Final Report

Safety of Cyclist Infrastructure

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Design I - Section R

For Professor Orrs

1.3 Introduction

1.3.1 Background

A bicycle-based commute benefits both the environment and the cyclist. The US Environmental Protection Agency estimates that for each mile driven, 404 grams of carbon dioxide are released into the atmosphere [72]. An equal distance bicycle commute releases only 34 grams [26]. There are benefits to the cyclist as well. According to research from the Harvard Medical School, cycling is associated with better heart health, greater ease of movement, and stronger balance, among other health benefits [61]. Given this, greater research into the areas in which biking can be made more common is warranted. According to research published in the National Academy Transportation Research Board, safety concerns are a primary issue limiting the number of individuals who use bikes to commute to work [43]. This suggests that making cycling safer is an effective way of encouraging others to choose it as a method of travel.

In light of this fact, understanding the dangers present when utilizing cyclist infrastructure is a high priority. Research finds that the addition of a bike lane makes cycling on roads significantly safer, though the strength of the effect varies based on factors like the number of lanes, daily traffic flow, and widths of the car and bike lanes [72]. This effect is robust, with many other studies finding the same [30][43]. This means that significant safety gains can be made by introducing bike lanes and making it easier for cyclists to stay within bike lanes. In addition to increasing safety through direct changes to infrastructure, it is also possible to address safety through safety gear.

There have been several attempts at improving cyclist safety through protective equipment in the past. Helmets have been found to be effective at reducing instances of concussion and are widely adopted [30]. Other safety gear also exists, including knee and shoulder pads, reflectors, lights, mouth guards, gloves, gloves, and protective clothing. Many factors cause these items to be less prominent as safety solutions, with mouth guards only seeing 4.4% adoption, for instance [42]. Cost is a concern in this area. John Weiler, an experienced cyclist interviewed for this project, reported a belief that the average cyclist would be willing to spend 3% more on safety gear than what they spent on all other bicycle gear. With the $500 that he cites as a low end entry budget to cycling, this only amounts to $15, an insufficient total to buy all listed safety items.

Finally, cyclist deaths have stayed constant over time, as shown in the graph below [15]. The lack of progress in this area implies that existing technologies have not already solved this problem. Greater safety associated with shared or separated bike lanes suggests that they could be used to lower this number. This is not a full solution, however, as research suggests that less than ⅓ of all cyclist-car crashes could be avoided with the presence of a new bike lane [30]. To reduce the number of cyclist deaths significantly will require innovation in cyclist safety methods.

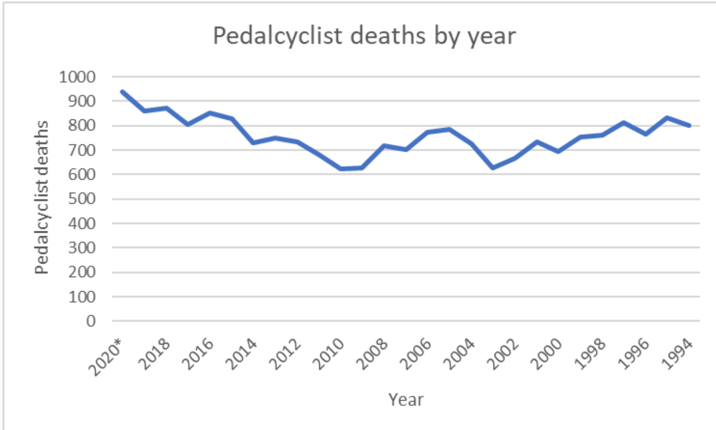


Figure 1: Cyclist deaths due to crashes with cars every year

1.3.2 Problem Definition

How might we improve the safety of cyclists on urban roads by limiting car-bike crashes?

1.3.3 Context of the Problem

As transportation in urban areas leads toward more environmentally friendly, human-powered forms of travel, cycling safety is becoming a more prominent issue. Throughout most of the urban U.S., there is little to no separation of bike lanes from major roads. Bike lanes are often too small to be safe, and bike-friendly infrastructure gets very little funding from most local governments. A 2021 study concluded that while 77% of jurisdictions intend to improve the safety of bicycle infrastructure, most fall short of their goals within 5 years. 61% of respondents report poor funding being the primary obstacle to safety improvements for cyclists [44].

Additionally, a majority of the U.S. populace is affected by cyclists and cyclist safety. Motorists, pedestrians, residents, and road construction workers are all impacted by the inadequate use of bike lanes in urban America. When there are no safe bike lanes, cyclists will use other pathways such as the shoulder of a roadway or sidewalks. Additionally, policymakers and local governments play a significant role in the viability of bike lanes and bike lane safety, as they decide how much and where funding goes in terms of road infrastructure.

Having safe lanes for cyclists is important everywhere, especially in areas with high-density populations such as cities or city centers. Bike lanes and safety are crucial in areas where cyclists, motorists, and pedestrians will be sharing a space. Anywhere there could be a risk of cyclists and motorists sharing a road, there should be adequate measures to ensure both parties' safety.

1.3.4 Existing Solutions

Numerous solutions and methods to protect cyclists on the roads already exist and have been implemented to varying extents. However, existing solutions suffer from limiting issues, either with their efficacy or feasibility of widespread implementation. Below is a list of currently existing solutions and what shortfalls prevent their success.

Separated Bike Lanes: Protecting cyclists by designating an area on the road for them exclusively has varied results. Many studies find that while the solution does make cyclists safer relative to roads with no designated bike lanes, its effectiveness is largely situational. Others have concluded that bike lanes have no impact on cyclist safety, and some claim that bike lanes increase the risk to cyclists depending on the situation and implementation due to increased motorist-cyclist interaction. [17] Bike lanes—especially on roads with high-speed traffic or on roads with high traffic flow—also make cyclists uncomfortable, limiting their effectiveness and rate of use. [47]

Protected Bike Lanes: Protected bike lanes are separated bike lanes with some form of physical barrier or separation between them and the road. [34] Protected bike lanes are safer than normal bike lanes for cyclists, and are more comfortable for cyclists to use. [15, 19] They see lack of implementation because they require more time, money, and are more space intensive to install than typical bike lanes. [73]

Shared Bike Lanes: Shared bike lanes are normal road lanes which are formally shared between cyclists and motorists, with some form of indication that the lane is shared. [34] Typical implementation of shared bike lanes is when typical bike lanes and motorist lanes merge. These help keep motorists more aware of cyclists being present, but there is nothing physically protecting cyclists. Signs alerting motorists help to prevent collisions, though research is mixed regarding the efficacy of shared bike lanes. Some studies claim shared lanes are more dangerous for cyclists due to the increased number of cyclists-car interactions than on an otherwise typical road, while others claim that shared bike lanes do improve cyclist safety by way of heightened motorist awareness. [17] Shared lanes see common use due to low implementation costs, despite their mixed results.

Bike Paths: Routes that run either adjacent to or independent of roads which are reserved exclusively for cyclists or pedestrians. [46] These typically are implemented in suburban settings. [46] This is a very safe route for cyclists to use relative to any form of infrastructure on roads due to even less interaction with vehicles, though fall far short of forming anything resembling a comprehensive route system due to their cost and space requirements. [76]

Below is a table from the Bureau of Transportation Statistics outlining the percent of the US population with access to several of the above forms of cyclist infrastructure in some capacity. Note that no distinction is made between different kinds of bike lanes, nor does the table offer any sort of measure of comprehensiveness of the cyclist infrastructure. [59]

Bicycle Infrastructure Available	Population with Access (percent)
Both Bike Paths and Lanes	26.3
Only Bike Paths	24.1
Only Bike Lanes	6.5
Neither Bike Paths nor Lanes	43.0

Table 1: Population Access to Bike Lanes

Traffic Calming/Slowing: Traffic Calming is meant to slow down vehicles. The most basic implementation of traffic calming mechanisms is the lowering of speed limits, though motorists oftentimes disregard speed limits, hindering its effectiveness. [68] Alternative methods involve speed bumps or similar limiting devices, or adding physical obstacles–as diagrammed below–to make it difficult for motorists to exceed speed limits. Traffic calming works effectively to prevent crashes and decrease the lethality of the crashes that do occur. Traffic calming measures see limited implementation because of increased road costs, bureaucratic limitations, and concerns about traffic flow. Concerns about vehicle damage limit implementation of speed bumps specifically. [26]

Figure 2: Traffic being rerouted around obstacles to slow speeds on Ford Street in Golden, CO.

Cyclist and Motorist Education Methods: Education methods are considered anything instructing cyclists and motorists how to act around each other, and alerting them to each other's presence. Generally speaking, there is lacking knowledge and awareness of when cyclists are present on the road, and both cyclists and motorists are often mutually unaware of how to behave safely with other road users present. Currently, there is minimal implementation of education methods. Reasons for the minimal implantation primarily involve the limited improvement on safety education mechanisms actually offer. [46]

Cyclist Safety Equipment: Generally refers to equipment that cyclists wear to protect themselves in the event of a collision. Helmets are the most basic part, but knee, wrist, and elbow guards, gloves, protective jackets, etc., all help to protect a cyclist in an accident, but can only have so much impact in major collisions and accidents.

Motorist Collision Prevention Detection Equipment: Though only limited forms exist, newer cars feature blind spot indicators for road users who the driver might not see. This helps to protect cyclists from collisions with motorists. [11] Implementation is limited because this feature was only invented in 2005 and did not see widespread use in vehicles until much later, meaning older cars can't utilize blind spot indicators. [38]

Cyclist Visibility Equipment: Clothing or equipment which is utilized by cyclists to make them more visible to cars and prevent collisions. This generally involves wearing bright, easily visible colors such as a neon tinted blue or orange, and equipping reflective components on bicycles, making the bike more visible to a motorist in low light environments. [47] These measures once again help prevent collisions, but do little to stop a negligent cyclist or motorist from causing a collision.

1.3.5 Ancillary Issues

It is relevant to bear in mind the current behaviors of those cycling as a form of transportation rather than recreation. According to a survey conducted in affiliation with the University of British Colombia, those who are commuting are greatly swayed to change their routes to be less direct if it allows them to take quieter (fewer cars) streets [75]. They also demonstrated extreme pushback to the idea of cycling on streets that are also shared by lots of car and bus traffic.

Also shown in [75], is a clear disparity in beliefs regarding the practicality of cycling depending on the respondent's background. Unsurprisingly, those who are regular cyclists felt more confident in transporting bulkier and heavier items by bike than those with less experience. This is demonstrative of how the act of doing leads to changes in behavior and judgment of what is possible. The current view of cycling is dominated by the light and sporty bikes used for sport rather than something possibly more suited for transportation in an urban setting.

Another issue is that of local politics. When changing roads and streets to either widen or create separate bike lanes, it is argued by critics that traffic conditions are negatively impacted. Many view the shrinking of the width available to cars on a street always as a negative due to the flawed belief that wider roads reduce traffic. Any changes to streets and roads will have to fight through a fair amount of local pushback either by those in government or those in the area that may object due to construction disruptions or the aforementioned flawed reasoning.

In a research paper into specifying the barriers to implementation of bike infrastructure on a government level, people were given a survey where they rated at what level (0 through 5) they see bike infrastructure in its importance in the wide infrastructure planning of their community.[44]

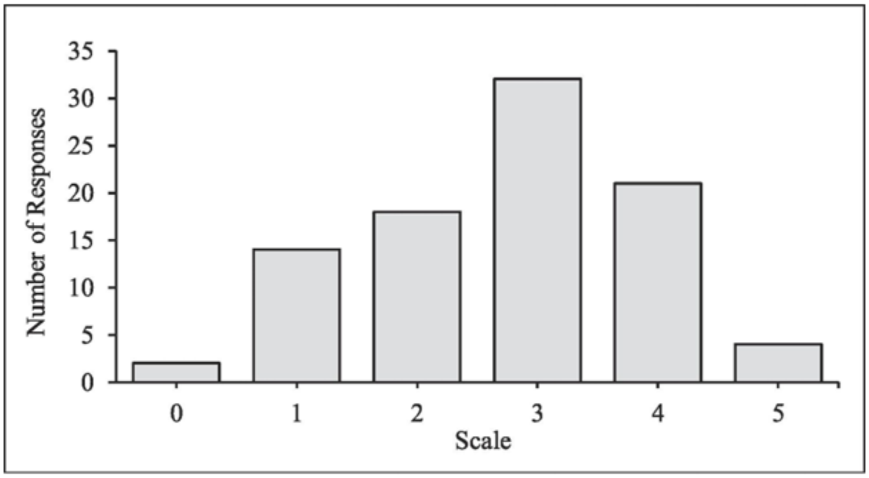


Figure 3: Results of the survey

This shows how bike infrastructure is something that people do care about, but that there is a middling response in how important it is. Though it is rated highly as 3 in a 0 to 5 scale, it still is trailed by a not negligible amount of people in the 1 and 2 categories. The hope would have to be that through the act of showing the benefits of bike infrastructure more and more people will place bike infrastructure on a higher rating over time

1.4 Stakeholder Engagement

Name	**Stakeholder Outreach / Problem Validation Activities**	**Totals**
Eadyn	1. Phone interview with Alex Modrzecki civil engineer 2. In person interview with Alexander Capehart 3. A comparative study of bike lane injuries : Journal of Trauma and Acute Care Surgery (lww.com) 4. Developing crash modification functions to assess safety effects of adding bike lanes for urban arterials with different roadway and socio-economic characteristics	Email Q&A: 1 Phone interview: 2 In-person interview: 3 Journal Article (x4): 4 Total: 10

	5. Bicycle Commuting and Facilities in Major U.S. Cities: If You Build Them, Commuters Will Use Them 6. Causal Exploration of Bike Accidents in the Bay Area 7. Scheduled in person interview with Mines biking club leader (John Weiler) on safety procedures a. No longer in person due to illness	
Jacob	1. Recreate the conditions of a problem 2. Interview with motorist about their outlooks on bike lanes and cyclist safety 3. Documentary: https://www.bikes-vs-cars.com/thefilm 4. Read Article: https://www.sciencedirect.com/science/article/pii/S2213624X21000183 5. 2 Videos documenting user experiences: https://www.youtube.com/watch?v=HOASHDryAwU https://www.youtube.com/watch?v=h-I6HFQXquU	Recreate conditions of the problem: 3 Phone interview: 2 Documentary: 2 Video (x2): 1 Journal Article: 1 Total: 9
Conor	Documentary x2 https://urbancyclinginstitute.com/library-of-cycling-documentaries/ -Genre de via (https://youtu.be/B9y93T_h3ks) -Mikael Colville-Andersen: The Importance of Designing Streets Instead of Engineering Them (https://youtu.be/jHA4xN1dEkM) scholarly articles x2 Authoritative Article x1 In person stakeholder interview (Taxpayer)	2x Documentary (4) 2x Scholarly Article (2) 1x Authoritative Article (1) 1x In Person Intervie (3) Total 10
Connor	1. Lecture recording from The Academy of Urbanism in London about pedestrian and cyclist infrastructure. (2) a. https://www.youtube.com/watch?v=T	30+ Min Documentary (2)

	gHI1R4psqI 2. Scholarly study evaluating the effectiveness of different existing methods to protect cyclists on the road. (1) a. https://www.sciencedirect.com/science/article/pii/S000145751931098X 3. Stakeholder Interview with Edward Pallis. (3) 4. Authoritative Source suggesting methods for the improvement of urban infrastructure in Britain. (1) a. https://www.udg.org.uk/publications/manuals/street-improvement-manual 5. Stakeholder Interview with Mines Civil Engineering Professor Jeffrey Holley and visit to recommended cyclist infrastructure locations around Golden. (4)	Scholarly Article (1) In Person Interview (3) Scholarly Article (1) Site Visit in Golden (4) Total (11)
Eoghan	15 miles off campus interview with cyclist and commuters	On-site interview x2 = 10 Total = 10 points

Table 2: Stakeholder Engagement Table

1.5 individual Team Member Sections

Jacob's Section

1.5.1.a Stakeholder Engagement:

Car dependency, population growth, and sustainability: Throughout my research and stakeholder engagements, I gained a significantly deeper understanding of the problems at play in cyclist safety. For my first part of stakeholder engagement, I watched "Bikes vs Cars," a documentary about climate change, how cars are contributing to it, and how bikes could play a significant role in limiting carbon emissions. A significant portion of the documentary discussed car dependency and how unsustainable it is. One of the major issues outlined was the astronomical amount of space cars take. In Sao Paulo Brazil, for example, approximately 20% of urban space was used purely to accommodate cars. Similarly, 22% of the average Americans income goes to transportation, namely cars [10]. This type of urban living is unsustainable, especially as the population grows. In July 2011, the 405, an expansive freeway leading to downtown Los Angeles, got shut down over a weekend for maintenance. This event, nicknamed “Carmageddon,” forced people to utilize public transportation and bikes which led them to local shops and businesses. Not only did this stimulate local economies, but lowered the amount of cars on the road which led to the air quality improving by 83%. Similarly, air pollution in the city dropped by about 25% over the weekend [10]. As the world population increases, we are seeing more people focused in cities. As this pattern continues, more people will be able to commute in their average daily life with just a bike. According to Bikes vs Cars, 50% of all trips in the U.S. are under 3 miles. If these trips were made through sustainable means such as public transportation or cycling, carbon emissions would be reduced drastically. If cycling is safer, general acceptance of cycling as a main form of transportation would be easier for society to accept and we can move away from our current car dependent structures.

Current Problems with Cycling in dense Cities: For my second and third stakeholder engagement activities, I watched two videos on cycling in urban areas. One of the main reasons people refuse to bike in cities is lack of safety. A significant part of cycling safety is visibility and signaling. In poor weather conditions, at night, or even just heavy traffic, cyclists can be difficult to see, which could lead to collisions and accidents. As seen in Figure 5, cyclists lingering in blind spots could lead to an accident as motorists may not see them before changing lanes. Cyclists often use hand signals to tell cars where they intend to go in order to further mitigate risk. The problem with this is it requires the cyclist to not only take one hand off the bike, but to turn and make eye contact with the motorist. While this is a small risk that could potentially prevent an accident, there could be another solution which would enable the cyclist to pay full attention to the road. When cycling in unfamiliar areas, it is common for cyclists to get lost, leading them to look at a map or GPS. This could lead to distraction and unpredictability and end up in a collision. We could design a device which is more intuitive and fast to use. In wet or icy conditions, paint markings on the road often get very slick, leading cyclists to either avoid them, or accept the risk of slipping on the surface. As seen in Figure 4, this can cause unpredictable movement that could end in an accident. This problem of slick material is also seen in train lines and manhole covers. In 2016, there were 37,461 traffic fatalities nationwide. Among these, 5987 involved pedestrians and 835 involved cyclists [44]. The goal of our project is to lower these numbers by designing a product that would increase safety.

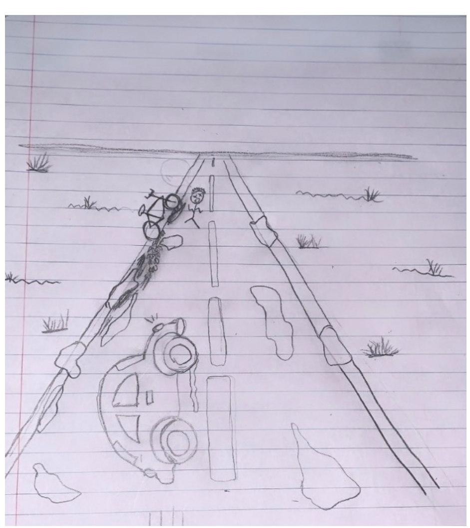


Figure 4: Field sketch illustrating how slick paint could lead to an accident

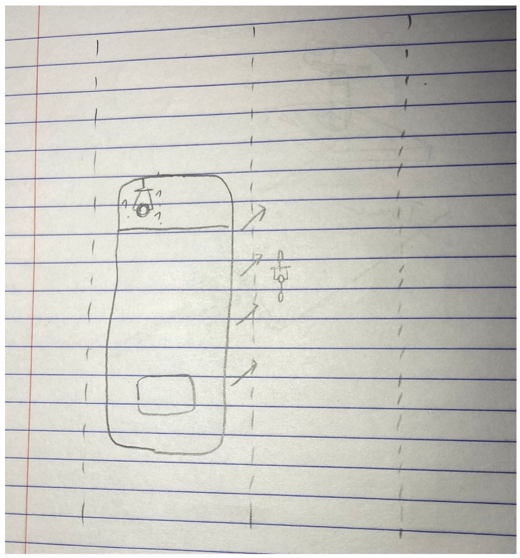


Figure 5: Field sketch illustrating how a cyclist in the blind spot of a large vehicle could lead to a collision

Why Cycling is Beneficial: In urban areas, cycling as a primary form of transportation has significant benefits over driving. In case of a pandemic or flu, as seen recently with COVID, cycling could significantly lower the spread as people are less likely to come into contact. Cycling lowers carbon emissions. Airborne pollution, which cars have a significant role in, are lowering the average lifespan of people who live in cities [23]. According to a Danish study, society gains $.79 cents for every kilometer cycled, but loses $.72 cents per kilometer driven [20]. Designing a product to increase cyclist safety could help build towards a greener future.

Motorists Outlook on Bike Lanes and Cyclist Safety: For my fourth stakeholder engagement activity, I interviewed a motorist who commutes to work from the suburbs of north Houston to downtown Houston. Jennifer Killen drives a 1 hour and 15 minute commute to her job in downtown Houston three days a week. On her drive, she sees little to no bike lanes. She does see cyclists however, they often ride on the shoulder of the road with only 4 feet of clearance between them and passing cars. Even in downtown, with high density living, there is poor use of bike lanes. Killen claims it’s not feasible to commute in downtown Houston with a bike, even if your place of work is close to home. There is absolutely no way to travel out of downtown as there are no bike lanes on freeways. In downtown Houston there are almost no cyclists, likely due to the poor infrastructure and car dependency Texas is known for.

Recreating the Conditions of the Problem: As my final stakeholder activity, I biked into downtown Golden to look at infrastructure. I noticed there are almost no bike lanes on Washington Avenue, the main street of Golden. As seen in Figure 6, there is no safe way to ride your bike to the businesses on Washington as all of the space on the side of the street is taken up by parking for cars. If you were to ride along the side of the parking spots, oncoming traffic would have to swerve into the oncoming lane to avoid you. Similarly, the sidewalks are unsafe as there are people walking as well as entering and exiting local businesses and shops.

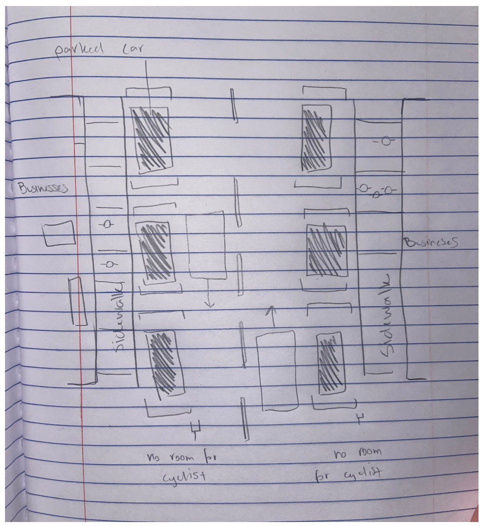


Figure 6: Lack of room for cyclists due to parked cars in downtown Golden illustrated in a field sketch.

1.5.2.a Remaining Unknowns:

Despite the research we have done, we know little about how much cyclists would be willing to pay for a device that could improve safety; if our design is too expensive it would likely be poorly implemented. Similarly, we do not know how new technology would be accepted in the cycling industry; new devices often take time to be accepted. We also know little about how much distraction is acceptable. If our design is focused on navigation for example, it would require attention for a short period of time, but decrease the chance of unpredictable behaviour in the future. Since there is no real way to change the way infrastructure is designed in a macro scale, we should focus on changes of infrastructure on a micro scale, or technology that involves the cyclist.

1.5.3.a Summary:

From the research done in stakeholder engagement, I have a thorough understanding of common infrastructural problems around cycling in urban areas. Cycling safety is certainly an area of urban infrastructure that is lacking, a project could be made to address one of the many issues in this area. I also understand the many positive benefits of cycling, as well as the consequences that come with a society that is over reliant on cars. Although I still have questions regarding the acceptance of new technology in the cycling industry, they could easily be resolved in the future with further stakeholder engagement.

Eoghan's Section

1.5.1.b Engagement Insights

People: In meeting and talking with those who actively use biking for commuting in urban areas in Denver and those open to the idea though not doing so I learnt that a lot of the inhibition is the complex physiological nature of safety perception. I spoke with 2 people in Denver city center, one who works as a bike tours operator (see Figure 7)part time and bikes to their other job, and another who uses the Rail and Transport Denver (RTD) network of buses and trains to get to their work in the city.

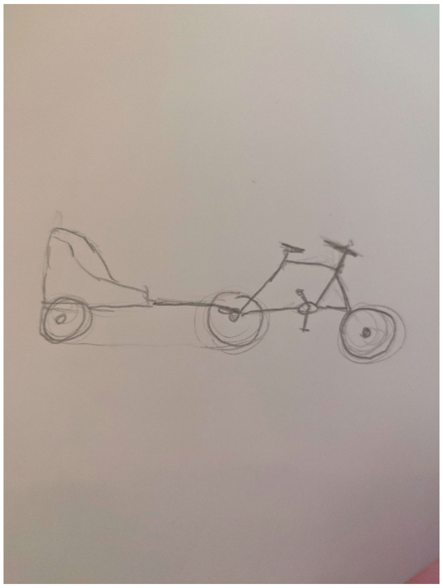


Figure 7: the interesting rickshaw style bike they were riding

I started out by asking both my subjects basic questions about their biking experience and comfort levels; unsurprisingly the experienced biker and commuter was fully comfortable with biking in shared traffic roads (either no bike lane or painted bike lane only) given that the cars were ideally below 30 MPH. Contrary to this the more timid yet open minded commuter expressed a level of fear at the idea of biking in a shared road, regardless of speed due to the chance of what they described as the mistakes of the car operators such as veering into the bike lane or failing to react in time to a biker who has fallen into the road. This showed me quickly the interesting difference in useful information that you can get from those with experience. For this specific issue, listening only to those with lots of biking experience probably is not the best strategy as they have gained experience and confidence using what others may see as unsafe conditions. This is an issue as they may see any improvement as great and more than enough rather than a more nuanced response that a person timid to begin cycling may give.

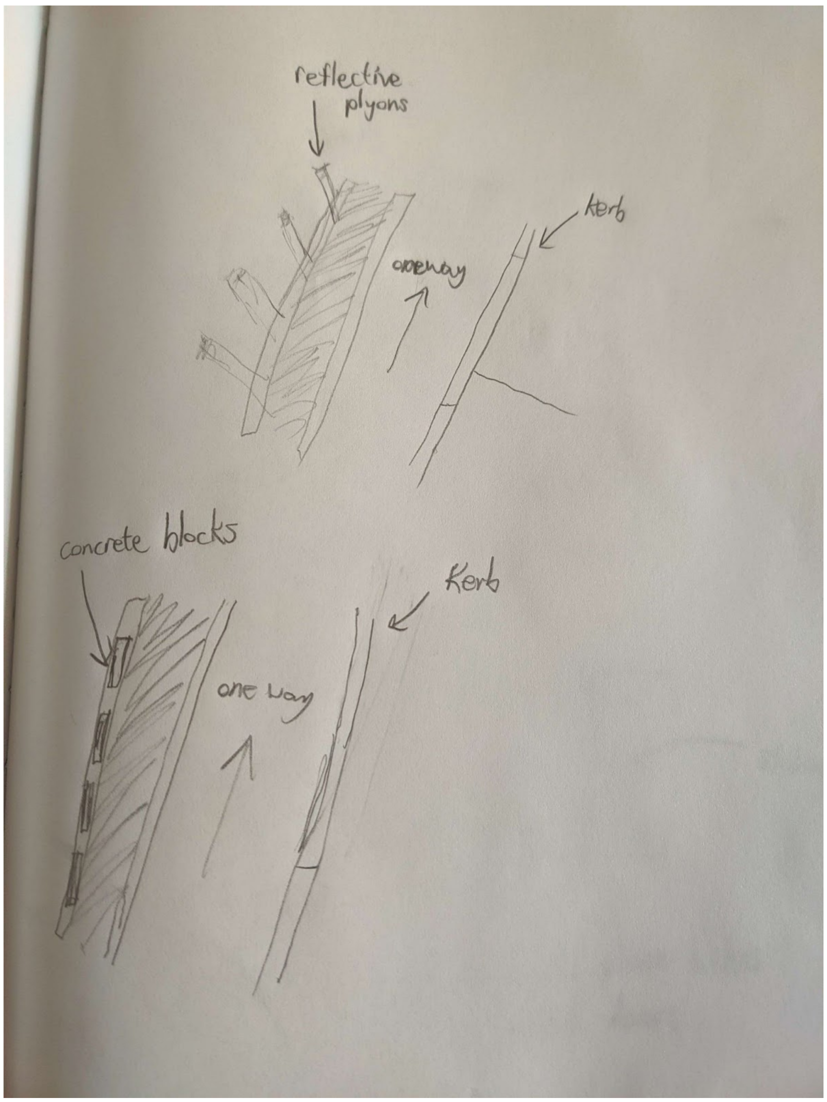


Figure 8: Field Sketch of the separated bike lanes in Downtown Denver

In the Denver Downtown there are separated one way bike lanes that flow in the same direction as the one way traffic (as seen in Figure 8). I met both of my subjects near these lanes and so asked them what they thought of them. Focusing on my timid subject's response, they said that they were helpful and welcome as they provide a barrier from the car traffic though they were worried about what to do when the separated bike lane ends as they have to commute much further than just the Downtown area of Denver. I followed up with them on the idea of combining the RTD network and biking. I gave the example of biking to their train station close to their home, taking that train to the Colfax at Auraria stop then biking the rest to their work, reversing the order to come home. They were a lot more open to this though felt that their was not proper storage available to place a bike without either taking up a lot of room in rush hour times or rolling about and possibly hitting someone. (see Figure 9)

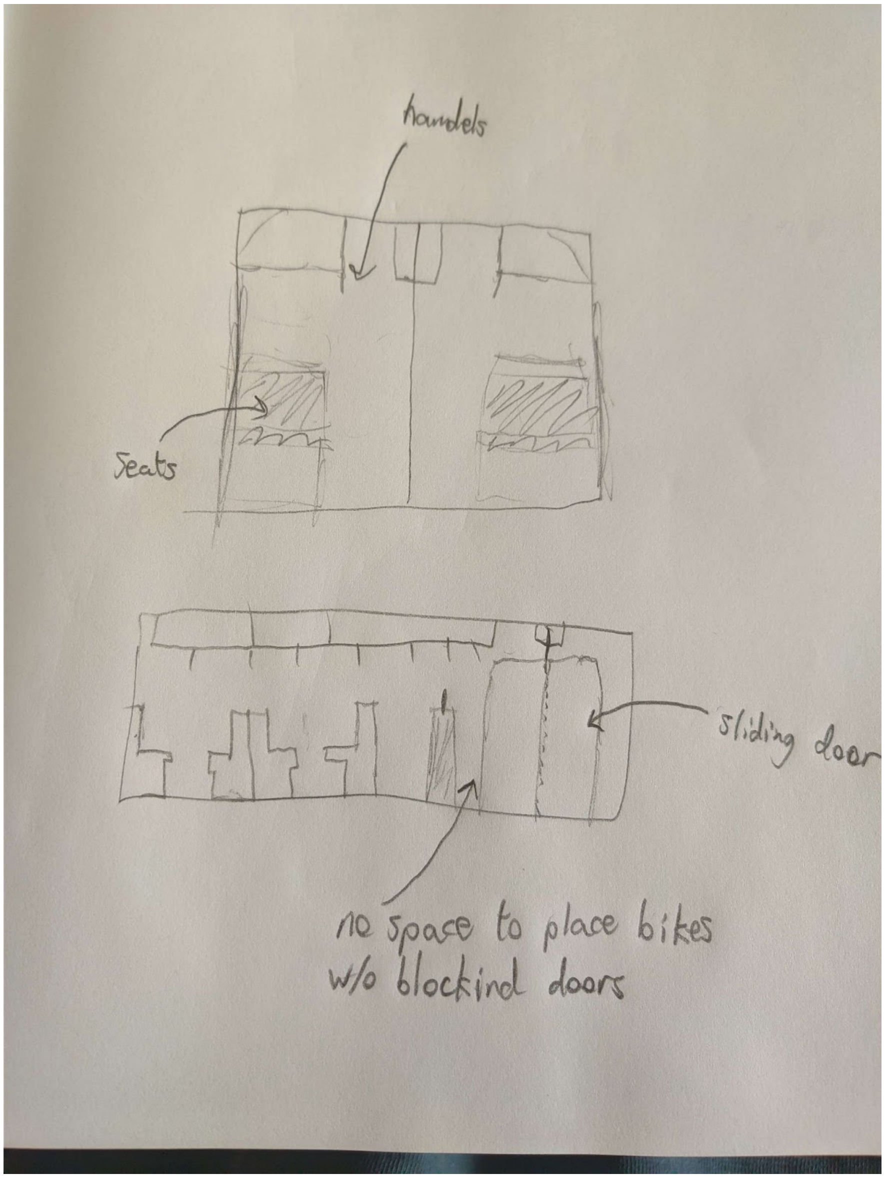


Figure 9: a sketch of the inside of a RTD light rail carriage, as you can see the only space to put a bike is in front of the doors on either side.

