be crucial to be able to optimize the amount of time spent on each portion of the final product. Having team members working simultaneously on different portions of the final product will be a crucial component to finishing the product on time.

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[2] “Why do people keep throwing electric scooters into rivers and lakes—and what should companies like Bird and Lime do to stop them?” slate.com. https://slate.com/technology/2018/12/electric-scooter-bird-lime-lakes-rivers-environment-vandalism.html (accessed Feb. 3, 2023).

[3] “Where have all the drivers gone? The complex reasons behind driver shortage.” therideshareguy.com. https://therideshareguy.com/uber-driver-shortage/ (accessed Feb. 3, 2023).

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