Leveraging Information Visualization Techniques and Driving Statistics for Influencing User Behaviour

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ABSTRACT

While the self-driving car is considered the future of transportation, safety has been a serious issue for a while. Research in the area of machine learning, human-computer interaction, and autonomous systems are trying to mitigate safety concerns. Until the autonomous vehicle reaches the state of full automation, manufacturers stress on the role of human drivers in semi-autonomous vehicles to ensure safe driving. In this paper, we present a visualization system where a human driver can analyze driving statistics with respect to community averages in a user-friendly manner. We incorporate gamification techniques to promote safe driving behavior. We present our findings from a usability test and discuss implications for design.

KEYWORDS

driving safety, autonomous vehicles, driver-vehicle interaction, driving statistics

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1 INTRODUCTION

Autonomous vehicles are currently seen by many as the future of transportation [22, 33]. Not only will they change traditional transportation systems, but will also create new opportunities for human activities during transit times. While people were initially skeptical about the future of self-driving vehicles due to the lack of logistical and technological support, this skepticism is declining with the rise of powerful computational resources such as deep learning. The hope is to ensure collision-free and safe future transportation. Research and practice of self-driving vehicles are responding accordingly. The big companies such as Google and Tesla are already testing their autonomous vehicles in controlled environments [6]. Forbes reports that 1700 autonomous vehicle startup that might destroy the existing car industries [42]. Overall, the autonomous vehicle is recognized as the next revolutionary change that will determine people's movability.

Despite the significant advancement of autonomous vehicles, there has been an emerging concern regarding their safety. In their current state, autonomous cars are far from being fully autonomous, or at SAE Level 5 [15]. There have been media commentaries and scholarly reports which indicate that the industry will need to go a long way to reach the state of full autonomy (see for example [9, 34]). Consequently, drivers still have to take the responsibility of operating the vehicles and autonomous systems are considered assistive to the driver. This is when the communication between the drivers and the autonomous systems becomes important.

Even though drivers are instructed several rules by autonomous car manufacturers, most of the accidents are occurring because of drivers not playing their parts. In the last few years, there has been several semi-autonomous car crashes for various reasons [1, 19, 30]. Companies tend to deny the responsibility of the crashes, while they vividly paint crashes as human errors (such as, [2]). It is difficult to say whether the accidents are occurring because of drivers optimism about the autonomous systems; proper research is necessary to understand the failures better. Nevertheless, there has been immediate importance to help drivers' train themselves to improve their driving behavior both in semi-autonomous and fully autonomous driving.

While end-to-end autonomous driving systems are likely at least a decade away, we can expect that many cars will have various functionalities such as lane assistance and highway automation as many car manufacturers such as Audi and Tesla currently employ. With this expansion in the capacity for vehicles to collect data in real-time regarding the driving experience, the proposed design in this project looks to utilize this data to help inform users about their driving behaviour through data visualization techniques.

Our main contributions in this study are as follows:

- Persuasive visualization of personal driving statistics with respect to community averages in a user-friendly manner
- Incorporation of gamification techniques to promote safe driving behavior

The remainder of the paper is broken down as follows. In Section 2, a review of the literature regarding safety in autonomous vehicles is discussed through various lenses including Human-Computer Interaction (HCI) and Psychology. Section 3 discusses the proposed design and rationale, while section 4 details the usability testing methods and insights obtained during the study. Sections 5, 6, 7

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offer a discussion regarding the implementation of such a system, as well as the limitations of the study, and directions for future work respectively.

2 LITERATURE REVIEW

2.1 Safety of Autonomous Vehicle, Ergonomics, and HCI

In its current state, research and practice in the field of autonomous vehicles are reasonably realistic about not reaching the state of full autonomy within the next decade, as recently mentioned by Ford CEO, Jim Hackett [4]. The current autonomous vehicles are in the domain of levels 2 and 3 according to the defined levels of automation by SAE automation [41]. Consequently, while current semi-autonomous driving systems are helping drivers with various driving tasks, drivers need to remain conscious and alert to take control of the vehicle at any given moment [14]. However, the drivers' role in vehicles equipped with semi-autonomous driving capabilities is often misunderstood by consumers given how car manufacturers advertise their autonomous functionalities. Recent events of self-driving car accidents have shown that the incidents occurred mostly due to the drivers' lack of situational awareness, fatigue, and inattention, or the usage of the system in inappropriate situations, among other reasons [11], most of which fall under HCI's core concern in design and implementation of computing systems [12].

The safety of autonomous vehicles is still an emerging area of research. HCI and ergonomics research on safety in autonomous cars have referred to issues related to contextual awareness, safety perception, warning systems, and communication tools and techniques between the environment and autonomous vehicles, among other topics. While earlier paradigms of automation recognized the role of humans and machines as independent tools in facilitating autonomous systems, the design was centered around the machine. Later, the transfer of this center of focus from machines to the human has accelerated research surrounding the safety of autonomous vehicles in HCI and related areas [24]. In initiating this conversation of human-centered safety, Hocs et al. started with the recommendation to the HCI community that positive cues in intelligent user interfaces increase learners' inductive capability [24]. Sirkin et al. developed a system named *Daze* to measure drivers' situational awareness in real time - both on-board and in simulated environments [43]. The system was built on four design principles: 1) It will work both in both simulation and on-road, 2) the measurements will be taken seamlessly and will not require pausing the experiment to ask interim questions to the driver, 3) the system gathers real-time responses of drivers, and 4) if need be, the system can ask questions to drivers in the form of an unobtrusive graphical tool. Based on their experiment, the paper suggests more research on increasing drivers' affordability to anticipate future events. With a goal for designing warning display systems, Li et al. conducted a study to understand people's perception of safety in terms of design elements of warning systems [31]. In a similar strand of research on warning systems for autonomous and semi-autonomous vehicles, Mok et al. introduced two types of transformed steering wheels and evaluated their relative performances [37]. They concluded that participants are more responsive to mechanical warning systems than their digital counterparts. de Clercq conducted a study to understand the communication between pedestrian and autonomous vehicles via an external human-machine interface (eHMI) when it comes to safety critical situations such as pedestrians crossing a road [17]. They concluded that pedestrians most clearly understood the information communicated via textual eHMI over other mediums (i.e., Knightrider, smiley, front brake). Lindgren and Chen provide a comprehensive overview of the works of autonomous vehicle and safety and provides ideas, functionalities, and possible human factor issues in autonomous vehicles [32]. They stressed considering the social cost while using technology to handle high-risk contexts.