The more experienced biker of course loved the separated bike lanes though as they already commute fully on bike from an area without these separated lanes to an area with, they were not discouraged to continue to bike if they were not expanded. They still were insistent that they would see it as a big failure if they did not expand.

Finally to test their outlooks on the future of urban transportation is asked what they see as the future of transportation in Denver in the next 5 to 10 years. They both agreed on a decrease in car dependency and usage; they differed in what would replace it. The more experienced biker responded with a rise in bike and pedestrian only streets along with expanded separated bike lanes and dedicated bike paths to connect the center of the city with the suburbs. The more timid biker responded with a continuation of separated bike lanes but a heavier focus on bus and train routes connecting people to their destinations. They hoped to see updated buses and trains that allowed for people to carry things like a box or trolley easily along with more frequent and consistent timings and routes. They said biking may be helpful as a way to transport goods between places like using a trailer on a bike to deliver packages or other goods.

People are Curious: My interviews and viewing of the infrastructure first hand brought a new meaning to the question of how to provide safer cycling in urban areas as though we have to provide a technical solution, a non-technical lens of perception and feelings towards certain transportation must be taken into account. Though a painted bike lane is separating it from traffic, it can be more unsafe than none at all due to the psychological interpretation of lane markings. Drivers of cars may pass at faster speeds and closer distances when presented with a painted bike lane due to the perception of separation from the biker.[30] Contrasting to this a unpainted bike lane forces a slow down and navigation around the cyclist by the car to remain safe. These issues must be kept in mind when coming with a solution and consulting with the least confident in cycling can actually bring safer infrastructure for all, even if they remain unconfident and timid, it will help those who are more confident though still on the fence.

When presented with new ways to get around and encouragements like bike infrastructure paid by their taxes, people will become curious to investigate and evaluate if they would like to take part. Any solution must be inviting and welcoming to all levels, like the confident bike tour operator all the way to the timid RTD user.

1.5.2.b Remaining Unknowns

I still do not know what they see as the solution apart from more separated bike lanes. I was not able to get them to think of any ideas they see as feasible in the short time I had with them. I also don't know their willingness to try new ways of cycling in urban areas, perhaps different road systems or alternative routes to name a couple of examples. These are things that I did not bring up as I was mostly focusing on the problem, but now reading back my notes of the interviews I believe it would have been helpful to just see their reaction to get a better understanding of where they are coming from and what they see as specifications that a possible solution will need.

1.5.3.b Summary

Through my research talking with those commuting in Urban areas, the issue of safe cycling is very real. It is something that not only can be addressed but is actively pushed to be addressed by those in the area and the local government, as shown by the separated bike lanes. I met two people in downtown Denver to discuss biking for commuting, one an avid biker and another a more timid biker. Both gave me unique and important viewpoints on their comfort levels and what they see as issues.

Conor’s Section

1.5.1.c Engagement Insights

1. **Scholarly article exploring the impact of walk–bike infrastructure and safety perception.**

This scholarly article details the findings resulting from the utilization of a random parameter model analyzing “the effects of traffic safety, walk–bike network facilities, and land use attributes on walk and bicycle mode choice decision in the New York City for home-to-work commute” [15]. It focused on statistical correlations between a multitude of factors to find the most influential factors in determining the use of an “active transportation mode choice”.

I found the key takeaways from this article in the context of our problem definition was that the utilization of an “active transportation mode choice” was majorly impacted by its perceived personal safety as well as the proportion of a fellow identity group's utilization of such methods of transportation [15]. In other words, how safe the individual felt about the medium and whether their friends and associates were using them were large determining factors. Locations that were acident prone saw a noticable decrease in cyclists. (Figure 10)

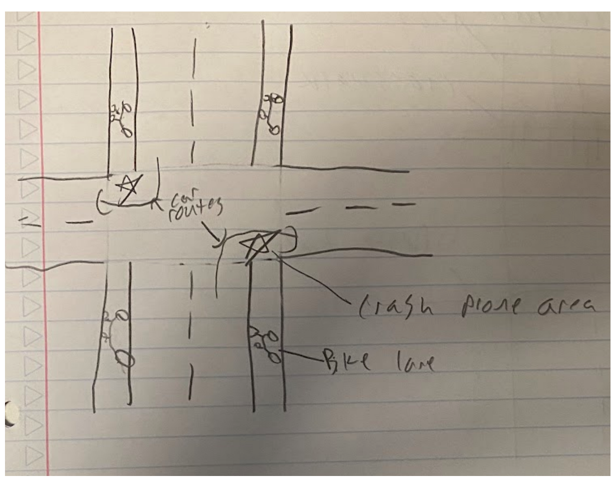


Figure 10: A sketch of the most crash-prone areas of roads with cyclist lanes. (Right turns on intersections)

2. **Stakeholder interview with taxpayer Juan Requena**

I interviewed local taxpayer Juan Requena. While Mr. Requena does not consider himself a cyclist or a bike user he did have some interesting opinions on cycling infrastructure as a whole. Most notably he maintained an opinion of majority indifference on the subject. He, as a whole, did not care whether or not his tax money was going to the implementation of bike lanes, just that the bike lanes would be properly implemented and useful should they be constructed and that he should not receive an increase in taxes to implement them. When asked about his opinions on bike safety he said that he felt the burden of safety was on the individual drivers and cyclists on the road and that he did not see how the government or infrastructure could majorly impact safety.

I think Mr. Requena's point of view embodies the large majority of non-cyclists in the area. The number one thing I gathered from his answers was that he did not feel the issue affected him and therefore does not particularly care about the issue unless it begins to affect him (i.e. an increase in taxes, roadwork on his daily routes, etc). This point of view can prove to be an obstacle in implementing any infrastructure changes due to their overall inflexible view of change.

3. **Authoritative article on how to improve bike lanes in the U.S.**

In this authoritative article, Peter Trinh, a multimodal engineer for the City of Seattle, WA, USA Department of Transportation, speaks about the challenges the Seattle Department of Transportation faced in construction bike lanes as well as the shortcomings of previous projects in the city. Trinh outlined a design process, one extremely similar to what we use in this design class, that ensured the problem is adequately addressed and tackled. In the design process, Tring proposes an extensive utilization of stakeholder opinions throughout the entirety of the process. The main takeaway that we as a design team can apply is that we should always be considering how our designs will impact not only the people using it but the people who surround the people who use it as well as any relevant parties relating to the product. [63]

4. **Scholarly article analyzing solutions to improving the safety of cyclists in road traffic**

In this scholarly article, the aspects that impact the route decision of cyclists are analyzed. The article details that cyclists determine their route based on perceived safety and whether or not cyclist paths are available. The article looks specifically at Poland, a place with cyclists only 2%

of the road traffic users and has limited cyclist infrastructure. The article also identifies aspects of the road that are particularly hazardous for cyclists including a lack of visibility, curbs that are too high, and a lack of marked crossings for cyclists. Furthermore, a lack of access to personal protective gear such as helmets, knee pads, and elbow guards (Figure 11) is also listed as a limiter to cyclist safety. What we can take away as a team from this document is that the problem has multiple different aspects that can be tackled to improve cyclist safety and that focusing on a single one may yield largely beneficial results [42].

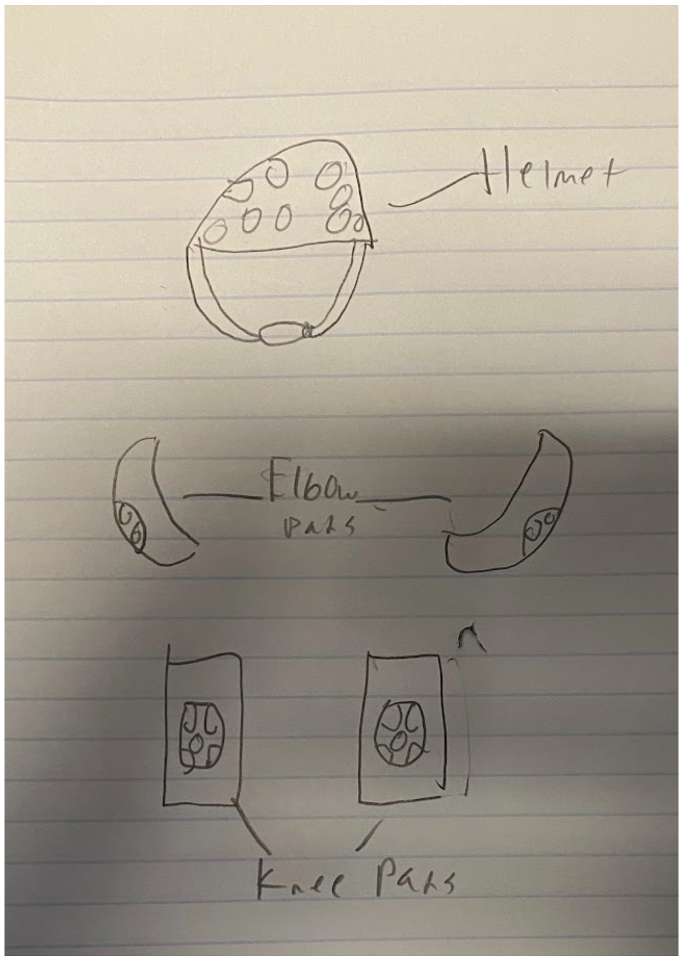


Figure 11: A sketch of necessary and common personal protective equipment for cyclists.

5. **Documentary on how bicycle use is a growing trend in cities in both the U.S. and Europe.**

Genre de Vie is a documentary made with the intention of promoting cyclist infrastructure in the U.S. It primarily focuses on New York City, New York, with occasional references to

Copenhagen, Denmark, and Paris, France. The documentary made a substantial effort to persuade the audience that the main obstacle to better cyclist infrastructure, and by extent cyclist safety, is a political one. The documentary noted that New York City is a city known for its narrow roads in the U.S. and that despite this fact, the city is finding space to implement cyclist infrastructure. The documentary also noted that cities across Europe, notably Paris and Copenhagen had narrower roads than New York City but these cities saw greater success than their American counterparts in implementing such infrastructure. Thus, the documentary suggested, cities in the U.S. that are looking to expand/improve/implement cyclist infrastructure should start small to show its functionality to detractors in order to gain approval for further projects. [46]

6. **Documentary on how cyclist infrastructure must be designed with the user in mind for it to be functional.**

This documentary focused on how car-centric cities were not a natural development of cities. The speaker claims that they are the product of advanced advertising and lobbying efforts that took place near the institution of car-capable road infrastructure. In order to reverse this claim, the speaker asserts that a human approach to road design should take place. The speaker puts specific emphasis on things such as “desire lines,” (Figure 12) the patterns of the users, and an overall human design perspective. The main takeaway of this documentary is the need for a human approach to designing roads and that corporate one should be actively avoided [47].

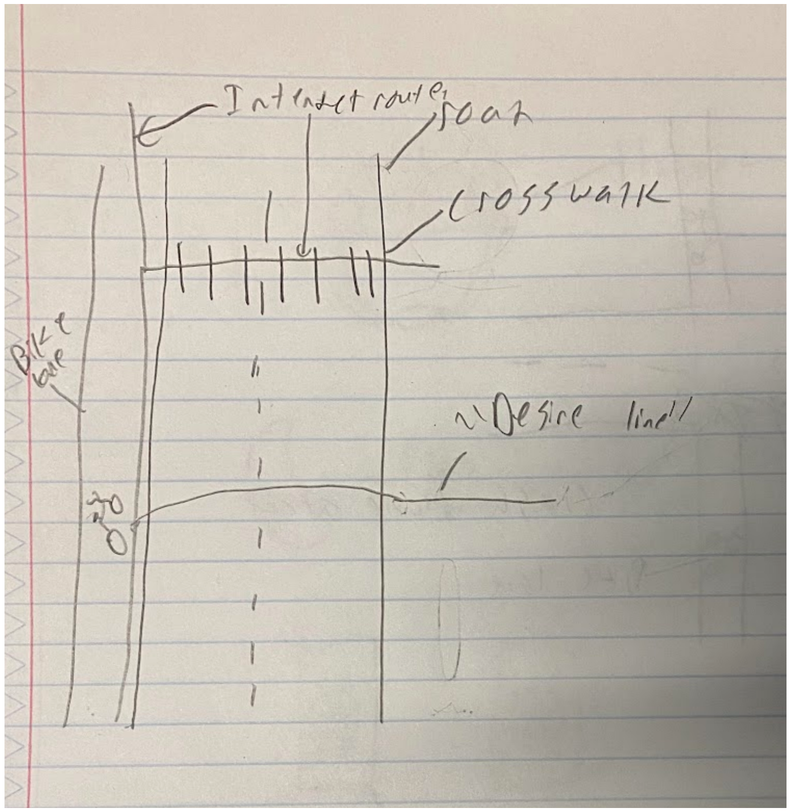


Figure 12: A sketch of “Desire lines”, aka routes which humans take due to convenience or otherwise that are separate from the intended route.

1.5.2.c Remaining Unknowns

The most important remaining unknown is how the different factors that obstruct the solution of the problem (i.e. political, economic, social, and environmental) will obstruct our development process. Notably, a common theme between the different stakeholders and articles I analyzed was that there exists an unwillingness to change road infrastructure in urban areas for a multitude of reasons. As we progress through our design process we must pay closer attention to stakeholders and other important factors at every stage of our process in order to succeed.

1.5.3.c Summary

The issue of cyclist safety and cyclist infrastructure has been addressed before, yet the problems still exist. This is resultant of a multitude of reasons including but not limited to obstructing forces, public perception, a failure to adequately address the problem, local issues, and pre-existing car dependency. In order to have any chance at navigating the many, many, factors that could cause ruin for our design project an attentive and in-depth approach to stakeholder engagement must be adopted. Changes must be made in small but impactful ways in order to have any chance at improving the safety of cyclists.

Connor's Section

1.5.1.d Engagement Insights

1. **Lecture from The Academy of Urbanism about Modernizing Infrastructure**

This source is a recording of two lectures given by partners of The Academy of Urbanism, and discuss how modern infrastructure design could be implemented to better service pedestrians and cyclists and obstacles which prevent their installation. The presentations discussed industry expectations for cyclist infrastructure; such as the low budgets that city planners typically work within, the limited space that can be allocated for cyclists, and regulatory statutes that need to be obeyed when designing infrastructure. In short, ancillary issues limit potentially ideal technical design. The lecture also discussed that a significant percent, 82% in Britain, is not up to modern code because local and municipal governments do not update infrastructure regularly.

The cumbersome nature of infrastructure makes it difficult to change on a large scale, so our approach to the problem should focus specifically on a certain area's infrastructure or very narrow aspect that can be improved in a simple to integrate way. Not focusing on the infrastructure itself is also an option, opting to look at another aspect of cyclist safety instead is a route we will explore moving forward.

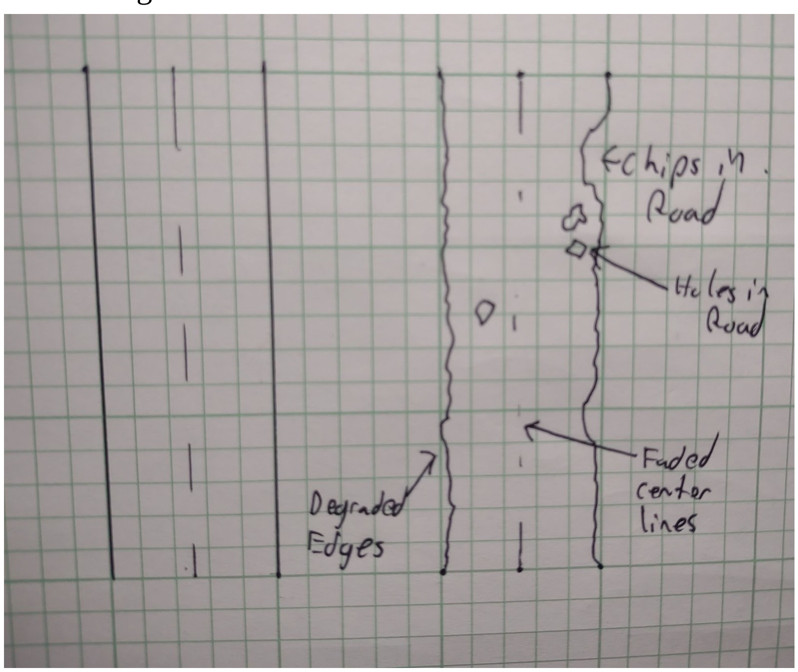


Figure 13: Demonstration of issues with outdated infrastructure.

2. **Not All Protected Bike Lanes Are the Same**

This source focused on the relative likelihood of an accident or collision involving a cyclist on different forms of cyclist infrastructure in different situations. The findings of the study were such that forms of infrastructure which decrease cyclist-motorist interactions were more effective at preventing collisions, and those which focused on decreasing the danger of the interactions which do occur also saw improvements.

Cyclists are best protected when they are nowhere near cars, however that becomes difficult because roads already exist on the most efficient routes between places, which are routes cyclists would like to take. The two approaches we will take from this study are; working to decrease interactions between cyclists and vehicles, and finding ways to make the interactions which do occur result in fewer and less lethal collisions.

3. **Stakeholder Interview with Edward Pallis.**

As a long time road biker, Edward was able to provide information about cyclists' views on the topic of cyclist infrastructure safety that otherwise our group lacked. In the interview he discussed how a cyclist’s top priority when choosing a route to cycle on is that it feels safe, and the efficiency of the route is secondary. Additionally, he discussed how existing cyclist infrastructure is largely in disrepair

This interview gave us a few possible approaches to look at. Firstly, whatever solution we design should be comfortable to cyclists if we want to see any widespread use or implementation. Additionally, focus on improving the usability of existing infrastructure could be a point. Cyclist infrastructure is proven to be safer for cyclists when it is used, so encouraging use of it would improve cyclist safety when cycling in urban areas.

4. **Street Improvement Manual**

This source is a guide for ways to improve the safety and quality of infrastructure during renovation and construction, and often addresses cyclist concerns. The two aspects it focused most on were traffic calming in cyclist heavy areas, and decreasing cyclist-vehicle interactions. It provides several specific suggestions for ways to achieve this, such as shorter curve radiuses and slowing obstacles for drivers.

Though the suggested solutions may be nothing more than starting points, they nonetheless give us ideas of existing methods of protecting cyclists on roads, and providing the guiding principles of decreasing vehicle-cyclist interactions and decreasing vehicle speeds as a method to protect cyclists, both of which are approaches the team can look at. Diagrammed below is an instance of an intersection with a shorter curve radius, which calms traffic by necessitating slower speeds around corners, and decreases vehicle-cyclist interactions by decreasing intersection length.

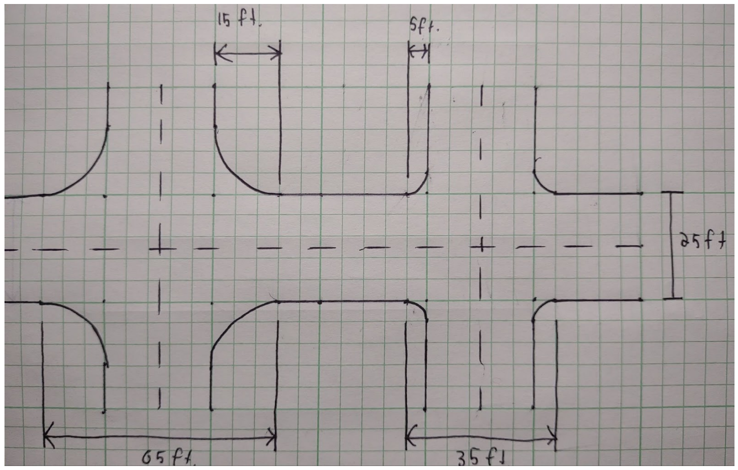


Figure 14: Diagram of a wide curve radius vs. short curve radius intersection.

5. Interview with Professor Jeffrey Holley and Visit to Infrastructure in Golden

Jeffery Holley is a The Colorado School of Mines professor who specializes in infrastructure. In the survey, issues with existing cyclist infrastructure were discussed, such as cyclists not utilizing existing infrastructure, that both driver and cyclist education is an extremely lacking area, and logistical issues that go into the implementation of solutions.

The most useful information gained was the discussion about cyclist and motorist education. Many motorists are too unaware of when they are around the other, and do not know how to properly behave when encountering the other. This is an avenue the team can explore addressing. Professor Holley also agreed with other sources that limiting interactions between cyclists and motorists would be the most ideal method of increasing cyclist safety.

The location visits were to the roundabout at 19th and Elm, the bike lane on 19th street, and traffic calming mechanisms on Ford Street, all in Golden, Colorado. The visit demonstrated the logistical difficulties with preventing vehicle-cyclist interactions, and how some traffic calming mechanisms might be implemented. Diagrammed below is 19th street, demonstrating the increased space needed on a road when separated bike lanes are included.

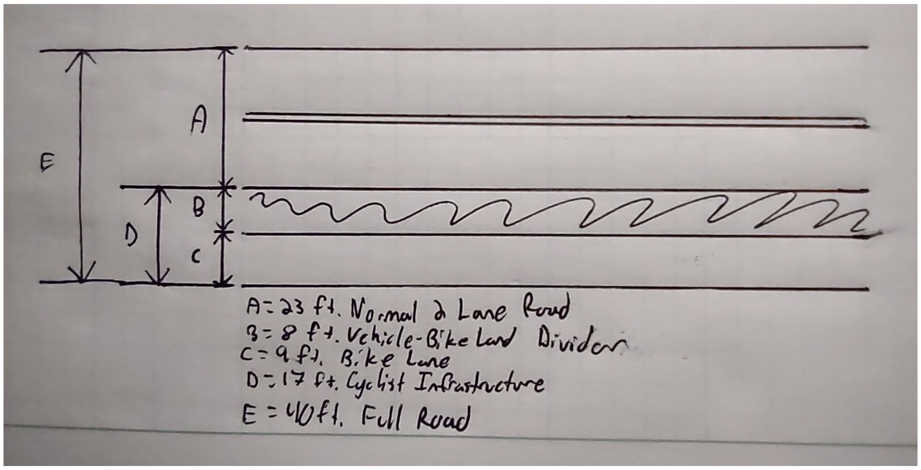


Figure 15: Diagram of the lane spacing on 19th Street in Golden, CO

1.5.2.d Remaining Unknowns

Local Economic Issues: Economic viability will be one of the biggest issues for the implementation of any design. More specific information regarding the fiscal capabilities of local governments and individuals to implement solutions is requisite to know what bounds the team will be working within.

Prioritization of Cyclist Infrastructure: The extent to which local governments and their constituencies are willing to prioritize cyclist infrastructure over vehicular or pedestrian infrastructure. If our solutions involve the roads themselves, we need to define the limiting bounds of what space must be dedicated to which mode of transit.

Willingness to Cycle: Currently various stigmas and logistical issues are the biggest obstacle to widespread cycling commutes in the US. If some of those logistical issues were to be addressed, would that reduce stigma and increase general perception of the viability of a cycling commute?

1.5.3.d Summary

Throughout these initial exploration stages, we were able to successfully glean previously unknown insights on the issue of cyclist safety. The most useful findings so far were the issues with previous solutions, including both their efficacy shortcomings and their implementation issues. This gives the team many pitfalls to avoid falling into, and some avenues to explore for future solutions, including traffic calming, motorist and cyclist education, and cyclist safety equipment improvements. We intend to base our solution less on our perceived goals and dedicate more primacy to the problems and ideas put forth by the stakeholders.

Eadyn's Section

1.5.1.e Engagement Insights

1. A Comparative Study of Bike Lane Injuries

This study, based out of Seoul, South Korea, assessed the conditions that led up to cyclist injuries by retroactively studying the circumstances in which bicyclists were admitted to a hospital after an accident. They had 387 cases of confirmable location and severity as shown to the right. As the data was collected after accidents, it will only consist of cases where severe injury has occurred, underestimating helmet use and overestimating injury. This data is useful for prioritizing sources of danger that this project can solve.

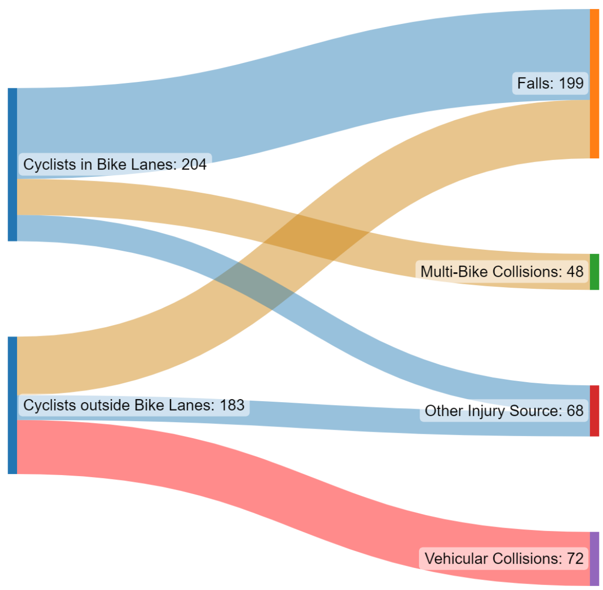


Figure 16: Injuries by Source

2. Bicycle Commuting and Facilities in Major U.S. Cities: If You Build Them, Commuters Will Use Them

This study attempts to establish the association between the presence of bike lanes and the number of people using bicycles to commute. This shows an increase in the percentage of commuters based on the percentage of roads with a bike lane, at an estimated 0.892% greater share of commuters being cyclists per 1% of roads with bike lanes. It also investigated other factors like average rainfall and vehicle commuters. This study confirms that bike infrastructure is useful and important for encouraging cyclists. This furthers the project by suggesting that the presence of bike infrastructure is itself valuable, even without the increases in safety that come with the infrastructure.

3. Causal Exploration of Bike Accidents in the Bay Area

This study uses data collected in San Francisco over five years to identify factors affecting the likelihood of a car-bike accident occurring, as well as the severity of the accident, and the party at fault. They found that cyclists were 27% more likely to suffer severe injury in a car-bike accident if the driver is at fault. They also found that single-cyclist accidents, such as those caused by falling after hitting a pothole as depicted below, are five times more likely to result in injury. There are higher chances of an accident in poor lighting conditions. This information allows the project to target more specific road conditions to be made safer through a technical solution.

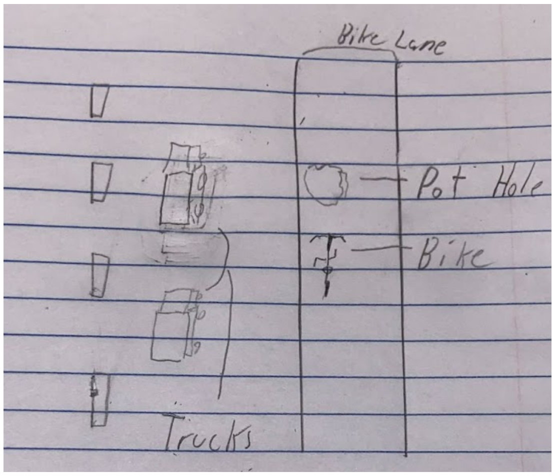


Figure 17: Single-cyclist crash

4. Developing Crash Modification Functions to Assess Safety Effects of Adding Bike Lanes for Urban Arterials with Different Roadway and Socio-Economic Characteristics

This paper attempts to estimate the effect of bike lanes on the number of crashes experienced on a given road. It does this by estimating the crash modification factor of adding bike lanes on roads that vary along several road characteristics. This is necessary as the effectiveness of adding a bike lane varies significantly. They found that the introduction of a bike lane is most effective in reducing crashes in roadways that have low average annual daily traffic (AADT), narrow median and lane widths, and at least 4-5 feet of bike lane width. This suggests an ideal road to introduce a bike lane as a narrower road with few lanes and a lower vehicle speed, as shown to the right.

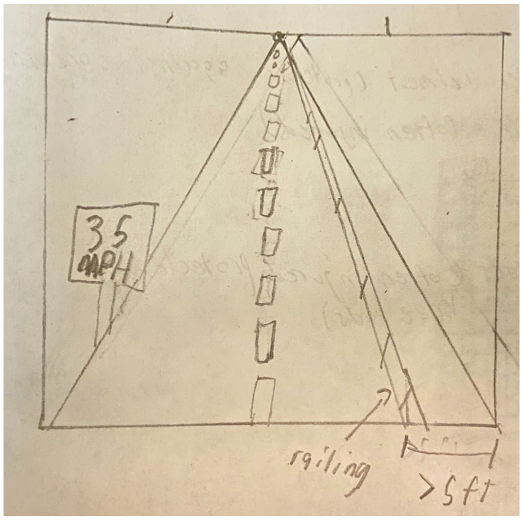


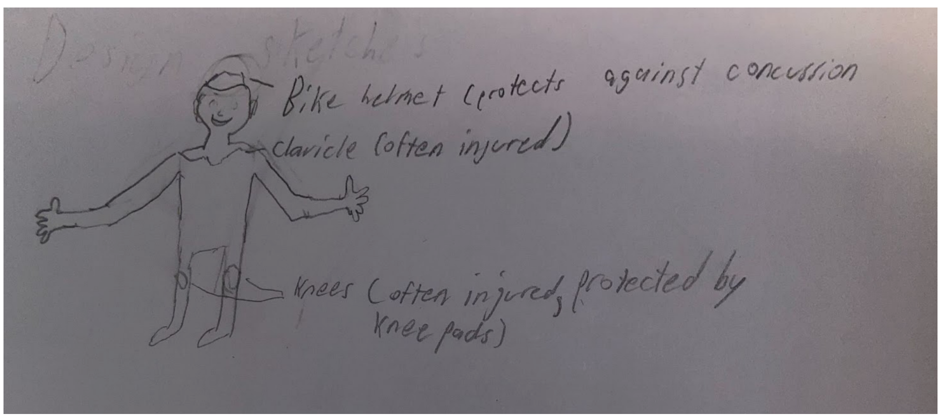
Figure 18: ideal road for cycling

1. Phone Interview: Alex Modrzecki

Modrzecki is an urban planner with experience designing roads and infrastructure planning. He provided input into current obstacles designing bike lanes, citing expanding lane-width needs as a particular problem. Similarly, he views the prohibitive cost associated with rebuilding roads or moving tree canopies as major obstacles. He believes that these issues are heavily impacted by the political will around them, with engineering difficulties being a secondary consideration as to the construction of bike lanes themselves. He also talked extensively about methods of evaluating bike lane success, focusing on retrospective analysis using police crash data to identify dangerous roads. He believes that this data-driven approach can be used to significantly improve on current conditions, making dangerous areas safe. He cites the example of Vision Zero, an organization aimed at eliminating vehicular deaths. He believes there is room to grow, both in how bike lanes are built in general, and in how they are evaluated when things go wrong.

2. Virtual Interview: John Weiler (Q&A)

John Weiler is an experienced cyclist, having been involved in the hobby for 15 years. On regular rides, Weiler reports that the only safety gear he and most other cyclists use are helmets. This



leaves room for injuries due to falls, with him identifying blunt impacts and “road rash” as the most prevalent. Despite this, concussions are common. Other injuries include lacerations to the knee, and a broken clavicle due to falls as shown in Figure 4. He identified common characteristics of roads that cause injuries: poor visibility or traction, or inadequate or bike lanes. Weiler believes that many injuries could be avoided if either drivers or cyclists were better educated and trained, suggesting that as an area of focus.

Figure 19: typical cycling injuries as identified by John Weiler

3. In-Person Interview Alexander Capehart

Alexander is a cyclist with some experience commuting. He talked extensively about issues with existing bike infrastructure. He references both a lack of bike lanes and inconsistencies in bike lanes. Cars are often parked in bike lanes, forcing him into the street or onto the sidewalk. He also finds that there are poor transitions between areas with and without bike lanes, slowing down commutes. He was more safety focused than John Weiler, having spent 15% more on safety gear than he did on the bike. This allows for a stronger sampling of the range of views held by cyclists on the importance of safety.

1.5.2.e Remaining Unknowns

1. How strongly correlated are cyclists' perceptions of safety with the actual safety in an area?

My research established that perceived safety in cycling in an area is strongly correlated with actual cycling in that area [43]. However, I have so far been unable to establish how effectively actual cyclist safety in an area correlates with perception of safety.

2. What aesthetic needs are there for the final design?

Many safety features such as the bike helmet are eschewed because of concerns around appearance. If the final design is a safety device, a tradeoff exists between the cost of the device and its appearance. It is unclear how much of a focus should be put on appearance versus safety to ensure that the solution is as widely used as possible.

3. If the solution involves cost to the government, how much would they be willing to spend on this measure?

The amount that a given state government would be prepared to spend on further safety measures is likely to depend significantly on how effective the measure is, as well as perceptions of the importance of the measure by state citizens. John Weiler, an experienced cyclist interviewed in this section, estimated that individuals would be prepared to spend about 3% more than they already had on cycling equipment on further safety precautions, but similar estimates have not yet been feasible for the government.

