Project M

Autonomous Vehicle Redesign via HCI Principles

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Abstract: This analysis seeks to improve the autonomous vehicle experience through HCI principles. A survey, participant observation, and exploring existing interface needfinding experiments are performed, which led to the development of three potential prototypes, a passenger screen implementation, AV mode light indicator, and voice interaction.

Introduction

Development of autonomous vehicles in the early 2000s (DOT, 2018)[1] sparked a new industry determined to revolutionize the driving experience by replacing human drivers with computers. As a result, these vehicles become heavily reliant on complex computation, detracting a users mental model of the system from what common vehicles have today. While the general goal of vehicles remains the same as a means of transportation, the interface in which users interact with to accomplish the goal has greatly altered. In light of recent advances in the Autonomous Vehicle (AV) space, use of these interfaces appears to be inevitable, advocating for the demand to ensure the complexities are supplemented with proper human-computer interaction principles. This analysis will investigate the importance of personalizing the passenger experience for riders in AVs as well as providing valuable feedback about the journey and vehicle conditions. In order to identify the specific needs for these interface alterations, three needfinding experiments will be administered, involving conducting surveys, participant observation and exploring the existing interfaces. After retrieving sufficient information about the problem space, analysis will continue by working on brainstorming design alternatives, prototype design, and evaluation of those prototypes.

User Types

Users affected by this redesign are likely current licensed individuals, passengers, manufacturers, pedestrians, other drivers, and potentially new drivers. Each of these stakeholders is affected in different ways but are all considered in the deployment of our needfinding.

Currently licensed individuals between the ages of 20 to 54 yield the highest amount of mileage (DOT, 2018)[1], with males averaging over 6000 more miles than females. This discrepancy is interesting and should be considered when identifying potential redesigns since there may be a loose correlation between body styles/design and gender (Marketwatch 2016; Edmunds 2016)[2,3].

Passengers are also significantly affected by the redesign since they will be traveling in a completely new experience. Their trust now lies in new technology expected to operate flawlessly or else they may face grim repercussions.

Manufacturers are also affected by this redesign since they are the ones to implement the interfaces. They likely consist of experts in a wide variety of disciplines all with the common motivation for maximizing their company's profits. Fulfillment of proper HCI principles will drive the product's interface closer to invisibility, leading to happier users and potentially more business.

Needfinding Plan

Needfinding Plan 1 - Survey Planning

In order to capture the needs of users for a potential redesign, a survey will be administered through http://peersurvey.cc.gatech.edu/ as a cost-effective means to gather preliminary data, with the goal of achieving 25 responses. Since the advent of AV's is still in its commercial infancy, this needfinding experiment aims to identify the behavior of users as well as their concerns. Since AVs are still in their commercial infancy, it's difficult to capture the public's personal experiences with them since that is a limited population. As such, questions will be high level, associate characteristics of current vehicles as a frame of reference, and attempt to identify what interface displays in an AV's system should be the focus. Additionally, basic personal information will be identified such as age and gender, which can lead to further personalization based on existing correlations stated in the introduction.

Question 1 & 2, *What is your age, What is your gender?*

Response options: Multiple choices, single answer, intervals.

These two questions are simple to quantitatively analyze and draw conclusions from by correlating to trends found in the current automobile market. As discussed earlier, there is evidence that certain designs and cars attract specific demographics.

Question 3 & 3a, *Do you prefer to drive or be a passenger? If so, why?*

Response options: Driver; Passenger / Free response

Since in AVs, everyone is effectively a passenger, this question will attempt to determine if there is a large portion that prefers to drive and then identify why to hopefully capture those criteria as a design alternative.

Question 4, *Do you follow speed limits?*

Response options: I drive 5 or more under; I drive close to the speed limit; I drive 5 or more over.

This question aims to understand the user's comfort with driving and the primary interest is to identify how many respondents drive under the speed limit. If the frequency of these individuals is significant, then AVs programmed to drive close to the speed limit may cause user fatigue as they are not comfortable with the speed they are traveling.

Question 5, *What part of a car's visual interface do you focus on most?*

Response options: Free text

This question is fairly straightforward and aims to identify which portion of a car the redesign should focus on. Since users are likely going to be transitioning from non-AV's, they are likely going to continue their behaviors to AVs. Providing them pertinent information while allowing the car to operate on its own may improve the user's comfort and reduce fatigue through the principle of consistency.

Further question analysis can be found in Appendix A.

Biases

Significant biases exist in this survey, primarily social desirability and observer bias. Many of the questions are self-incriminating, which may push respondents to answer with the "socially appropriate" response. For instance, driving over the speed limit is technically illegal but it is socially acceptable to driver slightly above it. As such, people who do speed often may not want to incriminate themselves by stating that they drive at the speed limit. Observer bias also affects this study. Since many responses are not free text to promote simpler processing, respondents are bound to answers that may not reflect their true remarks, making the survey potentially tailored to what our expectations are.

Needfinding Plan 2 - Participant Observation

For the second needfinding experiment, a participant observation will be performed. One of the team members will be driving the car and come up with a set of activities that share their cognitive load while driving. With the advent of autonomous vehicles, the intention is to specifically look for activities that can be off-loaded to an interface. In autonomous vehicles these activities may fall into the criteria below.

1) *Cognitive Load Sharing -*

   The autonomous car can be designed to enable users to share their cognitive load with it, which will enable the car system to work as a cognitively distributed machine. Some of these activities can be navigation or road condition monitoring.

2) *Information Sharing -*

   As the vehicle's autonomy increases, the expectation from the vehicular system to provide a continuous feedback to the occupants may also increase. It is necessary for the human occupants to be aware of what is the state of the vehicle to avoid any panic due to uncertainty.

As a participant, the expectation of this observation would be to identify activities that fall into these categories and enable the user accomplish them through the interface. The observer is going to drive in a normal or non-autonomous vehicle and identify activities in a contextual sense.

With the intention of guiding observation, the analysis has identified questions that can be answered through this approach:

- What are the activities that the user performs when she first sits in the car?
- What are the activities that the user performs while driving in the car?
- Can these activities be offloaded to the vehicle?
- What would be the feedback that the occupants would like to know about when they are driving in the car?
- Is there any extra feedback that the occupants would like to know about when the car is performing under autonomy?
- What is the frequency of the task and magnitude?
- Does different setup such as a family with kids or senior or differently abled have different needs?
- What are the impacts of users activity on driver?

Participant observation must and should perform the task of driving under diverse scenarios. This will support the study by extracting additional contextual information through identifying activities that are embedded into the interface. The plan is to perform these observations at different times of the day. Even though the driving conditions, cultural driving habits, and road etiquettes will differ from country-to-country, the intention of the interface design is to address broader relationships between occupants and their vehicles. Specific scenarios and information will be left to a later iteration of the design cycle.

This plan may lead to a high degree of confirmation bias, which this analysis will attempt to mitigate through using using multiple experimenters.

Needfinding Plan 3 - Exploring existing interfaces

Following the participant exploration, the analysis dives deeper by exploring the existing interfaces of autonomous vehicles. Since autonomous vehicles in the current market are still limited in some states or countries, they are often perceived as a luxury. Therefore, the method that this report will use to conduct this experiment is to research relevant news and user reviews instead. There is ample information available on the Internet that shows capabilities of interfaces in autonomous vehicles and hands-on user reviews. Hence, the sources of information that will be investigated are technology news and user reviews in the format of articles or videos from reliable online news websites and YouTube. Exploration of existing interfaces will focus on the interaction of either drivers and/or passengers with the autonomous vehicle inside the car and their personalization to autonomous vehicle interfaces.

The objectives of this needfinding is to identify potential problems or pitfalls of the existing interfaces and attempt to determine how it can be redesigned for improvements. Research on existing interfaces will also consider various makes and models.

Again, this needfinding plan is afflicted by potential confirmation biases which the study hopes to reduce through execution with multiple experimenters.

Needfinding Execution

Needfinding Execution 1 - Survey Execution

For the full detail of survey question and raw survey response, please find it in Appendix A: Survey Questions and Appendix B: Survey Response.

Survey result counts are displayed in the appendices. Some results were interesting and address some aforementioned concerns. To begin with good news, it appears that a majority 70% (17) of respondents do trust AV's, 70% (17) would use the autopilot feature, and 79% (19) are defensive. With these results, the passive and defensiveness of AVs will likely not be an area of concern for a majority of drivers, where it was proposed that this characteristic may be insufferable to some, more aggressive drivers.

Unfortunately, and the needfinding portion discusses this potential pitfall, while respondents do trust AV's, 75% (18) as pedestrians would still prefer knowledge of which cars are actively autonomous, and 92% (22) of passengers would as well. These results are beneficial however and does promote the potential re/design of a warning system to both the interior and exterior of the AV when in autonomous mode, with a focus on the interior. Secondly, 67% (16) of respondents have indicated that they prefer to be the driver, likely indicating that they prefer to be in control of the vehicle. With this in mind, the design of AVs should emphasize some of the tools that drivers pay attention to while driving to increase familiarity and potentially alleviate cognitive fatigue. Question 5 attempts to analyze this issue through asking the users what they prioritize when driving, and of those who stated that they prefer driving (16), 88% of them also stated that they primarily look at the speedometer. As such, this likely warrants a re/design of the AV interface to display the speed to passengers/drivers to improve comfort.

Biases in the survey were controlled through structuring the questions to account for sequential knowledge gain, as well as opening the survey to anyone with the link. Additionally, questions were kept high level to account for social desirability bias.

Needfinding Execution 2 - Participant Observation

Participant observation is to perform the activities and noting the contextual scenarios with the user being a participant in the experiment. The primary goal of this needfinding was to know about the contextual information while a use is in the car.

For this needfinding, we have done driving during the three possible times of the day, each with and without accompanying passengers. The goal is to understand what are the different things that are required by the occupants of the vehicle, and how such needs (or demands), be delivered to the users with the help of autonomous vehicle interface. As the autonomy increases, the vehicular intelligence to keep the passengers in the loop should also increase. With such intentions, the participant observation was carried out.

As the driver enters the car she first starts to adjust the seats of the car, and other adjustments to the car, based upon her preferences. For example, the driver might adjust the steering wheel height, or if the sun is too bright, pull down the sun visors. The driver also checks the weather conditions outside and based upon that, set the air conditioning. The passengers of the vehicle also start making some adjustments. For example the seats.

The observation revealed some good cognitive loads of the driver, that are important with the interface design, as explained below.