However, HCI literature on safety in autonomous vehicles is constrained with some serious concerns. Generally, most of the questions around contextual awareness arise from the fact that the studies are mostly completed in a simulated or lab environment, which is highly controlled and manipulable; the situation in real driving scenarios are full of unexpected and unanticipated events. Furthermore, many studies often cannot arrange the simulated or virtual environments due to various constraints and lack of affordability [44]. Nevertheless, the literature does not provide any realistic and accessible method to avoid this overarching limitation. Other than that, the studies mentioned above exhibit limitations in terms of generalizability, design choices, and users' responsiveness. Overall, one particular area in which HCI has a big role to play is in designing tools to increase drivers' learnability of driving decisions and carry that learning in various driving environments to mitigate risks that might arise from unsafe driving behavior by the driver and miscommunication between the system and the driver. Below we provide a comprehensive overview of research in sustainability, visualization, and HCI that might contribute to improve drivers' learning skills while operating semi-autonomous or autonomous vehicles.

2.2 Persuasion and Visualization

We draw on research in the area of sustainability, psychology, and visualization on how persuasion influence human behavior. Persuasive visualization tools have been a popular medium for of driving people's attitude, opinion, and practice in the area of sustainable living, energy conservation, water management, health, social integration, and ethics, among others [36]. Pandey et al. report two reasons for why people positively change their opinion: 1) when people see evidence, especially statistical evidence, and 2) when people are already persuaded in some ways citepandey2014persuasive. Further, they also report on the type of persuasive visualization tools that may drive human behavior. Kim et al. designed two ambient displays to see the effect of persuasion operationalized by the displays for ecologically sensitive behavior [28]. They observed among participants that persuasion leads to awareness which, in turn, leads to affirmative action. Moere proposes the potential for ambient display as persuasive digital tools [36]. Yun et al. provide a set of motivational, instructional, and supportive intervention techniques for workplaces for effective behavior changes [47]. While most of the techniques provided in the paper are for sustainable behavior, some of the techniques could be extended to encourage positive behavioral changes in other areas, too. Particularly, drawing on current literature, the paper suggests that self-monitoring could be improved if a person receives real-time information, appliance-specific data, and can make a comparison with current data with historical data. Bartram et al. examined the impact of visualization display for the use of energy-usage in a net-zero solar power home [7]. Particularly, they designed a visualization ecosystem including dashboards in the PC, mobile displays, ambient displays, embedded displays, and social networks. While they hope for behavioral change among users from such an ecosystem, they donâĂŹt provide any straightforward method for evaluating the success of such complex systems combining multiple techniques. Visualizing crowd data for understanding behavioral features and change them is also popular to persuade people. For example, Hingle et al. analyzed crowd data from Twitter and combined the analysis with a visualization software tool to see the relationship between food consumption and diet-related behavior [23]. The study inspires combining visualization tools with crowd data to inspire analytical tools for behavioral insights and changes.

The research mentioned above on visualization and visual analytics inspire and inform our work to use visual analytical displays as a persuasive tool for behavioral change of drivers of self-driving cars. However, the field of visualization itself has some challenges on its own. Some common challenges are personal contexts, the relevance of data to personal routines, varied way for defining baseline metric to make comparison with personal data, and sharing and privacy issues [25]. Some of the challenges are relevant to our study as well. Our study can extend the agenda of mitigating some of the limitations of visual analytics in the research of self-driving car.

2.3 Gamification

Use of gamification has extended beyond contexts of gaming. The research community is going towards applying gaming elements in other areas of design [18]. In the past few years, gamification has gained popularity in designing for motivation, engagement, education, and steering users' behaviors as seen in works such as [27]. These works are backed by the research done to scientifically show the effectiveness of gamification [21], and badging as one of the main behavior-modification mechanisms [38]. Points, leaderboards, and badges are among the most most salient tested and common mechanisms of gamification for such intentions. Works such as [10] and [20] [5] have provided evidence for the effect of badges on user behavior. Other works like [35] have studied the positive effects of points on user motivation and performance.

3 DESIGN

This section outlines the design of the proposed application for encouraging safer driving behaviour through the cognitive association of safety statistics with the mind of the driver-user. We start by demarcating our rationale for designing this interface to improve driver performance and safety. We then dive into the individual components of our system and their usage procedures, starting with a description of the data sets used. Afterward, we describe our method of user testing, including the criteria, participants, and testing procedures.

Driving procedures and associated safety behaviors are not limited to the time a person is inside a car and driving. Instead, the broad concept of driving safety encompasses several dimensions, including the skill of the driver [29] and the predetermined notion of the driving route [46, 48]. We aim to influence these factors through our system.

The skill of the driver is at least partially determined by the self-perception of the driver about his abilities to safely drive through various situations. How a driver pictures themselves handling those situations is as much a matter of their skills as their interpretation of those skills. If a driver becomes overconfident in their belief on their abilities, that may come up short in a dangerous situation, and the idea may ultimately prove fatal. Our system, with the help of driving statistics, will aim at improving the perception of the driver about their own driving ability and behaviour with respect to the average driver in their community.

The notion of an individual about a particular driving route usually comes from the experience of that person driving in that specific route. We aim to contribute to this area by providing statistics on their previous journeys on the same route (or a subset of any course). With the help of visualization methods, the driver will be able to review their behavior on any journey they had previously undergone, which would ideally change their perception about the danger and complexity of that route.