1.5.3.e Summary

A wide variety of road conditions can make cycling dangerous or unfeasible. Bike lanes, where they do exist, are inconsistent or dangerous. This project aims to improve safety by limiting motorist-cyclist crashes. 938 cyclists died in 2020, the last year in which data was available. Many of these deaths are preventable. Going forward, we will prioritize individual safety issues that are both impactful and tractable. We have identified both cost and aesthetics as constraints on viable solutions, which will have to be considered in the design. A prototype that fails to incorporate both of those factors will be ineffective. All of this leaves us more aware of the broader situation as we go into the prototyping phase.

2.1 Stakeholders and Existing Solutions

The stakeholders for this project encapsulate a wide variety of people and groups including most of those that interact with roads and public transportation. These include cyclists, motorists, pedestrians, taxpayers, and local governments. Cyclists' main concern is access to comfortable and safe roads, especially roads that are not hostile to cyclists. Examples of hostile design are excessive speed limits, constantly variable road conditions, or lack of bike lanes. Motorists prefer not to feel that they are being deprioritized in city planning and that the routes they take remain efficient and in good repair. For taxpayers and local governments, the requirements are mostly focused on cost-effectiveness, value, and ease of implementation. The solution must be cost-effective and increase safety for cyclists in urban areas. The group engaged with not only current cyclists but also prospective cyclists to understand what issues they find in the current situations presented in urban areas. Furthermore, consulting research papers that examined the effectiveness of certain methods of bike safety and infrastructure, found that many of the existing solutions resulted in less-than-optimal outcomes. In order to improve on this, our solution will have to learn from these mistakes.

Solution	**Brief Description**	**Pros**	**Cons**
Separated Bike Lanes	Designate an area on the road exclusively for cyclists to minimize motorist-cyclist interactions and decrease collisions.	Studies typically suggest they make cyclists safer than without. [4, 5]	Often inconsistent or damaged, and some studies suggest greater risk to cyclists associated with them [4, 5]
Protected Bike Lanes	Separated bike lanes with some form of physical barrier or separation between the bike lane and road.	Significantly safer than separated bike lanes and typically more comfortable for cyclists [3, 5, 9]	Cost more and demand more space than typical bike lanes. [3, 5, 9]
Shared Bike Lanes	Normal road lanes are formally shared between cyclists and motorists, with some form of indication that the lane is shared.	Some studies suggest these roads are safer due to increased awareness. [1, 3]	Some studies suggest these roads are less safe due to increased car-cyclist interactions. [1, 3]
Bike Paths	Routes that run either adjacent to or independent	Very safe and highly comfortable for	Expensive to implement and

Solution	Brief Description	Pros	Cons
	of roads are reserved exclusively for cyclists or pedestrians.	cyclists to use. [4, 7, 1]	require a significant amount of space. [4, 7, 1]
Cyclist Education	Education methods are considered anything instructing cyclists and motorists how to act around each other, and alerting them to each other's presence	Lack of prevalence of existing methods means that new methods could be very effective. [46]	Research suggests that education is minimally effective in increasing safety. [46]
Cyclist Safety Equipment	Equipment that cyclists wear to protect themselves in the event of a collision.	Highly effective at reducing the severity of injuries and see extensive use.	Adoption is limited due to factors like aesthetics and ease of use.
Cyclist Visibility Equipment	Clothing or equipment is utilized by cyclists to make them more visible to cars and prevent collisions.	Help to limit collisions and see extensive use. [47]	Limited adoption due to aesthetics, cost, or inconvenience. [47]

Table 3: A summary of existing cyclist safety solutions

2.2 Requirements, Customer Needs, Technical Specifications

General Design Requirements

- **Long Lasting:** the device needs to be able to last at least several months under a variety of conditions without breaking down or needing to be repaired.
- **Easy to Use:** the design needs to be accessible to cyclists without significant engineering or technical skills.
- **Safer**: the design needs to be effective in reducing the total number of accidents, or making accidents that do happen less dangerous.

Stakeholder Needs

- **Cheap:** the design must not increase the cost to the consumer above what most are willing to pay. John Weiler, an experienced cyclist interviewed in module 1, estimated that the average cyclist would be willing to spend 3% more on safety gear than they have on the bicycle itself, suggesting a lower limit of $15 for a $500 bicycle.

- **Easy to Introduce with Existing Infrastructure**: the design should be easy to introduce, not requiring significant changes to the road or bicycle design. The design must be integratable with existing infrastructure.
- **Does not make cycling significantly harder**: the design cannot destabilize the bicycle, lower mechanical efficiency below 85%, or otherwise make it unduly difficult to ride a bicycle. [56]

Technical Design Specifications

- **Light**: the design needs to be less than 5 pounds on the bicycle.
- **Balanced**: the design needs to balance its weight, such that the bicycle does not more readily tip over.
- **Adjustable**: the design must be able to attach to existing bicycles without requiring specific frame sizes.

Table of Design Requirements

General Requirements	Stakeholder Needs	Technical Specifications
Design needs to last through significant exposure to weather conditions	Design needs to be inexpensive so the average cyclist is willing to use it	The design needs to not introduce significant new weight
Design needs to be simple to use and understand	Easy to integrate with existing infrastructure; no significant retrofitting	Design needs to be reasonably balanced on the bicycle
Design needs to make cyclists safer on urban roads	Design cannot make cycling significantly harder or adoption will be limited	The design must be able to attach to a variety of bicycles without difficulty

Table 4: a summary of design requirements

2.3.A Individual Looks Like and Concept: Eadyn Thompson

2.3a.1 Prototype Description:

This prototype is a version of the front wheel and frame for a bicycle which is designed to reduce shock and allow for a safer, smoother ride on rough and uneven roads. It introduces a larger wheel, with an inner radius of 32 inches, making small disturbances less noticeable to the rider. This size was picked as a compromise between safety and efficacy and was informed by an interview with experienced cyclist Nathan Vahlberg [71], and previous research in the field [62]. In addition to the wheel, the prototype also uses a partially horizontal suspension system, with the goal of partially absorbing shocks that are otherwise likely to be unmitigated. The compression process is depicted in Figure 1 below. A modified suspension arose as part of a solution after considering previous shock-absorbing wheels such as the Loopwheel. Many of these designs struggle with issues like the deformation of the spokes or frame, which a traditional suspension system is unlikely to suffer from. Currently, some similar systems are used in bicycles for purposes like mountain biking on especially rough terrain. While efficiencies of relative wheel sizes are generally known, shock systems like the one proposed are harder to model and are therefore more of an unknown. Safety modeling is possible, however, suggesting a reduction in forces experienced in a collision proportional to the distance the shock can compress.

2.3a.2 Solution Field Sketch:

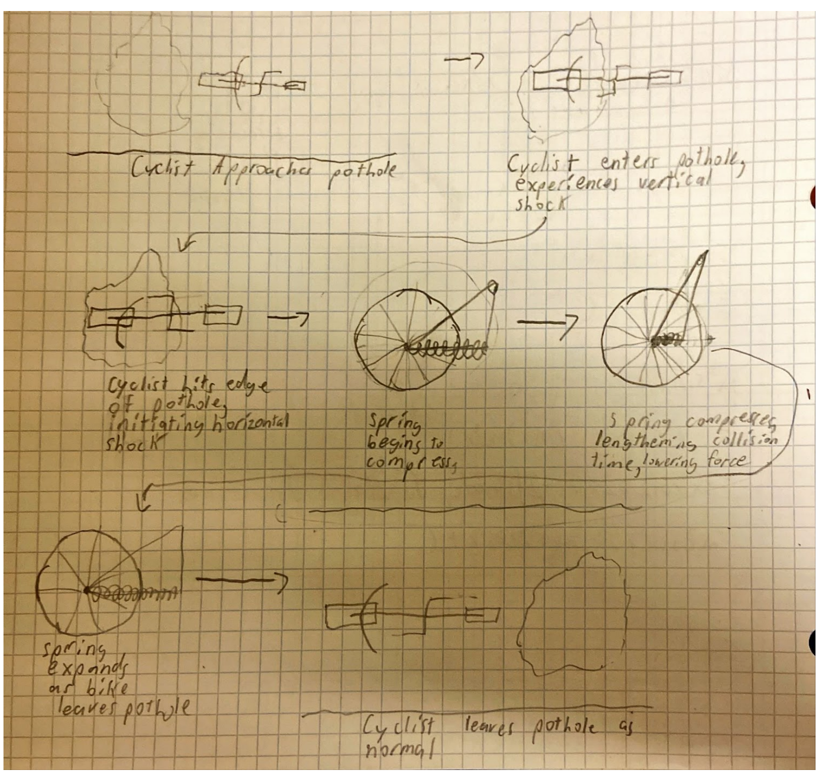


Figure 20: Shock Absorbent Wheel Sketch

2.3a.3 Looks-Like Prototype Photo:

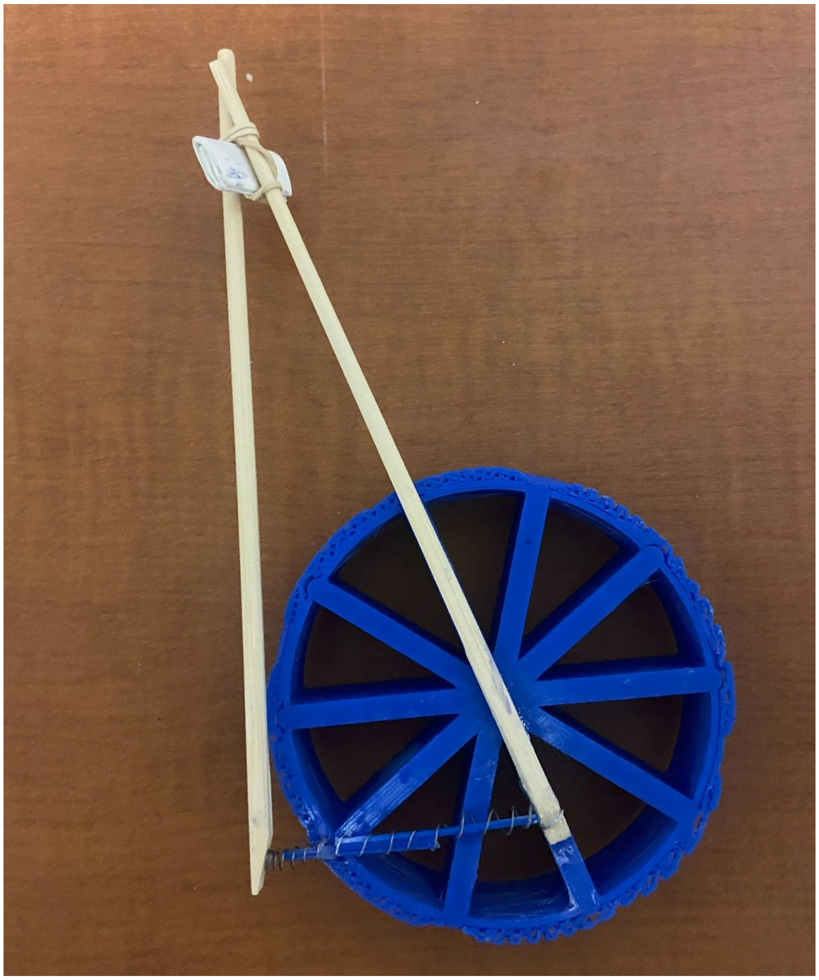


Figure 21: Shock Absorbent Wheel Prototype

2.3a.4 Solution Value Summary:

By combining the shock absorbent system and large wheel, this prototype aims to provide a safety-focused option for cyclists in uneven urban areas. This comes, however, with some loss in mechanical efficiency. This will likely limit the prototype’s adoption if fully executed. It is also a difficult device to manufacture, requiring a significant amount of work with metal under low tolerances. It also requires purchasing specialty parts which might be difficult to get or expensive.

2.3.B Individual Looks Like and Concept: Jacob Altizer

2.3b.1 Prototype Description:

The prototype I created was a proximity alarm system to alert cyclists of potential dangers behind them. The bike would have one distance sensor on each side that would detect a car or any moving foreign object. In the case that there was something behind the cyclist, the system would alert the rider by providing haptic feedback on the handlebars. The haptic feedback from the handlebars would also be directional, if there was something approaching from the left, the left handlebar would vibrate. The system would also be able to provide audio feedback to the cyclist. A speaker system could be retrofitted to a helmet, or headphones/earbuds could be connected that would play a sound alerting the cyclist. The high accuracy coming from two sensors could be used to provide the user with more accurate audio feedback. For example, if there was a car quickly approaching from the right, a series of beeps with increasing speed and frequency could be played to the right side of the user's helmet or headset. The volume and frequency of the sounds would be varied in order to provide more accurate details to cyclists on the approaching car.

2.3b.2 Solution Field Sketch:

As seen in Figure 3, the bike proximity alarm alerts the cyclist of potential danger by playing a sound through headphones/helmet, and vibrating the handlebars.

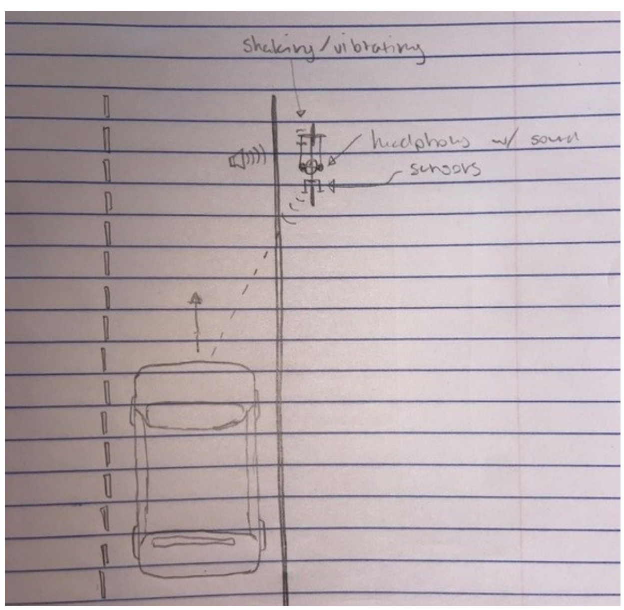


Figure 22: Bike with Proximity Alarm in Use

2.3b.3 Looks-Like Prototype Photo:

Figures 4 and 5 show different views of the bike with a proximity alarm looks-like prototype.

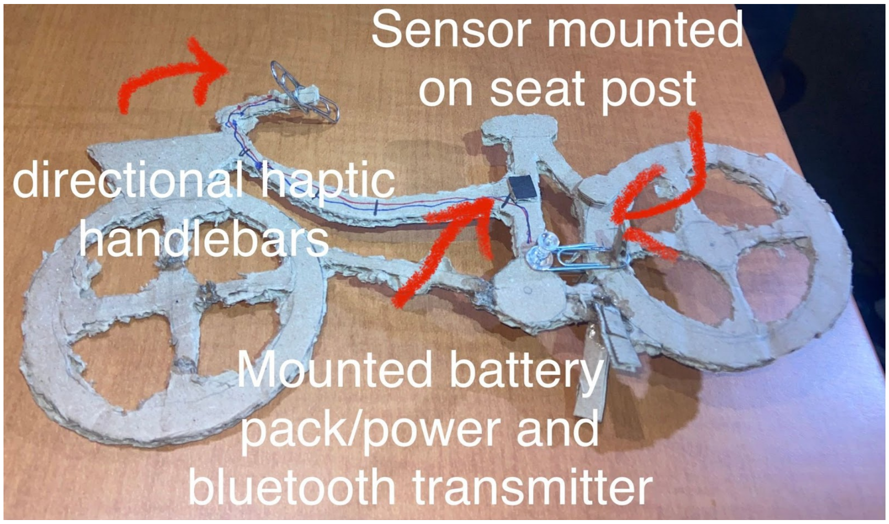


Figure 23: View of Bike with Mounted Sensors, Haptic Handlebars, and Battery Pack

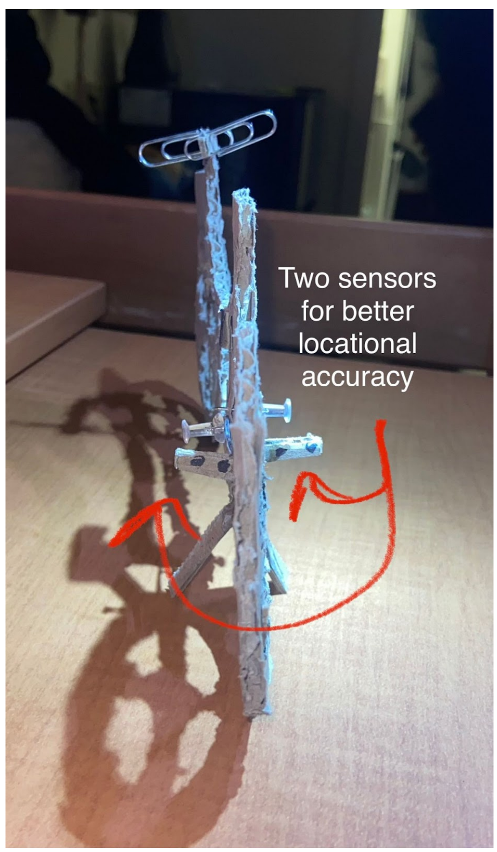


Figure 24: Back View of Dual Sensors Mounted to Seat Post

2.3b.4 Solution Value Summary:

This design would vastly increase the safety of cyclists by increasing their awareness of their surroundings. It would allow the user to be more aware of potential dangers that are outside of their field of view. By lowering the amount of time the cyclist has to spend looking over their shoulder and assessing their environment, the user would spend more time focusing on the road in front of them, which would prevent collisions.

2.3C Individual Looks-Like and Concept: Connor Pallis

2.3c.1 Prototype Description:

The product prototype is an add-on for bikes that is meant to retrofit bicycles with turn signals, headlights, and tail lights such that they can become standardized road users like motorcycles and automobiles. The product features a front component and a rear component connected by wire. The rear component, the simpler of the two components, has three lights, a red tail light that is always on during operation, as well as a left and right turn signal. It can be attached to the bike using a screw-on bracket. The front component has the same turn signal lights as the rear component, as well as a headlight in place of a taillight, a compartment for a battery to power the device, and a user interface. The user interface consists of a battery charge indicator, buttons to turn on and off the system and headlights, and buttons to activate the turn signals. As stated previously, the goal of this product is to make cyclists standardized like other road users, so that they are more visible, have more predictable actions, and have better visibility. A major cause of cyclist-motorist collisions is as a result of limited visibility [56], which this product addresses. While products exist for bike turn signals, headlights, and taillights individually, there are no comprehensive, combined, front and back systems such as this one. The turn signals also allow cyclists to indicate turns without removing their hands from the handlebars, as they would need to with hand signals.

2.3c.2 Solution Field Sketch:

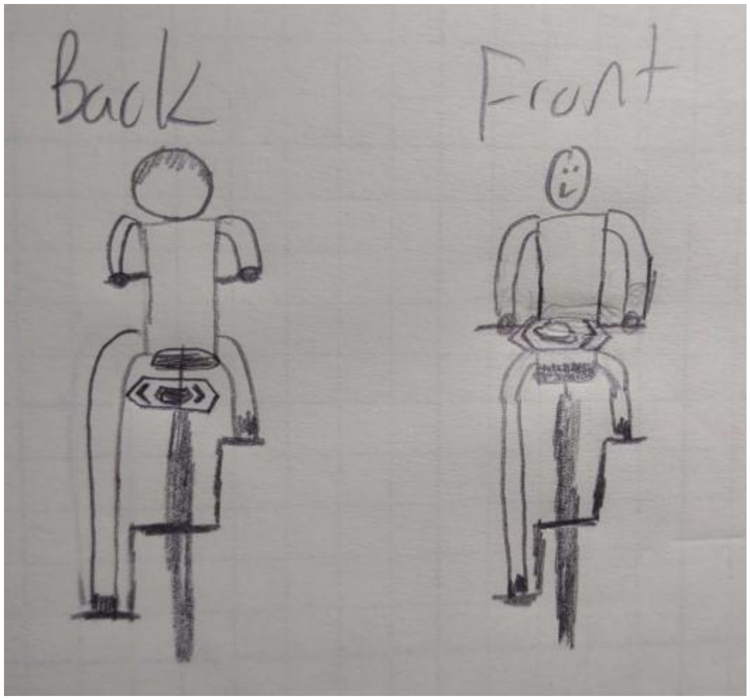


Figure 25: Front and rear view of bike turn signals mounted on a bike.

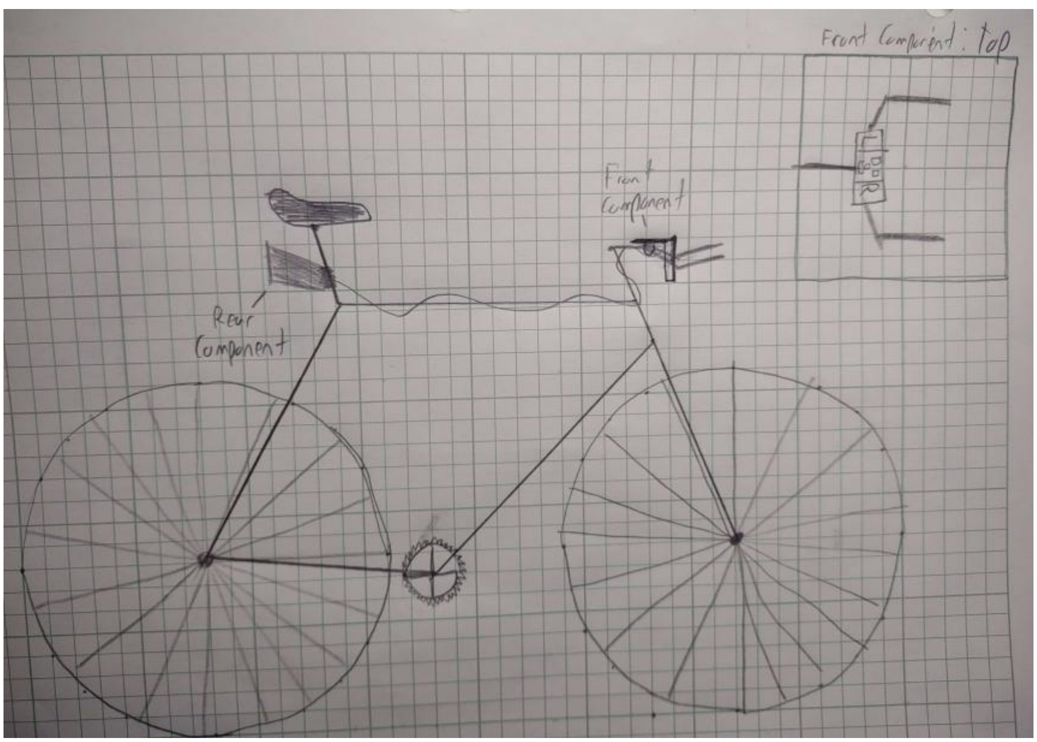


Figure 26: Side view of the turn signal mounted on a bike.

2.3c.3 Looks-Like Prototype Photo:

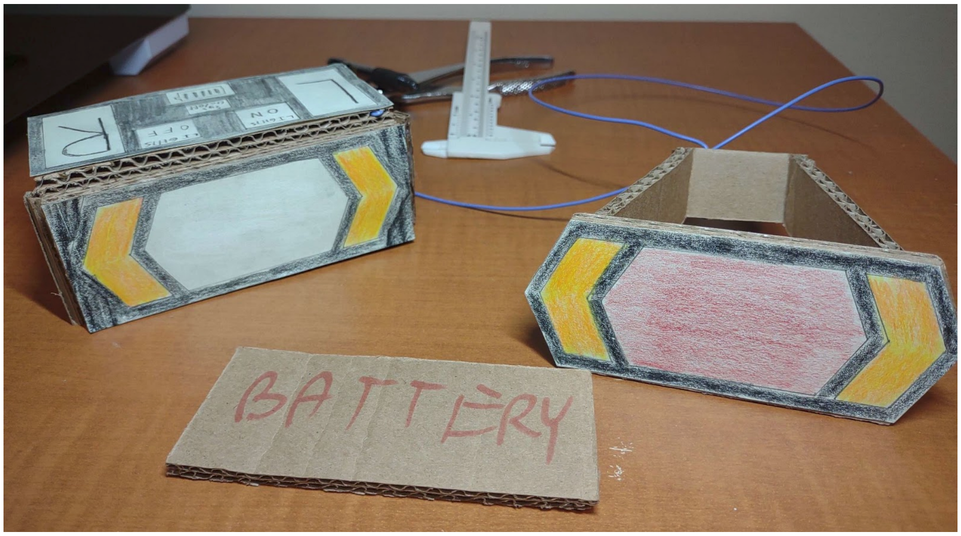


Figure 27: Bike turn signal apparatus.

2.3c.4 Solution Value Summary:

By making road users standardized like motor vehicles with headlights, taillights, and turn signals, they will be made more visible and predictable to other road users, will have greater visibility, and have a greater capacity by which to communicate with other road users. This would serve to make cyclists safer from motorists as well as other cyclists, and allow them to more safely navigate roads, especially in low light conditions. Generally speaking, this design is cheap, low profile, effective, and easy to use, addressing the relevant stakeholder requirements, although it was ultimately not selected for our group's final design because the product is not as original as the cyclist location emitter.

2.3.D Individual Looks Like and Concept: Eoghan Cowley

2.3d.1 Prototype Description:

My prototype was an airbag-like head protection device specifically targeting those who dislike wearing helmets when cycling either due to storage issues or the more aesthetic issues of possibly messing up their hair. The head protector would sit around the user's neck in a deflated state similar to an airplane neck pillow. It would house two gyroscopes on the left and right side that will take readings of the movement force and direction and compare what they are reading. This comparison will allow for the head protection to find the rhythm of what is considered a normal movement in cycling. When detecting a sharp jolt in an unexpected direction with a force greater than expected, the head protection will inflate like an airbag to cover the side of the head. This will allow for the head protection to stop the sides of the head from being hit.

2.3d.2 Solution Field Sketch:

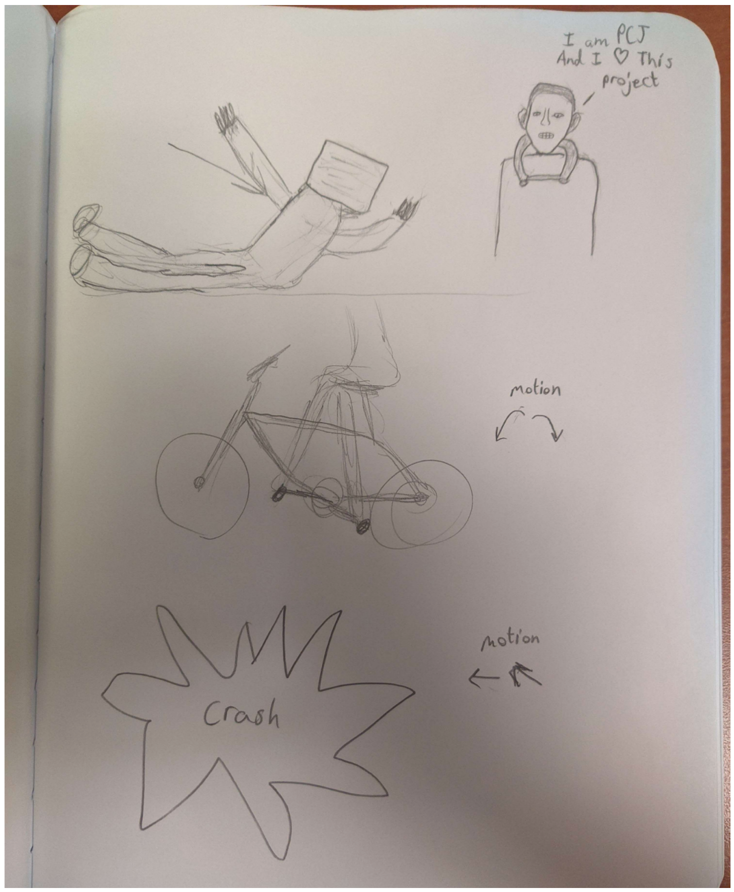


Figure 28: Field Sketch

2.3d.3 Looks-Like Prototype Photo:

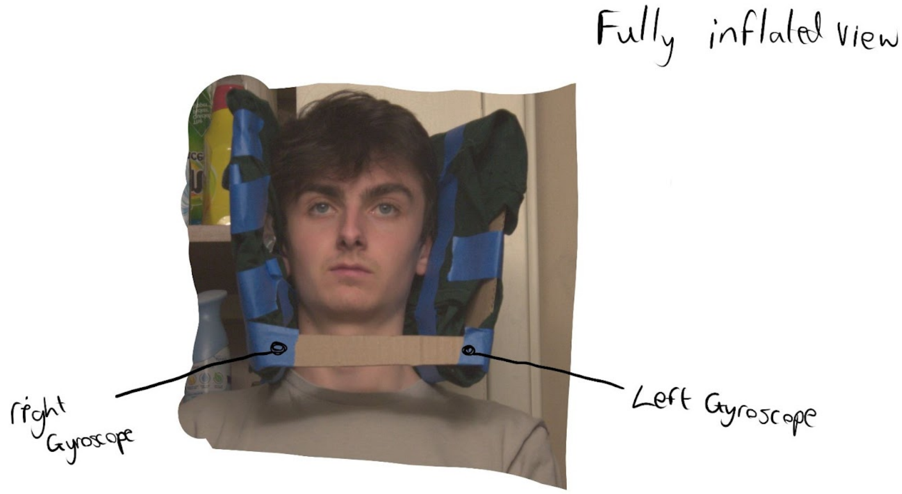


Figure 29: front view

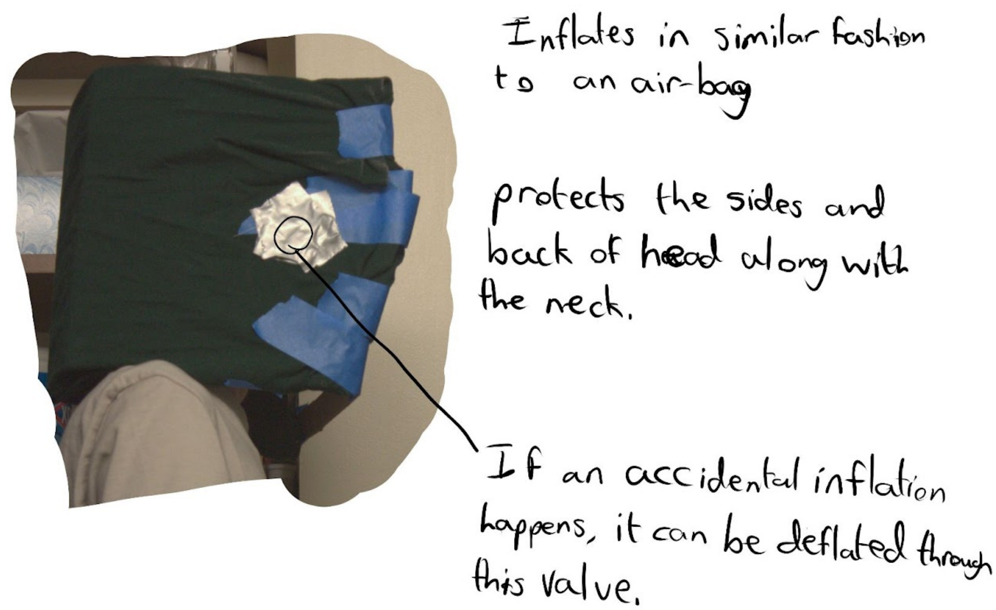


Figure 30: side view

2.3d.4 Solution Value Summary:

My design was deemed not feasible due to the technical difficulty in getting the airbag to deploy in a short amount of time but also being able to retract and deflate. It also required a lot of integrated parts that would be difficult to bring together into a works-like in the given time and budget allotment.

2.3.E Individual Looks Like and Concept: Conor Hanna

2.3e.1 Prototype Description:

This product prototype is a location emitter designed to reduce car-bike accidents at high-risk intersections. The prototype is in actuality two different products that work in tandem with each other in order to function. The first product, the emitter, is purchased by cyclists and attached to the midportion of the bike. It has an extremely simple design: a single on/off button, and an approximate battery level display, in order to reduce costs and ensure functionality after extended use. The second product, the sign, and receiver are purchased and installed by local governments at intersections where frequent car-bike accidents occur. The sign and receiver are designed to be as cheap as possible in order to ensure a high degree of feasibility to receive funding for installation. To accomplish this the sign and receiver can be installed on pre-existing polls such as the polls where pedestrian walk signs are located. No major infrastructure projects such as lane reductions are necessary so even less cyclist-friendly cities could realistically implement such a product. The product works by the emitter sending a repeating signal at a consistent interval when the emitter is on and nothing when off. The sent signal is received by the receivers located at high-risk intersections. Based on the time between each signal received the receiver can approximately calculate the direction and distance the bike is from the receiver. After the approximate direction and distance have been determined the sign will illuminate a light corresponding to the approximate position calculated. This sign is visible to both motorists and cyclists and informs motorists at the intersection that a cyclist is present and where their approximate location is. This information would allow motorists to make informed decisions when traversing the traffic intersections and therefor reducing the likelihood of a car-bike collision. The design as a whole is unlike anything that currently exist today in terms of how it communicates information. Almost all products currently existing focus on notifying the cyclist of the presence of motors while this design alerts motorists of the presence of cyclists.

