Beyond the Blind Spot

MEIE 4702

Technical Report

**Capstone II Final Report**

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Abstract *(Seb - first pass done)*

Early warning systems (EWSs) enhance road safety by alerting drivers and others around them of potential road hazards, increasing both the safety and the perceived safety of vehicles. They’re particularly useful for autonomous vehicles (AVs), which are often not trusted by the public. This project seeks to find useful ways to utilize EWS to increase the safety and perceived safety of AVs.

Surveys directed toward drivers of AVs and pedestrians/cyclists (external stakeholders) concluded that drivers felt safe with their AV’s technology, while external stakeholders felt mostly unsafe when near a self-driving car. This highlighted the need for external, non-driver centric EWSs.

The team’s narrowed project scope focuses on developing an EWS to tackle the “right-hook problem,” which occurs when a car takes a right turn through a bike lane, leading to an increased risk for collisions with cyclists traveling parallel. Near-field ground projection, a technology that projects signs from a vehicle onto the ground, is identified as a promising EWS that can notify cyclists of an AVs intentions and reduce risk of collision.

Through an in-lab cycling simulation, researchers conducted an experiment to determine what characteristics of near-field ground projections would be most effective at communicating to a cyclist a vehicle’s intention to turn. Using qualitative (e.g., verbal response, physical response such as braking) and quantitative (e.g., electromyograph readings, eye-tracking software) data, the team used human-machine systems principles to compare six newly developed signs.

Researchers concluded that projections with (1) simple/familiar icons of the host vehicle, (2) a directional arrow/indicator, (3) no text, and (4) low color contrast between icon and arrow/indicator are most effective at conveying a vehicle’s intention and yielding an appropriate response from cyclists.

Experimental results suggest that in a scenario in which, at least 80% of cyclists would react cautiously, with over 70% understanding that a nearby car is preparing to turn and cross their path.

Keywords

Early warning system (EWS), autonomous vehicle, external early warning system, near-field ground projection, right-hook problem

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# Acknowledgments

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# Copyright

We the team members,

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| xxxxx |
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# Introduction (Anya)

Early warning systems (EWS) aid drivers by notifying them of obstacles or situations ahead of time that may affect their driving and prevent hazardous situations. Some examples include symbols in a car’s side-view mirror that alert drivers of vehicles in their blind spot, vibration of the wheel once the driver is out of their lane, all the way to driving long distances on autopilot mode. In the autonomous vehicle (AV) industry, these advanced driver assistance systems are paving the way for the future of fully autonomous and safer driving. Even though these systems are advancing, and very reputable manufacturers are competing for better and further advancements, these companies pay very little attention to external stakeholders such as pedestrians, cyclists, and those with disabilities and how they are reacting to these ongoing changes in vehicles they share the road with.

## Problem Statement (Ines & Anya)

While Autonomous Vehicles (AVs) have seen significant technological advancements in recent years, the lack of consideration for the sense of safety of external stakeholders’, like pedestrians and cyclists, is concerning given the ongoing debates, conflicts, and legal battles surrounding AV integration in the US. After the team surveyed both AV drivers and external stakeholders, it became apparent that existing early warning systems prioritize AV drivers, leaving cyclists feeling neglected and unaware of vehicle actions. Recognizing this gap in the market, the team explored near-ground field projection systems to enhance cyclists' safety perceptions on shared roads. From evaluations and consultations with industry professionals, the team narrowed the focus to address the “right-hook” problem, aiming to enhance cyclists’ perception of safety.

A car crash on a road

Description automatically generated

**Figure 1.** Visual of the Right Hook Problem before an EWS.

## Goals and Specifications (Seb)

Focusing on the development and implementation of an external EWS for cyclists, this project aims to enhance overall road safety, fostering a more inclusive and secure environment for all stakeholders sharing the road with autonomous vehicles.

The team is dedicated to exploring the practicality and effectiveness of the design concept: a near-field ground projection from the side of the car to the bike lane, warning cyclists that the car will be turning right. Firstly, the team aims to engage with experts in the field who specialize in feature design for autonomous vehicles and ones studying urban planning for bicycle advocacy. This way the team can incorporate their expertise into the design process. An experiment, which includes projecting and evaluating different sign designs in a controlled environment, to assess their impact on cyclists, has been conducted to test the viability of the concept. Combining the effort of expert consultation and experimental testing, the team is confident in the ability to deliver a solution that will enhance the safety of cyclists and promote a positive interaction between vehicles and bike lanes.

# Background

## Context of Problem (Seb & Anya - first pass done)

As the number of autonomous vehicles introduced to the market increases, so do the kinds of safety technologies that accompany them. Autonomous vehicles come with a host of safety features that standard vehicles don’t need to consider. Car manufacturers design early warning systems to act as a way of warning drivers of hazards before they become a safety issue. Common forms of EWS include blind spot detection and collision warning, which use sensors around the outside of a vehicle to warn occupants inside of potential hazards in their proximity (i.e., parked cars, cyclists, curbs). With the introduction of self-driving cars and the importance of keeping a driver alert and aware with a reduced task load, these systems have evolved into more complex EWS, such as driver drowsiness detection systems. These more advanced systems can recognize abnormalities in a driver’s typical driving pattern and use sets of cameras to detect shift in blink rates to determine whether to recommend the driver take a break from the road. Autonomous vehicle car manufacturers have until now primarily focused on driver-centric early warning systems. To research more about the relationship

## Potential Client

Like here

### Potential Client (Anya)

During the meeting with an industry professional, the team narrowed down the list of parties who would realistically be willing to pursue and research this project further. When examining various autonomous vehicles companies, several distinctions emerged, such as those companies exclusively operating in the AV realm versus those producing hybrid cars. Another distinction observed was that between companies that produce vehicles that require a driver versus those that are driverless, such as robotaxi cars. Considering the market landscape and the substantial efforts of car manufacturers, like Tesla, in crafting intuitive driving environments with advanced Early Warning Systems (EWS) for the driver, the team realized companies of this nature wouldn’t want to invest resources into non-driver centric features like the proposed solution. Instead, the team delved deeper into the realm of robotaxis, which does not have drivers and relies heavily on fostering positive relationship with the public since the public would be their customer for their service.

To help demonstrate the robotaxi companies’ commitment to the public, the team proposes the development of an external warning system that could enhance visibility of vehicle action for external stakeholders. This would reassure those on the outside of the vehicle that the AV system is aware of their presence, actively monitoring their surroundings, and takes their existence into consideration when taking actions. Such initiatives can improve the reputation and perceived safety of robotaxis, while also fostering a better relationship between all autonomous vehicles and external stakeholders.

