A Novel Usability Evaluation Framework for Electric Vehicles

NISARG RAJPURA, Indiana University - Purdue University, USA
DHAIRYA VORA, Indiana University - Purdue University, USA
SHIVANI JAYAPRAKASH, Indiana University - Purdue University, USA
MANOHAR ANTHAKAPALLI, Indiana University - Purdue University, USA
RHEA SHETTY, Indiana University - Purdue University, USA

Additional Key Words and Phrases: usability framework, electric vehicles, surveys, contextual inquiries, user experience

ACM Reference Format:
Nisarg Rajpura, Dhairya Vora, Shivani Jayaprakash, Manohar Anthakapalli, and Rhea Shetty. 2023. A Novel Usability Evaluation Framework for Electric Vehicles. 1, 1 (December 2023), 13 pages. https://doi.org/10.1145/nnnnnnn.nnnnnnn

1 INTRODUCTION

The user interface in automobiles has advanced significantly in recent years covering everything from a few buttons on the dashboard to a full-fledged tablet. Many questions have arisen during this process, such as whether this feature is even required or even how efficient, if at all, is the enhanced feature from the prior one. While researching this issue further, we discovered that Electric Vehicle (EV) users face additional challenges that are distinct from those faced by traditional car users.

We aim to formulate a "Usability Framework" for Electric Vehicles that researchers, industry professionals (designers, engineers, and usability specialists), and other stakeholders can utilize to evaluate and develop industry standards for future EV design and engineering. Moreover, the proposed framework will be a valuable tool for the industry, academia, and other stakeholders involved in the development and testing of electric vehicles.

The paper also includes a User Survey to better understand the elements that influence consumers' decisions to prefer regular automobiles over EVs, as well as insights into usability issues that must be addressed. It also includes demonstrations of how stakeholders can utilize the proposed framework to evaluate and improve the user experience of the existing and future EVs.

Based on the McKinsey EV Consumer Survey 2016 and 2019, there is a 24% increase (from 29% in 2016 to 36% in 2019) in consideration of EVs among consumers over the three years in the United States, although the conversion remains low in single digits [1,2,3]. This indicates that despite the perceived benefits of EVs, the perceived concerns still outweigh them and that there are usability factors that need to be addressed to improve the user experience of

Authors' addresses: Nisarg Rajpura, nrajpua@iu.edu, Indiana University - Purdue University, Indianapolis, USA; Dhairya Vora, Indiana University - Purdue University, Indianapolis, USA, vorad@iu.edu; Shivani Jayaprakash, Indiana University - Purdue University, Indianapolis, USA, skolalaj@iu.edu; Manohar Anthakapalli, Indiana University - Purdue University, Indianapolis, USA, maantha@iu.edu; Rhea Shetty, Indiana University - Purdue University, Indianapolis, USA, rhshetty@iu.edu.

Manuscript submitted to ACM

EVs and increase their adoption. Studies suggest that the factors affecting the usability and user experience of electric Vehicles are complex and multifaceted [5,26]. Factors such as battery range, charging infrastructure, driving behavior, and in-car user experience Studies suggest that the factors affecting the usability and user experience of electric vehicles are complex and can impact the adoption of EVs. Furthermore, psychological and cognitive factors, such as trust, satisfaction, and comfort, play a crucial role in influencing users' decision-making processes. These factors can affect users' perception of the usability and user experience of EVs [5,6]. On the other hand, traditional non-electric cars have been around for over a century and have gone through several iterations of design and engineering, resulting in a refined and comfortable driving experience. Features such as comfortable seats, a well-designed dashboard, and intuitive controls contribute to the user experience of traditional cars.

The difference in user experience between traditional non-electric cars and EVs highlights the need to develop a comprehensive Usability Framework for EVs. This framework should consider the unique characteristics of EVs and address the usability factors that affect the user experience of EVs. By developing such a framework, we aim to improve the user experience of EVs, making them more attractive to potential users and increasing their adoption.