2.3e.2 Solution Field Sketch:

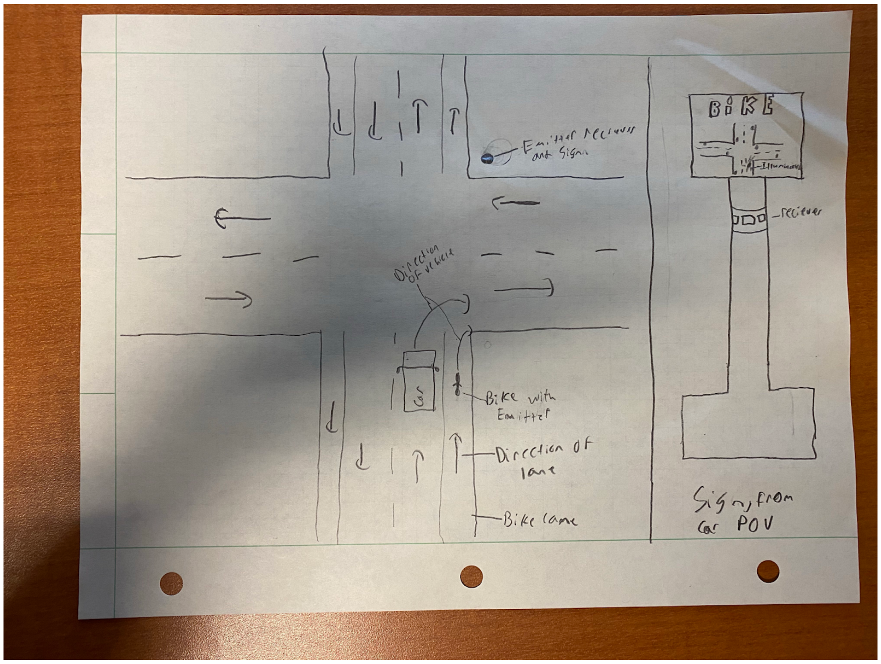


Figure 31: Sign + Receiver and common use scenario field sketch

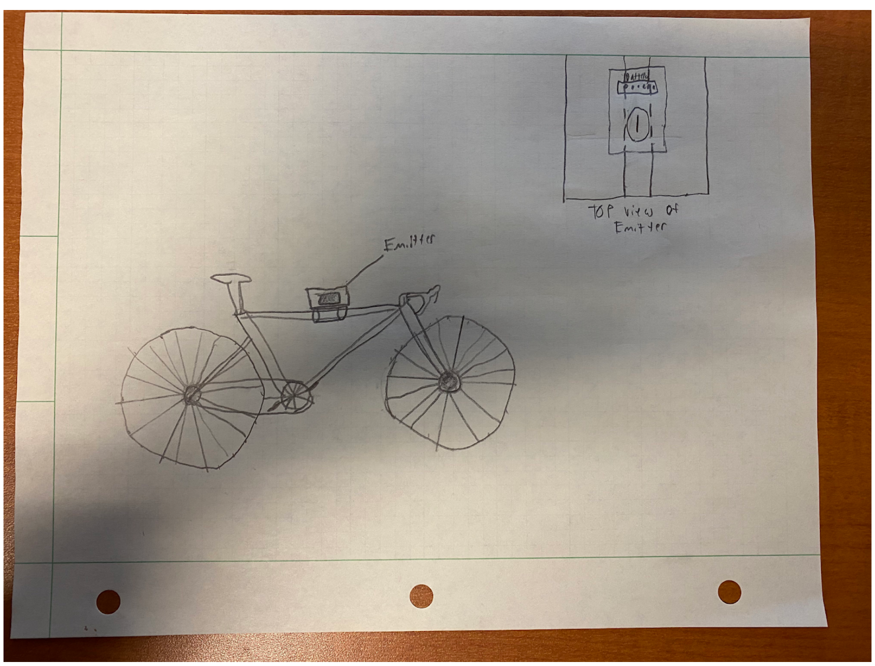


Figure 32: Bike with emitter installed/attached field sketch

2.3e.3 Looks-Like Prototype Photo:

Figure 33: Emitter looks-like prototype photo

2.3e.4 Solution Value Summary:

This solution is not only feasible for both cyclists and local governments to purchase and install, but can also significantly reduce the risk of a car-bike collision at high-risk intersections by informing motorists of the approximate locations of cyclists that they might not otherwise be aware of. Through the initial problem definition and stakeholder engagement in Module 1, some of the largest pitfalls of pre-existing solutions were identified. This design honed in on addressing a vital pitfall often experienced by pre-existing solutions: the cost of implementation on a governmental level. Stakeholders routinely identified the steep costs of pre-existing solutions such as lane shortening as the largest barrier to implementation. In order to realistically increase the safety of cyclists, this key pitfall had to be addressed. To do this the design was made to be as cheap as possible on the governmental side while not increasing costs on the consumer side in order to encourage adoption. Even while executing well on this, the design also did not sacrifice originality, feasibility, ease of use, or safety.

2.4 Summary of Concepts Considered and Explanation of Decision Tools Used

After the initial problem definition and stakeholder engagement in Module 1, the Group moved on to ideating potential solutions pertinent to the problem of cyclist safety. As seen in figure 4, idea-generation techniques such as the fishbone method and bifurcation were used in order to create dozens of potential solutions on a whiteboard. After creating the first large batch of ideas by writing down anything someone thought of, the group then narrowed the ideas down to a smaller group of 5-10 and each group member chose one idea: to base their looks-like prototype on. The results of this idea generation concluded with 5 distinct ideas, a modified bike wheel with horizontal suspension, inflating head protection, bike proximity alarm, turn signals, and bike location emitter.

Figure 34: Solution Brainstorming and Ideation

In order to choose one solution, the group outlined a variety of solution and design criteria and voted on which design fit these criteria best. As seen in Table 2, the primary solution criteria were cost efficiency, ease of use, safety, feasibility, and originality. It was also desirable that the design be reliable, comfortable, practical, aesthetically appealing, and appealing to all group members. To ensure the design matrix accurately encompassed our values, some criteria were weighted differently than others. Cost efficiency, for example, is weighted at 0.5 points per point, while feasibility is weighted at 1.5. This was done in order to ensure the stated priorities matched with underlying goals. Practicality and safety had, for instance, more of an impact on the decision than cost. When creating the design matrix, the group systematically went through each design and voted on a value between 1-5 for the given design criteria. Inputs from the group were then averaged and summarized, as seen in table 2. While the modified bike wheel and inflating head protection were original, they scored low in feasibility and ease of use, largely eliminating them from consideration. Similarly, the bike proximity alarm and turn signals scored high in criteria such as safety and feasibility, but scored lower in originality. The bike location emitter stood out for scoring high in all design criteria, leading it to stand out as a solution.

	Modified Bike Wheel	Inflating Head Protection	Proximity Alarm	Bike Turn Signals	Bike Location Emitter
Estimated Cost Efficiency (0.5)	2	2	3	4	4
Ease of Use (1)	2	3	4	5	5
Safety (1)	2	2	3	4	4
Feasibility of Design (1.5)	3	2	4	5	5
Originality (1)	4	4	2	2	4

Total	13.5	13	16.5	20.5	22.5

Table 5: Design Matrix

2.5 Final Design Chosen and the Design's Requirements

After employing the use of various decision tools, the cyclist location emitter stood out as the clear strongest idea. It specifically differentiated itself on originality, doing well on that without sacrificing efficacy, safety, feasibility, or ease of use. Furthermore, this device accomplishes these high scores while adequately addressing the stakeholders that the design of this device had in mind. The device has two main components, each purchased and installed by a different party: a receiver and sign purchased by local governments (Figure 5) and an emitter, purchased by cyclists (Figure 32duck). With this in mind, the device had to be feasible for both parties to purchase and install. To accomplish this, the emitter had to be durable, easy to use and install, and affordable while the receiver and sign must be entirely focused on affordability in order for funding to realistically be achievable.

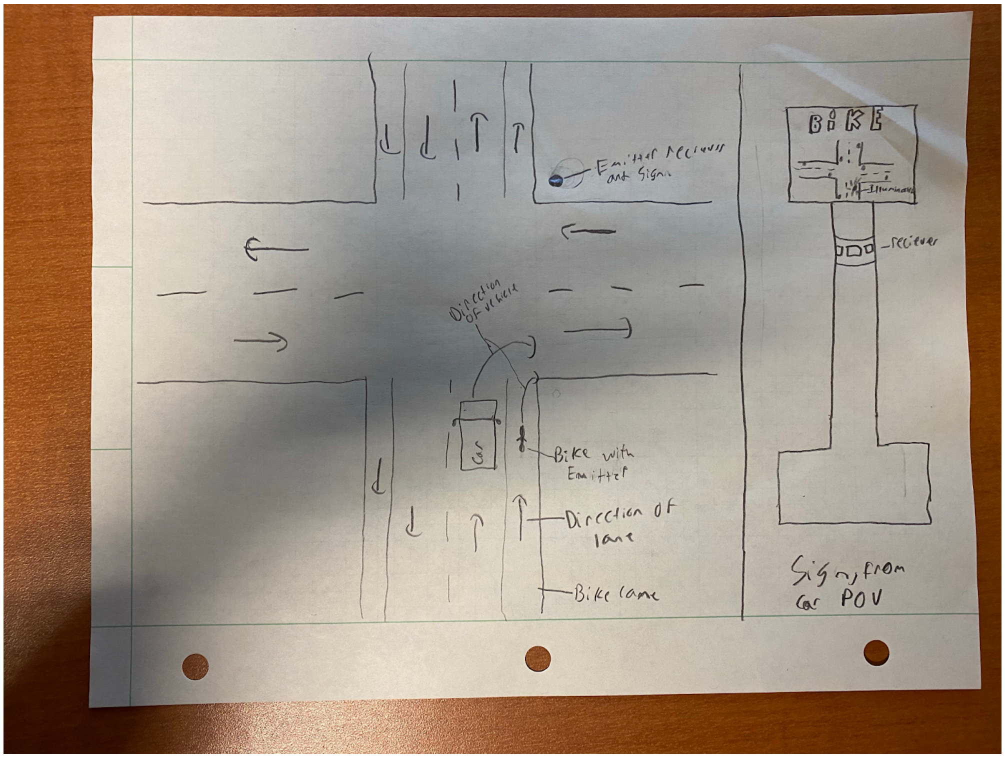


Figure 35: Sign and common use case field sketch

Figure 36: Looks-like prototype for our final design choice. Emitter portion.

For our final design, we will want to ensure the stability and reliability of our signal emission and detection as this is the greatest hurdle our group currently faces. We as a group hope to do extensive testing throughout the design and construction process of our works-like in order to ensure both a functional and realistic design.

2.6 Module 2 Summary

Cyclist safety remains a prevalent issue that needs to be addressed. Various attempts have been made at solving this issue, and in many cases have helped to make significant improvements in cyclist safety. Unfortunately, there are still hundreds of cyclist deaths annually, and there has been an increase in recent years. [15] The solutions the group explored took many different approaches once the initial brainstorming and iteration were completed, and the members explored solutions which helped protect cyclists in the instance of collisions, make collisions less likely, and overall make cyclists safer on the road. The affected groups – cyclists, motorists, pedestrians, governments, and taxpayers – were heavily considered in the design of this product, and the requirements for the design were all defined with the needs and wants of those stakeholder groups in mind. The decided upon requirements pertained to cost, efficiency, safety, durability, and ease of use. To select one of the product ideas to use out of the proposed ideas, a decision matrix was utilized and the group members collectively chose the cyclist location emitter, as we considered it the most original and potentially effective out of the given options. Going forward, the current bike location emitter will need all the internal components designed and fleshed out, and the technical and logistical aspects of the implementation of the sign and its connections with the individual bike location emitters must be fleshed out.

Jacob's Section: Display

3.1.A Subsystem description

The display subsystem interfaces with the receiver to indicate to motorists when a cyclist is in the intersection.

3.1.1.1.A Subsystem Objective and Key Components

The objective of the display is to clearly indicate to the motorist that there is a cyclist in the intersection. By effectively displaying this information, the motorist will be more aware of the cyclist which will reduce the chances of a collision. The display will be intuitive; the motorist will be able to glance at it and be aware that there is a cyclist nearby. It will also be resilient and efficient. The display should remain clear and effective even in inclement conditions and after years of weathering; it should not require a lot of maintenance. Power efficiency is also important; it should not draw too much power while still being clear. The key components include the following:

- Arduino Uno, where most of the computation happens, this is also where the display will receive information from the receiver
- Electrical wires to receive signals from the receiver and Arduino
- LED light to display to motorists that a cyclist is in the intersection
- A breadboard to connect components
- Traffic Controller Board

3.1.1.2.A How the Subsystem Achieves Outputs

Since the output of the Bike Location Emitter is increasing the awareness of motorists in relation to cyclists, the display is a crucial subsystem. To accomplish this output, the display will be clear and intuitive. It will receive input from the receiver that a cyclist is in the intersection, and turn on LEDs that will indicate that information to motorists. Since all of the computation for the receiver of the Bike Location Emitter will be done on one Arduino, once a signal is received, the Arduino will turn on the LEDs.

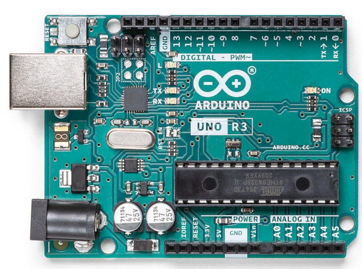
3.1.1.3.A What inputs are required in order to make this subsystem work?

Hardware requirements for the display include an Arduino (the same one used for receiving the signal in the receiver subsystem), a breadboard, electrical wires, LED lights, a traffic light controller, and connections to the housing. Software and code will also be necessary for the display; it will receive a signal from the receiver, and output power of HIGH to the LED, turning it on. The display will also get data input from the radio receiver when a cyclist has entered the intersection.

3.1.1.4.A Key Subsystem Components

As seen below in table 1, the key components used in the display are an Arduino, which will be the same one used for the signal receiver, a breadboard, LED lights, a traffic light controller, and electrical wires connecting all of the components.

3.1.1.5.A For Off-The-Shelf Components

Arduino Uno		Arduino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), a USB connection, a power jack, an ICSP header and a reset button.

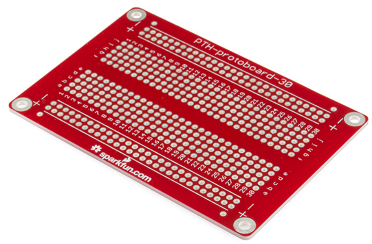
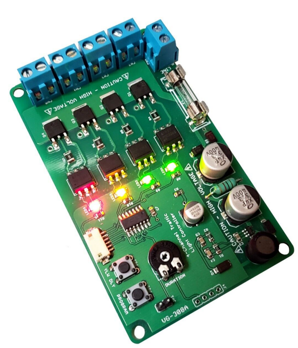
Solderable Breadboard		A bare PCB that is the exact size of a regular breadboard with the same connections to pins and power rails. It is used to electrically connect components outside of the Arduino.
FLTWC0311-22-2 Solderable Electrical Wire		This hookup wire is rated for up to 600V, utilizes tin-coated copper, measures .33mm in diameter, it has an operating temperature of 65-135 degrees Celsius.
Leotek 12” Red LED Traffic Light		The 12-inch LED traffic light is energy efficient, has a wide viewing angle, enhanced uniformity, and a constant current source to maintain consistent light output. Moisture and dust resistance.
Traffic Light Controller		The traffic light controller can activate and deactivate traffic lights. It’s powerful enough to drive extremely high-voltage lights while remaining sensitive enough to operate smaller LED bulbs safely.

Table 6: Off-the-Shelf Components for the Display Subsystem

3.1.2.A Physical Properties of Subsystem Components

Component Name	Dimensions (mm)	Material Type	Weight	Other Specifications
Arduino Uno	68.6 x 53.4	Non-conductive laminated composite with layers of circuitry built-in	25 g	Operating Voltage: 0-5V (depending on software) Input Voltage: 7-12V DC current per I/O pin: 40mA Clock speed: 16 MHz Memory: 32 kB EEPROM: 1 KB RAM: 2 KB
FLTWC0311-22-2 Solderable Electrical Wire	.33 (diameter)	Tin plated copper wire	< 3g	Voltage Rating: 600V Insulation: Flame resistant modified polymer AWG: 22 Cable Type: FlexLite TW
Solderable Breadboard - PRT - 12070	99.06 x 68.58 x 10.16	PCB board with gold plated holes and busses	90.72 g	Voltage: 9-12V buses, 5-3.5V rails 2 Ground and Power rails 30 Holes long. 60 Rails 5 Holes Long

Leotek 12” Red LED Traffic Light	305.4 x 305.4 x 157.2	120V LED with red textured fogged glass	~1800 g	Wattage: 4.4W Voltage: 10-28 Vdc Wavelength: 626 Intensity: 364 cd
Traffic Light Controller	101.6 x 50.8 x 12.7	Electronic PCB with electrical components embedded.	45.4 g	Voltage: 85-265 VAC 37 Unique light configurations Solid state switching for silent operation

Table 7: Physical Properties of the Display Subsystem

3.2.A Idea Generation and Decision-Making Tools

	Binary On/Off Light	Light Grid Depicting the Whole Intersection	Binary On/Off Light with Color to Represent Distance	Light Grid with Color to Represent Distance
Intuitiveness (1.5)	4	2	2	1
Cost (1)	4	2	3	1
Ease of Production (1)	4	3	4	2
Feasibility of Design (1.5)	5	3	2	2
Ease of Installation (.5)	4	3	4	3
Total	23.5	14	15	9

Table 8: Display Design Decision Matrix

As seen in Table 3, the single color binary on/off light was the chosen design due to its high ratings in all of the design criteria. Note that some criteria are weighted differently than others; this is done to ensure the decision matrix accurately encompassed our values for the display. For example, since we needed the display to be intuitive and easy to understand for motorists, intuitiveness was weighted higher at 1.5. Similarly, the feasibility of design was weighted higher to ensure the scope of the project was not too high. When testing, we found it difficult to accurately determine distance just using the just RF transmitter and receiver, so the designs that included changing colors to represent distance got weighted lower in the feasibility of design category. Similarly, when doing stakeholder engagement, it was revealed that if changing colors were used, they could be interpreted differently. For example, red could be interpreted as a far distance or danger. Since these interpretations are opposites, confusion that could lead to misinformation may occur. Due to this, the intuitiveness of designs with changing colors was lowered significantly. Overall, the decision matrix concluded that a binary on/off light would work better than a grid in this scenario due to its higher intuitiveness and ease of production, and that the light should not change color to represent distance since we can't accurately transmit that data with the RF transmitter and receiver.

3.3.A Validation of the Novel Aspects

3.3.1.A Test Results

Since the display subsystem incorporates many different parts, and interfaces with many other subsystems, in-depth testing was required to ensure the validity of our design. To complete these tests, I used Jeffrey Blum's book, *Exploring arduino: Tools and techniques for engineering wizardry*, as a reference for example code and wiring, as well as technical information about Arduino and relevant components [12].

TEST #1: Light up an LED when given an arbitrary on or off input

The purpose of this test was to ensure that the Arduino can interface with a small LED correctly. The reason I did this test rather than just moving directly on to lighting up the LED with a radio signal is to make sure the code and wiring I had for a small LED worked in a vacuum. I wanted to ensure that if something went wrong when I was doing the next test, it was not the code or wiring for the LED, but something with the RF data. I wanted to make sure troubleshooting and debugging would be as easy as possible. To create this test, I wired a small red LED and a small pushbutton to the Arduino. I then wrote code to turn on the LED when the pushbutton was depressed. The wiring used for this test is shown below in Figure 1.

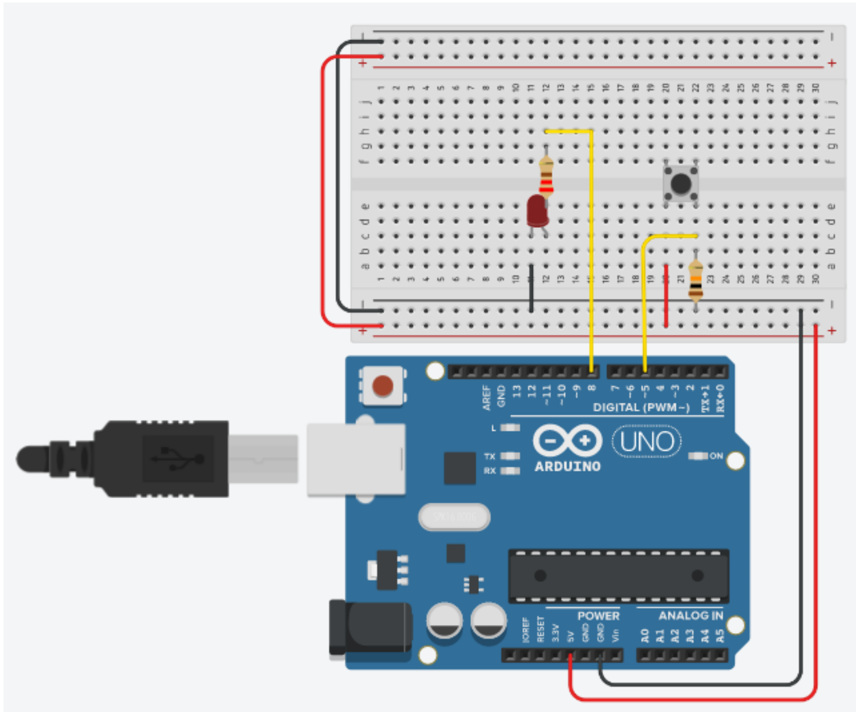
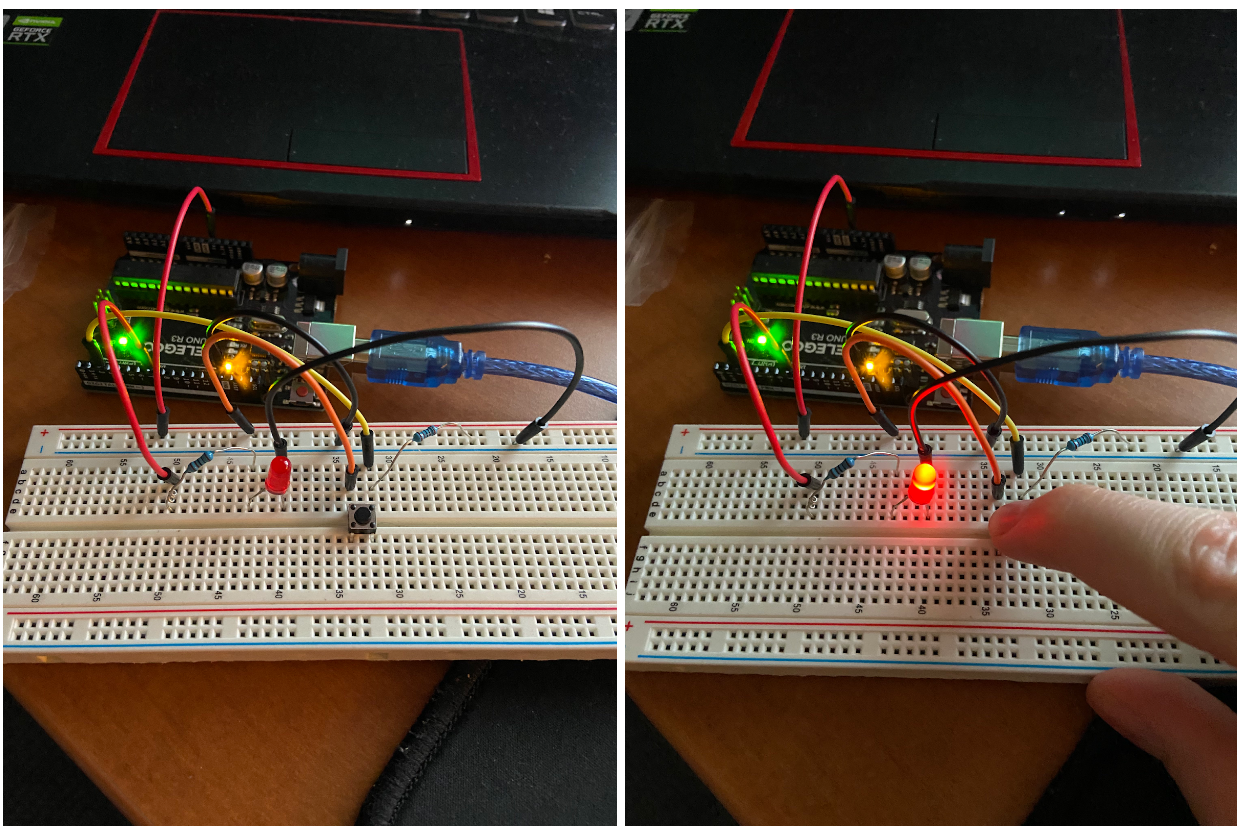


Figure 37: Graphic of the Pushbutton and LED wiring



Figures 38 & 39: Demonstration of Turning the LED on Utilizing the Pushbutton

As seen above in figures 2 and 3, the LED is off when the pushbutton is not depressed, and on when it is. This test was successful in proving that an LED can be turned on when given a binary on or off signal. I was also able to reuse a significant portion of the code and wiring from this test for other tests as well as the final design.

Test #2: Turn on an LED when given input from the receiver

This test was done to ensure the signal from the receiver could be received and processed in a way to turn on an LED. To create this test, I reused some of the code and wiring from test #1 but modified it so that the LED turns on when the receiver gets a signal from a transmitter. Shown below, Figure 4 depicts the wiring and setup used in this test.

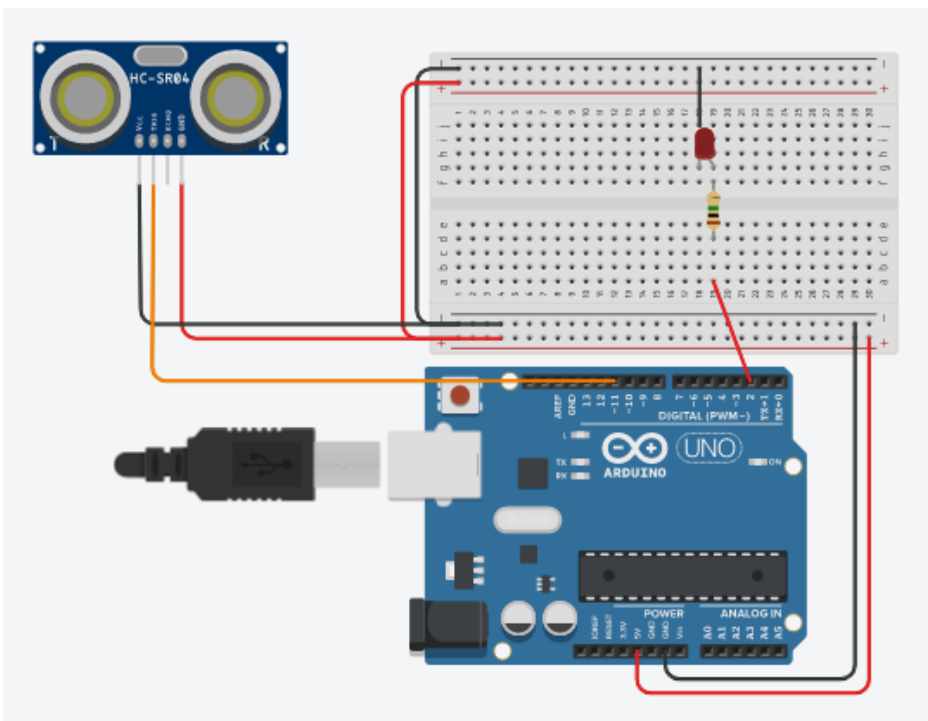


Figure 40: Graphic of the Receiver and LED wiring

Note that in the above diagram, the component in the top left represents the receiver, the software used to generate the graphic did not support RF receivers and transmitters. Also note that while the placeholder component has the same amount of pins as the real receiver, they are labeled incorrectly in the graphic. Consult the photos below as a reference to the real receiver.

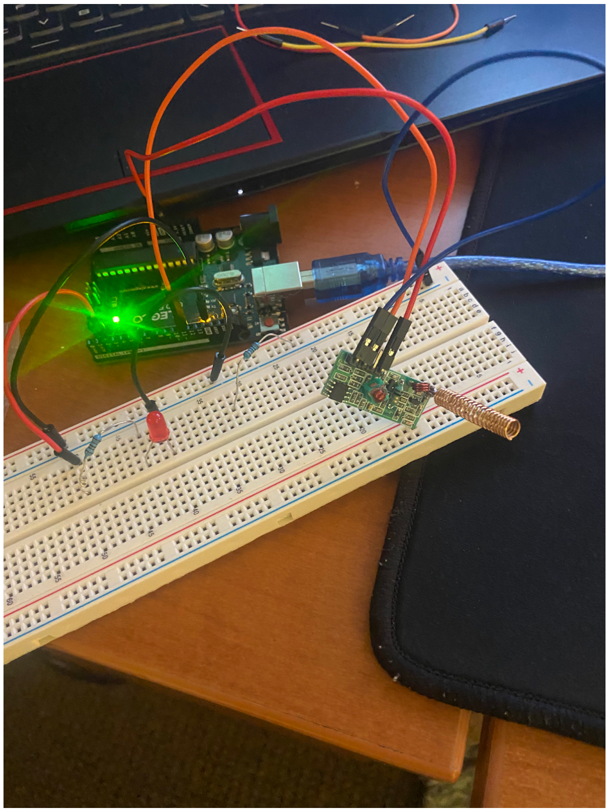


Figure 41: Receiver and LED when Transmitter is Out of Range

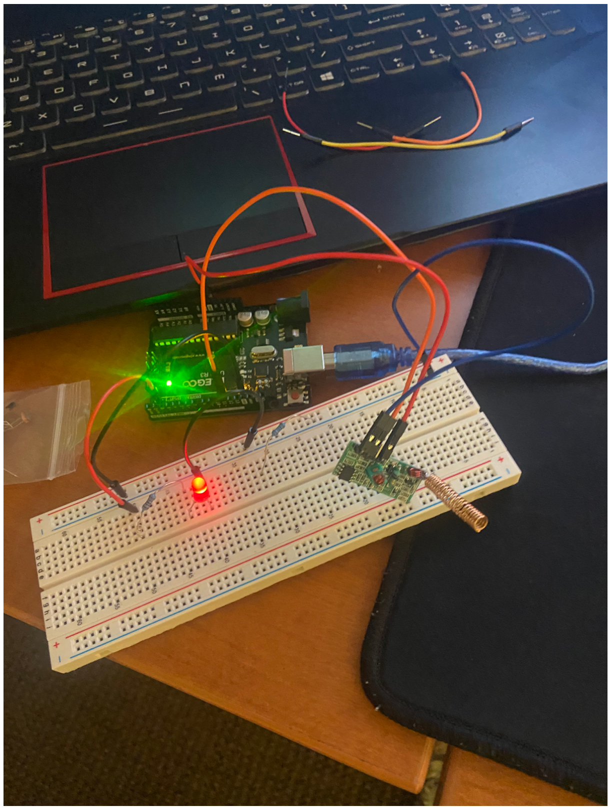


Figure 42: Receiver and LED when Transmitter is Within Range

As seen in figures 5 and 6, the test was successful; when the transmitter was in range the LED would light up indicating so. We also tested the working range of the transmitter and receiver and found that it worked until approximately 30 meters away. We believe the test conditions were sub-optimal due to the fact that there were people and obstacles blocking the radio waves. The test conditions were more conducive to realistic conditions than perfectly optimal conditions. We learned two things from the test: data from the receiver can be used to turn on a light/LED, and the transmitter and receiver still work under more realistic, less-than-ideal conditions.

3.3.3.A Secondary Research

For secondary research, I wanted to find sources that explored the ergonomics and intuitiveness of traffic lights and traffic infrastructure. Since a large part of the display is to be intuitive and easy to understand, I wanted to find research that gave tangible evidence of what to do to make the design fit these criteria. To accomplish this, I found 2 pieces of research. One that investigates hazard detection, action times, and how they change at different speeds. The other source examines communicative aspects of highway design as a whole, and how to accurately communicate the needed information.