While many applications currently exist to connect an individual with their vehicle's information [26], these applications only provide basic metrics such as the vehicle's current battery level, estimated range, and nearby charging stations. In addition, some applications also give the user the capacity to complete remote interactions with their vehicle, such as starting, summoning, unlocking, or adjusting the interior temperature of the vehicle. However, to the best of our knowledge, there is currently no system which aggregates and visualizes driving statistics, particularly with respect to community averages. The proposed system aims to help users rationalize their own driving behaviour using statistics collected within semi-autonomous driving environments. The metrics used in the system include simple data such as driving speed and two composite metrics of weaving and drifting, which we elaborate on further later in this section. In the next iteration of the system, we aim to incorporate various other advanced parameters of driving performance, such as instances of reckless turning and braking.

3.1 Data Set

This project utilizes the San Francisco Speed Limit (SFSL) data set published by the Municipal Transportation Agency of San Francisco. [3]. The primary purpose of this data set is to organize the speed limits of the city of San Francisco, CA, where streets can have speed limits ranging from 15 MPH for alleys narrower than 25 feet to 25 MPH, which is the de facto speed limit for most residential and commercial streets. The speed limit information is taken from conducted speed surveys, Municipality of Transportation Board (MTAB) resolutions, and legislation records. The data itself is updated bi-annually or on an as-needed basis. The data set contains information of individual motor vehicles plying on different streets, with associated metadata regarding the speed limit on that street, the geometric coordinates of where the car's information was recorded, the average speed on that street, and finally, aggregated statistics regarding people who over-speed on those roads. Some of the roads listed in the data set appear more than once due to recorded instances of multiple vehicles at different times.

Another data set that inspires our ideas of weaving and drifting is the UAH driving data set [39], which contains performance-related metrics of a vehicle and the associated driver. This data set includes GPS and accelerometer information which are termed as "raw data", along with some derived metrics such as scores for acceleration, braking, turning, weaving, drifting, and over-speeding which are together termed as "processed data". Based on the processed data, the authors develop a formula for detecting three types of driving behaviors: normal, drowsy, and aggressive. All the data is collected using a smartphone application named "DriveSafe", installed on a phone that is placed just below the rear-view mirror of the automobile in question [8]. One issue with the corresponding research papers is that they do not elaborate on the details of the algorithms that were used to generate the compound metrics.

3.2 Design

For our proposed system, we implemented a web application using Flask, a Python microframework. The reason for this choice is for our system to be easily integrable with existing in-vehicle systems. There are many APIs in Python to help with visualization development and that is another reason we chose this language. The database that we are using for this system is SQLite since our chosen dataset is relatively small and can be stored in a serverless, compact, cross-platform, single-file database for now. In the future, when this system is integrated with real in-vehicle systems, other databases can easily replace SQLite. We designed our system to be secure, fast, and accessible through various mechanisms such as secure password hashing mechanisms, user session keeping, etc.

With regards to the design of the interface, the user is presented with a number of tabs once they have successfully logged in to the application. The first is the 'Your Journey' section, which alternatively works as the home page of the user as well. This page includes the recent journeys undertaken by the user over a particular period which the user can adjust by selecting to group the journeys on a weekly, monthly, or yearly basis. The journeys are presented in reverse chronological order to present the latest journeys first. For journeys which the user has not yet visited on the application, a 'new' tag is placed to highlight the journey. Each 'new' tag is colored to indicate the driving performance of the user on that particular journey as rated by an algorithm which accumulates and rates the statistics collected (relative speed, weaving and drifting scores) from that journey into a single metric. Three colors (green, orange, and red) were used to intuitively signify driving performance. Within each journey on the home page, the user can quickly discern key information regarding the journey such as the distance, duration, and the vehicle's battery consumption, as well as additional route details such as the start and end points and times. The route taken during each journey is also visualized using a map which indicates the different streets taken, where each street is colored to highlight the relative speed of the driver with respect to the speed limit on that street. At the top of the home page, the user can obtain additional basic information regarding their vehicle, including its total mileage, charge cycles, and the next expected maintenance. The home page can be seen in Figure 1.

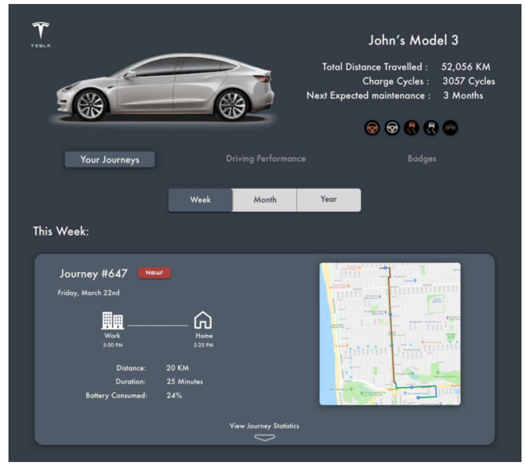

Figure 1: Home page, which also works as the weekly journey summary page for the user. There are also options for viewing detailed statistics or map for a particular journey.

The user is also afforded the opportunity to view a detailed breakdown of a particular journey by clicking the 'View Journey Statistics' button associated with each journey. By selecting this option the user is presented with the information from the selected journey and hides the other journeys from the immediate view. In this view, the route taken on the journey is broken down into individual streets. Numerical values related to the user's speed, weaving, and drifting are presented in this section. We borrow the definitions of weaving and drifting according to the definition of Romera et al [39], who define weaving as "the irregularities in switching between lanes, which can be produced when the driver is momentarily not aware of the road (slow change) or when the driver is being brusque (fast change)." Hence, the weaving metric evaluates involuntary lane changes through analyzing the presence or absence of a directional indicator, where an event detector module can conclude whether a lane change is intentional or not. Romera et al use a built-in microphone in a smartphone to capture the clicking sound generated by the indicator, in order to avoid external dependencies. Similarly, they describe drifting as lack of "the capacity of the driver to continue centered on its own lane." This is based on the Lanex (fraction of Lane exits) indicator, which is a measure of driver's tendency to exit the lane [16]. It is defined as the fraction of a given time interval spent outside a virtual driving lane around the center of 1.2 meter width. The drifting score is calculated by applying windowing techniques over the lateral position of the vehicle (x_0) during 60-second intervals. With regards to visualizing these values, in the initial iteration, the numerical values were placed within colored rectangles to signify the level of safety associated with the score. These values can be sorted (from highest to lowest) to enable the user to identify the legs of the journey where their driving was particularly unsafe. The detailed statistics of a particular journey can be seen in Figure 2.