While driving, the driver continuously checks the conditions on the road, and based upon the destination, requires a constant feedback on where is the car is, and how far/near the nearby cars are. While making the turn or changing the lanes, the driver would check the blind spots and make a calculated guess on when to turn. The driver relies upon the mental judgement on making the turn. Interesting thing about this is that the judgement provides the driver continuous feedback, and based upon that, builds up his confidence if the car movement is ok. In case of autonomous vehicle, the absence of this feedback loop, may hamper the driver and create a panic situation. This is one critical feedback that can be provided through the interface to the driver. This feedback is also helpful to subdue a panic among the passengers when the car is under control of artificial intelligence.

Another important judgement that the driver makes while driving is the speed of the vehicle with respect to the surrounding vehicles. When the driver is driving alone, the driver makes the mental judgement on what speed is he comfortable with respect to other drivers on the road. When any passenger is involved, the driver communicates the speed as well as his reasoning to the fellow passengers. This is an example of social cognition, where the driver understands, or senses the passengers needs and comfort level, and makes the judgement call on the speed.

Since driving judgement and feedback is what we are trying to address in this interface, the observation is primarily targeted at such nuances. Another mental judgement is involved when the driver is unable to clearly view the lanes on the road. In such situations, the driver is left to "predict" the lanes by either following vehicles ahead of her, or by using roadside landmarks as a reference. When a passengers is involved, such a decision is communicated to the passenger. For example, statements like "I can't see the lane, I think I am going to follow the car ahead of us", is a think-aloud mechanism through which driver communicates to the passengers. Another example, that I saw very often was "I think this is the lane that I must drive on". This was particularly exemplified when driving under night conditions or when the sun was too bright and it was impossible to view the road. Such surrounding conditions hamper the drivability of a person.

Cognitive load of the driver is also hampered by some distractions of the passengers. For example, the passengers may ask questions like following:

- *"Where are we going?"*
- *"What is our ETA?"*

When designing an autonomous vehicle, we would like to make the interface able to answer such questions to the passengers, while providing a constant feedback.

To account for biases, the needfinding was performed through different people in different environments.

Needfinding Execution 3 - Exploring Existing Interfaces

In the needfinding execution, we have explored interfaces of autonomous vehicles from different models and different levels of autonomous driving. For example, in Tesla model S has an enormous 17-inch screen to centralize the control of the car instead of physical buttons. In contrast, Waymo interface simplifies the interaction to minimal for serving as an autonomous taxi. In Renault Symbioz concept car, it shows the capabilities of fully autonomous driving with light indicators to tell passengers and pedestrians about autopilot status. New Mercedes Benz S class has integrated the capabilities of GPS navigation to level-3 autonomous driving. The images from existing interfaces can be found in Appendix E.

Analysis

Almost all of the current autonomous vehicle manufacturers are doing a good job in interface design. The design are universal for general drivers and focus on direct manipulation. Therefore, drivers can learn to use a particular interface and get familiar with the interface in the short amount of time.

However, we found that there are only the small amount of consistency across autonomous vehicle interaction. Every car manufacturer has its own ways to implement the autopilot feature, such as different buttons or methods to trigger the mode. There is no general agreement on using physical interactions and feedbacks from the interface like the others component such as light indicators or car horn. This is a challenge to design the standard of universal interface in autonomous vehicle field. The design should concern about consistency in driving across car models. Moreover, the design should get along with the level of autonomous driving in order to define the task and the context of the drivers. Too much of interaction on the interfaces can be a distraction in driving in lower level of autonomous cars. Bias in this execution is accounted for through utilizing different individuals to gain information from various sources.

Lastly, another thing that we learned from studying the existing interfaces is that the autonomous car interfaces still *lack of personalization* in which the interface will adapt to users in different age groups and technological literacy levels. The users need to learn more about the mechanism of driving assistance for each car model. For example, drivers need to know that they are supposed to keep holding a steering wheel while driving if they are driving level two autonomous vehicle. While, they don't need to do such a thing if they are driving in level five cars. The interface should instruct drivers in many different ways for each car makes.The personalization will bridge the gap in helping users better understand the interface in their own terms and representations with the good mapping principle. For instance, the interface will change the interaction style based on demographic in age, gender and culture of a person. With the personalized interface, the interface will become invisible for users quicker. Regarding to the personalization, the design should be the same equity across users. So that all users can get the same functionality despite the adaptive interfaces for the best user experience.

Control for the biases

In exploring the existing interfaces, we chose the interfaces from the fact that they have good self-driving technologies without any preference to a particular car make. we can avoid our confirmation bias by reading and watching review carefully and summarizing findings from facts. Therefore, we can see the wide range of design for the existing user interfaces.

Data Inventory

Who are the users?

Primary target users for needfinding will be the people who travel in vehicles but don't drive. Users can be related to the drivers i.e. personal relationship or driven by for the business i.e. a taxi. These users often interact with their driver for personal needs which may lead distracting the driver from concentrating on the road and may lead to accidents. Although there may be some cultural specific differences, the general utility of the car makes a users age, gender, race, and demography irrelevant. Since the controls of the cars are often only available to people sitting in the front seats, our target audience is the users who sit on the rear seat.

Where are the users?

Users who are driven by an autopilot enabled car. Since cars can be anywhere the potential users will be spread across the world. However, the needs for the users will be related with only them inside the car. Any person who is inside an autopilot car will be a person of importance.

What is the context of the task?

The context of the task is related to the passengers and an autopilot enabled car. An autopilot enabled car is a one that can be driven either manually or in autopilot mode. Tasks associated with these users would be valid when users are engaged with the car related to their need by either traveling in the car or preparing for imminent travel.

What are their goals?

Cars are mostly designed for drivers, and nearly all the controls are given solely to drivers; for example, management of rear speaker volume is given to the driver. In the new age economy, manufacturers are generally more open to new car designs, which sparked the motivation for this study. While there are numerous exploratory options for this market, this study will be restricted to non-driving related features such as:

1. Music and other entertainment content
2. AC
3. Seat adjustment
4. Misc (light, other driving & route related information)

Passengers are equal stakeholders in a driven car. When the car switches mode to autopilot (Steering and pedal), passengers should be informed so that they can help drivers.

Right now, what do they need?

Presently, user needs surrounding autonomous vehicles is scarce due to the limited market, but the interfaces currently available do not provide sufficient user interaction. For example, in some cars a screen is provided for the passengers but it is limited in functionality. Additionally, when an autonomous vehicle is in autopilot mode, there is very little feedback to notify passengers of this action,

What are their tasks?

The passenger tasks depends on their context. The main tasks are related to travel to the destination such as collecting information about the route, car, and environment. For monitoring task, passengers need to see battery level and temperature in critical case. The other tasks enhance user experience such as entertainment, seat adjustment and POI suggestion for hotels or restaurant.

Defining Requirements

Autopilot

At present, driver who initiates the autopilot mode knows the change of the mode. Car does deeps (and colourful icon on the display screen) to provide feedback about it but that is again aim towards the driver. Passengers should know not only know the change of mode but also for the whole duration. It should an interface that suggests everyone in the car that car is in Autopilot mode.

Passenger Controller

Since, there is going to be a dialog between passengers and driver who controls the utility of features, the interface requires a mode of information sharing interface. This controller will facilitate some level of control to them for e.g. ability to change music, entertainment, sound volume level, and AC. It also needs to purpose of sharing the entertainment content with the passengers .

Communication

There needs to be a communication between the driver's system and passenger's system. There can be many use cases for the communication for e.g the enquiry and information shared across : Particular content is suggested by the driver, passenger searches the item and sends back to the driver for review.

Authorization

In some cases, driver doesn't want a particular type of content to be played in the car. There should be an override mechanism and authorization for specific apps. For e.g. Taxi driver may want to prevent riders to play offensive content. Or at times a passenger may want to select the different route for safety or other reasons.

Apps

Most apps will be installed on the system with users credential and therefore needs some sort of monitoring and management tool.

Design Alternatives

Brainstorming Plan

With the needfinding exercises performed, this analysis will now transition into the brainstorming exercise to identify potential prototypes. In order to reduce social loathing, conformity, production blocking, and performance matching, individual brainstorming exercises will initially be done followed by a group brainstorming. Each member will report their ideas prior to the group effort via Google docs, which will then be discussed over a call. This analysis set the target of ten ideas per person over five days, leading to 40 ideas which will be compiled and reviewed for potential prototypes. Discretizing the effort over multiple days provides the opportunity for new ideas to form and it had been encouraged that participants perform it in this manner.

Brainstorming Execution

Table 1 : Result from individual brainstorming

Fon	● Physical button for autopilot with light indicator and special action to trigger the mode. ● Adaptive screen layout for senior; bigger font size.

	● Passenger profile for speed and driving-style preference ● Adaptive optimal seat position based on passenger height and body structure. ● Voice interface for on-going trip information (e.g. route, weather, fuel, POI). ● Augmented reality interfaces that overlay places information on windshield and windows. ● Adaptive air condition and shading automatically according to weather and external factors using voice interface and settings. ● Adaptive lighting based on user activity and interaction. ● Navigation interface on screen during trip that support self-driving. ● Head up display (HUD) at windows together with gesture interaction.
Mike	● Interior cabin light changes based on driving mode. ● Specific design requirements across AVs. ● Automatic personalization via IoT. ● Automatic climate adjustment based on body temperature. ● Automatic driving adjustments based on driving habits (braking distance, turning speed etc.). ● Multiple displays for vehicle speed. ● Virtual assistant specifically for driving. ● Recommendations for AV specific features. ● Cabin sensor to ensure someone has their eyes on the road.
Priyank	• Feedback for all the actions performed by the car. • Cognitive load-sharing between driver and the autonomous car. • Artificial assistant capable of responding with various requests from the passengers. • Lane-specific requests - slow lane driving or fast lane driving? • Similarly, speed specific requests - from drivers as well from passengers. • Location enquiry from the passengers. • Information regarding what is the current route the car has taken • Loading up the personalized settings for different users - for example, seat inclination/seat temperature/visor controls. • AI voice recognition.
Raj	• Creating A4 size laminated dos and don’ts of etiquette in the car. It is similar to security instruction card in the planes

	• All passengers mobile phones are connected to car and any change in the configuration is notified to everyone in the car • Audio played out. Any change in the mode is verbally communicated by the car • Haptic feedback: Car provides a haptic feedback to all passengers about the change of mode • A digital screen on the passenger seat to allow 2 way interaction with the passengers • Some character (dog, or mascot) that will communicate the changes (verbal or light colour based) • Light source on the dashboard to communicate with colours

Selection Criteria

Based on the brainstorming exercise, the ideas collected are tested with *Desirability, Feasibility and viability* [12] to select the ideas for prototype. Desirability determines what users want/need, feasibility explores the possibility and viability analyses the cost-benefit.