### Robotaxi Mistrust and Other News (Anya)

In regions like Arizona, California, and Texas, the rise of manufacturing and use of robotaxis started significant debate regarding their safety and effectiveness. Operational data has been collected by robotaxi companies to back their reputation, but these companies face media scrutiny because of minor and major incidents. An important statistic that was shared by the company Waymo regarding their safety is that by the end of 2023 the company was able to analyze 7.13 million miles of fully autonomous driving across Phoenix, Los Angeles, and San Francisco. Comparing their data to human-driven vehicles, Waymo found that their driverless cars were involved in injury-causing crashes at a rate 6.8 times lower than those with human drivers [2]. Despite these statistics, the perceived safety of robotaxi companies has been called into question due to recent incidents. For instance, Waymo recently recalled the software used in its robotaxis after two cars collided, and one vehicle struck a cyclist [3]. There have also been instances where robotaxis obstructed the passage of first responders.



**Figure 2.** Map of Autonomous Vehicle Collisions in SF

Figure 2 above shows all self-reported collisions of autonomous vehicles from January 2022 to October 2023 in the San Francisco region based on DMV records [4]. When these incidents are reported in the media, there is often a failure to differentiate between isolated incidents and labeling it as an overall performance crisis. When accidents do happen, there's a persistent lack of distinguishing between "safety" and "operational" incidents in media coverage, leading to misconceptions about the true risks of robotaxis involved [5]. This lack of differentiation and tendency to group all incidents fosters a fearful perception of the entire industry. The differentiation of AV accidents can help prove that while some incidents may cause disruptions in traffic, they do not necessarily pose safety risks. Furthermore, there's a failure to emphasize the difference between "traffic safety" incidents, which involve crashes between different road users such as cars, bikes, and pedestrians, and "public safety" incidents, which cause obstruction of passage for first responders. For example, incidents in which an autonomous vehicle blocked first responder’s response to a situation represent a small fraction compared to at least 168,000 successful interactions with emergency vehicles recorded by just one company, Cruise, in the first seven months of a single year [6].

The influence of the media has been very significant in San Francisco, leading to a series of protests and acts of vandalism targeting autonomous vehicles. There were incidents of citizens setting robotaxis on fire and placing cones on top of the vehicles to sabotage their operations. These guerrilla actions against robotaxis highlight the tension and resistance surrounding the integration of AVs into urban environments. Because of the evident stained relationship between the public and robotaxis, the team seeks to offer a potential solution to help highlight the efforts made by companies operating these vehicles to prevent accidents and prioritize the safety of external stakeholders, such as pedestrians, cyclists, and people with disabilities.

# Initial Concepts

## Scoping of Solutions (Anya)

The team’s research into the relatively unexplored area of external warning systems of autonomous vehicles helped hone down on surveying two demographics: AV drivers and external stakeholders. Before survey results came in, the team worked on predicting likely outcomes of the results by using the “Four Quadrant” method, illustrated in the figure below. This method helped visualize the data along two axes representing the spectrum of negative to positive sentiments regarding the perception of safety of AV driver(x) and external stakeholder(y) with each other. The team devised a plan to cover each quadrant by a prospective project idea. If the pedestrians feel safe and the drivers feel safe the project would then be turned into a research project on how and why there is great trust between internal and external stakeholders of AV driving. Regardless of driver’s perception of safety inside their vehicles, if pedestrians felt unsafe on the roads with AVs, the team planned to head in a pedestrian-oriented project by creating, prototyping, and designing an external warning system for the external stakeholders including pedestrians, bikers, and people with disabilities. If it turned out that the drivers felt unsafe in any scenario, the team was going to create a universal or car specific training guides for AV drivers.

A diagram of drivers

Description automatically generated**Figure 3.** The Four Quadrants Method

## Preliminary Data Gathering (Ines - first pass done)

To guide the project’s direction, the team decided to poll (1) drivers with experience behind the wheel of autonomous vehicles, and (2) pedestrians and cyclists who share the roads with autonomous vehicles. The team gathered 30 responses for each, as statistical theory argues that this is the sufficiently large sample size needed for the central limit theorem to be applicable and for the data to approximately follow a normal distribution. Demographics were not collected; however, the team hypothesizes most respondents would be of college age as the primary form of distribution of the survey was through conversations with university students on Northeastern’s campus.

The first survey was directed toward those with experience driving an autonomous vehicle. The primary goal for this survey was to understand how drivers interact with different early warning systems. This was used to help guide the team’s research into human-machine interactions and develop a novel early warning system. Drivers were asked questions such as “Which of the following early warning systems do you interact with in your vehicle,” and “When interacting with an early warning system, I best comprehend \_\_\_\_\_\_ signals.” The secondary goal of this survey was to gauge driver trust in autonomous vehicles. This data was used to help guide the direction of the project and aided in determining that the team should focus on external stakeholders rather than take the saturated driver-centric approach. To this extent, drivers were asked questions such as “How do you feel when your vehicle is in self-driving mode,” and “Is there any feature that you don’t completely trust or have hesitancy using?”.

The second survey was directed toward those who share the road with autonomous vehicles. The team created different versions of the survey based on three potential experience types: pedestrians, cyclists, and people with physical disabilities that limit movement. For the purposes of the survey, pedestrians were those who traverse the road and sidewalks by walking, jogging, or any other movement not aided by use of a mechanical device. Cyclists were those who use a mode of transportation with less than four wheels that does not match the safety provided by a car, and included bicyclists, motorcyclists, skateboarders, scooter riders (electric & non-electric), and any other mode of transportation that leaves the user exposed. Person with a physical disability that limits movement included individuals who rely/relied on the use of a wheelchair, crutches, or other support mechanism to travel. Questions were asked to all three audiences as they had a wide-spread impact, regardless of the way in which the road is shared. The primary purpose of questions like these were to better understand how individuals perceive autonomous vehicles. This data informed the team’s understanding of external trust in autonomous vehicles and helped the team determine that a non-driver-centric solution was needed. Questions to this effect included “Do you think autonomous vehicles effectively communicate their intentions (stopping, yielding, getting out of a parking spot, etc.)” and “You are crossing a road when the pedestrian light is green. Which of the following vehicles would you trust more to stop from hitting you?” The secondary purpose of this survey was to better understand the unique ways in which different external stakeholders do or could interact with autonomous vehicles. This data informed the creation of a specific external early warning system. Questions to this extent included “What visual or audial cues would help you understand what the autonomous vehicle is intending to do?” 30 participants responded to this survey, meaning that the team felt more confident in this set of data following a normal distribution.

## Calculations and Audience Feedback (Ines - first pass done)

The team hypothesized on what the survey results would yield and the direction this would take our project. Therefore, the team came up with the following hypothesis:

H0: There is no association between cyclists’ feeling towards sharing the road with AVs and how AVs communicate their intentions on the road.