The first document I used for research delves into how people perceive and react to complex traffic hazards. The source coins the term decision sight distance (DSD), the distance at which drivers can detect a hazard or signal in a cluttered roadway, determine its existence as a threat, and make the according changes to speed and path to maneuver to safety [40]. To obtain the following data, Mcgee developed the following steps to determine DSD:

1. Sighting - Baseline time point at which the hazard enters the motorist's line of sight
2. Detection - The motorist's eye fixates on the hazard and “sees” it
3. Recognition - The motorist’s brain recognizes the threat
4. Decision - The motorist analyzes different courses of action and chooses one
5. Response - The motorist initiates the required action
6. Completion of Maneuver - The motorist accomplishes the maneuver

With these criteria, Mcgee gathered data by doing test drives with hazards with willing participants, and measuring their reaction times. The data shows that most of the time involved in DSD is in steps 1-4, sighting, detection, recognition, and decision. On average 5-7 seconds are spent in steps 1-4, and 4-5 seconds are spent in the maneuver [40]. This is very significant as it highlights how important quick reaction times are in hazardous situations. If the time it takes motorists to detect and recognize that a bike is in the intersection is lower, the less chance there is of a collision. This information greatly helped in the ideation process of the design. It also helped in the creation of the decision matrix (Table 3) and is the reason intuitiveness is weighted higher. The source also provided data regarding the total distance from sighting to completion of the maneuver; this data will be used as a metric for deciding where in the intersection to put the display. The DSD distance for 40 km/h, for example, is 140 m, while the DSD distance for 100 km/h is significantly higher at 355m [40]. Intersections at lower speeds would have the display closer to the intersection, while intersections at higher speeds would have the display slightly further from the main intersection to accommodate for this change in decision sight distance.

The second source I used explores some physiological characteristics of drivers, and how they should affect highway design choices. Some of these physical characteristics include the height of the eye, perception-reaction time, deceleration, lane-changing behavior, and maintenance of headway between vehicles. The motorists' psychological state also affects how they drive. Some of these factors include attitude, philosophy, awareness, concerns, and capability [37]. Leisch also outlines some basic design objectives to ease some of these criteria:

1. Compensate for any momentary impairment of the motorist's physical or psychological state (anxiety, confusion, frustration, fatigue, monotony, alcohol, drugs, or illnesses)
2. Incorporate design features that would meet driver expectations
3. Design the highway in coordination with control devices in order to simplify the task of driving

The final design of the display was greatly swayed using these guidelines, specifically guideline 2, incorporating design features that would meet driver expectations. There are no road signs or displays that convey too much information, this is for a reason. Traffic and pedestrian lights are especially simple in order to be as intuitive as possible. This information helped the design stage by nudging me to keep in mind simpleness, this lead to the creation of the simple binary on/off design with the outline of a cyclist.

3.3.4.A Stakeholder and Expert Feedback

For stakeholder engagement, I gathered a small focus group of motorists and questioned them about the intuitiveness of different display methods. I drew two designs for possible displays on a sheet of paper. Design A depicts a complete 4-way intersection, with small lights in each part of the intersection. It was explained to the group that whenever a cyclist was detected in that part of the intersection, the light would shine, indicating to the motorists that a cyclist was nearby. Design B is a simple binary on/off light depicting whether or not a cyclist was anywhere in the intersection at all. Under both designs, I included two other options, with or without color. I explained to the group that a color design would change color from green to red based on how far away the cyclist was, i.e if the cyclist was far away and not a threat, the light would be green, and if the cyclist was close it would be red. I then passed the paper around and had the group put a tic or check under the option they thought would be the most intuitive and decrease the amount of car-bike collisions. The outcome is shown below in figure 7 [3].

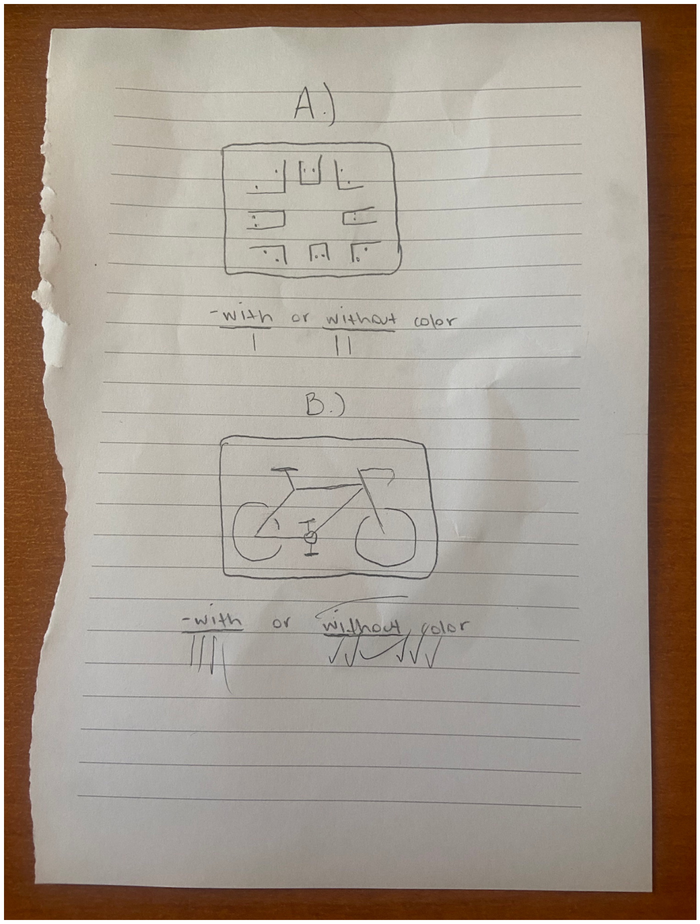


Figure 43: Image of the Survey Taken by the Focus Group

As you can see in Figure 7, design B, without color, was chosen by the focus group. When questioned about their decisions after the fact, many members of the group claimed that they chose design B due to its simplicity, they thought it would be easier to recognize and make sense of than design A. The people who chose design A cite the fact that it displays more information, which they liked. When questioned about why more people chose the designs without color, members of the group raised the idea that the colors could be confusing. They stated that the differing colors could be interpreted in two different ways, red meaning far distance, and red meaning danger. This kind of misunderstanding could lead to serious consequences as the two interpretations are complete opposites. Overall, stakeholder engagement with the focus group was incredibly useful in determining important and influential aspects of the design. It also highlighted a huge design flaw that could lead to extreme misinterpretation of the display, which may lead to a collision.

Eadyn's Section: Receiving and Processing of Signal

3.1.B Subsystem description

3.1.1B

3.1.1.1.B Overall Objectives

This subsystem is aimed at receiving and processing a signal from each Cyclist Location Emitter in the location. The subsystem needs to quickly and reliably identify every cyclist in the area, keeping track of both the number of cyclists and the time since a signal was received from each cyclist. This will allow us to maintain a counter of the cyclists present in an area, decreasing the counter when we have not received a signal from a cyclist in a certain amount of time. This design will be successful if it is able to do all of the following:

1. Receive and process signals from an arbitrary number of Cyclist Location Emitters
2. Identify and differentiate between individual Cyclist Location Emitters.
3. Track the total number of Cyclist Location Emitters
4. Identify when a Cyclist Location Emitter has left the range.

The receiver should be integrated with the rest of the design as shown in Figure 8, such that a signal can be received, processed, and displayed with the same controller. If this is possible, it will lower materials costs, and make the system easier to install and repair. This may be difficult if the location where we want signals to be detected is significantly different from the location of the sign itself. This may be the case, for instance, in a fast-moving intersection where drivers need to know if cyclists will be ahead well in advance, to account for decision sight distance.

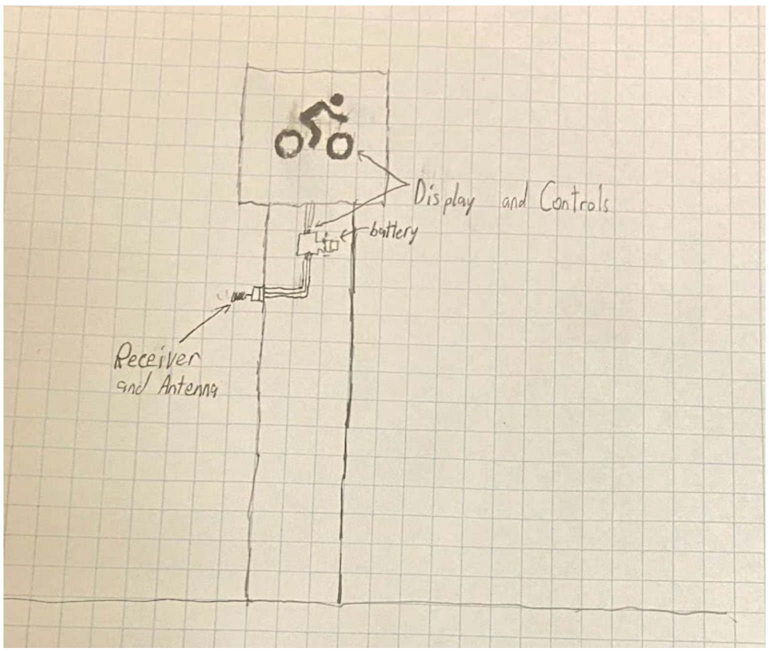


Figure 44: Receiver and Sign Layout

3.1.1.2.B How Does the Subsystem Work

To best fill all of these roles, the receiver needs to work on a constant loop. It needs to check input from the radio receiver at an interval not exceeding 20 milliseconds. This will ensure that data is received and processed in a timely manner. It will also help to compensate for any data loss due to obstructions or mechanical and electrical issues.

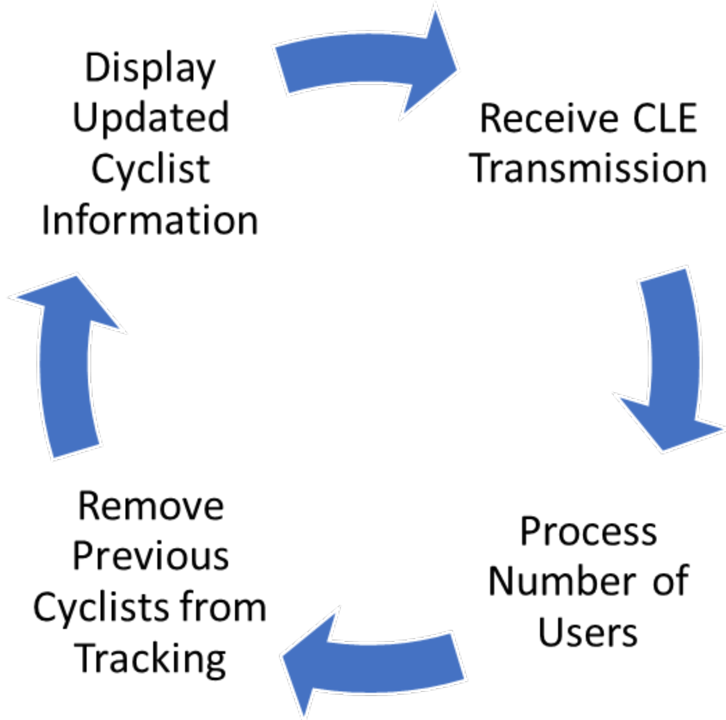


Figure 45: Receiver Processing Loop

This system, depicted graphically in Figure 9, is inspired by the Read Evaluate Print Loop (REPL) common in computer science. This implementation allows us to maintain an accurate list of cyclists in the area, removing them after they are likely to have left the area. It also ensures that the data displayed to motorists in the area is timely and accurate.

The period of the system is informed by the decision sight distance being used for the project. Drivers need time to process the information shown on signs and to take that information into account as they continue to drive. This requires that signs be posted in advance of intersections where cyclists are likely to be present. The below table shows generally accepted numbers for minimal distances. On a 40 km/hr road, for instance, signs will need to be posted 120 to 160 meters before an intersection [40].

Design Speed (km/h)	Time (s) Before Maneuver: Detection and Recognition	Time (s) Before Maneuver: Decision and Initiation of Response	Time (s): Maneuver (lane change)	Time (s): Total	Decision Sight Distance (m): Computed	Decision Sight Distance (m): Rounded for Design[a]
40	1.5-3.0	4.2-6.5	4.5	10.2-14	113-156	120-160
60	1.5-3.0	4.2-6.5	4.5	10.2-14	170-233	170-230
80	1.5-3.0	4.2-6.5	4.5	10.2-14	227-311	230-310
100	2.0-3.0	4.7-7.0	4.3	11.2-14.5	306-397	310-400
120	2.0-3.0	4.7-7.0	4.0	10.7-14	357-467	360-470
140	2.0-3.0	4.7-7.0	4.0	10.7-14	416-544	420-540

Note: 1 km = 0.62 mile; 1 m = 3.28 ft.
[a] Rounded up to the nearest 10 m for the low value and up or down to the nearest 10 m for the upper value.

Figure 46: Estimated Decision Sight Distance [40]

Whenever the Cyclist Location Emitter receives data, it needs to decode it, checking for a string to uniquely identify each cyclist. It needs to keep track of each such string received as well as the time in which it received them. For identifying strings in which no data has been received within a set period of time, it will be assumed that the corresponding cyclist has left the area. The receiver removes a cyclist from consideration after 4 seconds without a signal. We validated the emitter-receiver subsystems under a variety of conditions and found that this would be sufficient to count all cyclists within 40 meters. The results of this experiment are in Table 8, in 3.3B, subsystem validation.

3.1.1.3.B Necessary Inputs and Outputs

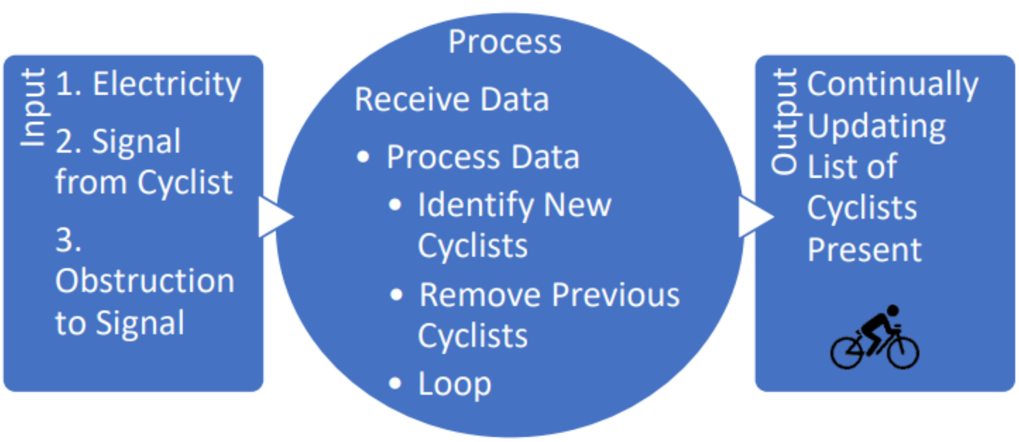


Figure 47: Process Diagram

This subsystem will need to take in electricity on a consistent basis from the sign housing subsystem. The receiver subsystem is built to accommodate common and small energy sources, such as 9-volt batteries. The subsystem will need to be able to receive any signals that are being transmitted by the emitter subsystem as well. An antenna ensures that it is able to do so over a long range. After internally processing data, it will need to output information to the display subsystem. Both the receiver subsystem and the display subsystem will be able to use the same Arduino Uno. This subsystem intentionally leaves enough pins on the board for the display to access the Arduino. It also outputs if cyclists are present as a boolean true/false value, which the display subsystem can process as part of the same code base.

3.1.1.4.B Key Components

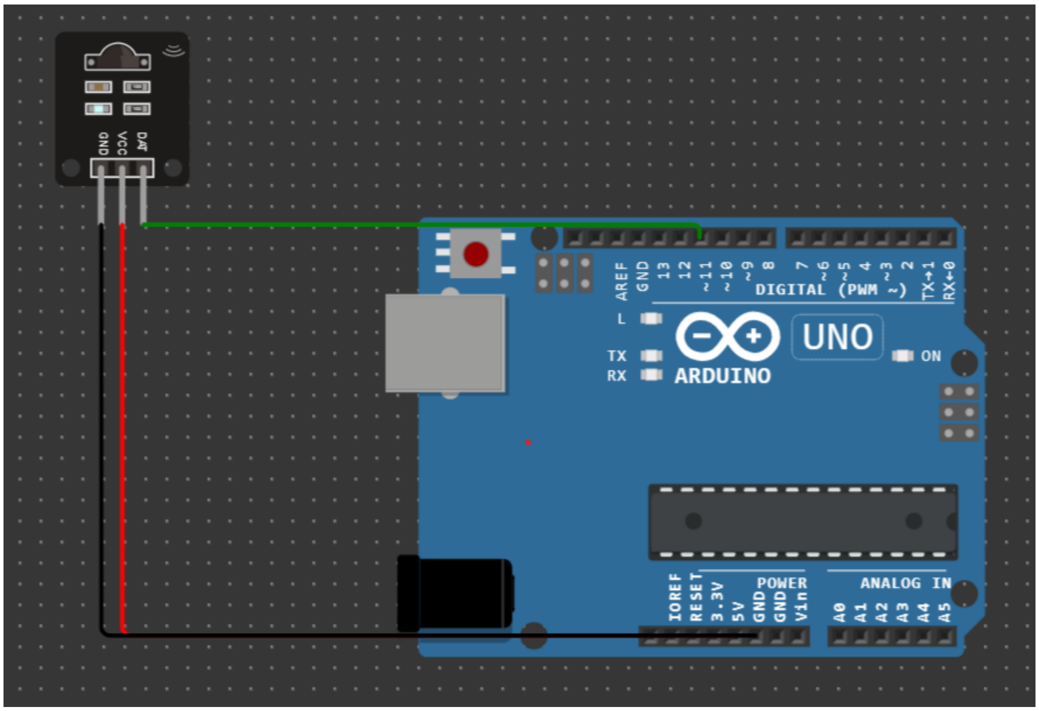
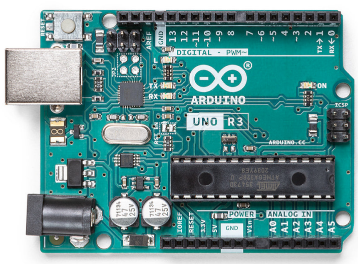
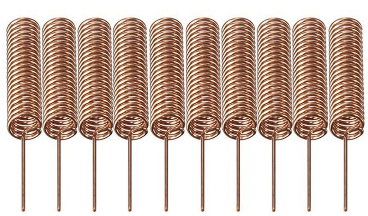


Figure 48: Arduino Microcontroller and RF Signal Receiver

All key subsystem components are displayed in the above circuit diagram. We need an Arduino Uno to do all necessary processing for the device, a radio frequency receiver to receive data, and electric wires to connect the components. The range of the receiver can be boosted with an antenna, with the specific antenna we used listed as the third off-the-shelf component.

3.1.1.5.B Off-the-Shelf Components

Item	Photo	Description	Cost
Arduino Uno		Arduino Uno is a widespread, effective, and cheap microcontroller meant to be easily customizable. This was ideal as it allowed for ready integration with the needed RF receiver and the associated processing [49].	$18
FLTWC0311-22-2 Solderable Electrical Wire		Wiring is used to connect the RF receiver and the Arduino Uno. This wire is flexible and of the requisite length to connect necessary components, without taking too much space in the housing.	$0.37 per wire, $0.74 for all needed wires
DAOKI Antenna Spiral Spring RC for Arduino 5mm		Antenna used to send and receive radio frequency signals over a distance. These are small, not taking up more space than is available in the housing. Additionally, they are moderately strong and resistant to damage.	$0.53 per antenna, with one needed for receiver

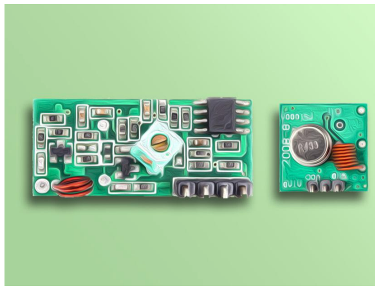
HiLetgo 315 Mhz RF Transmitter and Receiver for Arduino		Arduino attachment used to send and receive signals over radio frequency at 315 megahertz. This was chosen to limit signal interference and ensure an adequate range.	$0.38 for full kit, including transmitter and receiver

Table 9: Subsystem Components

3.1.2.B Physical Properties

Item	**Physical Descriptions**
Arduino Uno	Weight: 25 g Dimensions: 69mm x 54mm
FLTWC0311-22-2 Solderable Electrical Wire	Wire Gauge: 22 AWG
DAOKI Antenna Spiral Spring RC for Arduino 5mm	Diameter: 5mm Dimensions: 1.97 x 0.39 x 1.97 in
HiLetgo 315 Mhz RF Transmitter and Receiver for Arduino	Weight: 3.5 g Dimensions; 30 x 14 x 7 mm

Table 10: Subsystem Component Physical Details

3.2.B Idea Generation and Decision Making Tools

This subsystem is meant to ensure reliable access to cyclist information to cars nearby. It also needs to be cheap enough to be implemented on a mass scale. To this end, the subsystem has to evaluate both means of receiving information with a receiver, and means of processing with a microcontroller.

Criteria	**Arduino Uno**	**Raspberry Pi Pico**	**Raspberry Pi**
Cost	4	5	2
Processing Speed	3	1	5
Battery Life	5	3	3
Total	12	9	10

Table 11: Microcontroller Comparison

Cost estimates vary based on the location of purchase, however, Arduino Unos will generally cost less than $20. Raspberry Pis vary as well, depending on model and year, but they generally cost about $40. Raspberry Pi Picos are by far the cheapest, with costs of less than $10. These are less accessible, however, as they are frequently sold out or unavailable. Processing speed varies as well, with Raspberry Pis having significantly more power than an Arduino Uno, which is more powerful than a Pico. Arduino Unos have lower power consumption than Raspberry Pis, with similar accessibility to powering options. Both devices can be powered directly by batteries. Raspberry Pi Picos consume less energy than both devices, but are harder to power and require more specialized systems[49].

Criteria	RF Transmission	Bluetooth	WiFi
Cost	5	4	2
Power Consumption	3	4	1
Range	4	3	2
Signal Robustness	5	1	2
Total	17	12	7

Table 12: Means of Signal Transmission Comparison

Another core consideration of the Cyclist Location Emitter was the means of signal transmission. Here, needs were informed by what would be practical to implement and what would be able to work robustly under real-world conditions. Cost and power consumption were both aimed at ensuring the design can be implemented, while the range and signal robustness are meant to ensure that the design can work as it needs to. Cost rankings were based on prices for the devices present on Amazon. Power consumption and the range were pulled from datasheets for the associated products [2] [3] [53]. Signal robustness was informed by the types of interference that were likely to be present in the areas this system will be installed [54]. They were also discussed with Bryce Miller, an electrical engineering student and professional systems administrator. Ultimately, the prototype has been designed to use RF for emission and receiving, as depicted in Figure 13.

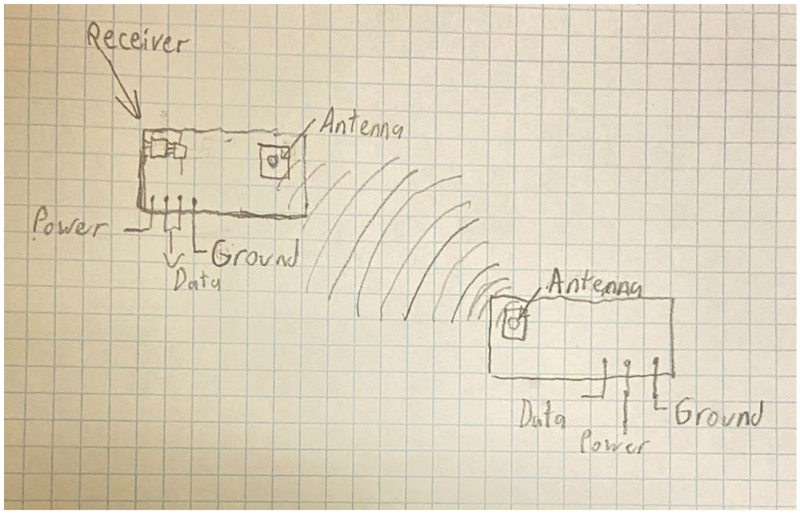


Figure 49: RF Transmitter and Receiver

3.3.B Validation of the Novel Aspects of Subsystem

3.3.1.B Testing

Test #1: Sending and Receiving

This test was meant to ensure that data can be sent and received from across a distance using the technology we had available. Specifically, we attempted to send the string, “Hello, it’s me”, from across a room. Initial trials were unsuccessful, requiring that we introduce an antenna to reach the ranges necessary for the device to work. After that introduction, we were able to send and receive data as necessary, as displayed in Figure 14.

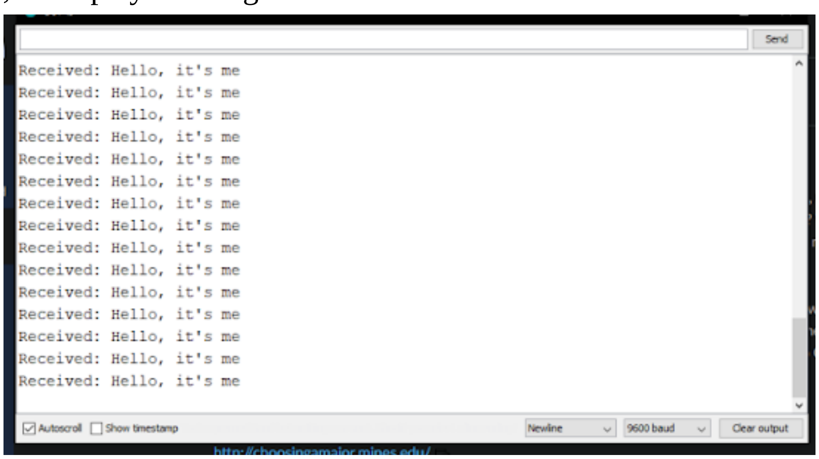


Figure 50: Message Sent over RF

Test #2: Transmission Distance

Distance	Obstacles Present?	Data received
5 meters	no	Yes
5 meters	yes	Yes
10 meters	no	Yes
10 meters	yes	Yes
15 meters	no	Yes
15 meters	yes	Yes
20 meters	no	Yes
20 meters	yes	Yes
25 meters	no	Yes
25 meters	yes	Yes
30 meters	no	Yes
30 meters	yes	Yes
35 meters	no	Yes
35 meters	yes	Yes
40 meters	no	Yes
40 meters	yes	Yes

Table 13: Signal Strength Test

From the table above, we find that the subsystem is able to work under the necessary ranges. This test was conducted on the upper floor of McNeil Hall, along a straight hallway with minimal obstacles already in place. This significantly simplified testing, requiring only that distances be marked off and that obstacles such as people and wifi connected devices be introduced. The Cyclist Location Emitter was capable of transmitting across the entirety of the hallway. It was not, however, able to penetrate the walls and flooring. This is likely due to the much heavier signal obstruction presented by them as a result of the wiring present.

3.3.3.B Secondary Research

Heterogeneous Visible Light and Radio Communication for Improving Safety Message Dissemination at Road Intersection

This work, published in the IEEE Transactions on Intelligent Transportation Systems in October of 2022 deals with estimates of current radio frequency (RF) interference, as well as projecting future levels of interference [54]. It largely focuses on vehicle-to-vehicle and vehicle-to-environment communication, which is likely to be critical to future fully or partially automated cars. This is of relevance to the project as it allows for accurate estimates of the interference the Cyclist Location Emitter is likely to face. The researchers note, "The vehicular-radio frequency (V-RF) communication tends to suffer from higher interference, longer communication delays, and lower packet delivery rates as the density of the vehicles increases. To improve the reaction time in critical scenarios and to obtain full situational awareness, one requires relatively long communication ranges, extremely low latencies, as well as high packet delivery ratios." While some of these concerns are present for the CLE, many are not. Communication delays and low packet delivery rates do not have a substantial impact, so long as the device stays above a minimum threshold. Similarly, due to the binary nature of the sign (displaying only whether a cyclist is present, rather than trying to add extra information like cyclist direction), CLE performance is unlikely to suffer as a result of more cyclists in an area. The researchers also note that current RF usage rates are low, with greater future utilization projected. This suggests the possibility that the device will interfere with other safety-critical systems. While this is not currently an issue, it suggests that alternative means of detecting cyclists should be considered before deploying the CLE at scale.

A Stochastic Model for Prediction and Avoidance of RF Interference to Cognitive Radars

This paper, published in the IEEE 2019 edition of the Radar Conference, addresses means of predicting RF usage times and frequencies to better avoid interference [36]. This technique could be implemented in busy intersections to improve device reliability and to limit interference with surrounding technologies. If RF becomes significantly more common going forward, as the first research paper in this section predicts, implementing this technology will be critical.

3.3.4.B Stakeholder and Expert Feedback

Interview with Jeffrey Holley

Jeffrey Holley is an experienced civil engineer with a focus on urban infrastructure design and a professor at the Colorado School of Mines. He is also a fellow of the American Society of Civil Engineers. He was interviewed with the goal of assessing the general design as well as obtaining more information about sign and receiver placement, necessary security precautions, and how widespread the design would need to be to test efficacy [48].

He was significantly enthusiastic about the idea itself, at one point stating, "The more I talk about it the more I think this concept[the Cyclist Location Emitter] is long overdue." While he was fond of the device itself, he was more skeptical of the means of counting cyclists. In particular, he was concerned that, if this device enters common usage, cyclists without it would be in greater danger, as motorists might come to rely on the sign to inform their levels of caution. To mitigate this, he suggested alternative means of counting cyclists built into the infrastructure itself. As possible alternatives, he referenced both tactile sensors to see when a cyclist has crossed over an area and optical sensors to count cyclists using machine learning techniques. While both ideas merit further consideration, the group has decided not to move forward with them out of concern for the possibility of false positives and false negatives.

In addition to the general information he provided on the design, Holley referred the team to specific resources on sign design and placement. He stated that the sign must be far enough from the intersection for motorists to perceive and process all information necessary, referring to this as "Decision Sight Distance."

He also clarified that the sign itself was likely to face vandalism attempts, and will therefore need to protect the internal components. He suggested that, in Colorado, it is common to protect electronic sign components by placing them inside of steel boxes. This is not viable for our design as that is likely to introduce too much interference to the RF signal.

The group also discussed with Holley how to lay out an effective trial for the device. It was his opinion that testing at an individual intersection would be insufficient to get a significant idea of how well this device will work. He did, however, think that an individual city or neighborhood would be a workable level to test at. It is specifically important to test in areas that have reliable accident and fatality data from previous years.

Connor's Section: Signal Emitter Housing and Power Delivery

3.1.C Subsystem description

3.1.1.C Subsystem in Context of Full Solution

The intent of this overall system is to allow for the presence of cyclists in intersections to be detected in real-time and then conveyed to motorists. This system can be subdivided into two modules, the sign component, and the cyclist location emitter. The sign component is meant to detect the presence of a cyclist in an intersection by receiving a coded RF transmission which is passively transmitted by the cyclist location emitter, and then activates a light to notify motorists that there is a cyclist in the intersection.

This subsystem is a part of the cyclist location emitter and involves the housing of electrical components, the powering of electrical components, and the mounting of electrical and powering components to a bike.

3.1.1.1.C Subsystem Objective and Key Components

The primary objectives and outputs of the subsystem are as follows:

1. Delivers power to transmission antenna and controlling Arduino. The Arduino and antenna must be receiving enough power to operate and transmit the signal.
2. Protects components from inclement conditions which may be encountered during cycling, ie. rocks, dust, water, plant matter, bugs, animals, etc. Outside contaminants should be unable to enter the case under typical cycling conditions.
3. Does not inhibit RF transmission. The transmitter should transmit nearly exactly as effectively as it would without the housing.
4. Provide a way to turn on and off the cyclist location emitter. To extend battery life, there must be a way to turn off the component.
5. Allows for the cyclist location emitter to be attached to a bike.

The key components to achieving those objectives and outputs are listed below. Greater technical and physical properties are detailed in section 3.1.2.C.

1. A battery to act as a localized power source.
2. A case to contain, mount, and protect components.
3. A user interface in the form of a power switch.
4. Internal wires to act as connectivity mediums.
5. A velcro fastening strap.

3.1.1.2.C How the Subsystem Achieves Outputs

The various interconnected components all contribute directly or indirectly to achieving the subsystem objectives. Objectives 1 and 4, power delivery and switching capabilities are achieved as diagrammed below, where the switch must be activated before power will be circulated in the Arduino. The power switch is physically situated on the outside of the case such that the user can access it. Though it would be logistically easier to have constant and uninterruptible power delivery to the Arduino, it is better for the longevity of the hardware and length of battery life to do so.

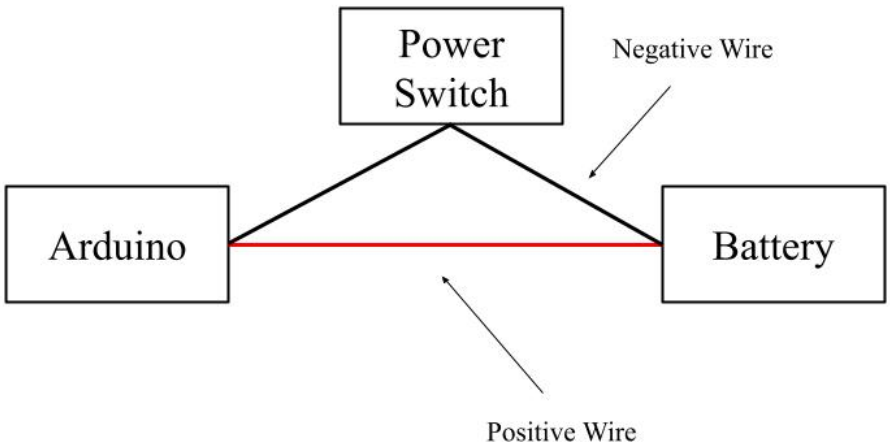


Fig 51: Diagram of the electrical connections within and without the subsystem.