Table 2: Selection Criteria

Idea	Desirability	Feasibility	Viability	Comments
Instructions	❌	✓	✓	Provide no control Execution is not guaranteed
Haptic feedback	✓	❌	✓	Difficult to differentiate Short time to live
Digital screen	✓	✓	✓	Flexibility to scale Complete control
Light Indicator	✓	✓	✓	No control Communicate effectively
Mobile Sync	❌	✓	✓	Need to pay attention Low battery
Audio	❌	✓	✓	Short TTL Distraction to all

Virtual Assistant	✓	✓	✓	Unstable tech Internet dependent

After analyzing all options, we are more confident on Digital Screen, Light Indicator & Virtual Assistant making the desired impact of the users.

Next, we will created prototype for each option and evaluate it with the users for further analysis.

Prototyping

Prototype 1 - Passenger Screen Card Based Prototype

The card based prototype includes a UI of the screen that will be available to passengers where the screen will be divided into three horizontal parts: 1. top part for quick data, 2. middle to provide interface for active app, and 3. bottom most provides access to apps.

Active app will be highlighted and associated interface will be presented to users for utility.

Figure 1: Example of passenger Screen

This screen will be mounted on the back of the fronts seats for easy access to passengers as shown in Figure 1 above

Main screen for the driver becomes a master which will interact with the slave instances for sharing the information. Users prefer something similar to information control on planes. This will be a touch screen for users to operate. It will have interface for user to select apps and also sync mobile. It will be powered by the car. Its utility will be restricted to the car and time to operate will be closely related to the operations of the cars i.e. screen will go blank when the car is switched off.

Although it will have app store kind of system to install any kind of app, it should come with few pre-install apps such as Car controls, Maps, Music, Mobile Sync, etc.

Giving controls to passengers creates a potential danger of distracting drivers, it is therefore important to create master-slave systems of approval. Drivers will have the ultimate authority on the controls. In some cases, system will confirm the changes only after driver's approval. For e.g. a child sitting in the backseat may trigger something which driver can easily override.

In other cases, passenger can change the direction for everyone in the car by selecting Maps app and entering the (new) destination. System will search for the destination and changes the maps for satellite navigation. Maps will start the navigation for new destination for the driver as well as presents the UI for the passengers.

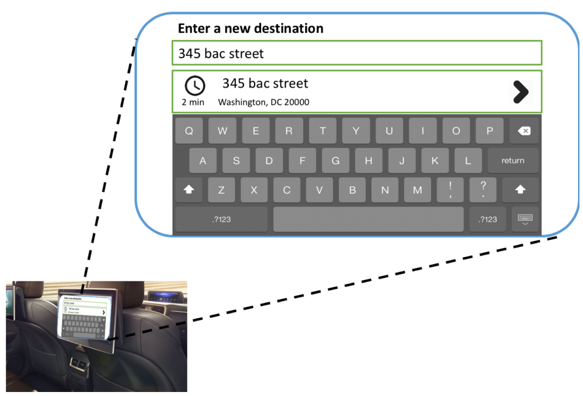


Figure 2: Card Based Prototype Example

This is mainly useful for the cases where the driver doesn't have the authority over the destination for e.g. car is operated as taxi or car is driven by a chauffeur. Slave screens carry added functionality to assist passengers that can take away the distraction from the driver and also enable system to system communication. It can also be used as tools to enable passenger so that cognition is distributed in the car and the passengers.

Please find full card based prototype in Appendix G: Card Prototype.

Prototype 2 - Light Indicator Textual Prototype.

From all of the needfinding and brainstorming experiments it became clear that there exists a desire to implement a persistent feedback indicator to identify whether or not the AV is in autopilot mode or not. The survey had found that over 92% (22) of respondents would like this interface design, which actually exceeds the number of responses for having this indication system on the exterior of the vehicle to warn them as a pedestrian. As such, this prototype explores the implementation of a feedback artifact to disclose the current status of the AV vehicle in order to increase the ease of the system.

From our brainstorming group discussion, a few designs have been considered, but they had mostly circulated around the use of a light indication, which provides an appropriate constant feedback. Use of sound, such as a ring when the vehicle first enters autonomous mode, was also considered but lacked the ability to be used constantly without overwhelming the users. The options eventually narrowed themselves down to various methods of lighting, primarily in terms of location, shape, brightness, color, and frequency.

Location, location, location, much like real estate, the location of the indicator is critical to its success. It needs to be in the view of all passengers but also cannot distract the driver, and should optimally be placed in an area that can be consistent across AVs (a signifier can potentially be used to alleviate this concern however). The places that had been discussed are the floor, accents, ceiling, and head unit, or a combination of the three. Having the indication on the floor is similar to how some cars have customizable ambient lights (ref). Our interface consideration is to utilize this technology to provide users of the driving mode based on the color of the light, and if implemented properly it provides a clear indication of driving modes, while not being a distraction to the driver. The other location considered is once again influenced by the current automotive industry. Similar to floor lights, some manufacturers provide the ability to customize accent lights in the cabin, such as door handles (ref). This application is a bit more subtle than the floor lighting but maintains its effectiveness. For the roof, the concept is not to cover the roof but accent the sides of it, similar to the door handles. The benefit of this approach is that it is much more visible to all the passengers, but this increased visibility also results in distracting the driver more. It may also not fare well with intense natural light. The last location considered is the head unit where most cars keep their radio and climate controls, or sometimes everything as shown and discussed in the Figure 4 Tesla car interface. Lighting considerations were along the lines of a bordered outline if the unit, so for instance, the trim or bezel on the display of the Tesla.

When considering the shape of the light, most of the options conformed with location of the light; accent lighting on the door handles are shaped to fit, the floor light should cover a portion of the floor etc. Variation did exist though for the head unit and ceiling, where a light can be used around the entire bezel or a portion of the unit to preserve aesthetics. As discussed with the ceiling, driver distraction is a concern and the redesign can be modified to limit driver interaction, such as placing the light strips on the back sides of the car, between the B and C pillars, or on the B pillars themselves (see Figure 3 below for pillar locations).

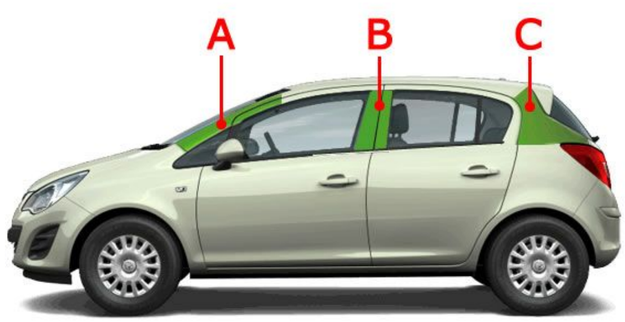


Figure 3: Standard vehicle pillar layout (ref)

Anyone using a digital screen understands the importance of brightness. In the extreme but common cases, displays can be nearly invisible or overbearingly bright. Control of the brightness is crucial for the lights to function properly, which should change based on the environment. Adaptive lighting sensors will be placed in the location of each light to monitor conditions, similar to how phones do the same.

Color will be an important consideration which may require standardization across AV platforms. If the color choice is not consistent across different manufacturers, they can easily lose their intended purpose. Additionally, this redesign attempts to choose neutral colors in order to reduce the potential emotional effect associated with specific colors such as red.

The last characteristic considered is the frequency of the light, or in short, if it should blink. Since blinking is often a technique used to gain attention, there may be a potential use case for this when the vehicle first enters autopilot mode, and the lights will flicker briefly to notify all passengers of the change. The flickering however should not be persistent, as it may be a distraction to everyone, and cause fatigue. An additional consideration are pets, who are able to distinguish higher frequencies (ref), potentially leading to the desire for frequencies higher than the human threshold (>~50Hz).

Summarizing the above discussions, the preliminary decisions were compiled to maximize the benefits of each characteristic. This prototype will implement floor lights along with accent lights on door handles, each as strips as opposed to a dot or bulb to increase visibility, mounted with adaptive lighting colored white, or no light, to indicate non-AV mode, while green signifies autonomous mode, and when the mode switches, the green light will slowly flicker a few times (half second delay) before becoming a consistent 100Hz. These criteria will ensure that passengers are aware of the mode change and current operating conditions, while minimally distracting the driver when not in autonomous mode.

Prototype 3 - Voice Interaction Wizard of Oz Prototype

The Wizard of Oz prototype refers to a prototyping methodology in which “the interactivity comes from a human, rather than an algorithm or software code, with users ‘ believing latter is the case”[11]. While doing brainstorming, we have planned to have a prototype involving an artificial agent, which can take voice commands of the human inside the car, and respond it accordingly. In order to satisfy such interface, we are planning to create a wizard of oz prototype.

The interface of the car will be activated by a predetermined phrase, which is common and consistent with many contemporary artificial agents. For instance, an activation phrase shall be customizable by the user, as shown in the example below.

Activation phrase (customizable) : say ‘Hey <car>’ or just ‘<car>’. The car name can be set up aliases for convenience.

After a user says the activation phrase, it will play a response sound as a feedback to let user know that it is listening to a command. It will play another response sound as well as provide a visual feedback by changing the color of the lights again, after the command is recognized and performed. Otherwise, it will ask for a clarification or ask user to say it again. In this prototype, assume that all of the interaction is based on the context and the flexibility to the keywords given by users, so the users can interact it with natural language. For the sake of the brevity, assume that all commands are preceded by the activation phrase as noted above.

For the full interaction script of this prototype, please find in Appendix H: Wizard of Oz Prototype for Voice Interface.

These are basic functionalities that the system can perform for personalization. The system can also load preset settings for the user, such as the car seat inclination/visors, etc. When the user sits in the car, the voice AI system is activated, and the user can command the car to load his setting. The system will load up the setting for the user.

Since the interface is about personalization, we would like to introduce some customizable approaches that be set over voice command. Simple restrictions, like what the car can or cannot do ,would be additional capabilities that can be explored. Also, the interface would be able to save those customizations. The benefit of the configuration setting over voice command would make sure that no other conflicting voice command is given while the car is in motion. This would not be taken into effect. For example, a voice command can be used to set a configuration for speed, lane, etc, using the commands included in Appendix H.