H1: There is an association between cyclists’ feeling toward sharing the road with AVs and how AVs communicate their intentions on the road.

A significance level of 0.05 was chosen to determine whether we would reject or fail to reject the null hypothesis. Then, the team performed a chi-squared test for independence to determine whether there is a significance association between the two categories: cyclists’ feeling toward sharing the road with AVs and AVs communicating their intentions appropriately.

Firstly, a contingency table including the observed frequencies was made to evaluate the values between cyclists feeling apprehensive around AVs and whether they thought AVs communicated their intentions appropriately was made, the results are below:

**Table 1.** Contingency table of observed frequencies.

A table with numbers and a few words

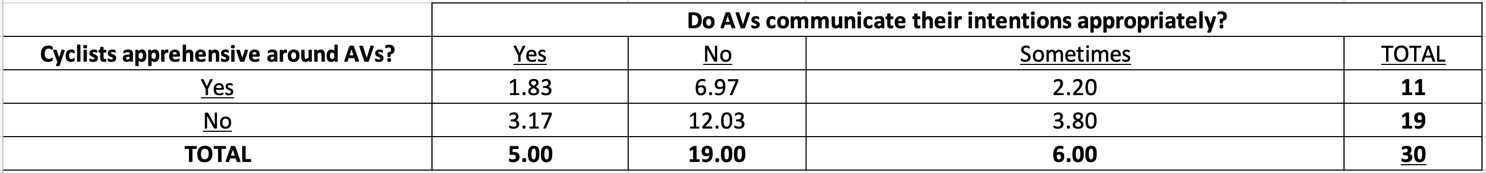
Description automatically generated with medium confidence

Then, the expected frequencies for each combination in the contingency table was calculated using the formula below, where Ri is the total count for row *i*, Cj is the total count for column *j*, and N is the total number of observations in the contingency table:

**Equation 1.** Expected Frequencies.

To get the following expected frequencies:

**Table 2.** Contingency of calculated expected frequencies.



Lastly, using the observed frequencies and the expected frequencies, the chi-squared statistic was calculated using the formula below where Oij is the observed frequency for cell *(i, j)* and Eij is the expected frequency for cell *(i, j)*:

**Equation 2.** Chi-Squared Value.

This was calculated on excel and a chi-squared statistic value of 7.566 was outputted. Calculating the degrees of freedom using the formula below, where *r* is the number of rows in the contingency table, and *c* the number of columns in the contingency table:

**Equation 3.** Degrees of Freedom.

It is calculated that there are 2 degrees of freedom for the chi-squared test. Looking at the critical value from the chi-squared distribution table with 2 degrees of freedom and a significance level of 0.05, it is approximately 5.99.

The value for the chi-squared statistic for the test, 7.566 exceed the chi-squared statistic for the distribution table, 5.99. Since 7.566 > 5.99 there is strong evidence to reject the null hypothesis of independence. In this case it means that there is a significant association between cyclists’ apprehension around AVs and AV’s abilities to communicate their intentions. This allowed the team to be confident that exploring an external early warning system to warn cyclists ahead of time or more clearly of what AVs intentions are, is significant.

## Criteria for Choosing a Solution (Ines - first pass done)

A question that was addressed in the survey was that if the cyclist didn’t feel safe sharing the road with an autonomous vehicle, what was the primary reason for that. Due to the nature of this question being very open ended, the team bucketed the answers into 4 categories: “Unexpected Moves” which included answers pertaining to the cyclist not understanding what the vehicle was going to do next, “Lack of Awareness” meaning the cyclist was scared that the driver and/or the vehicle wasn’t aware of them, “Potholes and Signage Issues” concerned answers to do with the environment of the road, and “No Bike Lane” which included answers worried about the lack of a bike lane. With these themes, a Pareto chart shown in Figure 4 was created.

A graph showing a number of people

Description automatically generated with medium confidence

**Figure 4.** Pareto Chart for categories of cyclists feeling unsafe sharing the road with AVs.

It can be observed that the area where most efforts should be concentrated are in cyclists feeling unsafe due to the vehicle performing unexpected moves such as turns or from the vehicle and/or driver not being aware that there is a biker in proximity. This emphasized the idea that the external early warning system should be solving problems dealing with these unsafe categories, leading to the team specifically picking the right hook problem. The right hook problem is a common situation when drivers must turn (usually right) and through bike lanes when the cyclists is not be fully aware that this is happening and may not have seen the blinker due to their positioning.

A blue pie chart with a few blue circles

Description automatically generated with medium confidence  
**Figure 5.** Pie Chart of sensory cues cyclists prefer an AV to show their next move.

In determining how to specifically address the right hook problem, the team referred to data gathered in the original set of surveys. In the survey for pedestrians and cyclists, participants were asked in an open-ended question: “What visual or audial cues would help you understand what the autonomous vehicle is intending to do?” Their responses were grouped into three general types: visual signals, audible signals, and combo signals which consisted of responses that indicated they wanted both. The data is gathered in the pie chart in Figure 5 above, and overwhelmingly signals that cyclists prefer a visual based signal to be warned about an AV’s unexpected moves.

## Near-Field Ground Projection Research (Yug)

The team decided to conduct some more research on applications of visual signals already in autonomous vehicles that could address the right hook problem for cyclists. They found information on a new piece of technology being developed by Continental called near-field ground projection. In 2022, more than 50,000 people in Germany alone were injured by vehicles that turned, reversed, or braked improperly [7]. Continental decided to develop a new system to help reduce the amount of traffic accidents. For pedestrians and cyclists who are walking nearby, the near-field ground projection system senses them once the vehicle is about to make a sudden move. This could be the vehicle changing direction by turning or backing out of a parking space. Once the system fully senses anyone nearby the vehicle, it will shine a projection onto the ground next to the vehicle to alert them that it is about to make a move and they should be cautious. The projection can contain a warning message, vehicle outline, or arrows that display which direction the vehicle is about to turn [7]. This warning system accomplishes a couple of key things when applied to safety between autonomous vehicles and external stakeholders. For one, it warns pedestrians and cyclists nearby about the presence of an autonomous vehicle and it also lets the driver inside the car know that there is someone nearby. Currently, the prototypes for this system are being tested for use during the night when visibility is low, because the projection is much easier to see on the ground at night than during the day. This general system is also being tested for all types of cars to warn all types of pedestrians, but the project's scope means the team will only focus on autonomous vehicles and cyclists.

# Experiment

## Overview (All - Ines made some edits)

With the primary investigation done by means of the survey, literature research and conversations with experts in the field, the team followed through to the next phase where the proof of concept was to be tested through an experiment. The team recruited 18 participants for the experiment to get a large sample size of data and each participant took about 45 minutes to complete the experiment. Throughout the experiment, the right hook problem response was tested, and quantitative and qualitative data was collected for 54 total trials. Once all participants completed the experiment, the team analyzed the collected data. Through the analysis, the team was able to pick which sign was the most appropriate and effective at warning a cyclist that an autonomous vehicle is about to turn into their lane.