The case addresses objective 2, protecting the electrical and other internal components. Foreign matter being introduced to the internal components can easily damage the functionality of those components, so a protective case is requisite for the extended function of the device. It does this by providing a physical barrier between it and the other internal components. Further protection is provided by the designed overlap of the base and lid components of the case, turning what would be an otherwise exposed crack connecting the inside and outside of the system into a sealed-off crack which would see far less foreign matter enter the inside of the case. The case is also strong enough to survive undamaged when faced with any typically encountered shocks of blunt force it would encounter over the course of use.

Objective 3, allowing uninhibited transmission of RF signals from the antenna, is achieved passively by the case, as the case is constructed from injection-molded polystyrene, which only inhibits the transmission of RF waves negligibly more than air itself. [52]

The velcro strap and the notch present on the lid of the case allow for it to be attached to and detached from a bike with relative ease and no specialized tools. It only needs to be fed through the notch in the case and fastened to a bike crossbar or other comparable attachment location.

3.1.1.3.C Subsystem Required Inputs

The primary input required for the function of this subsystem is user input. User input is required to operate the switch which will begin or discontinue power delivery to the electrical components of the system. Similarly, user input is required to charge and replace the batteries within the subsystem to allow it to have a power source to draw from. Maintenance on the other components, including the case, wiring, switch, etc., will be done via input from the user or technician.

3.1.1.4.C Key Subsystem Components

The full list of subsystem components is as follows:

1. Standard 9V EBL rechargeable battery with a standard snap connector on top.
2. Externally mounted power switch featuring only on and off positions.
3. Internally run narrow gauge copper wires connecting the power switch, battery, and Arduino.
4. Standard 9 Volt Battery Snap-on Lead
5. Heavy Duty Microfiber Velcro Strap
6. A case custom designed to house the components of the bike system

3.1.1.5.C For Off-The-Shelf Components

Below is a table of components necessary to produce the requisite inputs and outputs.

Component Name	Component Image	Component Description
EBL Rechargeable 9 Volt Battery		The system's battery measures the standard 48.5mm x 26.5mm x 17.5mm and has a standard snap connector on top. The subsystem is intended to work using standard ELB rechargeable cells, although any other standard 9-volt battery should function effectively in the system. [1]

Standard 9 Volt Battery Snap-on Lead		This 9-volt battery lead has a standard snap connector at one end and a standard Arduino power connector at the other, allowing for the Arduino to be connected to and draw power from the 9-volt battery. The cable length is 4.5 inches.
DaierTek Circle Round Rocker On/Off Switch		Typical on-off switches can be used to complete a circuit. The switches are round rockers and have an input and output prong at the end. [5]
FLTWC0311-22-2 Solderable Electrical Wire		Insulated wire was used to connect the battery to the power switch and subsequently the power switch to the Arduino. The wire measures AWG 22 and is insulated with typical thermoplastic rubber.

Heavy Duty Microfiber Velcro Strap		A long, velcro strip utilizing typical microfiber technology with a buckle-type device at one end to prevent unfurling. The item is meant to see excessive reuse and be easily replaceable. [5]

Table 14: List of off-the-shelf components used in the cyclist location emitter housing and power delivery subsystem.

3.1.2.C Physical Properties of Subsystem Components

Component Name	Dimensions (mm)	Material Type	Weight	Other Specifications
EBL Rechargeable 9V Battery	48.5 x 26.5 x 17.5	Steel, Zinc, and Manganese	45.0 g	Voltage Output: 9V Volume: 22,800 mm^3
On/Off Switch	23.1 x 23.1 x 25.4	Plastic, Copper, Zinc	< 10 g	Voltage Rating: 9 Volts Current Rating: 6.0 amps Contact Resistance: 35
Copper Wiring	.33 (diameter)	Tin Plated Copper Wire, Rubber	< 10 g	Voltage Rating: 600V Insulation: Flame resistant modified polymer AWG: 22 Cable Type: FlexLite TW
Battery Lead	152.4 x 12.7 x 7.6	Tin Plated Copper Wire, Rubber	< 10 g	Voltage Rating: 9V Connection Type: 9V Standard Snap-On Cable Length: 114.3 mm
Case	122.9 x 58.4 x 35.6 (Internal) 128.0 x 63.5 x 38.1 (External) 133.6 x 69.1 x 6.3	Polystyrene	65 g	Volume: 81,935.3 mm^3 Color: Black Lid lip extends 2.8mm outwards beyond the base, overlaps for 38mm.

	(Lid)			Mounting Risers extend 3.8 mm above the case floor. The lid notch extends 12.7 mm above the top. Additional dimensions are below.
Velcro Strap	203.2 x 19.5 x 2.5	Acrylic Microfibers	< 10 g	Width for all but the last ~25mm of the strip is 12.7 mm.

Table 15: Table of relevant physical properties and technical specifications of components used in the cyclist location emitter housing and power delivery subsystem.

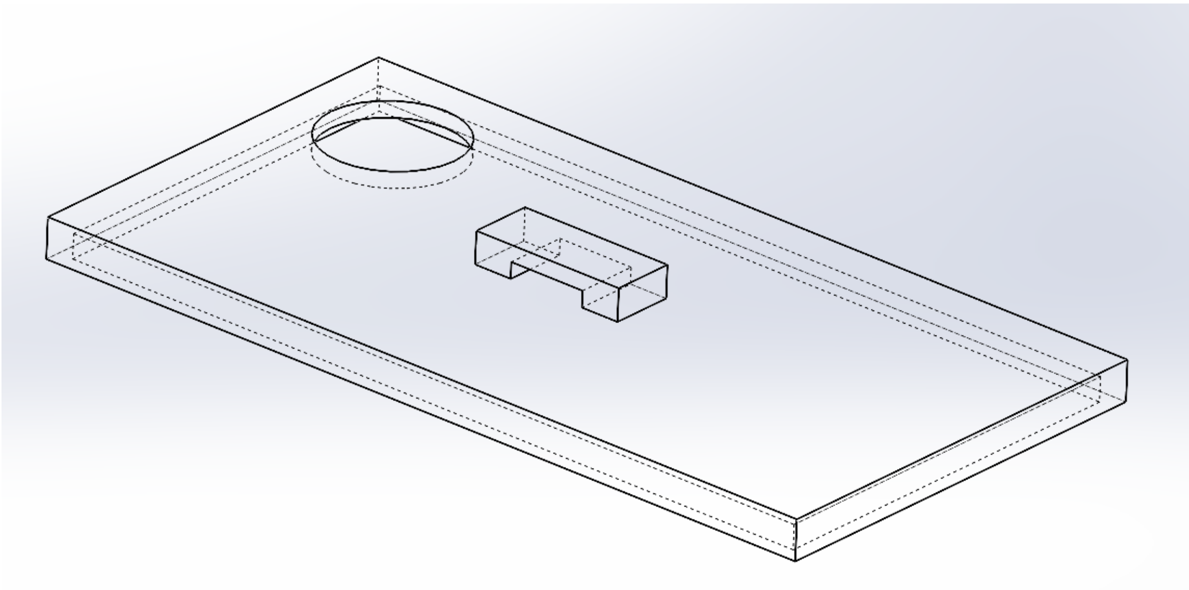


Fig 52: Isometric View of the top, lid component of the case.

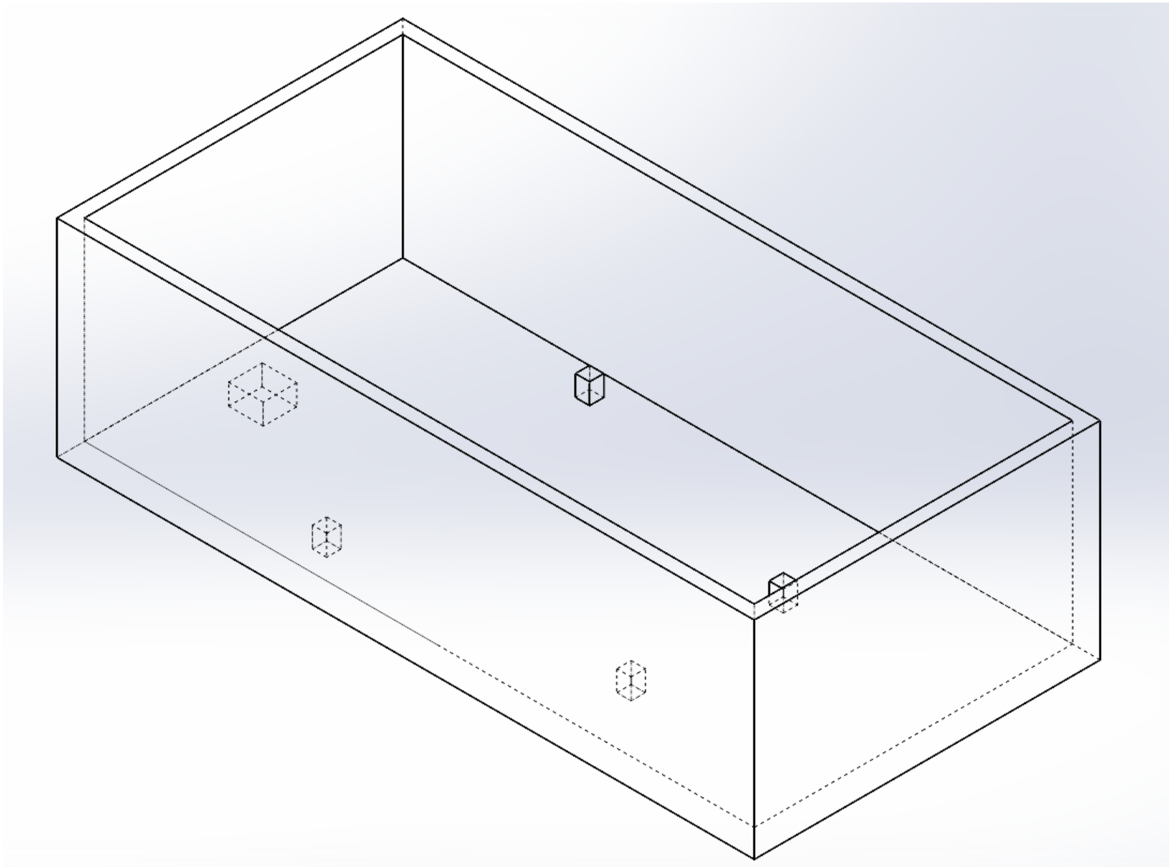


Fig 53: Isometric view model of the bottom, base component of the case, including walls and mounting risers.

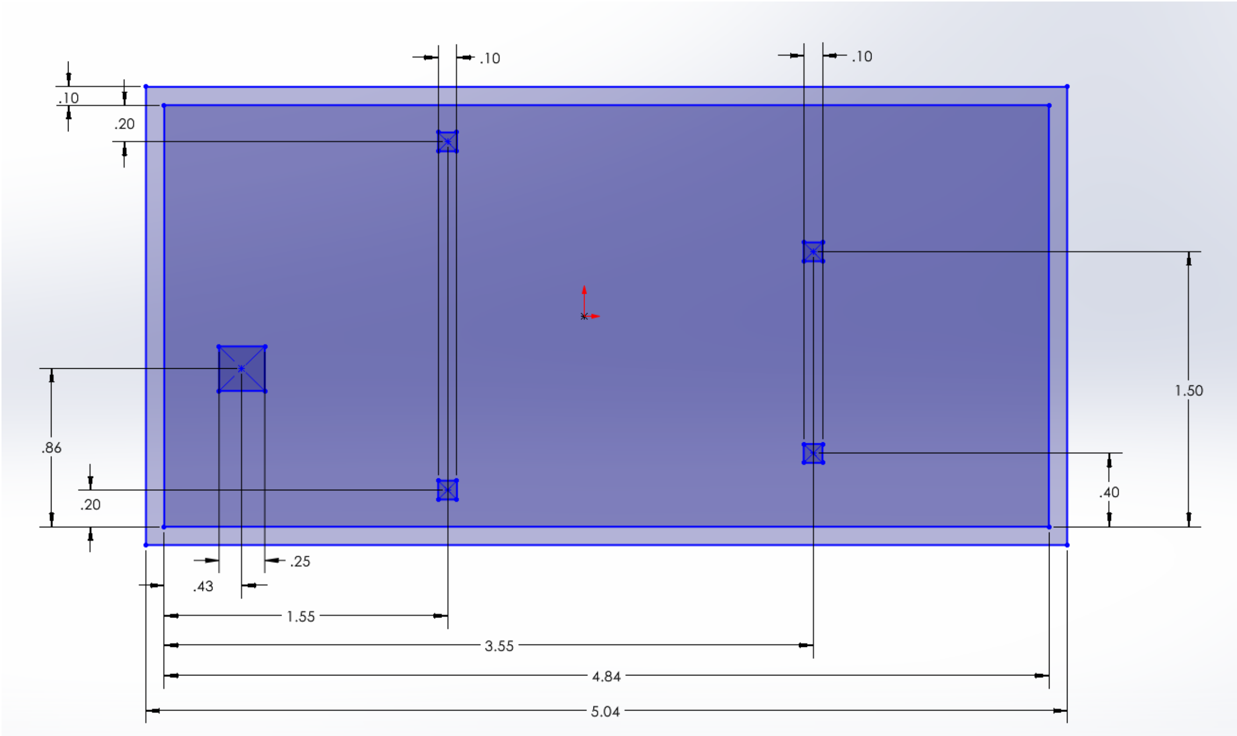


Fig 54: Dimensioned top view sketch of the case base.

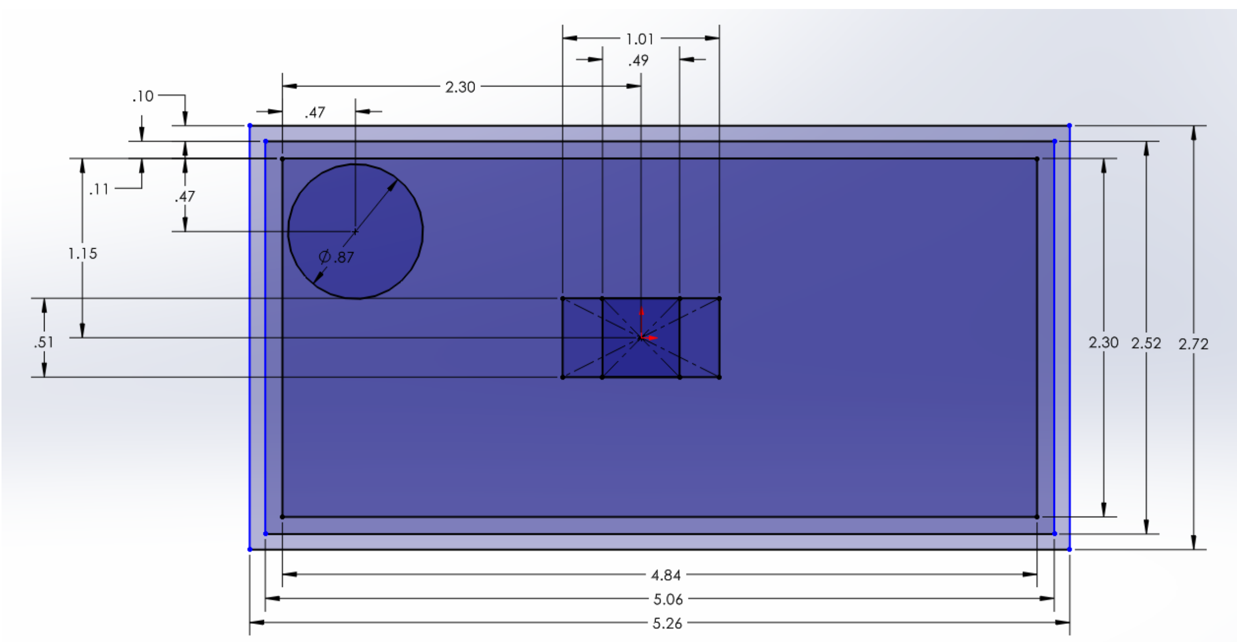


Fig 55: Dimensioned top view sketch of the case lid.

3.2.C Idea Generation and Decision-Making Tools for Critical

There were several choices to use for the materials of the case itself, the three primary ones considered were aluminum, steel, and polystyrene. I created the following decision matrix using the criteria of cost, weight, protective quality, and ability to not inhibit RF transmission. The most important aspect is that RF transmissions be emitted uninhibited, and as such the category was weighted 3x. Cost is also a major factor because this solution is being implemented on a large scale, so making something cheaper will greatly streamline its implementation. The cost will be weighted 2x.

	Aluminum	**Steel**	**Polystyrene**
Cost (x2)	3	2	5
Weight	4	3	5
Protective Quality	4	5	3
Allows RF Transmissions (x3)	4	3	5 [52]
Total	26	21	33

Table 16: Decision matrix pertaining to the construction material of the housing.

Another important area of question is the medium of power delivery. A localized battery, solar power, and even a mainline power system similar to that used by light rail trains were considered based on their cost, practicality, and effectiveness in delivering power. Practicality was valued 2x because an impractical idea cannot see implementation, and this design needs to be simple enough to mass produce on a gigantic scale.

	Battery	**Solar**	**Mainline**
Cost	5	4	2
Practicality (2x)	5	4	1
Effectiveness	4	3	5
Total	19	15	9

Table 17: Decision matrix pertaining to the power delivery mechanism for the cyclist location emitter.

The final central decision of contention was the comprehensiveness of the case. The original case which comprehensively contained all components was much larger than anticipated, so the question was raised if everything even needed to be in the case, or if there could be auxiliary cases. These possibilities were evaluated based on ease of use, effective protection of the components, footprint, and aesthetics, with aesthetics being weighted 0.5x because the visual appeal of the case is less important than how effectively it achieves the other characteristics listed.

	Unitary Case	**Auxiliary Cases**	**External Components**
Ease of Use	5	4	4
Protectiveness	5	4	2
Footprint	3	4	4
Aesthetics (0.5x)	4	4	2
Total	15	14	11

Fig 18: Decision matrix pertaining to the comprehensiveness of the cyclist location emitter case.

3.3.C Validation of the Novel Aspects

3.3.1.C Test Results

Over the course of early prototyping, several of the capabilities of the subsystem needed to be validated through testing. Firstly, it needed to be verified that the Arduino could be powered in a self-contained system using only a 9V battery. It's generally considered common knowledge that it can be, but nonetheless, early prototypes of the system were successfully powered using 9V batteries and were able to successfully transmit RF signals when doing so.

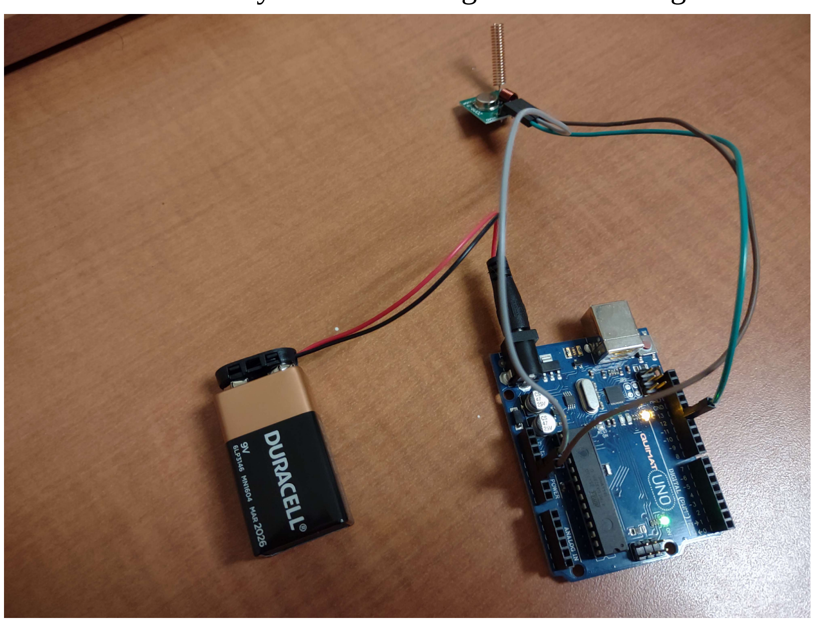


Fig 56: Image of Ardruno being powered with a 9V battery. Note the activated power indicator light.

The case itself also needed testing, the three different relevant concerns being that it could successfully house and mount all the components, would be able to protect them from foreign contaminants, at least to an extent, and would not inhibit the transmission of the RF signals. Though all of these things would theoretically be successful, they nonetheless needed to be verified in actuality. The first test was a test fit of the components. Below is an image from a test fit of prototype components within the case, demonstrating they were able to fit within each other as was intended without issue.

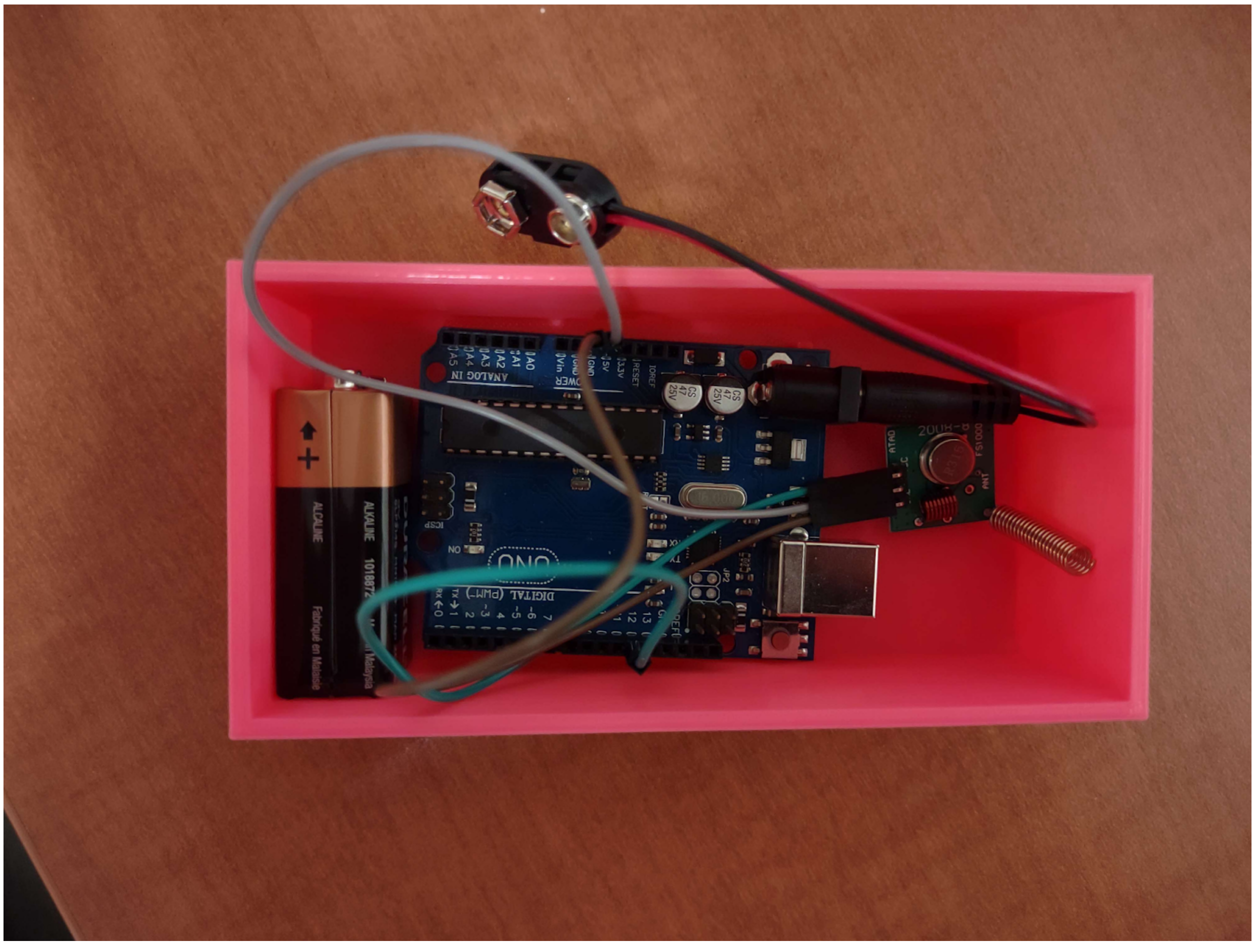


Fig 57: Test fit of prototype components into the 3D print of a case.

It was also necessary to test that the case would not allow foreign contaminants to enter the case easily. To test this, two trials of running the case underwater for 30 seconds were performed. The first one held the case at the most ideal angle to prevent entry into the case. In the second trial, the case was held upside down, at an unideal angle because water can more easily seep in through the crack. The results are qualitatively described below.

Trial	Amount of Water in Case
Ideal Angle	None
Unideal Angle	Some water entered the case, although not even enough to cover the bottom, and far less than would have reached components without a case.

Table 19: Data from experimentation of the case's water-resistant capabilities

The final experimentation done on the case was of the ability of the transmitter antenna to transmit the signal through the polystyrene of the box. For this experimentation, the only trial was simply placing the antenna inside the closed polystyrene box. Under these conditions, the receiver was still able to receive the RF transmission from the transmitter antenna, verifying that the housing will not interfere with the transmission.

Through testing, it was demonstrated that a number of the critical aspects of this subsystem are effective in doing what they need to. The case is capable of housing and protecting the components to a satisfactory degree while not inhibiting the ability of the antenna to transmit the RF transmission.

3.3.3.C Secondary Research

Because this component is one that will go on a person's bike, it's important that cyclists would actually be willing to install it, and that the dimensional and weight aspects are not problematic to the point of preventing adoption. To do this, an exploration of other bike attachments was done to establish that the physical properties of this component are not problematic.
Though there is no published data pertaining to kickstand use, they are a common bike attachment that people oftentimes chose to have for the added convenience, despite the extra weight and bulky profile. This product is estimated to weigh about 0.3-0.4 pounds, which is significantly less than the typical kickstand, which weighs 0.5-1.5 pounds. Considering that many people are willing to adopt the significantly heavier bike attachment, it is reasonable to extrapolate that the additional weight will not be a massive detriment to the adoption of the product. Cyclists also typically have at least a small pack of tools or other paraphernalia attached to their bike at all times, which is additional weight that provides utility and sees widespread use. [47]

Although a small difference in weight is demonstrated to make a significant difference in cycling speed and the effort required to do it, the additional weight from this product is negligible compared to the already present weight between a cyclist, their bike, and anything else they may be carrying. The average American weighs about 180 pounds, and the average road bike weighs another 18. [9] The cyclist location emitter would add approximately an additional 0.2% weight. Given the adoption of already existing bike attachments and their weight compared to this product, and given the overall negligible weight of the product, it is reasonable to assume that the weight from the battery and case, which constitute most of the overall weight of the cyclist location emitter, is not problematic.

However, the profile of the product is potentially an issue of concern too. If the product is inconvenient to position on a bike, then that would also inhibit its adoption. Compared once again to other, already existing bike attachments, such as water bottle cages, this product which also sees common implementation, has a similar profile to that of the cyclist location emitter of the product. [70] There are numerous convenient places where a water bottle cage can be attached, and all of those same places can be used to install a bike location emitter as well. [33] The crossbars, handlebars, sidebars, seat risers, and numerous other locations. [33]
One concern not pertaining to the logistics of the bike location emitter, but rather the strength of the box also needs to be researched. The material of the box, polystyrene, was chosen primarily on the merit of not inhibiting the RF transmissions and being low cost. [52] It has been demonstrated, however, that polystyrene is capable of withstanding 53 mPa of force, which is wildly more than is necessary considering what could be expected during the use of a bike under any typical circumstances. [51] Given the force tolerances of polystyrene, it would be reasonable to expect the case to not only survive any encountered hits but also likely survive intact in a collision with a car. [19]

3.3.4.C Stakeholder and Expert Feedback

Two stakeholders were revisited from the initial round of stakeholder involvement during subsystem validation, Professor Jeffrey Holley, who is a civil engineering professor at the Colorado School of Mines, and Edward Pallis, who has been a long-time road and mountain cyclist.

Professor Jeffrey Holley was asked in particular about his thoughts on whether cyclists would be willing to actually use the product because it does require some extent of user input to maintain and is not without some inconvenience to use. His thoughts on the matter were such that people may be willing to do that maintenance, although minimizing the extent to which they need to do that would be best. He compared it to other forms of maintenance, such as cars, saying that people are willing to do it, but typically only when they're pressed to and won't do things proactively.

For the material for the housing, he said that the department of transportation typically implements steel casings for electronic components in free-standing signs, though the primary motivation for that is preventing vandalism. Because the bike location emitter won't be as exposed to vandalism, it does not need to be constructed in such a robust manner.
Despite his concerns pertaining to the efficacy of user maintenance on the battery, he overall thought the solution would work. He agreed that a polystyrene box would be fine as component

housing, in that it shouldn't mess with transmission and would be durable enough for general use.

Professor Holley also stated that the overall project of a bike location emitter and its corresponding sign was "Long overdue," and indicated that he thought the solution and all the involved subsystems were a viable approach to addressing our problem of protecting cyclists on urban infrastructure. [48] The other stakeholder interviewed was Edward Pallis, a long-time road and mountain cyclist. He agreed with the other research that the weight and profile of the design were not inherently inhibitory to the adoption of the design because it is ultimately a small, light, low-profile box. He also agreed that cyclists would typically be fine adding even a substantial amount of additional weight if it means they would be safer during commutes. He also agreed that the mounting mechanism would be fine, although that velcro is maybe not the most reliable or secure way to do that, and a screw-in bracket might be less likely to fall off or be stolen. [47] Overall, the stakeholders who were interviewed on the topic generally considered both the overall idea and the specific mechanics of the housing and power delivery to be viable within the scope of the issue.

Eoghan’s Section: Transceiving Signal

3.1.D Subsystem description

3.1.1.D

3.1.1.1.D

The Cyclist Location Emitter’s (CLE’s) purpose is to emit a 315Mhz RF signal at regular intervals so that the receiver can detect and activate the warning light for motorists to be alerted to a cyclist. The purpose of this subsystem in the scaled-up version will be to provide a power-efficient and compact RF emitter that can easily be integrated into a wide variety of bikes. It will also need to be cheap to produce to maximize the adoption of the idea.

3.1.1.2.D

To fulfill this, the CLE will use a microcontroller to operate and power a simple 315 Mhz RF emitter. The reason for using a microcontroller is due to the commoditization of computing chips leading to extremely cost-effective general-purpose microcontrollers. For our works like prototype, we will use an Arduino, but in the scaled-up version, we can use a multitude of different controllers that can all complete the same purpose.

3.1.1.3.D

The job of the microcontroller is to provide ground and 5v power to the RF emitter along with a data cable to transfer an RF message at regular intervals. The controller will create a user ID every time it is turned on and send that to the receiver through the RF emitter. The controller will also create regular delays (1000ms) in between sending messages so that there is not an excess of messages being sent along with reducing the drain on the battery.