To evaluate the Wizard of Oz prototype, we had reviewed and had a discussion about the prototype to make sure that the prototype is valueable and aligns with user needs. We had tested the transcript before conducting execution in the next step.

Evaluation Planning

Qualitative Evaluation Plan - Interview for card based prototype

The card based prototype will be evaluated with the users through the interviews. We will select the users from the personal connect and explain them about the reason of the arrangement. Users will be selected based on their profile:

1. Users who have cars and has use case more than just an office commute
2. Users who have family and take passengers in the car
3. Users who ideally have Tesla or similar car with autopilot functionality.
4. If we can't find someone who has Tesla in our immediate network then we will select users who are aware of the autopilot functionality.

We will schedule the interview by communicating to users about the assignment. We will also communicate to them that it shouldn't take away the seriousness of the interview. Although it will mainly to be support us on our assignment, the main objective of the interview is to provide us the insights on the prototype. We intend to conduct the interview in a quiet place : either in a coffee shop or at home or any place where there aren't many things that can distract us. We intend to have the following structure of the interview.

Introduction involves laying the groundwork about the subject, the team that is exploring the interface, importance of the interview, and the problem related to the prototype.

Agenda of the meeting (interview) will be informed to the user. It is to evaluate the prototype and explore the possibility of improvement.

Problem Statement will be shared with the users: How passenger (an important stakeholder in a driven car) is clueless and helpless while driven by.

Prototype will be shown to users to interact with it. Since it is card based, we need to set the expectation or remind the objective of the interview (evaluation of the prototype) on a low fidelity wireframe.

Questions will be answered. We are sure there will be tons of questions from the user. A dedicated section for question is just to instigate users thoughts but we will take it up as and when users have doubts.

We will constantly capturing the insights of the interview by manually taking notes. We are looking to conduct 3 interviews depending upon the availability.

Empirical Evaluation Plan - Textual Prototype Light Indication Distraction

From the textual prototype described above we have decided to continue to approach the idea of a light indication to provide feedback to passengers that a car is both entering or in autonomous mode. This quantitative evaluation is to analyze the response time of passengers to the changes in the light indication. To capture the prototype discussion, different colors, frequencies, and location of the light will be used to evaluate the placement that results in optimal location for visual feedback from the perspective of a passenger in the back seat.

The experimental setup for evaluating the visual feedback is intended to be simplistic to reduce the number of lurking variables. It involves a LED light that displays colors: Red/Green/Blue/White, as shown in Figure 6 in the appendices. Two different lighting modes will be trialed as well, a solid/still lighting mode, and a flashing mode at ~1Hz. Lastly, the lights will be placed at three different locations in the vehicle, the center console, on the B pillar (attached to the sunroof), and on the floor; images of the location can be found in Figures 7 through 9 of the appendices.

A within-subjects setup will be performed with a group of five participants, exposed to a random sequence of all conditions. Participants will be sitting in the rear driver side seat, while the driver will control the experiment by both remotely turning on the light at a random moment in time, as well as starting a manual stopwatch to time the response rate. The participant is then asked to shout out the color of the light if they see it, which will then stop the watch and the time recorded will be documented. Each participant will create 24 data points; 4 different colors at 2 different frequencies at 3 different locations.

A significant lurking variable is the effect of participant bias. Even when participants are told to act normally, the knowledge of how to perform the experiment will likely still keep them alert to the situation. This is attempted to be minimized by conversing with the participants during the experiment to hopefully distract them.

The null hypothesis in this case would be that the placement/color of the lights would not matter; there is no statistically distinguishable response time for the different colors, frequencies, or location.

Contrary to the null hypothesis the alternative hypothesis would be that there is a particular set of lighting conditions that results in a statistical difference in the participants response rates.

Qualitative Evaluation Plan - Wizard of Oz prototype

In order to evaluate voice interface prototype, we will conduct a qualitative analysis of wizard of oz asynchronously and think-aloud. The way we are planning to do that is to write a simple conversation between the interface and the user, and gather some qualitative data over the survey from readers about the prototype.

The users can assume being in a situation and provide feedback on whether the prototype lives up to the expectation. Since, this is a very low-fidelity prototype, the early user feedback will set up a guideline on how to take the prototype forward.

The reason for choosing such an evaluation method over interviewing is that the voice interface does not provide any "scenarios" that interviews can exploit. The interface does not have structural nodes defined, and hence the experience for most users would be in the form of question and answer. This does not serve the purpose of evaluation from this point of view. A better evaluation would be to provide some framework of capabilities that the interface can work with, and users can comment on the quality of the interface. This can be done asynchronously without involving live audience.

The other part of the analysis would be the think-aloud protocol via an interview process. First, we will introduce the prototype and its objective to participants. Then, we will tell the participants about how Wizard of Oz works, so is protocol or convention during the session, for example, asking participants to use a specific syntax to express their thought, such as *(thought)*, for thinking aloud protocol. Second, we will give them a scenario of driving a self-driving car on a road, and inform participants about the designed capability of the voice interface prototype, what it can do. During the execution, we will interact with the user as if we are a voice interface system. Next, we start the session. For capturing the method, we will record the evaluation either from chat history, in case of using chat communication, or recording the audio during the session. The chat communication is preferable because the chat session can be conducted remotely from anywhere and it has a written evidence after execution.

Evaluation Execution

Empirical Evaluation - Textual prototype

Experimentally performing the empirical prototype was successful, capturing the responses of five different participants given a variety of lighting conditions through an LED light. A few environmental variables were difficult to control which may have consequences for the results of the experiment.

Of these, lighting conditions were probably the most impactful. Discussed in the prototyping phase, the lighting system should automatically adjust to the environment by controlling the brightness. Unfortunately, due to limitations in construction, this was not a feasible endeavor for our experimental setup. Often, with brighter locations the light was much more difficult to see, while in darker locations the light was overwhelming. This issue was most prevalent when the sun was setting and it was fairly dark outside.

The other environmental variable not accounted for was the difficulty in both driving a manual car and administering the experiment. Multiple takes were required for a few individuals, which led to the removal of certain data points, and the participants response rates not being independent of each other through potential learning.

The last deviation encountered is the conversations held in the car. During the experiment, the experimenter and participants were communicating, and some conversations were more thorough than others which may have caused varying degrees of distraction from the actual experiment.

All of the above deviations will likely alter the results. Due to the limited number of participants (not a lot of friends wanted to sit in a car on their Friday and Saturday off), these effects may greatly affect the results.

Results

Raw data is shown in the appendices as Table 3, where a total of 120 data points were collected. With the three primary conditions laid out for analysis (color, frequency, and location), various plots are generated to display the information, shown in Figures 11 through 17 of the appendices. The results were not too surprising aside from the few outlier values (often either distracted by a conversation, or the sun was very bright).

From the analysis, we find that a flashing light often received a faster and more consistent response (less outliers). The p value found using a Student's T-test on the distribution between flashing and still lights is 0.047, which is just below the generally acceptable limit of 0.05 for null hypothesis rejection. We do have to take into account the limited population size however which does skew this report.

Following frequency, the impact of the indicator color is analyzed using an ANOVA measure is used to capture the p value across the response time for red, green, blue, and white. The p value is found to be 0.022, which appeared great on paper. Once plotting the values however, it is found that the color white has a significantly higher response time, and once removed from the test, the p value increases to 0.325, which does not allow us to comfortably reject the null hypothesis.

Lastly, the location of the indicator is analyzed, once again with an ANOVA measure. We find that the p value for response time of the three locations is 0.034, which again is near the limit of null hypothesis rejection. Unfortunately, graphically plotted, it is found that the dashboard location is significantly higher than the other two. With the dashboard location removed, a new p value is calculated with a Student's T-test, which is now found to be 0.592, significantly above the threshold for accepting the alternative hypothesis.

The empirical analysis may not have led to a specific combination of color or location that would optimize response time, but it has determined that a flashing light will likely increase the response rate of passengers, a white light should be avoided, and the location is likely best suited to be on the floor or b-pillar. With this information, additional studies can be pursued to analyze the potential effects of color and location in isolation.

Qualitative Evaluation - Wizard of Oz prototype

As described in the previous section, we have created a wizard of Oz prototype for a voice enabled AI agent that can interact with the passengers of the car and help them interact with the ecosystem of the car, in general. The key objective of this project is to explore the way in which the passengers of the car (which includes the driver), can all be aware of the car's functioning, and can customize and control it as a whole unit.

The AI agent, as explained in the prototype description, helps provide an embedded ecosystem, and the passengers of the car can interact with it through voice commands. To evaluate this prototype, we implement a 2-forked approach - we are evaluating this prototype qualitatively with the help of the surveys as well as conducting thinking-aloud interviews with a few participants.

The reason to go with this two-forked approach is to get a general idea of the perception of how people feel amidst such an AI agent. The surveys provide a good post-event evaluation, whereas users have read the interaction method between the agent and the user, while the interviews will provide an interaction method with the users.

Surveys

For the surveys, we presented the Wizard of Oz prototype transcript for voice interface, and the users were asked a few questions on what they feel about it. One of the survey questions was "Did the prototype address the concerns of the passengers?". The idea behind this question was to get the participant's feel as a passenger if they were able to get their questions answered while they were in the car. Around 80% of the users responded with a favorable response. Although, the survey question offered an opportunity for the users to describe what to be concerns to passengers the car did not address, the responses were gibberish, so we'll exclude them as noise.

Overall, the survey results favored that the AI agent was discoverable and easy to use, but at the end we provided users an opportunity to share their thoughts, which was the main intention of the post-event evaluation. Some interesting feedback resulted from this. Primarily, most users agreed that "safety" was a concern that was not properly assured by the prototype. For example, what about the speed configuration due to local laws. One user suggested that "adjusting speed to too specific and mitigates the safety feature that makes autonomous driving a valuable product! the other features are fun but otherwise familiar. It would be nice to have them in a car though, definitely". This is a good feedback and countintertuitive to what we had in mind. But such a feedback exposed some issues that we had not thought about in brainstorming. Another concern revolving around the speed, is that since the voice command does not provide a proper annotation, and the AI agent may get confused regarding speed from different users. In the next iteration, such a security feature regarding speed would be a good addendum. As one user put it that such speed commands may result in "conflicting" adjustments. The survey feedback was also to have some intelligent feedback from the agent where it can sense the presence of kids or elderly and control the speed.