1.1 Significance and Broader Impact

The significance of the proposed research lies in the fact that the usability of electric vehicles is a critical factor affecting their adoption and widespread use. Electric vehicles present unique usability challenges that need to be addressed to enhance the user experience and increase adoption. Currently, there is no standardized approach to evaluating the usability of EVs, and this lack of standardization can hinder the adoption of these vehicles[4]. Based on our research, the broader impact of developing a usability framework is that it offers:

(1) **Improved user experience:** A well-designed user interface can enhance the user experience by making it easier for drivers to access and use their electric vehicle's functions. A usability framework checklist may ensure that critical design factors such as user-centered design, clear and succinct labeling, and easy navigation are taken into account.

(2) **Increased adoption of electric vehicles:** One of the main barriers to the widespread adoption of electric vehicles is the perceived difficulty of using them. A user-friendly interface can make electric vehicles more appealing to drivers and help to increase adoption rates.

(3) **Enhanced safety:** A clear and intuitive user interface can also improve safety by reducing the time drivers spend looking away from the road to operate their vehicle's features. A well-designed user interface can also provide drivers with information about their vehicle's performance, which can help them to make safer driving decisions.

(4) **Standardization:** A framework checklist for usability can help to establish industry standards for user interfaces in electric vehicles. This can make it easier for drivers to switch between different electric vehicle models and reduce the learning curve associated with using a new vehicle.

Overall, the proposed framework can help significantly to improve the user experience of existing and future electric vehicles, leading to an increased adoption of electric vehicles, which is crucial for achieving a sustainable future for transportation.

2 RELATED WORKS

2.1 Usability in Electric Vehicles

Usability is essential when creating interfaces for automobiles, particularly for electric vehicles. Usability testing can assess the effectiveness of features in navigation systems, which now include real-time traffic updates and routing to nearby charging stations. The importance of battery management system and charging station usability has also been emphasized. To improve the user experience, electric vehicle makers and charging station suppliers should focus on building intuitive and user-friendly systems. A recent study found that charging station instructions and user interfaces significantly affected the utility of range estimation devices for electric car drivers. To deliver a seamless driving experience, navigation systems must provide accurate and relevant information to drivers. A usability testing framework for electric vehicles is needed to evaluate these components [1, 2, 24].

2.2 Safety and distractions

Vehicle safety features such as ESC, automatic collision avoidance, and lane departure warning are critical. Automatic collision avoidance systems employ sensors and cameras to recognize objects and apply brakes if a collision is near, whereas ESC detects and decreases skidding. Lane departure warning systems notify drivers when their vehicle begins to drift out of its lane, assisting in the prevention of accidents caused by driver distraction or drowsiness. A study identified visual, cognitive, tactile, and aural distractions from car screens. Bright colors, complex interfaces, and manual or aural distractions can distract drivers. To ensure safety, designers must address these issues while building car screens. [10] The safety of electric and hybrid vehicles was evaluated through collision warning system testing and crash tests. Electric vehicles performed well and had sufficient safety features. Future research may lead to further safety improvements. [11,12]. The study investigated the safety benefits of vehicle-to-vehicle communication systems and the risks associated with high-voltage electrical systems in electric and hybrid vehicles. Sharing information can prevent collisions, while high-voltage electrical systems pose electrocution risks. More research is needed in both areas to improve safety[11,13].

2.3 User Experience and Interface

Two distinct studies were carried out to investigate various areas (such as safety and driver assistance, range anxiety, climate effect) of driving technology. The first study concentrated on the use of automated experience sampling techniques for gathering data on driver behavior and preferences. The study gave special attention to the design of the user interface as well as the data collection methods used. The second study looked at how augmented reality displays could improve driver safety by delivering real-time information about road risks and obstructions[12,14]. Some of the studies focus on different aspects of electric vehicle user experience: driving distance, range displays, and user interfaces. The studies emphasize the importance of considering user feedback in the design of electric car technology[15,16]. The article discusses two studies on in-car technology user experience and interface design. One study found that multi-finger interaction on touch screens improved user satisfaction. The other study highlighted the importance of user-centered development for electric cars as mobile devices. Both studies emphasize the need for user-focused design to improve user experience and adoption of in-car technology[13,17].