## Experimental Design (Ines - first pass done, Anya – second pass done)

The experiment was designed with two legal policies in mind. Firstly, that when cars are turning, the driver should be putting the turning signal at least 100 feet before making the turn. This means that the sign should be projected about 100 feet before the car would be turning as well. Secondly, that at a minimum, drivers, cyclists, and operators of any vehicle on the road should have at least 20/40 vision [8]. This means that a cyclist should be able to read and/or identify a sign that is 20 feet away. These two remarks are important for the validity of the testing because the team won’t need to account for the projection to be turning on to imitate the car turning their blinkers on in real life since in the lab, the cyclist will always be closer than 100 feet from the car. Additionally, the bike stand will be as close to 20 feet from the projection as possible to account for the lower bound of how well people need to be able to see signs on the street. The error that may happen in this distance is due to the laboratory having space constraints, but it should be as close to these 20 feet as possible.

During the experiment the team looked to gather two types of data, biker self-reported responses and objective measurements. To analyze the biker’s introspective response to each sign the team looked out for their physical response such as braking, slowing down, turning. This allowed to give a sense of their immediate response and indicated their reaction time, which will be explained in the next paragraph. After each projection, the team asked the participant *“What do you think the sign is trying to communicate?”.* Their answer is an insight into what their thinking when looking at the sign which can be compared to what the signs are communicating: the vehicle is about to take a right turn. These two data collection metrics fell under the biker self-reported qualitative data and the main goal for these was to compare the signs with a common benchmark. The responses were analyzed in terms of precision, how the participant physically responded to the sign and was this consistent with a feeling of caution. Any of the signs indicated there was some danger approaching, the team aimed to analyze the responses as either the participant braking and therefore understanding that something was coming, or if just continuing biking and therefore not being aware of the danger. A sign that showed higher precision indicated as more successful on the road since cyclists were more likely to understand they had to look out. Secondly, the responses were also analyzed in terms of accuracy, how closely the participants’ interpretation of the sign was to what it was communicating: the vehicle is about to make a right turn. The team wanted to analyze accuracy because it was concluded the most appropriate sign would not only produce a short reaction time and precise physical response but would also be the most consistent in participant’s knowing exactly what the danger was.

The experiment also gathered objective measurements: using Tobii Pro glasses and an electromyograph (EMG), the team was able to investigate the more physical metrics of the participants responses. The Tobii glasses allowed for the interpretation of where on the sign each the participant’s gaze was fixating. This allowed the team to explore familiarity, recognition, and attention points for elements on the signs. The data results from this were plotted on heat maps to look for consistency across all participants. The EMG was on the participants’ forearm and measured muscle contraction. This was used to calculate the reaction time of the physical response for each sign and usefuihhv

## Experimental Deployment (Seb)

In adhering to human-machine principles surrounding icon characteristics -- concreteness, familiarity, semantic distance, and visual complexity -- the team designed six “signs” that participants would have a chance to respond to in the experiment.

Data gathered from the survey, as well as consultations with various cyclists indicated that a strobe-like blinking pattern would be an effective baseline sign. While this sign has a larger semantic distance (i.e., minimal relationship between icon and function), it is very visually simple, and cyclists noted that it is extremely familiar as they are already used to similar stimuli emitting from the blinkers of cars. If true, the team would expect this sign to have to fast reaction times.

Two signs of the six, figures 6 and 7, were designed to incorporate familiar road signs: figure 6 boasts a large yellow “Yield” symbol, while figure 7 boasts a large red “Stop” symbol. Both are accompanied by a large, curved arrow pointing in the direction of the turn. These signs are expected to be very familiar given that they incorporate arguably two of the most common pieces of public signage. As such, these signs rate well in terms of semantic distance (i.e., close relationship between icons and the signs’ functions) and are visually simple. They are designed with high contrast and use of bright colors which will is meant to help with visibility and recognition.

A yellow triangle with an exclamation mark and an arrow

Description automatically generated  
**Figure 6**. Sign designed by team for testing during experiment. Boasts a familiar large yellow “Yield” symbol and an arrow in the direction of the intended turn.

A stop sign with an arrow pointing upwards

Description automatically generated  
**Figure 7**. Sign designed by team for testing during experiment. Boasts a familiar large red “Stop” symbol and an arrow in the direction of the intended turn.

Two additional signs of the six, figures 8 and 9, incorporate vehicle icons in the designs: figure 8 has a car positioned in the direction of the intended turn, and figure 9 has a bicycle positioned in the direction of the intended turn with a yield sign directly above it. Both are accompanied by a large, curved arrow which also points in the direction of the turn. These symbols are the most concrete of the bunch as they depict real objects relevant to the situation. They also rate well in semantic distance as the icons indicate a clear function (turning car and yielding bike). While the icons in the image are familiar, their familiarity is not believed to significantly impact their function. These signs have the lowest visual contrast of the bunch as they are primarily monotone and will serve as baselines from which to better understand the impact of color and high contrast on near-field ground projection signage.

A car with an arrow pointing up

Description automatically generated  
**Figure 8**. Sign designed by team for testing during experiment. Boasts a car and arrow positioned in the direction of the intended turn.

A black and white image of a bicycle

Description automatically generated  
**Figure 9**. Sign designed by team for testing during experiment. Boasts a bicycle and arrow positioned in the direction of the intended turn, alongside a small red hazard sign.

The last sign, figure 10, comprises of a bright orange arrow in the direction of the turn, accompanied by the text “Right Turn” or “Left Turn,” based on the direction of the vehicle’s intended turn. This is the only sign with significant text outside the bounds of the main icon. While the team believes it will clearly indicate to participants the motivation of the vehicle, it may require cyclists to take an extra second to read the sign, meaning that while the team expects participants will have higher accuracy with guessing the function of this sign, they also expect to record higher reaction times for this sign as well.

A orange arrow with black text

Description automatically generated  
**Figure 10**. Sign designed by team for testing during experiment. Boasts a bright orange arrow in the direction of the turn, accompanied by the text “Right Turn” or “Left Turn,” based on the direction of the vehicle’s intended turn.