The full survey questions and survey responses can be found in Appendix L and Appendix M respectively.

Interview

We have conducted Wizard of Oz interview with three participants. The transcript from the interview session is included in Appendix K: Wizard of Oz Interview Transcript. We interviewed the participants in person and recorded the session by typing the transcript at the same time. The session went well and participants had tested various voice command functions. Overall, they like the voice command and cannot find a major flaw in the voice interface. The minor scenarios that we didn't included in the prototype likely require a higher fidelity, and will be approached in future iterations.

At the end of the session, participants were asked what they liked and disliked, as well as what they found easy and not. Result shows that all the participants found that using the voice interface is intuitive if it perfectly understood human language. Participant 1 liked that the voice interface is informative and well-adaptive to the context. Participant 2 and 3 liked that it can act promptly using only voice command and no need to learn much about the interface comparing to on screen interface. For participant 2, she mentions that she felt like she was travelling with a friend who she could talk with when travelling alone. In contrast, participant 3 thought that it would be creepy and lonely that he talked to no one. In this case, we think that passengers should feel the presence of the voice interface by adding some signifier in order to let this invisible interface more discoverable. Lastly, the voice interface should work universally with everyone to interpret its feedback.

Conclusion

As society continue to witness the inevitable deployment of autonomous vehicles, there exists an emphasis on enhancing the driver's experience. Modern autonomous vehicles should also place a focus on passengers, as well as other important stakeholders. Passengers in particular should be privy to the information on anything related to the driving and environment, especially since as vehicles become more autonomous, their level of abstraction decreases.

Exploration of these fallacies is explored through a survey, participant observation, and exploration of existing interfaces, which established a greater understanding of HCIs most precious resource, users. Once the study captured additional knowledge of the interface, a brainstorming exercise is performed where team member was assigned the task of conceptualizing ten redesign ideas. From these ideas a selection criteria matrix is created which isolated prototype opportunities for a improved/new passenger screen, an autonomous mode feedback indicator, and a voice interaction system.

With the potential prototypes established, each one is evaluated, specifically the passenger screen with a card based prototype; the autonomous mode indicator with a textual based prototype; and the voice interaction system with a Wizard of Oz prototype. Following these evaluations, it had been decided to pursue the light indicator with an empirical evaluation for light indicator textual prototype and the qualitative evaluation for voice interaction prototype with a survey and interview process.

After performing the empirical evaluation the only conclusive redesign considered for integration would be a light that flashes any color except white and is not on the dashboard of the car. The specific color and location for optimal response rate is still yet to be determined, and may spark a new design life cycle process.

Results from the qualitative evaluation show that people would like to a adopt voice interface into an autonomous car. Using natural language to communicate with the car is ease of use and flat learning curve. Despite its ease, universality is difficult to accomplish and requires additional research. There is also a personalization aspect of the voice agent that is not explored, where users would like to add in some adaptation when passengers are present.

Plans for continuation on the design cycle

Needfinding

As summarized above, we would like to improve the design exploration to a broader user base. For this, we have primarily concentrated on the users who were driving or had experience with driving, and as most of the survey and interview participants were from the age group of 20-50, the user concerns cannot be generalized. We would like to increase the gamut of the users involved in this design. The broader user age-range will enable us to observe and infer passenger requirements from these extended age groups.

Design improvements

As mentioned during evaluations, there are opportunities for design improvements. Some of these were exposed by survey feedback, and some of these were known but most are covered by the brainstorming exercise, which we hope to attempt in future iterations. These feedback loops will increase the fidelity of the interface and overtime will hopefully lead to an invisible one. As the proposed redesign options increase in fidelity, emphasis will be placed on empirical evaluations which focus on comparative analyses.

From this design life cycle process it is clear that additional studies should be performed to best capture user demands and overall enjoyment of autonomous vehicle interfaces. This is primarily due to the infancy of interface development in autonomous cars, which currently are not even commercially available. The goal of this analysis is to serve as a baseline for where future design life cycles may improve upon.

Appendices

Appendix A: Needfinding 1 - Survey Question Details Continued.

Question 6, *Would you consider yourself a defensive or aggressive driver?*

Response options: Defensive; Aggressive

This question attempts to identify if there is a large portion of aggressive drivers. Since AVs are naturally more defensive and passive, if the larger portion of drivers find the system to be intolerable then it may be important to implement a system that can shift from self-driving to manual quickly, allowing the driver to have control when desired.

Question 7/8, *Do you trust a taxi driver/autonomous vehicle to drive you?*

Response options: Yes; No

In essence, an AV acts similarly to a taxi driver. This question will work in contrast with the next, which asks respondents if they would trust an AV to do the same. It will be interesting to understand if it's the self-driving system that concerns them or if they personally prefer being in control of the vehicle.

Question 9, *If you had an autonomous vehicle, would you use the autopilot feature more often than not?*

Response options: Yes; No

If the autopilot system is not used often by users, it may be more effective to focus the redesign on other factors of the vehicle as opposed to when it is or isn't in autopilot.

Question 10/11, *As a pedestrian/passenger, would you like to know if a vehicle is in autonomous mode?*

Response options: Yes; No

What these questions aim to accomplish is approximate people's trust in autonomous driving modes. As a follow up from question 9, if people stated that they trust AVs to drive them, then there shouldn't be a need to know whether or not they are in autopilot. If there becomes a significant number of cases where users trust autopilot systems to drive them but also would like to know if a vehicle was in autopilot, a possible conclusion to this is that while they are trusting of the system, there is still a desire to have a mental preparedness for any adverse events, establishing room for improvements to make the interface more invisible. The separation between pedestrian and passenger explores control. As a pedestrian, they have more control when interacting with AVs on the road, but as a passenger, that control is in the hands of both the driver and vehicle. It will be interesting to see if there is a disparity between these two responses. A major benefit of the peer survey system is that it allows for analysis of respondent's answers individually, which can further extract insights based on the correlation between each answer. From these insights, designs can be implemented to ensure user comfort when interacting with AVs

Appendix B: Survey Questions

Q1) Select your age:

- Under 18
- 18 - 29
- 30 - 39
- 40 - 49
- 50 - 64
- 65+

Q2) What is your gender?

- Male
- Female
- Other

Q3) Do you prefer being a driver or passenger?

- Driver
- Passenger

Q4) Do you follow the speed limit?

- I usually drive 5 or more under the speed limit.
- I usually drive around the speed limit.
- I usually drive 5 or more over the speed limit.

Q5) What part of a car's visual interface do you focus on the most? (e.g. speedometer, radio)

- Free response

Q6) Would you consider yourself a defensive or aggressive driver?

- Defensive
- Aggressive

Q7) Do you trust a taxi driver to drive you?

- Yes
- No

Q8) Would you trust an autonomous vehicle to drive you?

- Yes
- No

Q9) If you had an autonomous vehicle, would you use the autopilot feature more often than not?

- Yes
- No

Q10) As a pedestrian, would you like to know if a particular vehicle on the road is in autonomous mode?

- Yes
- No

Q11) As a passenger, would you like to know if the vehicle is in autonomous mode?

- Yes
- No

Appendix C: Needfinding 1 - Raw Survey Responses

Link to Survey Response on Google Sheets :

https://docs.google.com/spreadsheets/d/1XjShbXKssaICv2NIfxMC0sEXhkFc8KP_NPlZL0qvI4U/edit?usp=sharing

Appendix D: Needfinding 1 - Analysis of Survey Responses

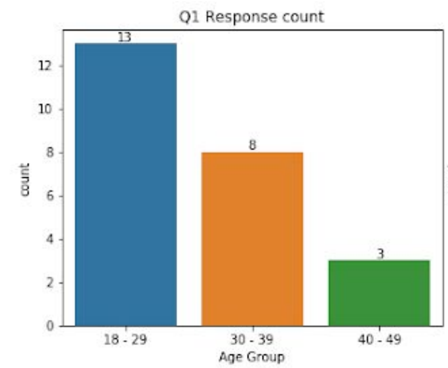
Link to Analysis of Survey Response on Google Colab :

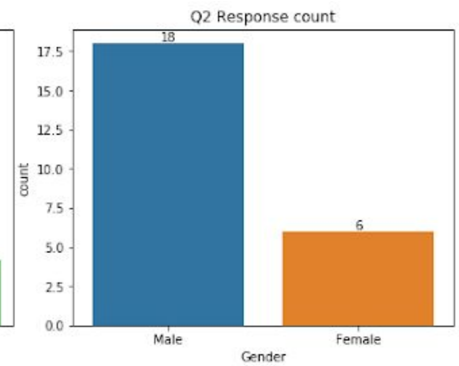
https://colab.research.google.com/drive/183qhqFTNPAiXiM_tBgiHk2zcwDi6swsa

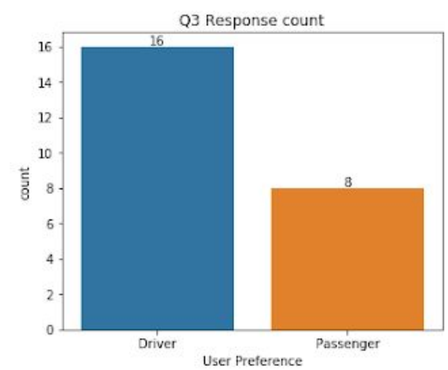
Appendix E: Needfinding 3 - Analysis of the existing interface images

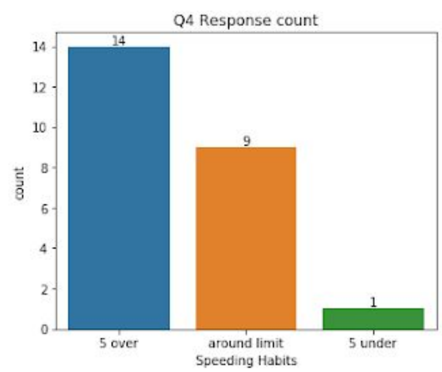
Figure 4: Exploration of existing interfaces; Top left: Tesla Model S (ref), Top right : Renault Symbioz (ref), Bottom left: Mercedes Benz S class (2018) (ref), Bottom right: Waymo passenger interface (ref)