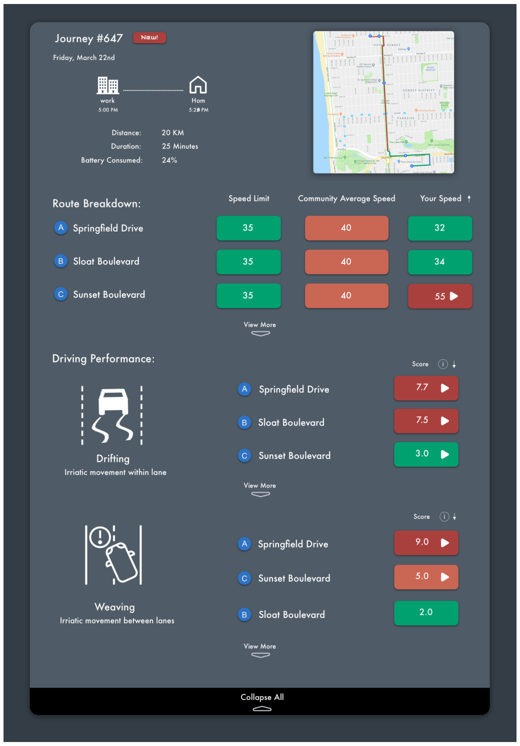

Figure 2: The details of a single journey can be viewed, with each leg of the journey shown separately with their own statistical evaluation. The values can be sorted according to the order of appearance or weight of the numbers.

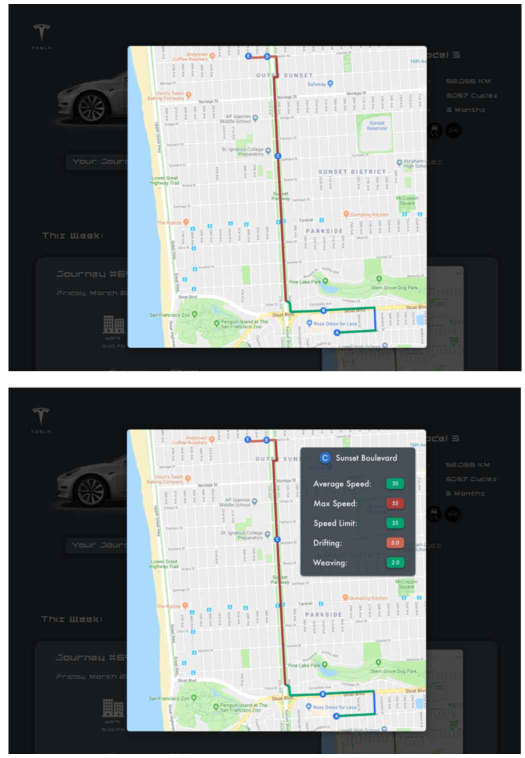

Figure 3: Clicking on the map on the journey details page enlarges the map to a comfortable viewing resolution and gives the user the ability to move in any direction. The individual legs of the journey provide more information when clicked.

The design also incorporates the ability to visualize the different stages of a journey through an interactive map. Each journey is equipped with the clickable thumbnail of a map for that particular journey. Clicking on the map expands it to the size of the screen of the device and the user can evaluate their entire journey or any subset of it. An example of the interactive map is shown in Figure 3, which contains a mock route of a person driving on the streets of San Francisco. The map also provides statistics associated with each individual leg of the journey. Clicking on the individual streets of this map will highlight that particular leg for increased visibility and will visualize statistics (highest speed on that leg, drifting and weaving scores) for that leg. An example of the visualization of an individual leg for the sample journey is presented in the bottom image in Figure 3.

A central aspect of self-evaluation and self-correction entails providing the user to evaluate the journey and driving skills [45]. In this respect, the proposed design provides the users with the ability to re-watch the potentially problematic parts of the trip through recorded video footage. Since many semi-autonomous cars in the present day are equipped with cameras, either for the purpose of security as in the cases of dash-cams or for the purposes of autonomous functionalities, we aim at exploiting this ability for capturing unsafe driving behaviour by the user. The design incorporates small video playback buttons associated with particular legs of a journey in the Journey Statistics page, which enable the user to play a video for that leg of the journey. However, video playback options are only included with legs where at least one of the metrics of driving performance was above a corresponding warning threshold. The rationale is that a user is unlikely to watch the video of a leg where the system indicated that they had driven safely along that leg. The video screen will be expanded above the numerical tables, once the video option is selected.

In addition to the weekly view of the journey summaries, the design also enables the user to sort their journeys on a monthly and yearly basis. The monthly view of a user's journeys can be seen in Figure 5.

Under the tab "Driving Performance", a temporal view, in the form of an interactive graph, of the user's driving behaviour with regards to the metrics analyzed provides the user an opportunity to examine the changes in their driving behaviour over a particular period. Within the visualization, individual points on the graph can be selected to view the journeys associated with that particular point of time, in order to facilitate easy access to particular journeys which the user may want to re-visit. To view their performance over various time periods, the user can select a start date and an end

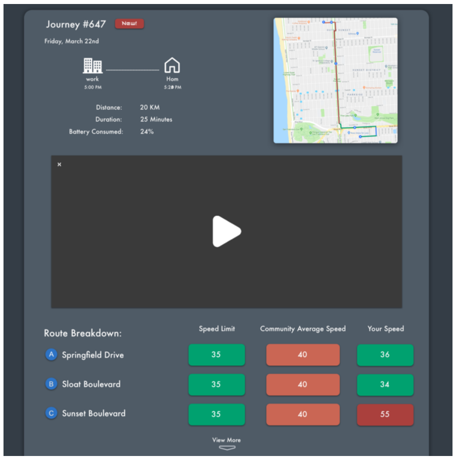

Figure 4: The user has the option to play the video of the journey leg which had a worrying score in terms of either speeding, drifting, or weaving. This video can help the user review their behavior and self-identify the mistakes.