## Experimental Deployment (Seb - first pass done)

When a subject first arrives at the IHMS lab, they are asked to review and complete a participant consent form, found in \_\_\_\_\_\_\_\_\_\_\_\_\_. Upon providing consent, the subject is brought to the stationary bicycle. The experimental setup is explained to them as they are fitted with the necessary hardware: Tobii Pro Glasses and an electromyograph (EMG). The Tobii Glasses are fitted to the subject’s head and calibrated to ensure that gaze and fixation are accurately tracked. Three gel nodes connected to the EMG are then placed 10cm apart on the subject’s dominant forearm. They are then asked to look at various specified objects in the room, as well as make a fist with their dominant hand, to verify data from both pieces of hardware are being tracked and recorded correctly. When confirmed, the simulator is turned on, displaying on a 180° screen in front of the bicycle a first-person view of the subject traveling down a city road. The subject is asked to sit on the bicycle and begin cycling.

Each trial consists of ten projections, each showing a different sign, shone onto the ground in front of the cyclist in random intervals. The projection is manually turned on by a researcher, and turned off when the EMG indicates a physical response from the subject. If no physical response is recorded, the sign is manually turned off after it is clear from the eye-tracking software that the participant has viewed the sign. Four points of data are collected upon showing each projection:

1. Tobii Pro Glasses produce a **gaze plot** **highlighting fixation/attention points**. From this, a heat map is generated which emphasizes the points a user primarily or recurringly focused on.
2. EMG produces a graph tracking **measurement of electrical activity** in the muscle between nodes **over time**.
3. Physical response is observed and manually recorded: a researcher notes **how the subject appears to react to each sign** (e.g., braked, slowed down, turned, kept cycling) and manually records their observations.
4. Verbal response is collected by **asking the subject what their interpretation of the sign is** and what their reaction would be should they see it in a real-world environment.

Upon concluding each trial, participants are presented with a NASA Task Load Index (TLX) form, which measures workload of the task on five scales. This is to ensure participants are not over-exerting themselves in the exercise and to clearly establish a designated time for any uncomfortable participant to stop and rest or exit the experiment. In total, researchers tested 18 subjects for three trials each.

## Limits and Constraints (Yug)

There were a few limitations that the team had to account for in their experimental design and setup. One of the main limitations was the allocation of space inside the IHMS laboratory. The experiment needed to be conducted at that location since the model car and data collection equipment were all located inside the lab. However, there was no space on the right side of the car where the team could put the bike and shine a projection for the experiment. As a result, the team decided to put the bike and projection on the left side of the car.

A group of people playing a video game

Description automatically generated

**Figure 11.** Experimental setup of the lab

The team is now solving the left hook problem rather than the right-hook problem. The quantitative and qualitative data collected is still relevant, because there are areas in real life where the cyclist is riding on the left side of the car instead of the right side of the car. The heat maps and self-reported responses still would yield similar results even if the cyclist was on the right instead of the left. The signs have the same elements, but they were inverted for the experiment and the self-reported responses still give valuable insight into what a cyclist interprets when they see the projection on the ground.

The lab also had a lot of computers, which interfered with the readings of the team’s speedometer once they started the experiment. The computers needed to be on to collect data for both the Tobii Glasses and EMG. Also, the qualitative responses were recorded in an online data collection sheet, so it was important for the experimenter and the data analyzer to keep their computers running. Speedometers cannot run in areas with high technological interference, so our team could not use the speedometer to look at the max speed of the participant for each sign during the experiment. Ultimately, the team reasoned that the max speed would not be a useful metric for drawing a conclusion on which projection is the best at warning a cyclist that an autonomous vehicle is about to turn in their bike lane, because everyone’s speed before they see the sign and react varies. There could not be any type of quantitative statement made from analyzing each participant's max speed data.

When analyzing the data for the Tobii Glasses, the team first tried to fill in the gaze patterns of each participant automatically. This meant that the recordings from the Tobii Glasses could be synced up to the heat maps for each sign to automatically fill in where each participant looked on the sign and in what order they looked at the elements of the sign. Unfortunately, the experiment area did not have a solid mono-colored floor background, so the projection’s background also consisted of multiple colors on the floor. As a result, it was hard for the software to automatically pinpoint the exact locations that each participant looked at. The team’s solution was to manually input each location using the data that they had received from the Tobii Glasses, which took up a lot more time, but still provided them with enough evidence to prove that Sign 4 was the best at warning a cyclist that an autonomous vehicle was about to turn in their bike lane. The manual plotting the team conducted did not affect the data results.

# Proof of Concept

## Experimental Results

### Biker Self-Response Analysis (Ines - made some edits Anya)

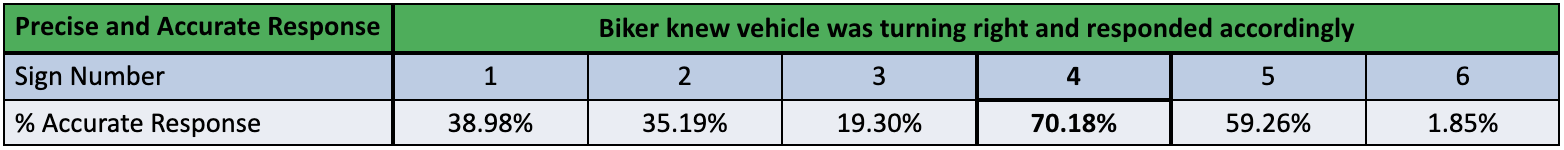
All participants were asked to complete an action as a response to each sign, this could include but was not limited to braking, slowing down, turning, or doing nothing at all. This was evaluated based on precision, most precise response being braking and slowing down or others that demonstrated the participant knew there was a danger ahead and they had to proceed with caution. Additionally, all participants were also asked *“What do you think the sign is trying to communicate?”* and their response showed how accurate their understanding of the sign truly was. The most accurate responses were the ones most closely relating to the correct interpretation: the car is about to turn right. The participants' verbal, or comprehension, responses were divided into 5 categories as listed in the table below.

**Table 3.** Participant Verbal Self-Response Categories.

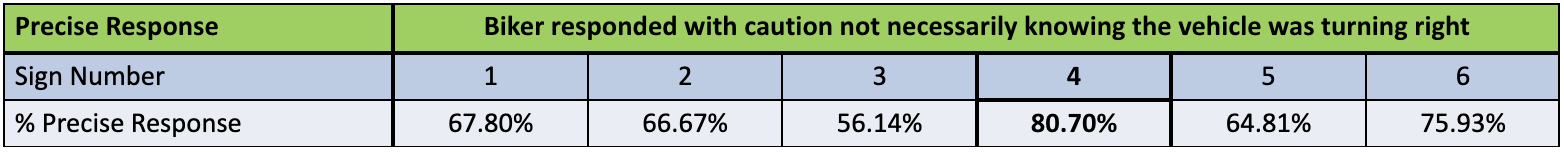
|  |  |
| --- | --- |
| **Participant Response** | **Example Response** |
| **Precise and Accurate** | “Car is about to turn right” |
| **Precise** | “I should be cautious,” “I need to watch out” |
| **Imprecise** | “Car is changing lanes,” “Car is moving towards biker” |
| **Inaccurate** | “Biker needs to turn right” |
| **Disoriented** | “I’m confused,” doesn’t know what sign means, keeps biking |

Based on the 5 categories listed above, the team analyzed how many responses pertained to which category out of total 54 participant trials, as each of the 18 participants saw each sign 3 times. In Table 4 below, the percentages indicate how many responses were both accurate and precise, meaning the biker exercised caution because they were aware that the car was about to make a turn in their direction. Table 5 shows only precise responses where the participant responded indicating caution but didn’t necessarily know what the danger was. And the imprecise responses in Table 6 show the percentage of how often the participant responded inconsistently to what the sign was trying to communicate, was confused by the sign in general, or just continued biking without any response.