2.4 Connectivity

A research has explored the feasibility of over-the-air (OTA) upgrades, which allow for remote software upgrades and feature additions, which prolong the lifespan of the vehicle and improve the customer experience[13]. The project studied V2G methods that allow electric vehicles to supply energy back to the grid, giving benefits to both the user and the utility provider[18]. The research examined how infotainment technologies in electric vehicles, such as touchscreens and mobile device integration, can provide drivers with entertainment, communication, and navigation services. It also looked into the impact of mobile applications that enable drivers to control and check their electric vehicles, such as tracking battery levels and charging to the maximum capacity of the car. Through the connectivity aspect in the cars, it helped us to understand what are the issues drivers are facing with the connectivity feature. For example, is the interaction with connectivity feature good enough for the drivers to connect their devices quickly and without distracting themselves while driving?

2.5 Usability Evaluation Methods

2.5.1 Questionnaires and Surveys. Surveys and questionnaires were used in this study to collect customer input on several aspects of the electric vehicle experience, such as range anxiety, charging infrastructure, and driving dynamics. The obtained data can be used to identify areas for improvement and to lead the development of electric vehicle technology that meets the demands and expectations of consumers[25].

2.5.2 User testings and Prototype Testing. The study conducted comprehensive user testing to examine the intelligent in-car system and AR head-up displays. The evaluation of AR HUDs, including their impact on driving performance, safety, and usability, was a crucial aspect of the research. Additionally, the validation of results through further user testing ensured the study's outputs' validity. Prototype testing of the intelligent in-car system provided critical insights on its accessibility, engagement, and satisfaction. However, the study's small sample size and lack of diversity may limit the generalization of its findings. Future studies should address these limitations to improve the accuracy and predictive ability of the conclusions[20,21].

2.5.3 Heuristics and Expert Evaluations. To assess the efficiency of the assessment framework, the study used expert evaluation approaches such as heuristic evaluations and usability testing. The researchers contrasted heuristic evaluation approaches with the MALTU model for assessing the usability of ubiquitous systems, highlighting their different strengths and drawbacks[22]. Furthermore, expert evaluation methodologies were used in to examine the usability of non-visual controls, such as cognitive walk-through[23, 24].

3 PROBLEM STATEMENT

3.1 Research Question(s)

The use of Electrical Vehicles (EVs) has been growing in recent years, driven by the need to transition to sustainable transportation systems. Despite the increasing demand for EVs, there are still usability challenges that need to be addressed to enhance the in-car user experience and increase adoption[1,2]. As mentioned in the "Related Work" section, different research works to address different aspects of the devices like ubiquitous devices or mobile computing or electric vehicles but there is a need to develop a dedicated novel Heuristic Framework that just focuses on the complete experience of electric vehicles. So that by using that framework, engineers, designers and industry experts can use that framework to test the usability of experience of EVs and thus they can improve the experience which can lead to more increase the more trust and adaption to EVs. And that's why, this study aims to answer the following research question: *What are the key usability factors that need to be considered in developing a comprehensive Usability Framework for Electrical Vehicles, and how can this framework be designed to enhance the in-car user experience and increase the adoption of Electric Vehicles?*

To answer this research question, the study will first identify the key usability factors that are essential for developing a comprehensive "Usability Framework", which can be used to evaluate the in-car user experience of the Electrical Vehicles by measuring the usability of in-car features and functionalities. The key usability factors that are important to consider include controls, displays, infotainment systems, charging, climate control, etc[29]. Once the key usability factors have been identified, the study will develop a comprehensive Usability Framework for Electrical Vehicles that addresses these factors.

4 METHODOLOGY

4.1 Secondary Research

During our research, we focused on acquiring a deeper understanding of the latest trends and technologies being used in the automobile industry. To achieve this, we conducted secondary research and identified five key categories: Connectivity and Entertainment, Safety and Driver Assistance, Human-Machine Interface, Cognitive Perception, and Important Parameters for EVs.