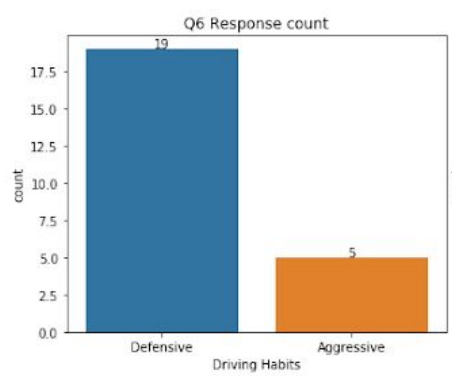
Appendix F: Needfinding Execution 1 - Survey Results

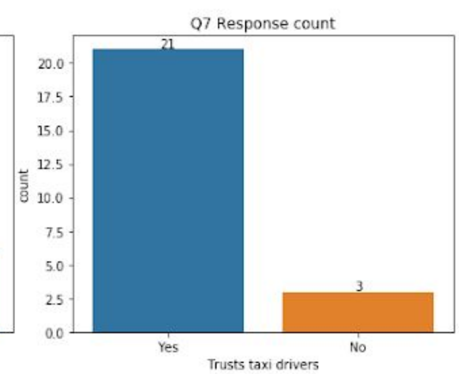












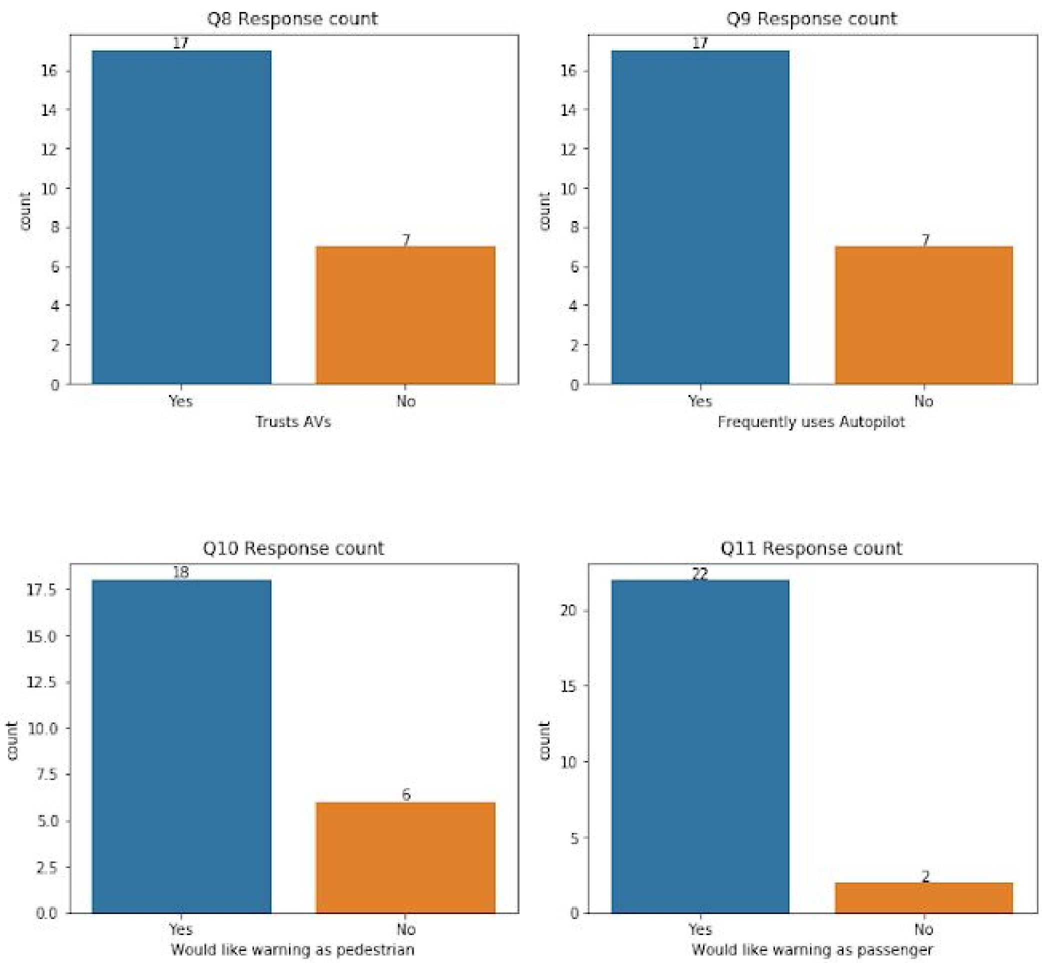


Figure 5: Count plots of categorical responses for the needfinding survey

Appendix G: Prototype 1 - Card Prototype

Link to the card prototype on Google Slide :

https://docs.google.com/presentation/d/1VlHddnJf73Y8DRQz4oGw4y3sXEwXaZk7PNdPqWTRou0/edit?usp=sharing

Appendix H: Prototype 3 - Wizard of Oz Prototype for Voice Interface

On-going trip interaction

1. **Driving and Speed control**
    a. **Reduce the speed**
    User: **:** ”slow down | reduce the speed | too fast!”
    System : Reducing the speed
    Action : The system reduces the car speed and the feedback is provided to the user.
    System : Car speed is reduced. Current speed is <N>. Do you want to reduce the speed further?
    b. **Increase the speed**
    User : “hurry up | speed up | I’m late | too slow”
    System : Increasing the speed
    Action: The system increases the car speed and the feedback is provided to the user.
    System : Car speed is increased. Current speed is <N>. Do you want to increase the speed further?
    c. **Lane preference**
    User : “Drive in <xxx/carpool lane> | Change to <xxx/carpool lane>”
    System : Noted, changing the lane
    Action: The car changes the lane at an opportunist time, and then provides the feedback to the user
    System : The lane has been changed.
    d. Pull over to the side of the road
    User : “pull over | stop here”
    System : OK, will pull over to the nearest spot.
    Action : The car will pull-over to the next possible spot.

2. **Interior control**
    a. **Adjusting air condition**
    User : “Increase[/Decrease] the temperature [to <N> degrees]”

System : Increase the temperature

Action : The system increases or decreases the temperature based upon the request.

b. **Get shading in sunny day**

**User : **“Pull the visors down.”

System: Pulling the windshield visors down.

Action: The system pulls the visor of the windshield. The system also controls the shading on the passenger’s side windows as well as the window on the back.

c. **Adjust seat position**

**User : **“Increase[/Decrease] seat incliner.”

System: Increase[/Decrease] seat incliner.

Action: The system increases/decreases the seat incliner as requested by the user.

3. Entertainment control

a. **Play the music/movie**

User : “Play song[/movie] <> from my library.”

System : Playing <> from your library.

Action : The system plays a song/movie from the user’s library.

4. Navigation control

a. **Location**

User : “Where am I? | where are we now?”

System: You’re at <location>. <N> km/miles away from destination. You will arrive at <arrival time>.

b. **Time**

User : “When can I arrive? | can I make it by <time>?”

System : You’re at <location>. <N> km/miles away from destination. You will arrive at <arrival time>.

5. Surrounding information

a. **Finding restaurants**

**User : **“Can you find a nearby <> restaurant? “

System : Finding nearby restaurants. Here's the list.
Action : The system displays a list of restaurants requested by the user on the screen.

b. **Finding a place to stay**
User : "Find a nearby place to stay"
System : Finding nearby places to stay.
Action : The system display a list of available accommodations nearby.

Car speed preference

1. **Set the preference speed**
User : "<car>, please set the current speed for me."
System : Current speed preference for <moderate|fast|slow> saved.
Action : The system displays the current speed setting.
Such speed setting configuration can then be applied to whenever the user would want his particular speed settings.
2. **Get the preference speed**
User : "<car>, please restore my speed configuration. | Get the preference speed"
System : Getting your last speed preferences
Action : Last speed preference would be displayed on the screen.

Appendix I: Empirical Evaluation - Light indicator

Figure 6: Top left: Red Indicator. Top right: Green Indicator.
Bottom left: Blue Indicator. Bottom right: White Indicator.