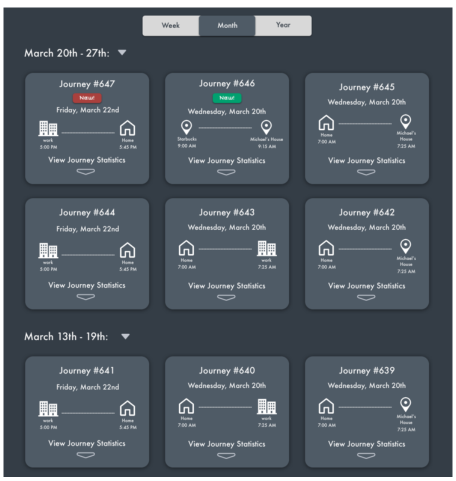

Figure 5: The user has the option of viewing the journeys on a monthly or yearly basis. This figure shows a snapshot of the monthly view.

Figure 6: Driving performance of a driver over all their journeys between two chosen dates. The individual performance is also compared with the community average over the same timeline. The user has the option to choose between three separate metrics: percentage over the speed limit, weaving score, and drifting score. Clicking on any individual point on the graph shows the statistics for that day.

date to limit the data included in the graph. The design incorporates visualizations of several metrics (percentage over the speed limit, weaving score, and drifting score) against which the user can gauge their performance in the given timeline and compare with the community averages during the same period. In addition, the areas in the graph are highlighted with contrasting colors to signify the level of safety associated with each region. An example is shown in Figure 6.

Drawing from the works on the effectiveness of gamification on steering users' behavior, aligned with our goal of encouraging drivers to drive more safely, we use three of the most salient tested mechanisms of gamification, badges, points, and leaderboards in our proposed design. We introduce two different types of badges based on the data we have on drivers' behaviors: personal badges and community badges. Personal badges are created in relation to each of the three metrics mentioned in this paper (speeding, drifting, and weaving) where each badge is further broken down into three tiers: bronze, silver, and gold, in increasing order of importance. Each badge is associated with a particular goal (e.g "Complete 200 journeys with a safe driving speed") which the user can aim to obtain by driving safely. On the other hand, community badges have a similar effect as leaderboards as they show the standing position of a driver among the drivers using the system within the same community. While a user may be able to complete all personal badges, community badges can be updated on a monthly or yearly basis to encourage active and sustained safe driving behaviour by the user with respect to their community. In the 'Badges' section, we also show the progress of the user towards badges that the user has not yet obtained. A snapshot is provided in Figure 7.

4 USABILITY TESTING

4.1 Overview

In order to evaluate the propose design, usability testing was completed with ten individuals. Each individual took part in a moderated User Experience (UX) testing method which included a heuristic evaluation of the interface as well as a short interview to obtain qualitative insights regarding the application. With regards to the heuristic evaluation, participants were given tasks to complete with the interface and were asked to evaluate the difficulty of completing the task. The age of the participants ranged from 24 to 33, with a mean of 28.5 years and a standard deviation of 2.75 years. The participant group comprised of four females and six male members. All of the participants had a valid drivers license, with driving experience ranging from 2 years to 15 years (mean 7.1 and standard deviation 3.98). Participants of the study came from a diverse ethnic

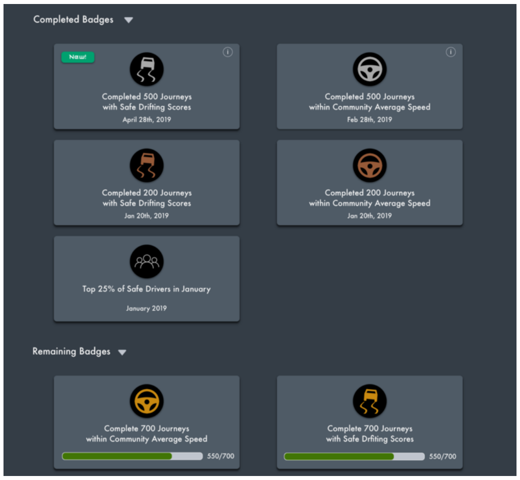

Figure 7: The badges that have been earned so far and the ones that are currently in achievable distance are shown in the Badges section.

background, including Brazilian, Iranian, Indian, and Chinese. We include the questionnaire used in the moderated user experience test in Appendix A.

4.2 Insights

The user study participants gave an overwhelmingly positive response when asked about using the proposed system in their daily life. All of the participants described their chances of using the software as either 'high' (66.7%) or 'very high' (33.3%). The rational behind this positive response by the participants mainly stemmed from the fact that the system provides a holistic overview of different legs of the journey in terms of safety-critical metrics. Participant P4 noted:

> "Knowing the speed limit on all the streets ... I am a new driver, so it is nice to know the speed limit to be more mindful next time once I break the speed limit." (P4)

Participants also indicated that they would utilize the system in order to keep track of their travel times which is recorded and displayed to the user. This enabled participants to see how much they spend in the car on average in order to better plan their tasks around the journey. One participant noted:

> "I would want to know on average how much it takes from home to work - I have a rough sense of time. This is the main reason I will use the system." (P6)

With regards to the difficulties associated with each task, almost all of the tasks earned the average rating of 'very easy', with the only notable exception being that of selecting a date on the calendar. Participants indicated that they enjoyed the simplicity of the interactions and intuitiveness of the navigational directions while performing different tasks within the application. However, some of the participants noted that the selection of the date within the "Driving Performance" tab to change the time frame of the aggregated performance metrics while changing the range of the display of the driving performance was not intuitive. These participants preferred to have default view of the graph to be their entire driving history, where they can alter the time-frame by zooming in on a particular section of the graph. This was exemplified by Participant P3 noting:

> "I hate this type of clickable calendar, because I cannot remember what date I want [once I open the calendar view]. Maybe it would useful for some people to have it as a calendar. [My preference:] the default view is my entire history - I can then brush the timeline to go to a particular time: show me my yearly history, history since October." (P3)

The inclusion of the map in the system was highly praised by the study participants. They noted that the visual appeal of the different legs of the journey being differentiated and the presentation of the associated statistics would act as a motivation for improving driving performance. One participant mentioned that this would be a learning experience especially when they are driving alone and there is no one else in the car to provide feedback. In addition, participants also spelled out many feature requests to be added into the map view to improve the overall experience, such as:

- Visual icons associated with the different metrics to exploit familiarity
- Using color gradients (such as varying shades of the color red) with individual legs to emphasize the gravity of a bad driving performance
- Orienting the map such that the starting position always appears below the ending position as is typically the case in mobile GPS applications
- Grouping the metrics into logical sets (e.g. Speed Limit and Average Speed), and group the speed limit as a part of the street description

User feedback was also obtained for the weekly journey view, which can be accessed through the navigation bar at the top of the screen. For example, in a group of journeys, participants noted that the date is the critical piece of information for identification of a particular journey. As such, the date of the journey should be highlighted using a unique color which is not used otherwise in the interface in order for users to quickly associate the color with the date. However, a design attempt which confused some of the participants was the color of the 'new' tags attached to journeys that the user had not yet gone through. The original intention of utilizing different colors for the tags was to provide a small indication regarding the overall driving quality of that journey. However, this variation in color confused the participants as they noted that the 'new' tag was providing two pieces of information within one design element.

On the journey statistics page, a great deal of valuable feedback was obtained (some of which apply to the overall design in general). For example, it was noted that the battery consumption on a journey (or, in the same vein, gas consumption) was not prominently displayed enough in both the summarized and detailed journey information elements. In addition, participants indicated that the statistics section contained too many numbers which could be improved by portraying some information using a graph as Participant P1 noted:

"Speed limits can be displayed as a graph; [currently there are] too much information (which can be somewhat misleading) and too many numbers." (P1)

Overall, with regards to the proposed design, the insights from the usability testing highlighted a number of misrepresentations and design peculiarities which were not immediately apparent while developing the interface. We catalog these items in the following list:

- The top element that contains the tabs 'Your Journeys', 'Driving Performance', and 'Badges' was not immediately recognizable as a navigation bar, as some participants struggled to locate the 'Driving Performance' tab while completing a task.
- The 'Further Details' button was not clearly apparent to several participants.
- The intuitiveness of including the speed limit on a particular street as part of the street name was discussed by several participants. The speed limit for a particular road is static and therefore can safely be grouped together with the street name.
- Another point of confusion was about the definition of the metrics of weaving and drifting, since these metrics were fairly new to some of the participants. The definitions of these two terms had been verbalized within each journey statistics element; however, this approach proved to be inefficient since the user may encounter other statistical elements which include drifting and weaving on a different page, and hence, they may need to look for the definition elsewhere.

4.3 Design Modifications

After completing the usability testing, the design was modified to include the various feedback points noted by the participants. A summary of the different changes implemented to each view can be seen in Table 1 and the images of the updated design can be seen in Appendix B.

5 DISCUSSION

The system we have proposed focuses on the cognitive change of the user based on the displayed individual and cumulative community statistics. We target the elevation of the information in the subconscious mind to the conscious awareness of a person related to their driving behavior through the display of concrete evidence in the form of video and recorded data and resulting rating categories. Furthermore, we promote the awareness of safe driving practices that are standard through comparison of individual statistics with that of the community. By doing so, we aim to promote safe driving behavior specifically on an individual level and on a community level in general.

It should be noted that when such a system goes into production as a fully-fledged software, the issue of privacy and security of information arises as a concern. In this project, we propose a method of comparison between individual driving statistics and community averages, hence, potentially privacy-critical user information including their journey details and vehicle make could be susceptible to data breaches. Particularly, since the proposed system is web-based, the data would be transferred over the internet to a cloud or central storage system. Hence, the possibility of hacking the data while it is being transferred, the probability of the database being hacked through any fault of the security, or revelation of any identifiable information from the larger data base arise as serious concerns regarding the implementation of such a system. With the recent private data leaks within large corporations such as Facebook [13] or Equifax [50], solutions for data privacy remain an active area of enquiry.

With regards to the collection of driving data and statistics, we envision this process taking place in two different ways. Firstly, as semi-autonomous vehicle manufacturers currently collect an incredible amount of data regarding the vehicle's performance and surroundings [40], this data could then be incorporated as input into the proposed system. However, this approach would likely be met with concerns from car manufacturers that would object to making the data available to external sources due to the risk of competition in the field of innovation. Alternatively, data collection could be done by using a third-party hardware system or smartphone to capture the necessary driving statistics for the purpose of the proposed system. Many smartphone devices in the present day are capable of capturing all the information necessary for calculation of different driving metrics such as speeding, weaving, and drifting. One such existing system that can capture the data easily is a mobile phone application named 'DriveSafe' [8]. Bergasa et al implemented their system to record the GPS and accelerometer data that are captured by the middle-end and high-end mobile phones with required sensors and converts the information into processed metrics in real time. The application uses computer vision and pattern recognition techniques on a smartphone to assess the condition of the driver using the rear-camera, the microphone, the inertial sensors, and the GPS. A follow-up of their work builds on the concept of weaving and drifting [39]. Integrating our proposed system as an extension of the DriveSafe application may ease the data collection method without depending on any external processes. The setup example of the mobile phone for utilizing the DriveSafe application is shown in Figure 8.

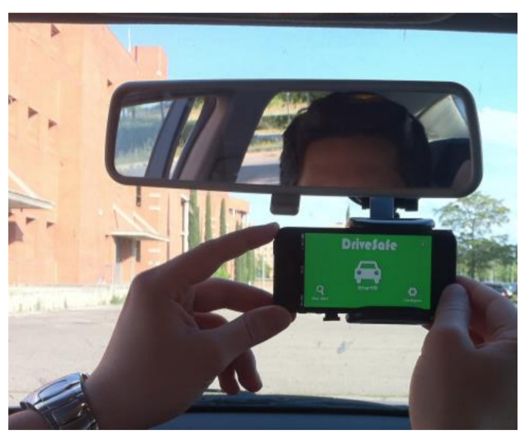

Figure 8: A view of the setup of the mobile phone for using the DriveSafe application. The figure is taken from [8].