Fig 58: Sketch showing the possible positioning of the CLE (position is not overly important)

3.1.1.4.D

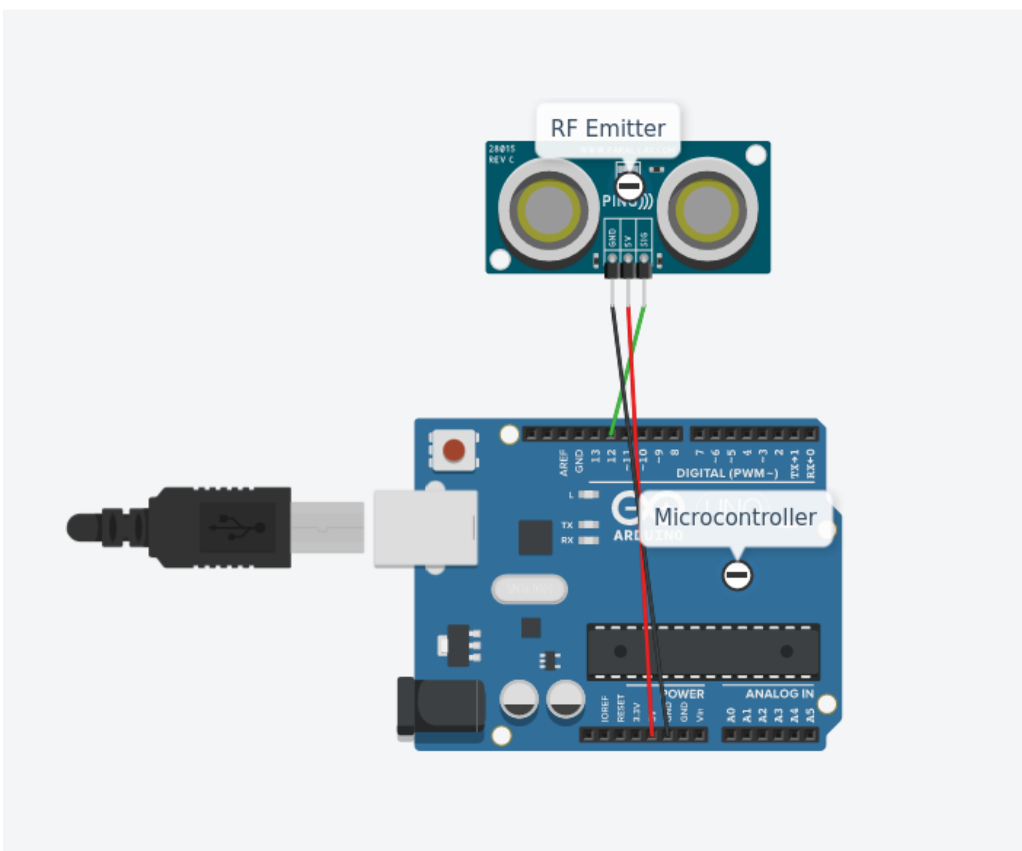


Fig 59: Diagram showing the pinout and layout for the emitter

3.1.1.5.D

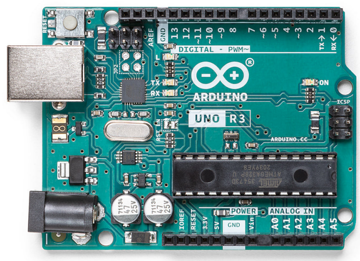
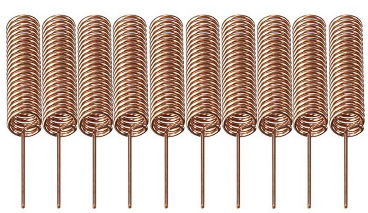
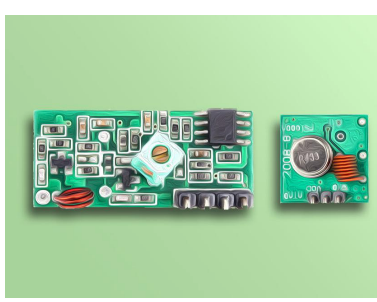
Item	Photo	Description	Estimated Cost
Arduino Uno		Arduino Uno is a widespread, effective, and cheap microcontroller meant to be easily customizable. This was ideal as it allowed for ready integration with the needed RF receiver and the associated processing. [12]	$18
FLTWC0311-22-2 Solderable Electrical Wire		Wiring used to connect the RF receiver and the Arduino Uno.	$0.37 per wire, $0.74 for 3 (3 needed)
DAOKI Antenna Spiral Spring RC for Arduino 5mm		Copper antenna to send and receive radio frequency signals.	$0.53 per antenna
HiLetgo 315 Mhz RF Transmitter		Arduino attachment used to send and receive signals over RF at 315 megahertz.	$0.38 per

Table 20: Table showing the off-shelf components with their specs and pricing

3.1.2.D

Component Name	Dimensions (mm)	Material Type	Weight	Other Specifications
Arduino Uno	68.6 x 53.4	Non-conductive laminated composite with layers of circuitry built-in	25 g	Operating Voltage: 0-5V (depending on software) Input Voltage: 7-12V DC current per I/O pin: 40mA Clock speed: 16 MHz Memory: 32 kB EEPROM: 1 KB RAM: 2 KB
FLTWC0311-22-2 Solderable Electrical Wire	.33 (diameter)	Tin plated copper wire	< 3g	Voltage Rating: 600V Insulation: Flame resistant modified polymer AWG: 22 Cable Type: FlexLite TW
DAOKI Antenna Spiral Spring RC for Arduino 5mm	5 (diameter)	Copper	<2g	Dimensions: 1.97 x 0.39 x 1.97 in
HiLetgo 315 Mhz RF Transmitter	19x19x6	Non-conductive laminated composite with layers of circuitry built-in	3 g	Product Model: MX-FS-03V Launch distance: 20-200 meters (different voltage, different results) Operating voltage :3.5-12V Dimensions: 19 * 19mm Operating mode: AM Transfer rate: 4KB / S Transmitting power: 10mW Transmitting frequency: 315M

Table 21: Table showing the components of the subsystem and their dimensions and specifications

3.2.D Idea Generation and Decision Making Tools

	RF	**WiFi**	**Bluetooth**
Cost	5	2	4
Practicality	5	2	4
Effectiveness	4	2	3
Range	5	2	3
Vulnerabilities	4	2	1
Total	23	10	15

Table 22: Table showing the decision matrix for medium of data transmission

The choice to use RF as the medium to transmit the signal was based off the criteria above. As this is supposed to be a cheap and robust system, making sure that the medium of transmission is the best for what we need is important. RF provides a cheap and effective platform. With a wide range of pre-existing products using RF and the simplistic design of how it works to make it is the best choice. If we were to use Bluetooth or WiFi it would require a lot more work and may cause more issues due to the protocols and expected packet types. On top of this WiFi and Bluetooth are used widely on roadways for other purposes so there is a high chance of interference. RF, especially low-frequency RF like 315Mhz, is not used as much and others a simplistic framework [53] to send a receive only what we need rather than Bluetooth or WiFi where we would have to send a lot of excess data to fulfill the packet standards.

RF is also less power-intensive [52] which is an important consideration when we would like this transmission system to have as long of a battery life as we can give it. This is due to the expectation from cyclists that they only have to recharge every week or so depending on how long it is used for.

3.3.D Validation of the Novel Aspects of Subsystem

3.3.1.D

- Test of sending with a multimeter
- Test of sending with receiver
- Test of range

The first step to understanding if the RF emitter works as expected was to use a multimeter to check for the proper voltage transferring through the pins and out of the antenna. This not only helps us make sure the component itself is working but also that the software running on the microcontroller is outputting the expected results. When testing I observed a consistent pulse coming from the data line which was in line with the 1000ms delay set in between pulses.

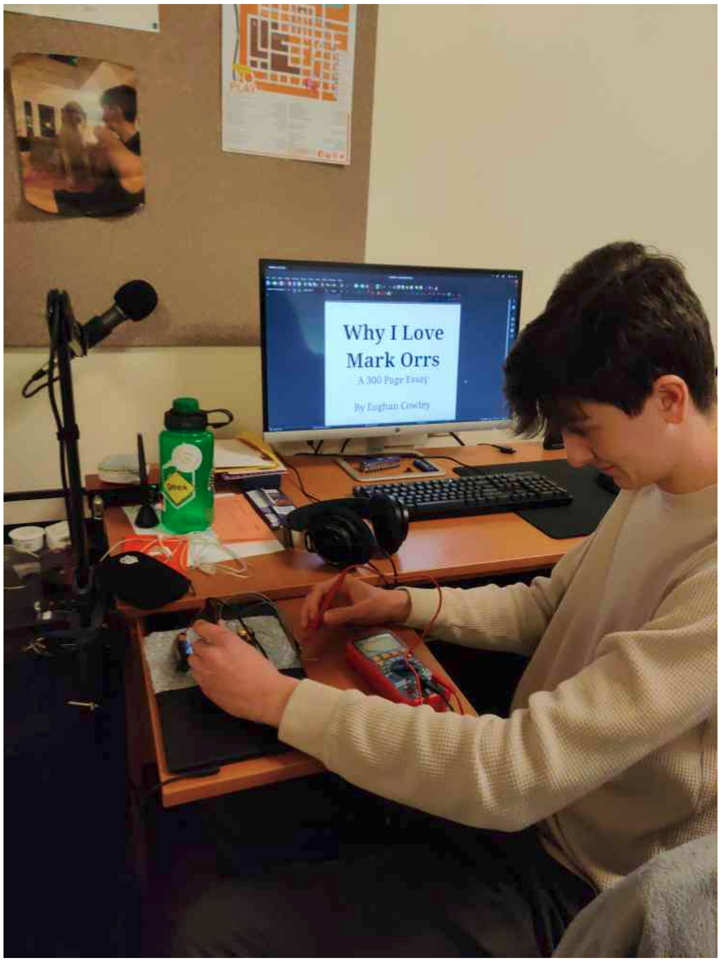


Fig 60: Testing the pins of the RF emitter

I then went on to test the antenna itself by reading to see if any voltage is moving through the coil. This would be indicative of a signal of some sort being passed through the coil. I took this as a possible success but there was more testing to be done to ensure that this is the correct signal being passed through.

Next, I validated the emitter by sending a simple “Hello” packet to the receiver. This was a very big success and worked perfectly. The packets arrived intact and in the expected regular intervals.

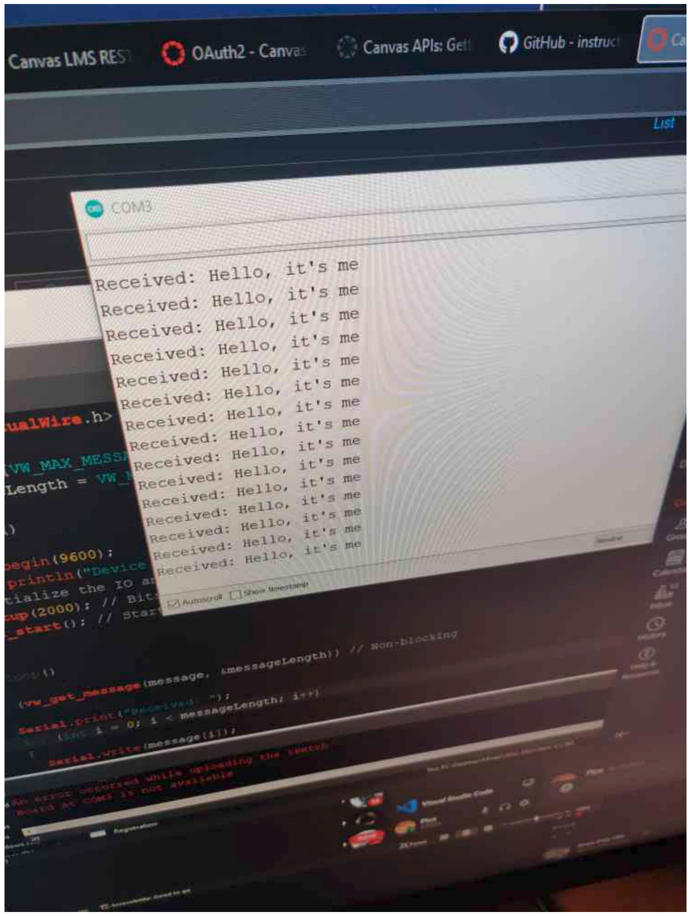


Fig 61: Image showing the successful receiving of the “Hello” messages

To make sure that the RF was emitting at a range we wanted we tested the maximum distance we could push the emitter and receiver away from each other before they lose contact and also how fast the can regain contact. We did this in the long hallway of McNeil and measured out systematically the distance that worked with a simulated real-world interference by doing the testing during the busiest time between classes when people are moving in and across the hallway, blocking the RF.

Distance	Obstacles Present?	Data received
5 meters	no	Yes
5 meters	yes	Yes
10 meters	no	Yes
10 meters	yes	Yes

15 meters	no	Yes
15 meters	yes	Yes
20 meters	no	Yes
20 meters	yes	Yes
25 meters	no	Yes
25 meters	yes	Yes
30 meters	no	Yes
30 meters	yes	Yes
35 meters	no	Yes
35 meters	yes	Yes
40 meters	no	Yes
40 meters	yes	Yes

Table 23: Table showing the results of our testing up to 40 meters

As you can see, the results were quite impressive; we were even able to get it working at a distance that we would estimate 80 meters. This was well above what we were expecting especially with all the interference. [52]

3.3.2.D

When testing the emitter we quickly realized that our antenna was not strong enough for a signal to pass through it. We believe this issue was caused by our use of a braided copper wire instead of a solid piece of copper. To remedy this we ordered purpose-made antennas that we could solder to the emitter and receiver. To make sure that what we were ordering was going to work we researched how antennas are normally done in commercial products. We looked at RC controllers used in various applications in the hobbyist space and saw that most use copper as opposed to aluminum and coiled the copper so that the RF can pass through it and reflect off it better. Using this information we found a coiled copper antenna that met our size requirements. Upon receiving and soldering we tested the system again and it worked as expected on the first attempt.

3.3.4.D

Bryce is an on-call Systems Administrator who is also a student studying Electrical Engineering at Mines who I talked to and showed my subsystem to get his feedback.[67] His overall response was positive. He noted that the simplistic design itself was a benefit of the subsystem as it meant that very few things were prone to breaking. His other concern was the housing that the emitter would be placed in. He was worried that if it was placed in a thick metal or other conductive material it could cause interference and issues with the transmission. Though this is not my subsystem I confirmed with Connor that the materials to be used will not cause issues.[52]

I also interviewed Jeffrey Holley [48], a Civil Design Professor at Mines to talk about the practicality of the project. He again offed widely positive feedback though did note some concerns. His biggest concern was the accessibility and need for wide adoption by cyclists of the CLE. This is a valid concern and one that made me rethink the way the project is going to work. Though I did not end up changing much of the design, the conversation did impact the way the product may be pitched/implemented.

Due to the need for a cyclist to purchase, install, and charge the CLE he raised to us if there was another way of detecting the cyclists in the intersection. From our discussion, we came up with two main alternatives, an optical recognition of cyclists and a rubber pipe sensor.

The first alternative would hopefully involve the already existing optical cameras at stop lights that detect motorists and pedestrians but would add new functionality to detect cyclists. This would then trigger the warning light much the same as it does now. The main issue with this is surrounding the use of optical recognition which can make mistakes and produce false negatives. Furthering the issues was the recognition that the cameras are unlikely to spot a cyclist from far away until they are in the intersection, (the RF would be able to spot them earlier).

The second alternative would involve a flexible rubber pipe with an air pressure sensor on one end to detect changes in air pressure as something rolls over it. This is a system in use to count cars and gauge their speed in many areas but it is one that can easily be adapted to be used in a bike lane and act as the trigger for the warning lights. There are not many issues with this design apart from the possible maintenance needed for the sensors that would have to offload to the city as opposed to the maintenance for the RF being placed on the cyclists themselves. This is, in my opinion, a perfect system to offer in tandem with our solution if there are concerns about the adoption of the CLE.

Professor Holley also stated that the overall project of a bike location emitter and its corresponding sign was "Long overdue".

Conor’s Section: Road Signal Housing and Signal Power Delivery

3.1.E Subsystem description

3.1.1.E

The signal housing is a simple but vital component of the whole system. Not only do the receiver and light need to be able to secure a continuous, uninterruptible supply of power to ensure round-the-clock functionality, but the signal must also be easily understood at a glance in order to provide enough decision time for motorists before they reach the intersection. The signal housing design is similar to that of a pedestrian signal head [39]. It is an aluminum-coated, polycarbonate rectangular prism that a receiver and light sit securely inside.

3.1.1.1.E

The objective of this subsystem is to provide a durable, weather-resistant signal housing similar to existing infrastructure that is easily discernible to motorists and cyclists alike and to secure a stable power source for the internal components of the signal (i.e. the light and receiver). The internal components as a whole are connected to the nearby intersection’s UPS (Uninterruptible Power Supply) which is in turn connected to the wider electrical grid [66].

3.1.1.2.E

The subsystem is responsible for ensuring two key things: the continued operation of the light and receiver and the communication of information to motorists. To accomplish these vital tasks the signal is designed using the same materials as existing signals located at and around intersections. These materials have already undergone extensive testing at the local, state, and federal level to ensure their functionality, longevity, and cost-effectiveness in road signage and signals [18][64]. Furthermore, the design is exceedingly familiar to already existing road signals in terms of shape and general look [39]. This was an intentional decision to make it extremely obvious to a motorist that the signal is a traffic signal that should be adhered to.

3.1.1.3.E

This subsystem relies solely on electrical input from the nearby intersection’s UPS which is connected to the wider electrical grid. Receiving power from the nearby intersection’s UPS ensures that unless a continuous and sustained power outage occurs or some other electrical failure occurs within the design, the wider system as a whole will have continuous and stable power.

3.1.1.4.E

As stated previously, the design of the subsystem is extremely simple. Other than the polycarbonate, aluminum coated casing, and the aluminum bike stencil the only other component is the physical wires from the nearby UPS to the light and circuit board. The wires chosen for this design were the standard wire type and size for road signals in the US: No. 12 AWG Wire. This wire can provide ample power to both the light and the circuit board without any sort of strain or stress on top of being readily available to infrastructure contractors as most other signals use this wire.

3.1.1.5.E For Off-The-Shelf Components

Below is a table of components necessary to produce the requisite inputs and outputs.

Component Name	**Component Image**	**Component Description**
No. 12 AWG Wire		The standard wire for traffic signals in the U.S. [2][66] High strand count tinned copper core, 12 AWG silicone stranded wire has 680 strands 0.08 mm tinned copper wire, the copper strands are tinned, protecting them from corrosion and making it easier to solder.

Table 24: List of off-the-shelf components used in the road signal housing and power delivery

3.1.2.E Physical Properties of Subsystem Components

Component Name	Dimensions	Material Type	Weight	Other Specifications
No. 12 AWG Wire	2.05 mm (Diameter)	Copper with Silicon Coating	41.67 g/m	Current Rating: 25 amps
Road Signal	18.7” H	Polycarbonate w/	4.5 kg	Ultraviolet and heat

Housing	18.5” W 9.1” D	Aluminum Coating [39]		stabilized, flame retardant, permanently colored, 10% fiberglass reinforcement; Operating temperature: -37° C to +74° C Humidity: 0 to 95% (non-condensing) [39]
Bike Stencil	15.25” H 16.5” W 0.25” D	Aluminum	0.5 kg	Operating temperature: -37° C to +74° C Humidity: 0 to 95% (non-condensing) [39]

Table 25: Physical Subsystem Components

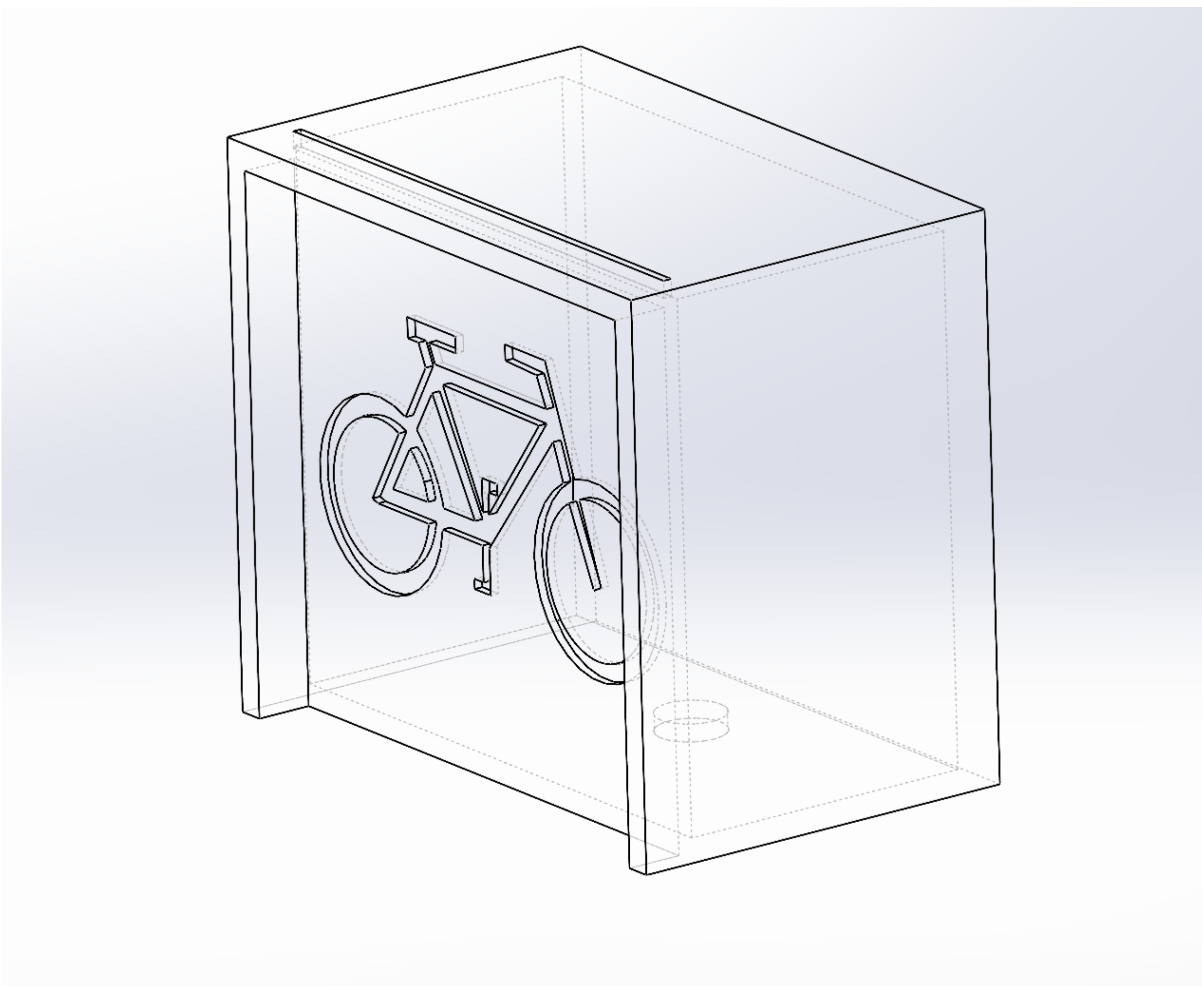


Figure 62: An isometric view of the signal housing

Figure 63: A front view of the signal, with light and back removed.

3.2.E Idea Generation and Decision-Making Tools for Critical

The material of the housing/stencil and the type of wire were decided based on extensive research into road sign regulations across a multitude of states in the U.S. The materials that were chosen are already in use and extensively tested and regulated by local, state, and federal governments to ensure reliability, cost-effectiveness, and durability in a multitude of harsh weather conditions and environments. This being the case, the decision-making for this subsystem was not the components themselves but the style of signage and/or signal instead.

A multitude of sign and signal designs were considered, some combining aspects of existing signs/signals and some simply changing the display of already existing signs/signals. The decision for the actual housing and sign/signal itself was decided using a decision matrix.

	School Zone Warning-Like Design	Pedestrian Signal Head-Like Design	Traffic Signal-Like Design
Readability	1 [65]	4[18]	3
Decision Time	1	5[18]	4 [35]
Ease of Installation	3	4	5
Safety of RF Receiver	2	5	2
Final Score	7	18	14

Table 26:Decision matrix pertaining to the design of the road signal/sign housing.

3.3.E Validation of the Novel Aspects of Subsystem

3.3.3.E Secondary Research

As mentioned previously, the structure and material of the signal housing and power delivery are already in extensive use across the U.S. [18] and as a result, this specific design subsystem and its components have already undergone an extensive amount of testing and validation through its widespread use across multitudes of climates. The design of the sign is externally identical to a pedestrian signal head and is powered the same way [39]. More importantly, there is very specific local, state, and federal regulations on the look, material, and design of road signs specifically to ensure their readability, longevity, and cost-effectiveness in nearly every scenario imaginable [64].

For example, the Texas MUTCD has laid out extremely specific dimensions for their signs and signals in the Texas Manual on Uniform Traffic Control Devices (TMUTCD). This includes signal and sign placement, color regulations, size regulations dependent on the type of road, and more [64]. Similar documents containing extensive rules and regulations exist for the state of Oregon [2], Jefferson County [35], Minnesota [65], and the City of Fredericksburg [66] to name an extremely small few. As such the subsystem was designed to be as compliant with these regulations to not only ensure their functionality and durability but to also avoid any sort of design complications due to regulations or specific criteria.

3.4 Subsystems and Subsystem Interfaces

3.4.1 Description of Each Interface

The design has two main components; a transmitting component, and a receiving component; these two larger components were then split into other smaller subsystems. The transmission and receiver subsystems interface with each other through data sent over RF. The transmission is powered and housed by the power and housing subsystem on the bicycle and is responsible for emitting all necessary data. The receiver subsystem is powered and housed by the road signal subsystem and is responsible for processing received data to keep track of the number of cyclists. The receiver subsystem also sends data to the display subsystem regarding whether or not cyclists are present in the intersection. This information is then displayed to motorists through a light in an opening in the road signal in the shape of a bicycle.

3.4.2 Subsystem Diagram

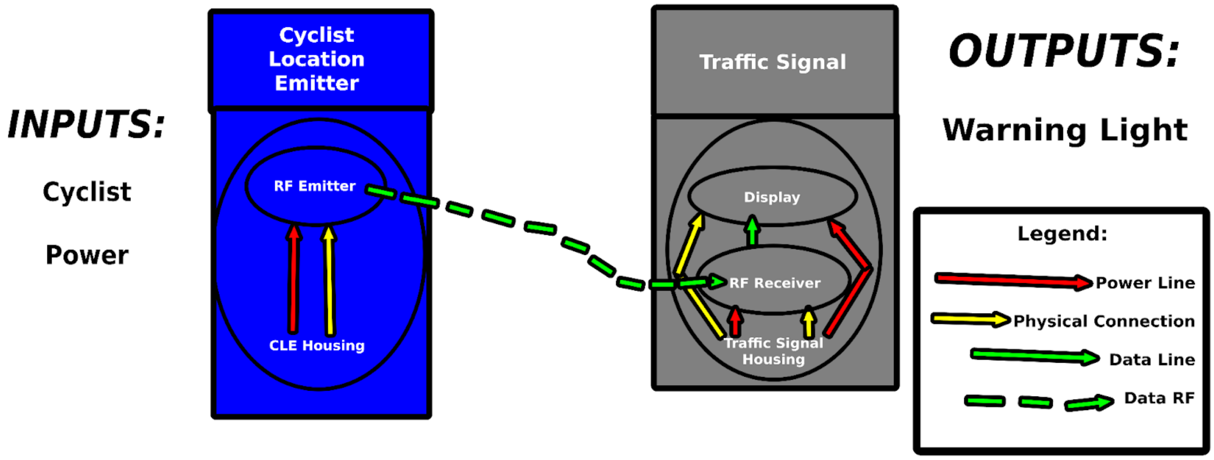


Figure 64: Subsystem Diagram

3.4.3 Key Interface Interactions

The information sent by the transmission was tailored to provide information to the receiver. Specifically, the transmission subsystem sends a uniquely identifying string, the time that the packet was sent, and the time between packets being sent. This makes it possible to estimate more accurately when a cyclist has left the area that a road signal accounts for. Additionally, the transmission and receiver subsystems were built with consideration towards the power sources needed. The housing subsystems managed the power supplies, so it was necessary for group members to come to a consensus about what was feasible there. The display and road signal subsystems also had to work together to use the same size and shape for the opening side of the road sign. Similarly, the display and receiver subsystems needed to communicate in order for the display to light up when the receiver got a signal. There is additionally a physical interface between the cyclist location emitter's internal components and its housing, and a similar interface present within the sign, its housing, internal components, and the display light.

4.1 Value Proposition

This design aims to improve the safety of cyclists at intersections by ensuring that nearby motorists are aware of the cyclists' presence. This prototype is relatively cheap and feasible to implement, passing on a cost to cyclists of $18.52 per Cyclist Location Emitter, and costing the government an estimated $12,247.02 to install the associated sign. If implemented at scale, this design is capable of significantly reducing cyclist accidents and deaths in one of the areas where they are most prevalent, busy urban intersections [8]. The main costs in implementing this solution include materials costs, materials used in the production of the product, and the requisite production equipment, all of which are explained in the tables below, and labor costs.

Overall, this design is cheap enough to be implemented in any major intersection or other areas where cyclists are likely to be present. Of course, this product's obvious benefit is protecting the safety, well-being, and lives of cyclists. Solutions to alerting motorists of the presence of cyclists do exist but typically rely entirely on high visibility gear, whereas this sign does not require the motorist needs line of sight to the cyclist in order to make decisions to avoid colliding with them. More secondarily though, this solution indirectly encourages cycling. Cyclists stated that one of the biggest deterrents to cycling is feeling safe on the roads. [47] Adding an extensive measure, such as the cyclist location emitter, should ideally greatly increase the actual safety of cycling, and more importantly, the perceived safety of cycling. Areas where cycling sees greater adoption enjoy fewer carbon emissions, less congested roadways, and a happier and healthier population. [22]

4.1.1 Full-Scale Solution Criteria

The overall purpose of the Cyclist Location Emitter is intended to increase the awareness of motorists of cyclists in an intersection. Most existing designs that serve to increase cyclist safety do not focus on alerting drivers and increasing their awareness. Many safety measures increase the safety of the cyclist after the collision, examples of this include safety gear such as knee pads, helmets, and inflating braces. The only other solution that increases the awareness of motorists is bike turn signals, which already exist and leave little room for innovation. Since most severe bike-car collisions occur in intersections, we created our design to increase safety and alertness in these areas.

Some specific design criteria created for the Cyclist Location Emitter are: long-lasting, easy to use, and safe. We wanted to ensure the product was as easy and intuitive for the user as possible, which would increase usage rates. Research has shown that basic situational influences tend to induce behavior that reflects deep dispositions or preferences [8]. Essentially, simple factors, such as ease of use, can lead to extreme reactions from users. Because of this, we wanted to ensure our design was as user-friendly as possible to better the consumers' opinion of the product. We also wanted the design to be cheap and easy to introduce to existing infrastructure, as these would increase the rate of adoption in local governments. In order to meet these criteria, we created our final design to be as easy and cheap on both the consumer end and governmental end. The consumer-bought emitter would have an intuitive on/off switch, as well as a battery indicator and mounted charging ports. The emitter would also be compact, taking little space in the cyclist's bag. The sign/display was also designed to be as easy to implement as possible. It is a simple on/off display and can be retrofitted onto existing street sign infrastructure.

4.1.2 Prototype Solution and Materials Cost

Item	Price
Sign Housing Material	$0, Made out of materials provided by Digger Design Lab
Black Spray Paint	$2.48 (Lowes)
Arduino Uno Microcontroller	$10 (Microcenter)
FLTWC0311-22-2 Solderable Electrical Wire	$7.67 per 5 meters, (Ali-Express) $0.74 for requisite length
Antenna	$0.08 (Ali-Express)
5V Single Channel Relay Module	$3.99 (Microcenter)
Total	$28.80

Table 27: Prototype Materials

4.1.3 Full-scale solution costs

Item	Price
Sign	
16" X 18" Polycarbonate Signal Housing	$60 [28]
No. 12 AWG Wire	$22/100ft (Industrial Retailer)
Aluminium Signal Facing	$10 (Custom Stensil)

Arduino Uno Microcontroller	$10 (Microcenter)
Antenna	$0.08 (Ali-Express)
FLTWC0311-22-2 Solderable Electrical Wire	$7.67 per 5 meters, (Ali-Express) $0.74 for requisite length
315Mhz 433Mhz RF Receiver	$0.20 (Ali-Express)
Estimated Production Equipment Cost	$138,600
Estimated Production Labor Costs	$550
Estimated Installation Costs	$11,616
Total Cost	$12,247.02 /Sign + $138,600 Flatout
Emitter	
Arduino Uno Microcontroller	$10 (Microcenter)
FLTWC0311-22-2 Solderable Electrical Wire	$7.67 per 5 meters, (Ali-Express) $0.32 for requisite length
315Mhz 433Mhz RF Transmitter	$0.20 (Ali-Express)
Estimated Production Equipment Cost	$33,000
Estimated Labor Costs	$8
Total Cost	$18.52/Emitter + $33,000 Flatout

Table 28: Final Design Materials

Labor Cost Explanation

Sign Installation

This labor cost was informed by local minimum and median wages, the availability of labor, and the level of technical expertise necessary to reliably and successfully install the sign. Colorado minimum wage is $12.56 per hour, while the mean wage is $29.25 [28]. The actual labor rates are likely to fall between the two numbers, as installing the sign does not require specialized skills. The group estimates that installing the sign will take two hours with approximately eight people and heavy machinery [32]. This provides an upper and lower bound labor cost from $201 to $468. Machinery costs add approximately $200 per project to this number. Taking the average of these positions, we estimate labor costs at around $550 per sign installed.

Emitter Manufacturing

The emitter will be able to be manufactured with injection molding with minimal installation. Some labor will have to go into placing electrical components within the emitter and ensuring that the emitter is correctly set up. Done at scale, this is likely to take 40 minutes, at the Colorado minimum wage of $12.56 per hour, for an estimated $8.40.

4.1.4 Design Benefits

The Cyclist Location Emitter would decrease the risk of a collision between cyclists and motorists at intersections as well as increase the perceived safety that the common individual has of cycling. The past twenty years have seen a roughly constant rate of cyclist mortality despite recent improvements to safety gear [17]. The final implementation of the Cyclist Location Emitter would decrease this number due to enhanced driver awareness at the intersection.
The device is designed to be as cost-effective as possible for both the signal and the emitter. This relatively low cost allows one of the most common roadblocks, cost, to be mostly avoided in the implementation process. This enhanced ease due to the low costs will increase the design's overall effectiveness through its increased usage.