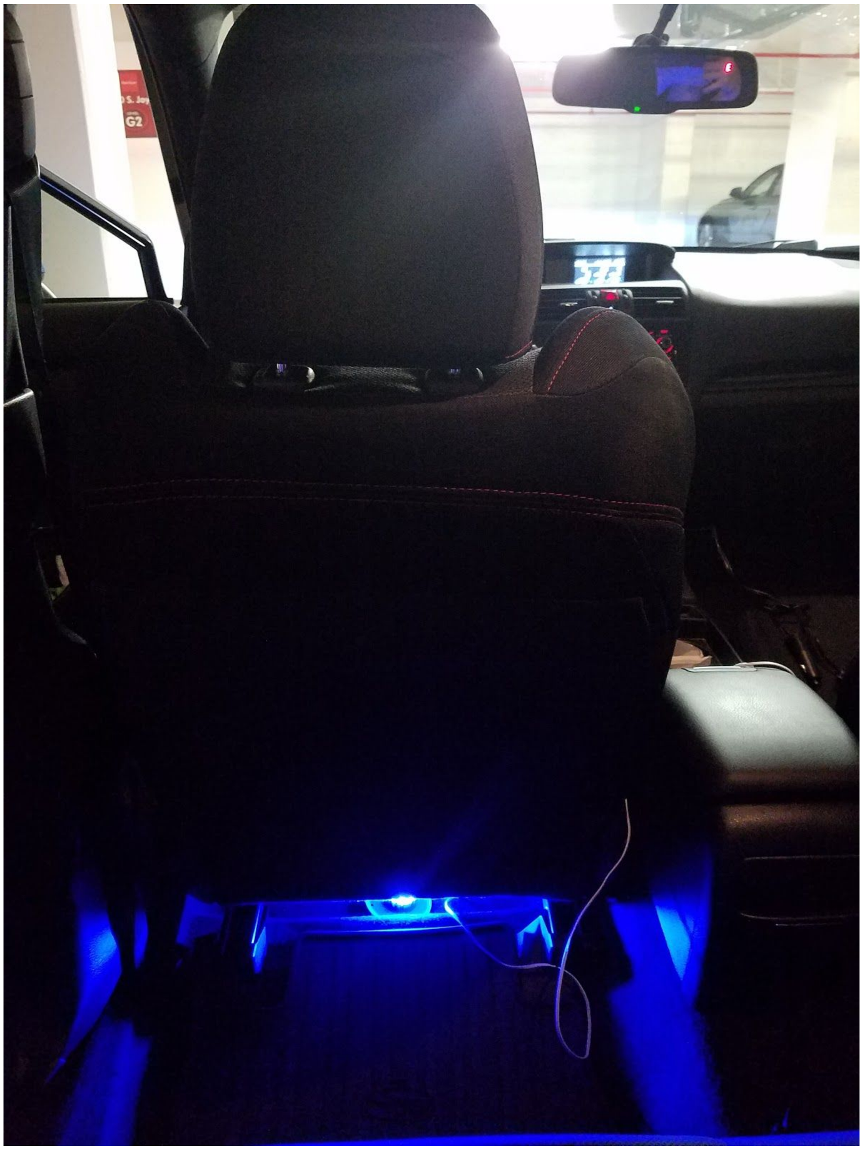


Figure 7: Light indicator floor location

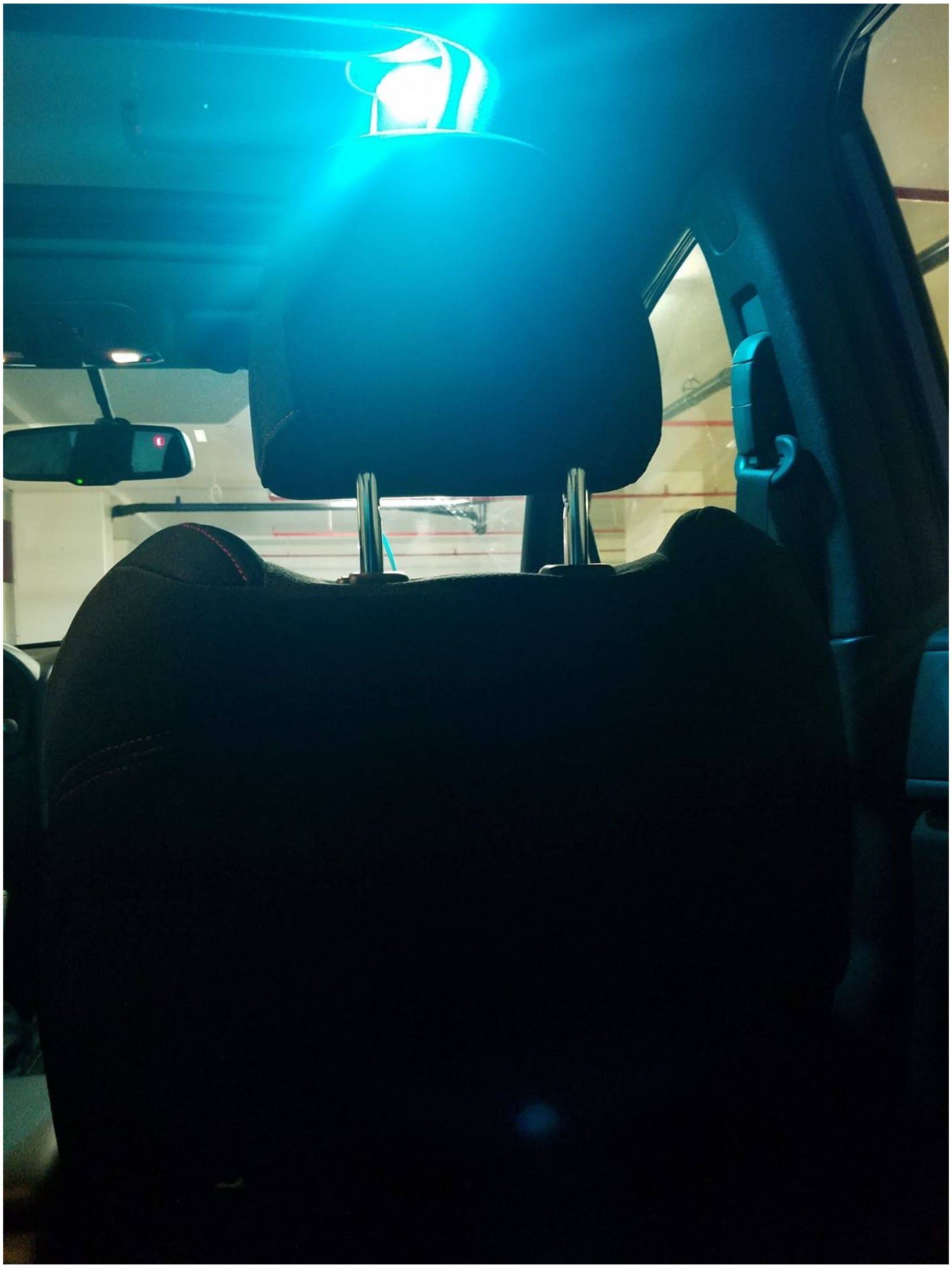


Figure 8: Light indicator B-pillar location

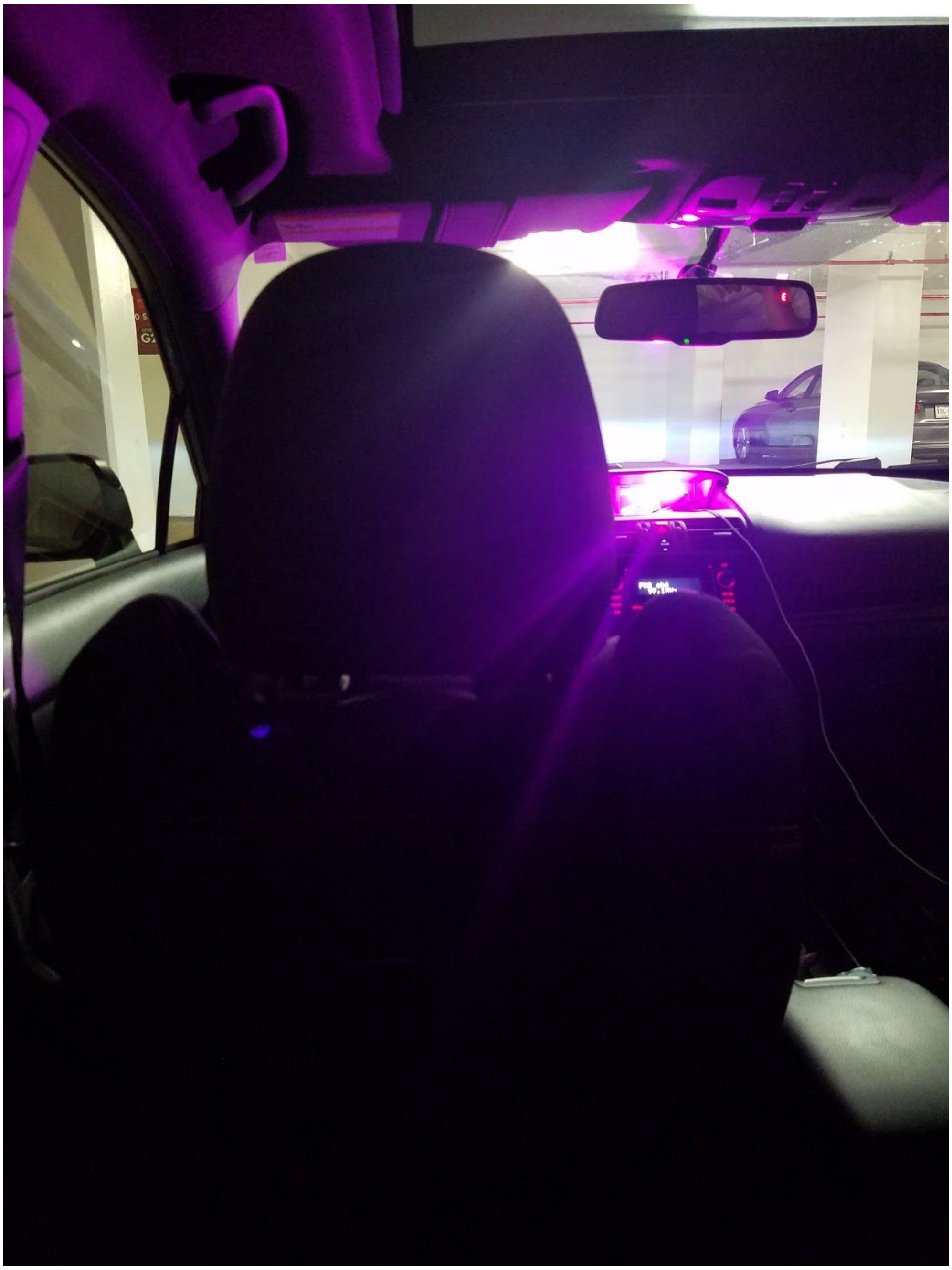


Figure 9: Light indicator dashboard location

Table 3: Light indicator prototype raw data

Dashboard	red_still (s)	green_still (s)	blue_still (s)	white_still (s)
1	7	1.4	1	2.4
2	1.3	1.3	1.5	1.6
3	0.9	13.4	0.7	1.1
4	1.6	9	1.8	8.6
5	1.4	0.7	1.9	0.8
Dashboard	**red_flash**	**green_flash**	**blue_flash**	**white_flash**
1	0.9	0.7	0.7	1.6
2	0.9	1.4	0.9	10.3
3	0.7	0.7	0.8	0.9
4	1.2	2.2	1.5	2.2
5	0.8	0.9	1.2	1.1
B_Pillar	**red_still**	**green_still**	**blue_still**	**white_still**
1	1	0.8	1.2	0.9
2	1.1	0.7	0.8	8.8
3	0.7	0.7	0.9	1.3
4	0.9	1	1.3	0.8
5	0.9	1.1	0.8	4
B_Pillar	**red_flash**	**green_flash**	**blue_flash**	**white_flash**
1	0.7	0.7	0.8	0.7
2	1	0.8	1.1	1.3
3	0.7	0.7	0.5	1
4	0.7	0.8	0.7	0.9
5	0.8	0.8	0.8	0.9
Floor	**red_still**	**green_still**	**blue_still**	**white_still**
1	1.6	1.3	0.9	6.3
2	2	1.1	1.1	2.2
3	0.8	0.8	0.7	0.9
4	1.1	0.9	0.9	0.9
5	1.2	1	1.2	1.7

Floor	red_flash	green_flash	blue_flash	white_flash
1	0.9	0.7	0.9	1.2
2	0.7	0.9	0.8	0.8
3	0.8	0.9	0.8	1.2
4	0.7	0.8	0.7	0.9
5	0.8	0.8	0.7	8.2