	Views/Modifications	**Home page**	**Journey Statistics**	**Map Details**	**Badges**	**Monthly View**	**Driving Performance**
1	Making the navigation bar prominent	✓	✓	✓	✓	✓	✓
2	Making the 'view more' button prominent	✓	✓	✓	-	✓	-
3	Changing numbers to graphical representation	-	✓	✓	-	-	-
4	Changing the battery consumption to graphical representation	✓	✓	-	-	-	-
5	Using appropriate icons for representing Work	✓	✓	-	-	✓	-
6	Removal of the 'New' tag	✓	✓	-	-	✓	-
7	Adding information button for drifting or weaving	-	✓	✓	×	-	-
8	Changing the colour of community average	-	✓	✓	-	-	✓

Table 1: The modifications done to the proposed design after obtaining user testing feedback. We denote the non-applicability of a modification in a particular view by using '-'.

One alternative use case where the proposed system could be beneficial is the correction of dangerous driving behaviours through institutional interventions. Individuals that drive recklessly on the streets not only endanger their lives, but also put the lives of the others on the roads into jeopardy. The government could take initiatives to account for the driving scores generated by the proposed system during the process of driving license renewal, so that this method could work as a motivation for people to drive more carefully. However, this approach has ethical and privacy concerns in the sense that government will have to access data that people might view as personal and consequently private to them.

6 LIMITATIONS

While this study aims to design and evaluate a system to help drivers understand and rationalize their driving behaviour through information visualization and consequently make a contribution to driving safety, the study suffered from a number of limitations described hereafter.

With regards to usability testing, while effort was made to incorporate a variety of different opinions with respect to the developed prototype, this system would ideally be evaluated with a longitudinal study where users actively work through the system within their driving ecosystem over a period, throughout which the researchers (and participants) could track changes in the driving behaviour of the participants over time. However, given the time and resource constraints of this study, the longitudinal study was not feasible, and hence, a simple usability test was conducted in order to verify the ease of use of the application.

In addition, while the community driving speed averages were collected using the San Francisco Speed Limit (SFSL) data set mentioned previously [3], the individual driving speeds and processed statistics were mocked for the purposes of comparison with the average speeds obtained from the data set. Similarly, the journey routes portrayed within the application demo used for usability testing were mocked using streets included in the SFSL data set in order to ensure that the speed limits and community averages were modelled from existing data. However, ideally, the user data that would be included in such an application would be aggregated data collected from its users rather than from an external data set as performed in this study.

7 FUTURE WORK

This paper presents a starting point into the enquiry of utilizing personal driving data for the purpose of improving user driving behaviour. However, while the proposed design incorporates three different metrics (speed, drifting, weaving) to be visualized to the user, many other metrics could be included as additional statistics to be visualized within the system. For instance, recording and analyzing unsafe turning behaviour at intersections where users do not use their indicators could be a valuable metric to improve driving behaviour. Similarly, recording the average distance between the user's vehicle and the vehicle directly ahead of the user with respect to the user's speed could be an additional metric that could be incorporated to encourage safe vehicle separation distances in accordance with a given standard.

Expanding the proposed system to include a mobile component in addition to the web application is a future direction for the project. As mentioned previously, the data collection process could be implemented using smartphones, and therefore, developing an all-inclusive mobile application which functions both as a data-collection tool, as well as a dashboard for driving statistics and visualizations would be ideal. In the same vein, a user account could be tied to only a single user (and not to a particular vehicle) to increase the robustness of the platform by making the system vehicle-independent. In this way, the user can switch their vehicle and still have access to all their data.

A further step in driving behavior modification could build on the work of Zhao et al, who successfully used deep belief networks to predict the speed and steering angle of a vehicle [49]. Speed and steering angle which reflect the longitudinal and lateral behavior of drivers are two important parameters for behavior prediction and Zhao's method shows highly adaptive behavior in learning from driver data without human intervention or hand-picked features. Enmeshing this concept with the notion proposed in this paper, we can imagine a modified system which, by collecting rich data from the driver and the surrounding environment, can predict the next move of the driver for a particular time. This prediction is compared to the real-life behavior of the driver for the same time and any discrepancy could be reported to the driver themselves for comparison, evaluation, and behavior correction.

8 CONCLUSION

In this paper, we presented a persuasive visualization system to improve drivers' driving behavior. In this system, the drivers' can statistically compare their driving behavior compared to the community. Drawing on literature from visualization and persuasion as well as gamification, we discussed how visualization techniques can play an instrumental role in improving the driving behavior. We explained the design and development of the system. Our user study provides insight into the usability and effectiveness of our tool. The participants rated the system positively in terms of usability. In addition, they provided suggestions for including a few more evaluation features. We believe that we could extend the system to include more safety concern to address them in future research.

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A USER TESTING QUESTIONNAIRE