4.2 Risk Assessment and Mitigation Plans

Risk	Likelihood X	Impact =	Magnitude	Mitigation Plan (only for MEDIUM, HIGH, and EXTREME Risks)
False Negative Due to Sign Failure	Unlikely	High	Moderate	This issue is both likely to happen and somewhat dangerous if it does happen, as drivers might be overly confident that cyclists aren't present when they are simply not being detected. This can be mitigated by designing robust components and testing everything possible.
False Positives	Likely	Low	Low	#N/A
False Negative Due to lack of Emitter & Motorist Reliance on Signal	Very Likely	High	Extreme	Educate drivers on the possibility that cyclists might be present even if the sign isn't lighting up. Consider additional signage mentioning the possibility.
False Negative Due to Emitter Failure	Likely	High	High	This can be mitigated by making any emitter issues obvious to cyclists, such as by adding a clearly visible status display
Sign Failure Due to Water Damage	Unlikely	High	Moderate	This can be mitigated with extensive testing of sign casing to ensure waterproofing
Sign Failure Due to	Unlikely	High	Moderate	This can be largely avoided with proper design of the sign box, as

Vandalism				well as by using practical and sturdy materials for the design.
Sign Failure Due to Electrical Failure	Unlikely	High	Moderate	This issue can be mitigated with periodic checks of sign functionality and with proper training of workers responsible for installation.
Brunt Force Damage to Emitter	Likely	Low	Low	#N/A
Emitter Failure Due to Water Damage	Unlikely	Low	Low	#N/A
Emitter Failure due to Component Failure	Unlikely	Moderate	Low	#N/A
Emitter Failure due to Battery Failure	Likely	Moderate	Moderate	This can be mitigated with clear signaling of battery levels to the user
Emitter Becomes Detached From Bike	Likely	Low	Low	#N/A
Case Damage has Long Term Potential of Compromising Components	Unlikely	Low	Low	#N/A

Table 29: Design Risks and Mitigations Plans

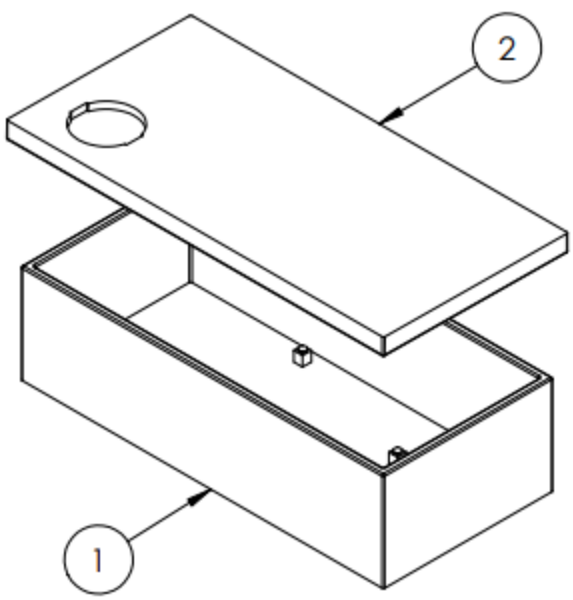
4.2.3 Risk Mitigation Plan

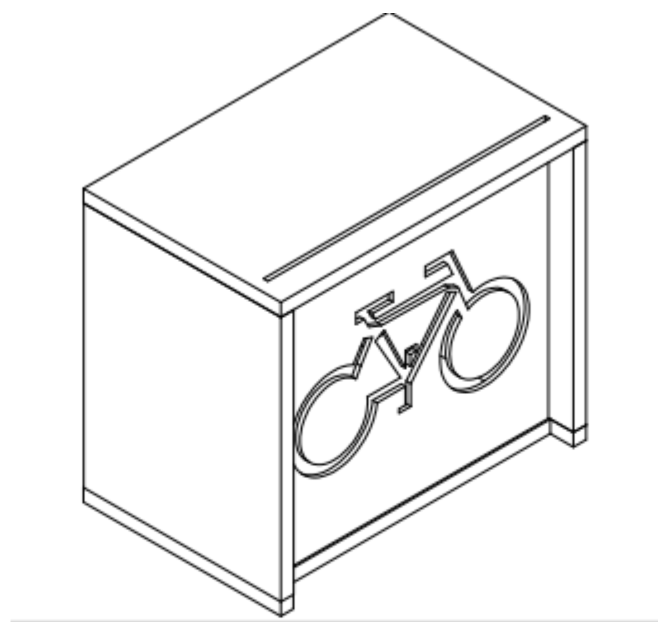
Through our risk mitigation matrix communication with the user proved to be a major pitfall in our design. We found out that the user had no way of knowing if their device was functioning properly, the level of battery charge, or any other information about the device's status. To address these issues the full-scale solution will have a charge level display similar to that of portable battery rechargers. Furthermore, we decided to add a status light adjacent to the switch. The light will flash dictating the status of the device such as if it's properly sending the signal, having the signal received, or if there is some other issue with the emitter. The issue we rated as “Extreme” is not specifically the fault of our design and is instead more of a byproduct of the design's success. The scenario in which motorist reliance on the signal occurs combined with a cyclist lacking the emitter product can only occur after wide use of the design on both ends. As such, the problem is ultimately unpreventable but can be mitigated through motorist education that not all cyclists will possess the emitter product and as such, they must remain vigilant even if the signal is not illuminated.

5.1. Description of the team’s concept in the real-world environment that has been selected

Intersections are hazardous for cyclists. They are environments with a large number of road users moving, changing speeds, and changing direction simultaneously, which creates numerous blind spots and an overall prime environment for cyclist-motorist collisions. The purpose of this solution is to address the danger of intersections by increasing motorist awareness of cyclists in intersections. Each cyclist will equip and activate a cyclist location emitter, which consists of a housing, power delivery system, and internal emitter components. This overall device emits a constant radio signal coded to a specified pattern such that the second component, the sign, can detect when a cyclist is present in an intersection. The coded transmission will be according to a specific pattern so the sign can differentiate a cyclist and background RF (radio frequency) emissions, and the sign’s receiver will detect that then a microcontroller will activate a light which indicated to motorists that there is a cyclist present in the intersection.

5.1.1. Isometric CAD View





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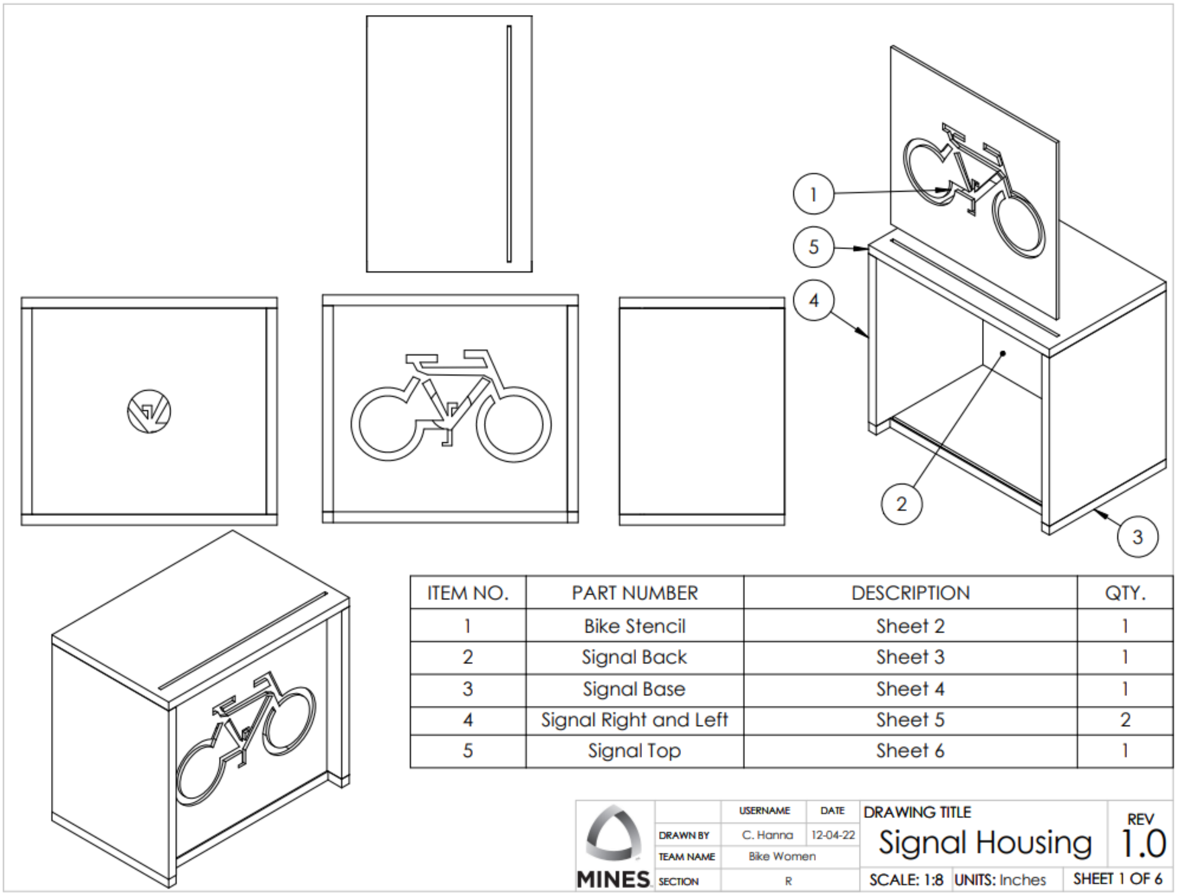
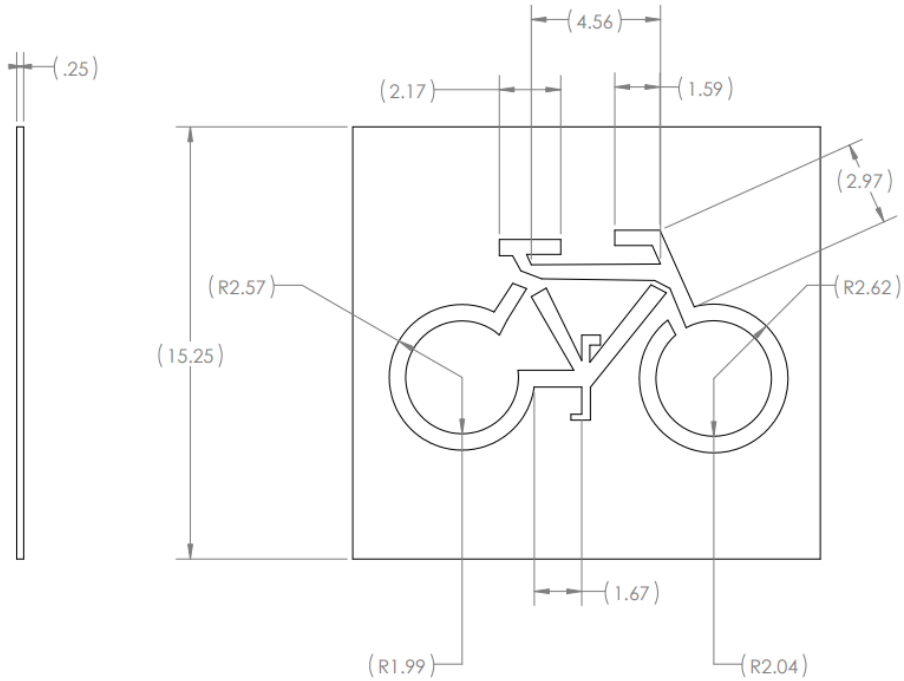
Appendixes

Appendix 1: Working Drawings



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Bike Stencil	Sheet 2	1
2	Signal Back	Sheet 3	1
3	Signal Base	Sheet 4	1
4	Signal Right and Left	Sheet 5	2
5	Signal Top	Sheet 6	1



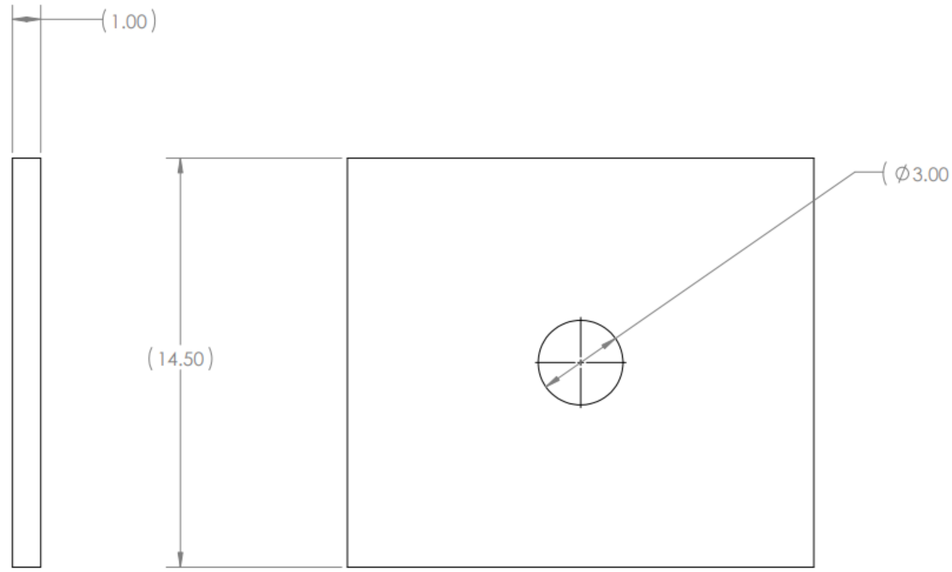
MINES

	USERNAME	DATE
DRAWN BY	C. Hanna	12-04-22
TEAM NAME	Bike Women	
SECTION	R	

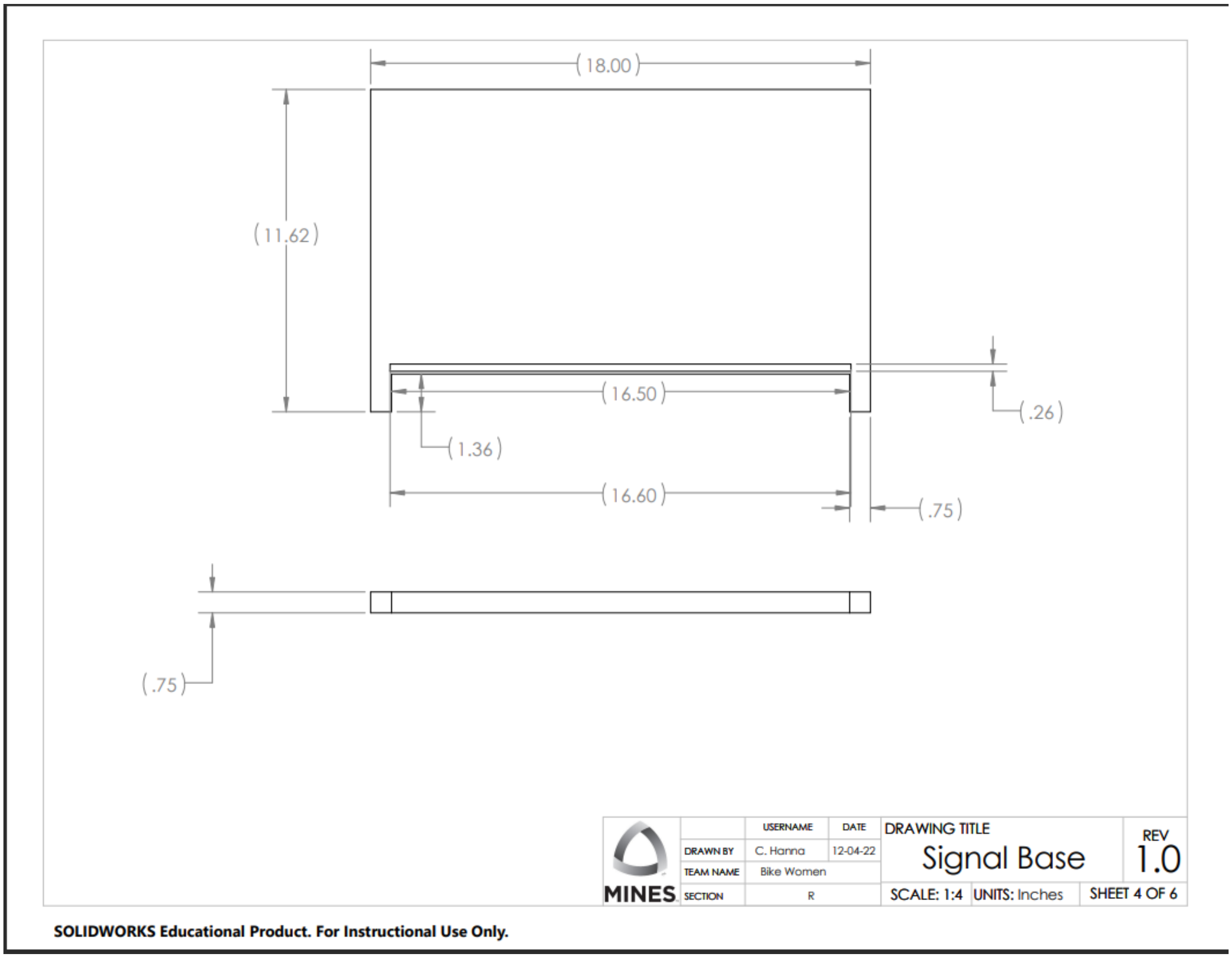
DRAWING TITLE: Bike Stencil

REV 1.0

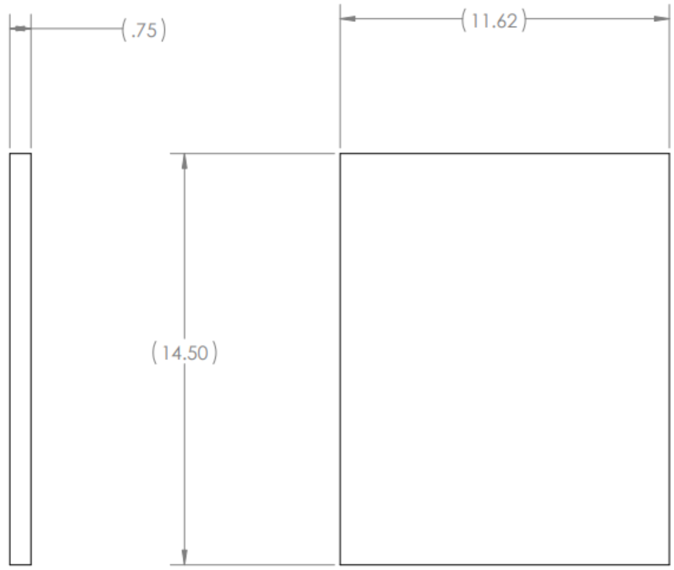
SCALE: 1:4 | UNITS: Inches | SHEET 2 OF 6



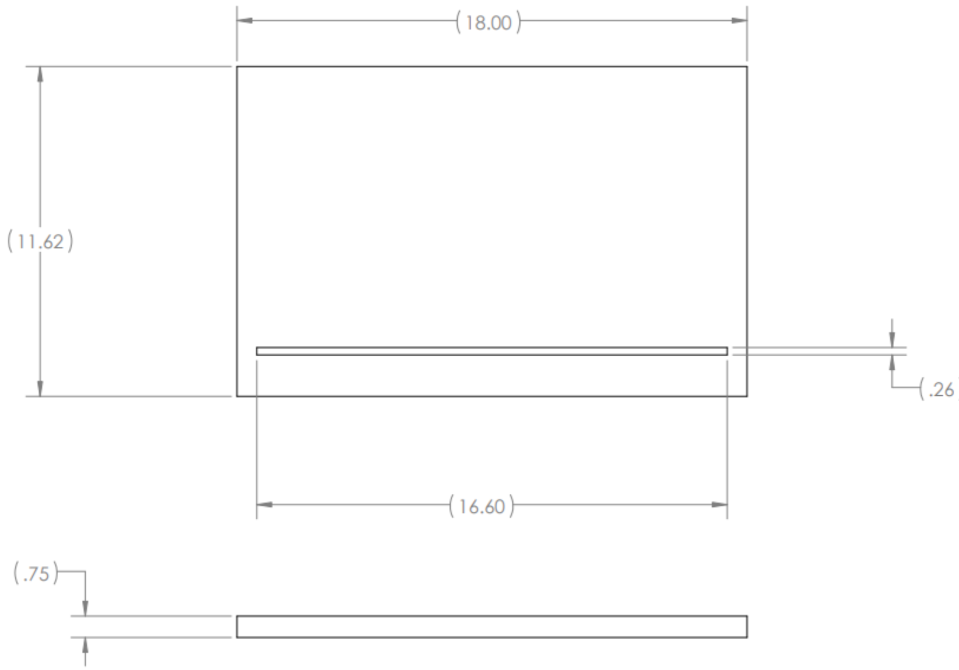
		USERNAME	DATE	DRAWING TITLE		REV
MINES	DRAWN BY	C. Hanna	12-04-22	Signal Back		1.0
	TEAM NAME	Bike Women				
	SECTION	R		SCALE: 1:4	UNITS: Inches	SHEET 3 OF 6



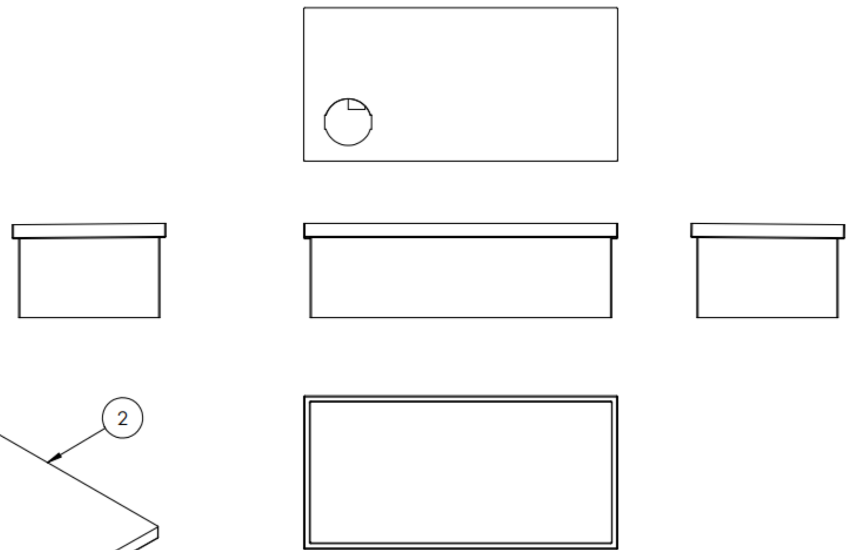
18.00
11.62
16.50
1.36
.26
16.60
.75
.75
USERNAME
DATE
DRAWN BY
C. Hanna
12-04-22
TEAM NAME
Bike Women
SECTION
R
MINES
DRAWING TITLE
Signal Base
REV
1.0
SCALE: 1:4
UNITS: Inches
SHEET 4 OF 6

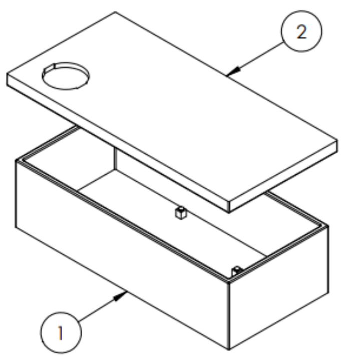


MINES		USERNAME	DATE	DRAWING TITLE	REV
	DRAWN BY	C. Hanna	12-04-22	Signal RIght and Left	1.0
	TEAM NAME	Bike Women			
	SECTION	R		SCALE: 1:4 UNITS: Inches	SHEET 5 OF 6



		USERNAME	DATE	DRAWING TITLE	REV
MINES	DRAWN BY	C. Hanna	12-04-22	Signal Top	1.0
	TEAM NAME	Bike Women			
	SECTION	R		SCALE: 1:4 UNITS: Inches	SHEET 6 OF 6





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Housing Bottom	Sheet 2	1
2	Housing Top	Sheet 3	1

MINES

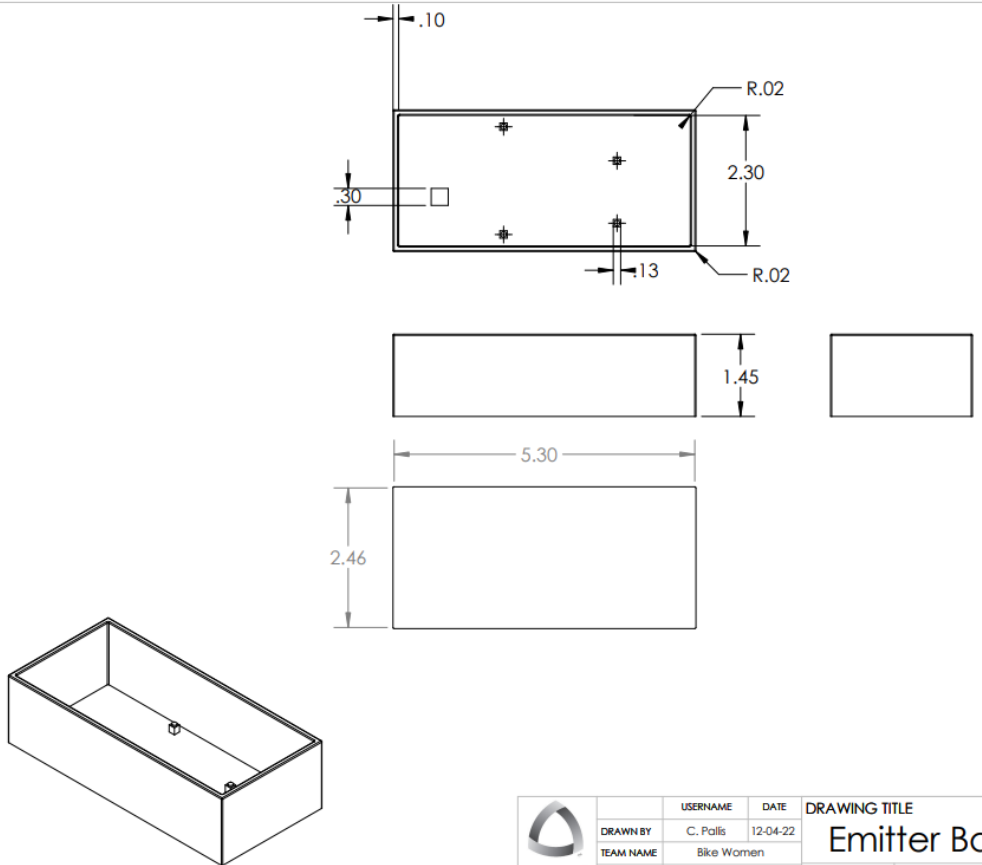
	USERNAME	DATE
DRAWN BY	C. Pallis	12-04-22
TEAM NAME	Bike Women	
SECTION	R	

DRAWING TITLE

Emitter Housing

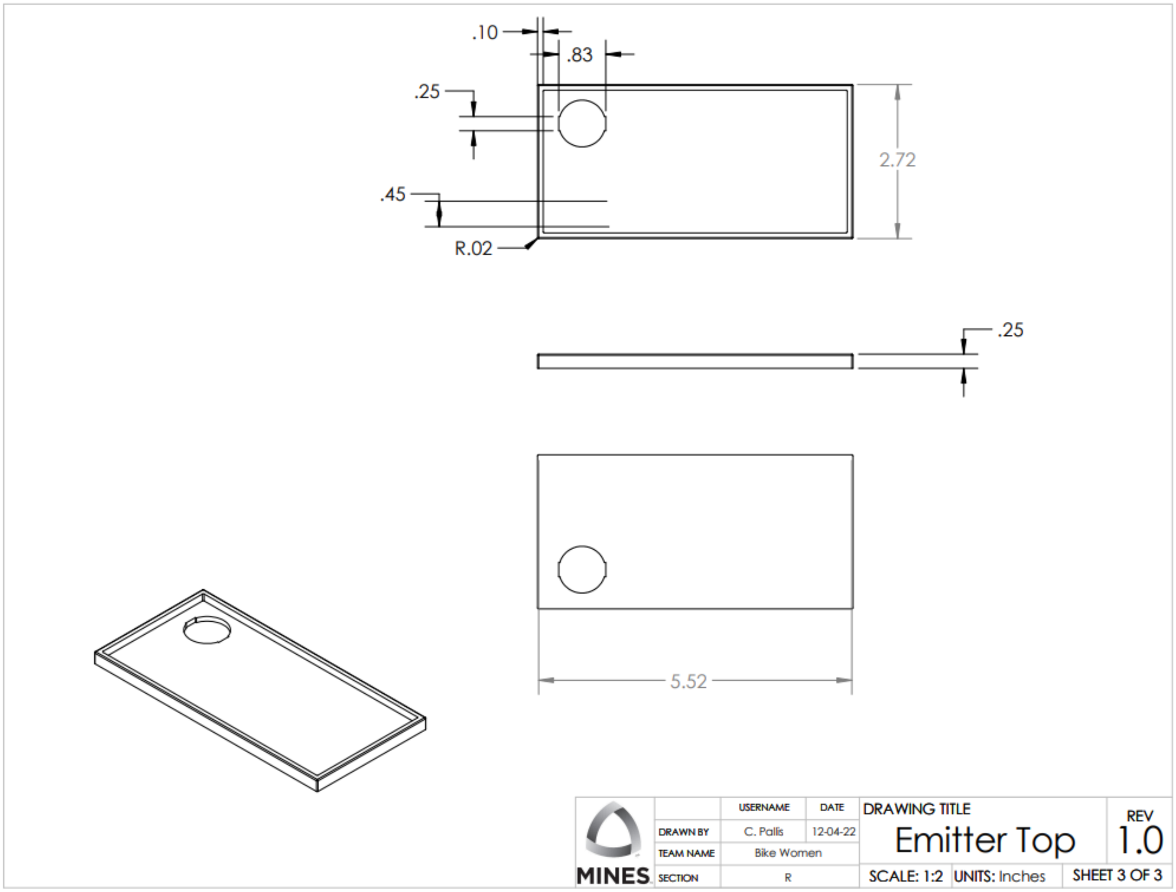
REV 1.0

SCALE: 1:2 | UNITS: Inches | SHEET 1 OF 3



	USERNAME	DATE	DRAWING TITLE	REV
DRAWN BY	C. Pallis	12-04-22	Emitter Base	1.0
TEAM NAME	Bike Women			
SECTION	R		SCALE: 1:2 UNITS: Inches	SHEET 2 OF 3

MINES



Appendix 2: Code

- Transmitter Code

```
#include <VirtualWire.h>
#include <string.h>

// using namespace std;

int wait_time = 1000;
// String user_id;

String generate_random_user_id()
{
  String user_id_string = "";
  for (int i = 0; i < 6; i++) {
    byte rand = random(0, 26);
    char c = rand + 'a'; // Adding lowercase a brings it
    if(rand > 26)
```

```
    {
      c = (rand - 26) ;
    }
    user_id_string = user_id_string + c;
  }
  return user_id_string;
}

void setup()
{
  // Initialize the IO and ISR
  vw_setup(2000); // Bits per sec

  // Initialize the user's identifying string
  user_id = generate_random_user_id();
  // user_id = "1234";

  Serial.begin(9600);
}

void loop()
{
  int time = millis();
  String send_data = "{\n\tUser : " + user_id + " \n\tTime : " + time +
"\n\tRepeat Time : " + wait_time + "\n}";
  String print = "Sending: \n" + send_data;
  Serial.println(print.c_str());
  Serial.println("Sending ");

  char message[100];
  send_data.toCharArray(message, 100);
  char *pMessage = message;

  send(pMessage);
  delay(wait_time);
}

void send (char *message)
{
  vw_send((uint8_t *)message, strlen(message));
```

```
  vw_wait_tx(); // Wait until the whole message is gone
}
```

- Receiver Code

```
#include <VirtualWire.h>
#include <string.h>

byte message[VW_MAX_MESSAGE_LEN]; // a buffer to store the incoming
messages
byte messageLength = VW_MAX_MESSAGE_LEN; // the size of the message

unsigned long long int timeOfLastReceive = millis();

const int relayPin = 5;

void setup()
{
  // Initialize the IO and ISR
  vw_setup(2000); // Bits per sec
  vw_rx_start(); // Start the receiver

  // Initialize the user's identifying string
  // user_id = generate_random_user_id();

  Serial.begin(9600);
  Serial.println("Initializing");

  pinMode(relayPin, OUTPUT);

  // user_id = "1234";
}

void loop()
{
  unsigned long long int time = millis();

  if (vw_get_message(message, &messageLength)) // Non-blocking
  {
```

```
    timeOfLastReceive = millis();
    Serial.print("Received: ");
    for (int i = 0; i < messageLength; i++)
    {
      Serial.write(message[i]);
    }
    Serial.println();

    // delay(6000);
    // digitalWrite(relayPin, HIGH);
    // delay(1000);
  }
  // else {
  //   digitalWrite(relayPin, LOW);
  // }


  if (time - timeOfLastReceive <= 6000) {
    // Received a message recently

    digitalWrite(relayPin, HIGH);
  }
  else {
    // Haven't received a message recently
    digitalWrite(relayPin, LOW);
  }
  // delay(3000);
  // delay(3000);
}

void send (char *message)
{
  vw_send((uint8_t *)message, strlen(message));
  vw_wait_tx(); // Wait until the whole message is gone
}
```