**Table 4.** Percentage of participants showing a precise and accurate response for each of the six signs tested.



In the table above, the highlighted sign number 4 is the one with highest precision and accuracy this indicates 70.18% of participants correctly responded to the sign with caution and knew the car next to them was going to make a right turn. This is also much better than the second-best sign, meaning number 4 was the most appropriate at having participants recognizing the car was turning. When looking at the elements of the sign it makes sense, since the sign is simple and only has a car and arrow indicating where the car is going.

**Table 5.** Percentage of participants showing a precise response for each of the six signs tested.

In the table above, the highlighted sign number 4 is once again the one with the highest precision, meaning 80.7% of participants recognized there was a danger ahead and they had to proceed with caution. The precision values for the other signs are higher across the board meaning that generally participants responded with caution to all signs. Sign number 1, for instances, has high precision which makes sense since one of the elements on it is a “Stop” sign and participants are familiar with having to be cautious and brake or slow down when they see one. The second-best sign is sign number 6, a red flashing light, it makes sense that participants with respond with caution. However, when looking at how the precise and accurate table is different for sign number 4 and sign number 6, these are very different. This means although participants responded with caution to the red flashing light, they did not know it meant the car was about to turn right.

**Table 6.** Percentage of participants showing an imprecise response for each of the six signs tested.

In the table above, the highlighted sign number 4 is for the third time the most appropriate in this category since only 19.3% of participants were confused or unsure of a danger being present ahead. All other signs had much higher values for the number of participants being confused in their response, with some signs having more than a third of the participants responding against what the sign was communicating such as for signs 2, 3, and 5.

In conclusion, from the team’s analysis, sign number 4 demonstrated the most effective results in providing the cyclists with a clear sign that they responded with the highest accuracy and precision. The team understands that this is relevant and factual data and further analysis of future data collected in similar experiment can yield even stronger support for sign number 4 or lead to different conclusions.

### Objective Measurement Analysis (Seb)

The electromyograph (EMG) captured 256 points per second of electrical activity in the muscle between three nodes in the participant’s dominant forearm. The resulting data indicates spikes in electrical activity in the muscle over time. These spikes are observed when a subject performs an action that causes their dominant forearm to flex, such as braking, slowing down, or turning.

The Tobii Pro Glasses produced a video tracking the participant’s gaze over the course of the experiment. Gaze was tracked in intervals of 200ms. Videos were isolated for each individual sign over three trials of the experiment, resulting in 30 clips per participant tracking gaze for each sign. Researchers then manually generated gaze plots in which each point in the video was plotted against a 2-dimensional image of the corresponding sign. This allowed the team to track the specific points on each projection that participants were fixating to, as well as where their initial gaze was and the order in which they observed the sign. This resulted in 30 gaze plots for each subject. From their gaze plots, Tobii software automatically created heatmaps illustrating the points on the signs that users paid most attention to. Heatmaps for corresponding signs were overlaid, creating a set of six heatmaps representing overall participant fixation for each sign.

Signs with high contrast, bright colors, and familiar elements (e.g., familiar “STOP” sign) had a big impact on gaze. Participants presented with signs that had these elements often fixated

A stop sign and arrow

Description automatically generated A sign with a green and red light coming out of it

Description automatically generated

**Figure X.** In

A yellow triangle with a black arrow pointing to a yellow triangle

Description automatically generated A traffic sign with green lights

Description automatically generated

**Figure X.** In

A black and white image of a bicycle

Description automatically generated A green and red light on a bicycle

Description automatically generated

**Figure X.** In

A orange arrow with black text

Description automatically generated A green and red sign

Description automatically generated with medium confidence

**Figure X.** In

A red rectangular object with white border

Description automatically generated A blurry image of green and red spots

Description automatically generated

**Figure X.** In

A car with a curved arrow

Description automatically generated A car with a traffic light

Description automatically generated

**Figure X.** Heatmap corresponding to overall sign

Researchers concluded that projections with (1) simple/familiar icons of the host vehicle, (2) a directional arrow/indicator, (3) no text, and (4) low color contrast between icon and arrow/indicator are most effective at conveying a vehicle’s intention and yielding an appropriate response from cyclists.

* Talk about results from data analysis tables – Sign 4 was deemed to be the best sign for warning cyclists that an autonomous vehicle was about to turn in their bike lane (HMS familiarity principles of stop sign made it quicker for cyclists to react?)
* Talk about results from Tobii Glasses and EMG/what conclusion does it show?

## Impact on Trust of External Stakeholders (Anya & Seb)

Anya’s bit about being realistic

As self-driving technology becomes increasingly cheaper and more readily available, more and more people will flock toward autonomous vehicles. At the same time,

Given the current mistrust in autonomous vehicles, these two trends are incompatible.

## Solution Approach (IE Concepts Used) (Seb - first pass done)

The team drew upon a variety of industrial engineering-based skills and tools to design and carry out the project.

Use of human machine system principles was key in supporting all aspects of the project. The team’s initial understanding of how autonomous vehicles interact with drivers and external users relied on HMS principles to interpret how people use and perceive the machine’s usage and impact on themselves.

The design of the survey required an understanding of human machine systems, but also required the use of advanced statistical analysis techniques. The survey design was specifically curated to represent a user’s possible feelings toward autonomous vehicles and was designed to eliminate the perception of bias present in our data collection. The team’s initial goal of 31 responses stemmed from statistical principles that state n=31 responses constitute a proportionally representative response. Upon receiving the survey results, statistical analysis was conducted to determine if there was a statistically significant association between cyclists’ feeling toward sharing the road with AVs versus sharing the road with human drivers. Similar analysis was later used to determine the reasons cyclists feel particularly unsafe around AVs, as well as what measures would be best perceived to increase safety.

When a tentative solution was identified, the team used experimental design techniques to determine how they could test participant interactions with the proposed external early warning system. Human machine principles were used extensively in determining the design of each sign and the experiment's set-up. Cyclists were also consulted to ensure the experiment felt as realistic as possible.