(1) Name:
(2) Age:
(3) Gender:
(4) Driving License?
(5) Driving experience in years?
(6) How easy is it to view 'Monthly Journeys' and 'Details of the Latest Journey' from the home page? Rank from 1 to 5, with 1 being the least likely and 5 being the most likely.
(7) How easy is it to view the map? Rank from 1 to 5, with 1 being the least likely and 5 being the most likely.
(8) Understanding detailed information from the "journey details" (how many info, which is the most visible)
(9) Understanding detailed information from the "journey details"
 (a) Indicate any headings that are missing, confusing, or excessive
 (b) Indicate any material that should be designed as a list
 (c) Give examples of material that might be clarified by a visual
 (d) Give examples of misleading or overly complex visuals
 (e) Identify anything you misunderstood on first reading
 (f) Identify anything you couldn't understand at all
 (g) Identify expressions that seem wordy, inexact, or too complex
 (h) Other:
(10) After seeing your journey in the map and the portions where you did not drive safely, how likely are you to drive safely on that road next time? Rank from 1 to 5, with 1 being the least likely and 5 being the most likely.
(11) Understanding detailed information from the "Map View"
 (a) Indicate any headings that are missing, confusing, or excessive
 (b) Indicate any material that should be designed as a list
 (c) Give examples of material that might be clarified by a visual
 (d) Give examples of misleading or overly complex visuals
 (e) Identify anything you misunderstood on first reading
 (f) Identify anything you couldn't understand at all
 (g) Identify expressions that seem wordy, inexact, or too complex
 (h) Other:
(12) How likely is it that you will drive more safely after seeing these stats related to speed, drifting, weaving? Rank from 1 to 5, with 1 being the least likely and 5 being the most likely.
(13) How perception of your skill is changed after you see the details of your driving behavior?
(14) Understanding detailed information from the "Driving Performance" (how many info, which is the most visible)
(15) How easy it is to change the date range or metric type? Rank from 1 to 5, with 1 being the least likely and 5 being the most likely.
(16) How easy it is to view the details of any particular date? Rank from 1 to 5, with 1 being the least likely and 5 being the most likely.
(17) Understanding detailed information from the "Driving Performance"
 (a) Indicate any headings that are missing, confusing, or excessive
 (b) Indicate any material that should be designed as a list
 (c) Give examples of material that might be clarified by a visual
 (d) Give examples of misleading or overly complex visuals
 (e) Identify anything you misunderstood on first reading
 (f) Identify anything you couldn't understand at all
 (g) Identify expressions that seem wordy, inexact, or too complex
 (h) Other:
(18) How well do community averages help rationalize your own driving behavior? Rank from 1 to 5, with 1 being the least likely and 5 being the most likely.
(19) Understanding detailed information from the "Month View" (how many info, which is the most visible)
(20) Understanding detailed information from the "Month View"

(a) Indicate any headings that are missing, confusing, or excessive
(b) Indicate any material that should be designed as a list
(c) Give examples of material that might be clarified by a visual
(d) Give examples of misleading or overly complex visuals
(e) Identify anything you misunderstood on first reading
(f) Identify anything you couldn't understand at all
(g) Identify expressions that seem wordy, inexact, or too complex
(h) Other:

(21) What effect does the badging system have on your willingness to use the system? Why?

(22) How likely are you to use such a system? Rank from 1 to 5, with 1 being the least likely and 5 being the most likely.

B MODIFIED DESIGN

In this section, we present the modified design after incorporating the feedback of the user study participants. We present a collage of the interface, with changes incorporated into the design inspired from the feedback obtained from the user study. The modified design is presented in Figure 9.

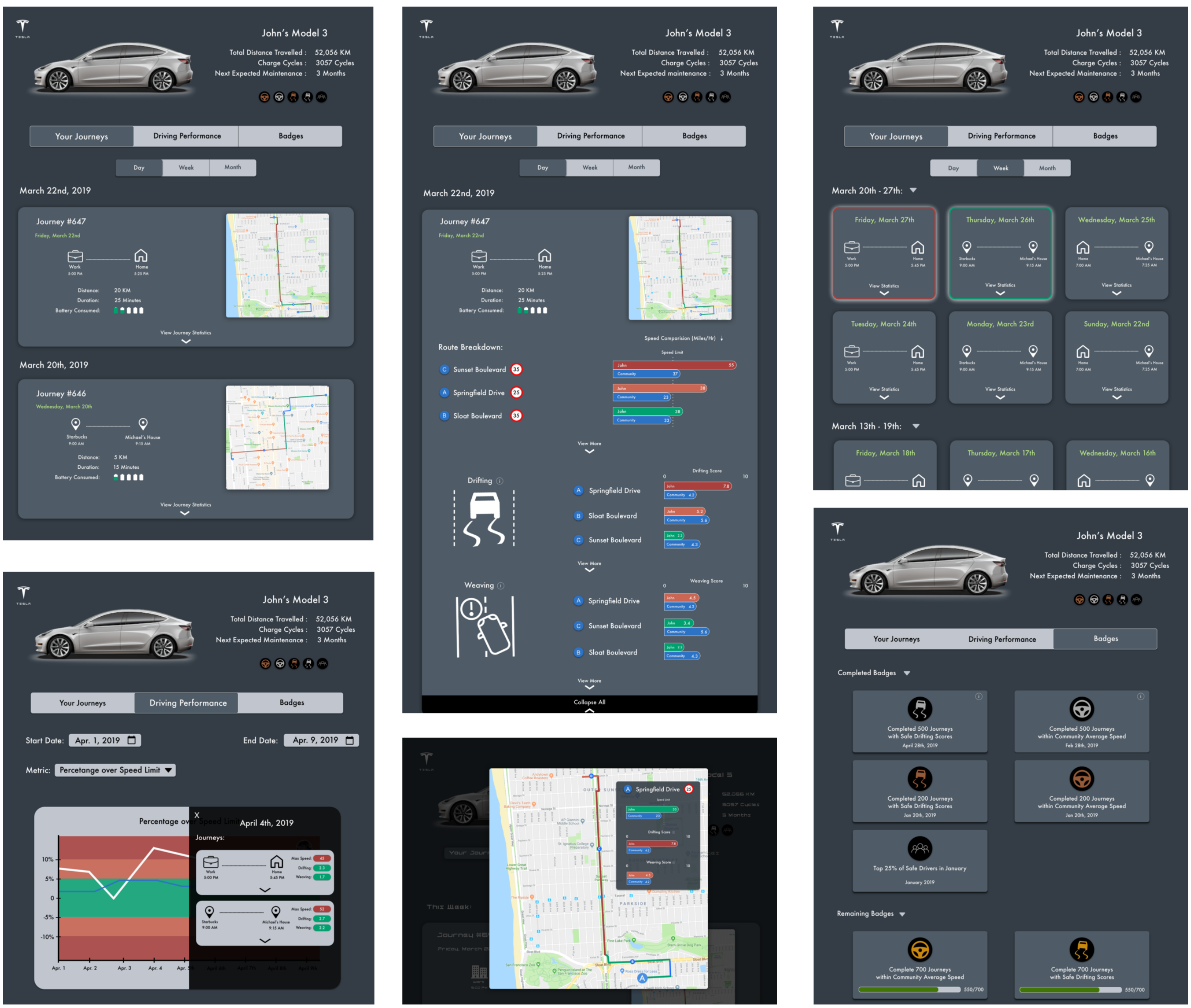

Figure 9: The modified design based on user testing feedback.