Appendix J: Empirical Evaluation Execution Analysis

Link to data analysis code on Google Colab :

https://colab.research.google.com/drive/1NER6dV0eXyNqgmQHREN1LiBE2fbFal-I

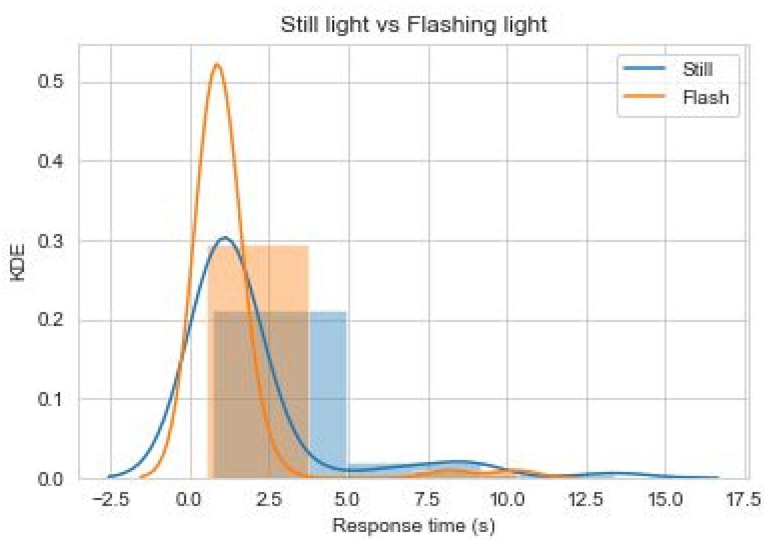


Figure 11: Still vs Flashing light average response results

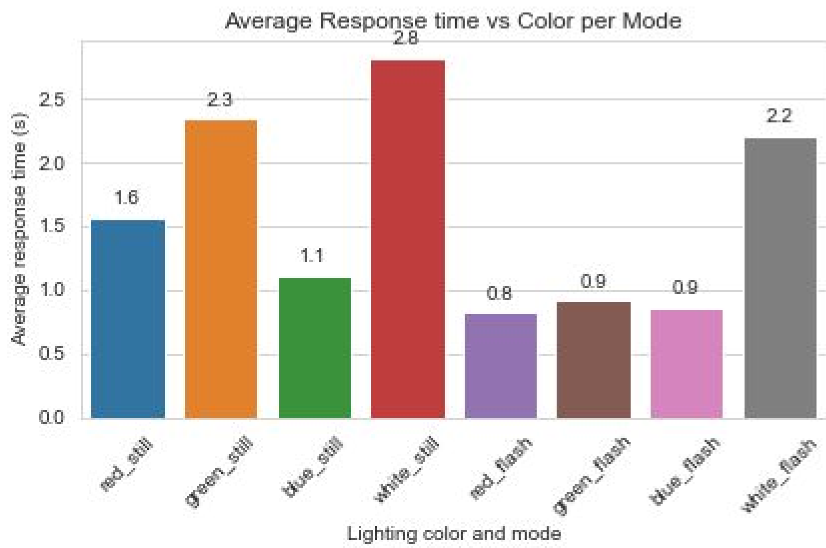


Figure 12: Average response time for each color and mode per person

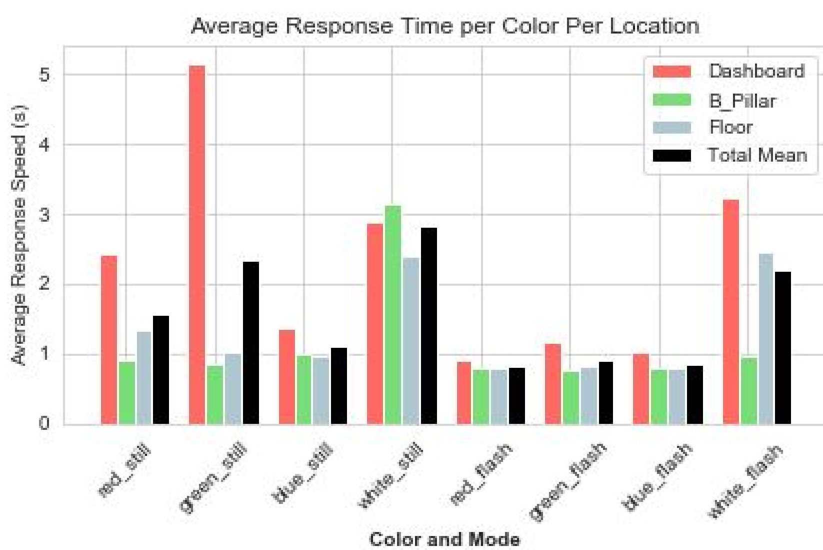


Figure 13: Average response time per color and mode for each location

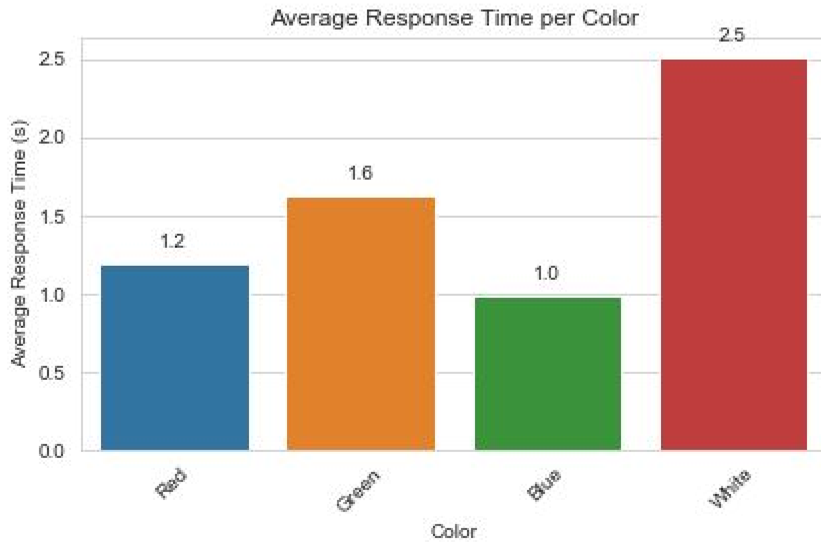


Figure 14: Average response time per color

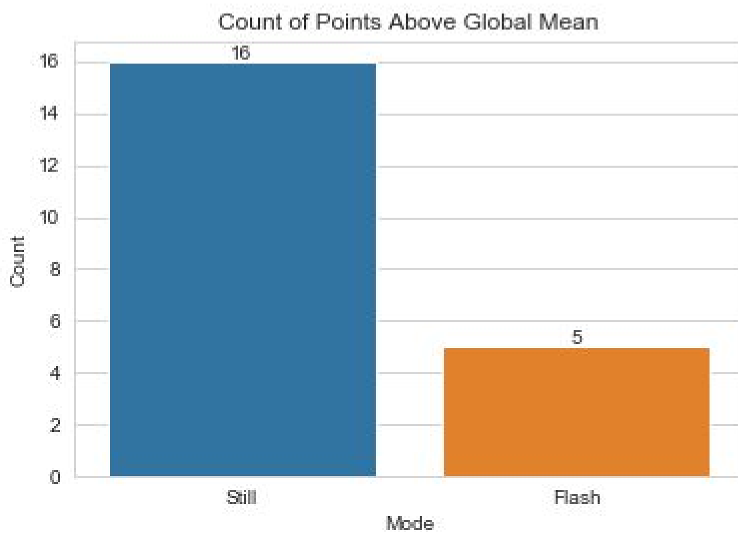


Figure 15: Number of outliers between still and flashing

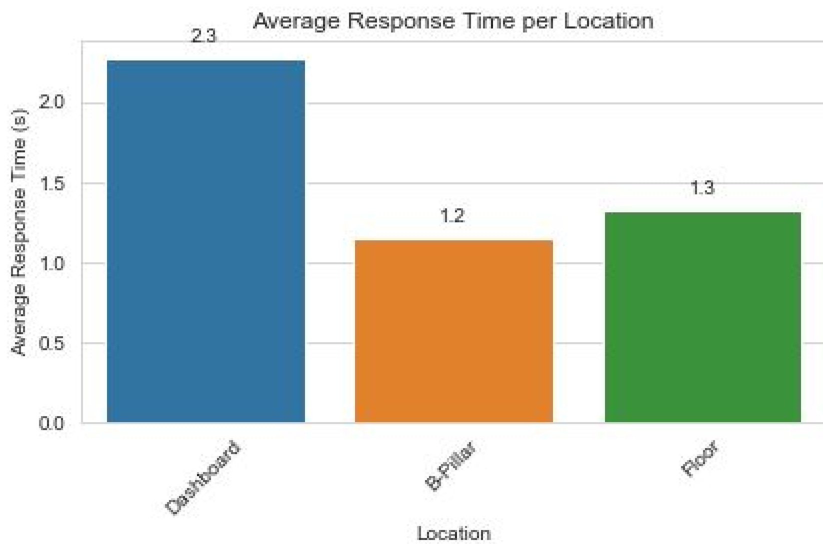


Figure 16: Average response time per location

t statistic for still vs flashing is: **2.006**
p value for still vs flashing is : **0.047**
~~~~
F statistic for car location is: **3.477**
p value for car location is: **0.034**
~~~~
F statistic for car location without the dash is: **-0.538**
p value for car location without the dash is: **0.592**
~~~~
F statistic for indicator color is: **3.329**
p value for indicator color is: **0.022**
~~~~
F statistic for indicator color without white is: **1.139**
p value for indicator color without white is: **0.325**

Figure 17: Statistical results from empirical prototype

Appendix K: Qualitative Evaluation - Wizard of Oz Interview Transcript

Link to the interview transcript for Wizard of Oz prototype on Google Docs :

https://docs.google.com/document/d/18xYA6jIkFEUO-Ns8nfYhXwz_ecQ-NGdaU_FHrXw_cwQ/edit?usp=sharing

Appendix L: Qualitative Evaluation - Wizard of Oz Survey Questions

Link to the survey questions for Wizard of Oz prototype on Google Docs :

https://docs.google.com/document/d/1O84oPnNetdA5BPCYatiSOJXVtNBUyFacOyrc_s3ab8A/edit?usp=sharing

Appendix M: Qualitative Evaluation - Wizard of Oz Survey Result

Link to the survey result for Wizard of Oz prototype on Google Sheets :

https://docs.google.com/spreadsheets/d/1J_2weXk8fvfLA1fSDcI9vYLqgeeIODwVeQPCXrGMLI4/edit#gid=160019991

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