# Ethics and Societal and Global Impact

## Ethics (Yug)

The team focused on maintaining an ethical standard in all aspects of their project. Before the team could collect survey responses, they had to get their survey approved by the IRB. The IRB office ensures that data collection is done ethically. The team had to state on the IRB application that no personal information of the participants would be required. Each subject would be labeled with a number in the order that they participated in the experiment. This would help maintain confidentiality between the participants and the researchers. Anyone else in the future who would be shown the final version of the project would also not have access to the survey participants’ personal information. If the participants wanted to contact the team about the survey, they were encouraged to do so through email.

A diverse cast of participants were interviewed to adhere to the principles of DEI. The team wanted to gather a wide range of opinions, so all types of groups could be represented in the survey. The survey was open to both able-bodied and disabled people even though the latter could not participate in the experiment. Since the experiment required the participant to physically sit on a bike and pedal, disabled individuals could not have their data collected. The scope of this project was geared towards cyclists, but future iterations may expand to warning disabled pedestrians that an autonomous vehicle is about to turn in their direction.

The team also understood that there was things Jonas, their design reviewer, could not divulge about his work, so they asked general questions about autonomous vehicles during the design review to facilitate their discussion with him. The experimental subjects’ treatment was also considered when designing the experiment. The team made sure they wouldn’t be put in danger and could do the experiment without any trouble. The team filled out an IRB form and were approved to conduct the experiment once the IRB office reviewed its steps. During the experiment, the team made sure to question the participants on their well-being after each set of trials to ensure they weren’t feeling any physical or mental discomfort. If they were, the team would give them the option to stop the experiment completely. This ensured that no participants would feel pressured to continue the experiment if they were not feeling up for it.

## Societal and Global Impact (Yug & Seb)

There are a couple of stakeholders directly affected by the proposed near-field ground projection system. Cyclists will be able to see a visual warning that an autonomous vehicle is turning in their bike lane before they get hit. This will have a direct positive impact on their safety because there will be less of a chance that they will run into the vehicle while it is turning. Drivers of autonomous vehicles will also be impacted because they will be in less accidents on the road when turning. They will be safe from any potential accidents or collisions that might occur if the cyclist does not see the warning from the autonomous vehicle that the car is turning. There are also a few groups of stakeholders that are indirectly affected by the new external early warning system. Poor public perception of autonomous vehicles has contributed to people trusting them less than regular cars. If the new early warning system was successful in protecting cyclists and drivers, consumers would have a positive reaction to the autonomous vehicles that use this system. This would lead to an indirect effect on the sales of autonomous vehicles. Car manufacturers would make more money from selling more vehicles. There would also be a larger market for autonomous vehicles, which would increase the number of consumers that buy them. The early warning system would also promote safety on the roads due to less accidents between cyclists and autonomous vehicle drivers. This would have an indirect effect on other drivers on the road because they don’t have to worry about stopping suddenly or having to make a sudden turn. If they were forced to do that, it could cause them to crash and other cars behind them to crash as well. People who are walking or biking nearby are also at risk of getting hurt. All these groups of stakeholders would be much safer with the near field ground projection system.

# Future Work (Yug)

The team will hand off their work to the IHMS Lab who will continue to research this topic and potentially expand on the solution presented in this paper. One of the things that the team realized was that their current model didn’t increase the safety of cyclists in protected bike lanes. Peter Furth talked extensively about protected bike lanes in his meeting with the team. Protected bike lanes are lanes that have a row of parked cars between the road and the bike lane. These lanes are becoming more common as time passes. Since there is a row of cars between the cyclist and the autonomous vehicle, the projection on the ground can’t reach far enough for the cyclist to see it. In other words, the autonomous vehicle will turn onto the bike lane and potentially crash into an oblivious cyclist. If this project is being improved upon in the future, a key step would be to design an early warning system that can warn cyclists who are in a protected bike lane. Currently, these lanes are out of scope for this project mainly due to time constraints. The team is cognizant of the fact that these lanes exist, so they are taking them out of scope in hopes that other innovative solutions can be created in the future using the research and data that they have already compiled for this project. The current solution only caters to cyclists while other research about near-field ground projection has focused on solutions that protect all types of pedestrians on the street. This includes people who walk and people who use wheelchairs. They also must share the roads with autonomous vehicles and are in just as much danger of getting hit as a cyclist when they cross the street. The IHMS Lab can expand the current solution to include some kind of near-field ground projection that can aid those who walk or are disabled along with cyclists. Long-term, this would help the original goal of reducing mistrust between external stakeholders and autonomous vehicles.

# Summary and Conclusions (ALL - Ines made some edits, Anya made edits)

The Capstone portion of the project is concluded, and the team is confident that with the concept created will improve the perception of safety of cyclists while sharing the road with such vehicles. The surveys designed in Capstone 1 prove there is a need for an external early warning system designed for cyclists to be made aware of autonomous vehicles that are turning into their bike lane. It was further explored that the system should warn them about the movement and awareness of the AVs through a visual signal. This led to the near-ground field projection idea to be brainstormed and validated with the design reviewer. The following phase of the project helped the team narrow down the specific scenario they wanted to solve. The team learned about the right hook problem and applied the concept to their scenario. The scenario would be when an autonomous vehicle is turning right and by doing so will cross over a bike lane. The team designed and performed an experiment to prove this concept, testing the effectiveness of the projection and different signs to pick the most appropriate one to be displayed in the scenario. The experimental results identified that when a sign with a car and arrow positioned in the direction of the intended turn (Figure 8) is projected onto the ground from a vehicle using the near-field ground projection, 100 feet before an autonomous vehicle is about to take a right turn and pass over a bike lane leads to an effective and accurate response from a biker. If this near-field ground projection system were to be implemented without prior explanation to cyclists, the team's experimental results suggest that at least 80% of cyclists would react cautiously, with over 70% understanding that a nearby car is preparing to turn and cross their path. The team is optimistic that this system will enhance cyclists' sense of safety and readiness to take appropriate actions to avoid the right-hook problem.

# Project Management

## Earlier Phases of the Project (Anya)

The project originally started with a general investigation topic of “Early Warning Systems in Autonomous Vehicles” with the IHMS lab at Northeastern University. As the team learned about the advanced early warning systems that enhance the safety of autonomous vehicles drivers, the team found that comparatively less attention is directed towards addressing external stakeholder (pedestrians, bikers, etc.) needs. During Capstone I, the team gradually moved towards the relatively unexplored area– external warning systems of autonomous vehicles. By the end of Capstone I, the team crafted two surveys, one for drivers of AVs and another one for the external stakeholders. The AV driver survey served to gain insight on current AV users and their opinions on their driving experience. The external stakeholder survey was intended on helping pedestrians, bikers, and individuals with disabilities to share their experience with autonomous vehicles. Additionally, this survey sought to encourage participants to consider potential impacts of uprising AV technology and identify needs to enhance their own sense of security in the presence of AVs. By the end of summer, the team applied for an exemption form for these surveys with the IRB office of Northeastern University.

When Capstone II started, the team hadn’t received approval from the IRB and decided to, nevertheless, act and assume what the most likely survey outcomes could be. The team did this using a “Four Quadrant” method illustrated in Figure 3.

As survey results were coming in, the team’s hypothesis was confirmed: the external stakeholders do feel more unsafe compared to the drivers of autonomous vehicles. The drivers were more likely to describe their driving experience with words like “Absent” and “Alert,” while external stakeholders like bikers stated that they sometimes fear when cars get “too close,” or think that the cars “don’t see them.” With these results, based on the Four Quadrants method, the project was set to advance towards the development of a new external warning system. At this stage, the team believed the final Capstone deliverable would be a prototype of this new external warning system.

The team had about a week to brainstorm about this proposed new system. The extensive brainstorming and research session helped the team narrow down their ideas to a few advancements that are currently being researched in the field, including near field ground projection systems. Thankfully, the team was able to bounce these ideas off their Design Reviewer: Jonas Herfarth (Mechanical Design Engineer at Tesla). Jonas's insights highlighted that companies centered on driver-focused autonomous vehicle (AV) development invest significant resources in creating a safe and comfortable environment for the driver. Their priority lies in optimizing the driver's experience and ensuring their safety within the vehicle, rather than emphasizing external interactions. He emphasized that a system like the one that the team was contemplating would likely attract attention from companies prioritizing perceived vehicle safety and overall safety, especially those focused on driverless services such as robotaxis. Also, since Jonas is a Northeastern Mechanical Engineering Alumna that excelled at his own Capstone Project in 2022, he advised the team to concentrate on a singular scenario to help bolster the project development. After finalizing the findings from the Design Review, the team’s focus shifted toward the relationship between, specifically, cyclists and autonomous robotaxis.

Once these findings were shared with the team’s Capstone Advisor and the IHMS lab, the team was strongly encouraged to formulate an experiment to test aspects of the potential external warning system. It was decided that the external warning system will have to do with the near field ground projections. And, after a comprehensive brainstorm of experiment ideas, the team narrowed down the scenario to the Right Hook Problem, which is when a car is taking a right turn and is required to cross the bike lane that exists along the right side of the road. This is a common problem for bikers and requires a lot of pre-planning, assumptions, and experience to smoothly interact with the turning vehicle. To gain expertise on setting up this experiment, the team met with two professors at Northeastern University: Professor Hugh McManus and Professor Peter Furth. The meeting with Professor McManus helped establish a version of the experiential design for testing the near ground projections solution and best practices to set up the most real-life-like experiment. The meeting with Professor Furth helped establish the experiment constraints and envision potential future expansions of the project. After sharing all the latest findings with the Capstone Advisor and IHMS lab researchers, the IHMS lab space was investigated, and potential experiment set-ups were concluded. With the whole team present, the lab researchers and capstone group finalized the experiment design on Feb. 15th and prepared the IRB non-exempt form with detailed experiment explanation. After the team got approval to proceed with the experiment, the team obtained all materials necessary and quickly set up the experiment. Eighteen participants were part of the experiment and provided invaluable data. After all trials were finished, the team analyzed the results and concluded based on the data, please refer to section 7 of the report.

## Project Management Tools (Yug)

Throughout the project, the team decided to update their Gantt Chart to mark the team’s progress from the end of Capstone 1 to the present day. The chart had a positive effect on the team’s productivity. It kept them organized and helped each member divide up the work, so that nobody was confused about what was expected of them each week. Real-time progress was compared with the team’s goals for each week to ensure they were finishing their assignments on time. The Gantt Chart was the main source of the team’s project management, but the communication displayed by each member helped to keep the project on track.

## Challenges (Yug)

One of the unique challenges that the team had to face was that one of the team members was based in Jordan from July 2023 to December 2023. They were in a vastly different time zone, so the group had to work around their schedule. Since everyone was on co-op, the members in Boston could not meet during the weekdays until 6 PM EST. For Jordan, that is equivalent to 2 AM, so the group had to come up with a plan to meet on the weekends. The team had already anticipated this would be a problem, so nobody was caught off guard by the change in meeting dates. Being able to manage the project effectively was a blessing for the group, because it meant that their schedule wasn’t thrown into disarray. Every member communicated in case anything arose and the meetings had to be rescheduled. Once again, the Gantt Chart also helped the group keep track of their deliverables and scheduled meetings. This helped monitor progress and ensure that changes could be made quickly.

# Intellectual Property (Yug)

In the performance of the team’s research, experiments, and presentations, they are making use of a variety of pre-existing intellectual properties. Providing the technological basis for their project is the intellectual property surrounding near-field ground projections. Near-field ground projection is currently in its development and testing phase as the system is still quite new. Utilizing background research on the technology, the team worked on developing a realistic solution for their project. While they haven't been using information from specific patents in their project, the way these projectors were designed and their performance under different environmental conditions form the technological basis for their project. For their experimental setup, the team discussed the possibility that the pre-existing road signs they are using in their near-field ground projections may be copyrighted. However, they verified that the design of all basic road signs falls under the public domain in the United States. Lastly, during their Capstone journey, the team has completed a variety of presentations for internal (e.g., advising team) and external (e.g., design reviewer, capstone class, alumni jurors) customers. Many of these presentations have included images of autonomous vehicles and concept art of near-field ground projections; some of which are public, and others that have been copyrighted.

The team’s primary project output, which comprises of any research findings from our experiments, will be left for use by their sponsors within the Intelligent Human Machine Systems (IHMS) Laboratory. Any additional pieces of intellectual property that are produced in relation to their project will likely similarly be left for use by their sponsors within the IHMS Lab, however, will be subject to the team’s discretion at that time.

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# Appendix A: Raw Driver Survey Results

# Appendix B: Raw Pedestrian Survey Results

A screenshot of a computer

Description automatically generated

# Appendix C: Experiment Analysis Data

## Qualitative Data

A chart with different colored squares

Description automatically generated**Table 6.** Participant Responses Grouped For Each Sign

**Table 7.** Key For Participant Response In Table \_\_

A screenshot of a phone

Description automatically generated

**Table 8.** Count of What Participants Responded For Each Sign Using Key In Table \_\_A table with numbers and text

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## Quantitative Data

### TOBII Glasses Timestamp Analysis

# Appendix D: Executive Summary

# Appendix E: Virtual Poster