Under the Connectivity and Entertainment category, we delved into features such as infotainment systems, vehicle-to-everything (V2X) communication, and smartphone integration to provide convenience and entertainment for users. Our research into Safety and Driver Assistance covered advancements in collision avoidance systems, adaptive cruise control, and lane departure warning systems to improve safety and minimize stress for drivers. Moreover, we also examined how the design of the vehicle and its interface can affect the user experience under the Human-Machine Interface category. We studied interfaces such as voice control, touchscreens, and haptic feedback. In the Cognitive Perception category, we focused on the impact of lighting, sound, and color on a user's mood and behavior, which, in turn, can significantly impact the overall user experience. Lastly, under the Important Parameters for EVs category, we researched the critical factors that impact the user experience, such as range, climate, charging infrastructure, and battery technology. By combining all of our findings, we gained a comprehensive understanding of the EV industry's current state and identified potential areas for improvement in enhancing the user experience of electric vehicles.

4.2 Survey

To gather insights from a large number of users within a shorter period of time, our team conducted a survey. Our aim was to gather a significant amount of data and insights, which we were pleased with the results. To ensure that we obtained both qualitative and quantitative data, we designed the survey questions accordingly. The survey was conducted over a period of one month, and we made sure to send the survey link to various platforms, such as Reddit, Quora, and other communities, to reach a diverse group of users.

The survey questions were focused on understanding the pain points and preferences of the users, which is why we included a mix of likert scale questions and open-ended questions. The open-ended questions allowed the users to provide in-depth feedback on their pain points or preferences. The survey was divided into three parts: demographics, questions related to the user interface of the car, and the electric car's issues that the users were facing.

Overall, the data collected from a total of 48 users, we gained valuable insights into the pain points and preferences of the users in their driving experience. Analyzing this data gave us a good understanding of what the users were experiencing, and helped us identify areas for improvement. Moreover, the survey was an effective way to obtain valuable data and insights from a large number of users in a shorter period of time, which helped us to consider the areas to improve the user experience.

4.3 User Interviews

We wanted to gain a more comprehensive understanding of the issues users face with their current car experience. To achieve this, we conducted user interviews to gain descriptive insights and better understand users' experiences. We understood that the experience of a car cannot be fully explained without seeing actual images of the car dashboard and other features.

In total, we conducted five user interviews, three of which were with EV car users and two were non-EV car users. Before the interview, we requested users to upload pictures of their car dashboard or any other features that they felt needed improvement. This allowed us to curate our interview questions to their specific concerns and pain points.

In conclusion, the user interviews proved to be an invaluable source of information for our team. By hearing directly from the users, we were able to identify pain points that we may not have otherwise discovered. Furthermore, the interviews helped us gain a better understanding of the context in which users were experiencing these issues, such as how they impacted their daily lives and overall car experience. The insights we gained from the interviews helped us tailor our research and address users' specific needs, leading to a more effective and user-centered design.

5 RESULTS

For designing the final evaluation framework, our study aimed to address two research questions: (1) Are there any existing evaluation frameworks specifically for in-car user experience? and (2) What parameters should be considered when designing a usability evaluation framework? To answer the first question, our study found that multiple usability evaluation frameworks exist, but they are limited to non-electric vehicles. As a result, we identified a design opportunity to create a usability evaluation framework specifically designed for electric vehicles.

For the second research question, we utilized primary and secondary research data to identify key themes. Based on the data, the majority of participants (53%) preferred touchscreens as their mode of interaction, followed by buttons (27%), gestures (11%), and voice commands (7%). We also conducted a thematic analysis to identify the key parameters that should be considered when evaluating the in-car user experience. Six Key Performance Indicators (KPIs) were identified, namely, Self-Identification, Accessibility, Feedback, Consistency, Hierarchy, and Task Completion.

5.1 Key Performance Indicators (KPIs)

(1) **Self-Identification:** Based on our research, we found that users often struggle to understand the functions and features of in-car systems, particularly if they are not aligned with their mental models. To address this issue, we propose the KPI of self-identification, which measures how easily users can identify and understand the functions and features of the in-car system. In-car systems can be designed with clear and concise labels, icons, and visual cues that align with users' mental models to improve overall usability. For example, a well-designed in-car infotainment system might use icons that clearly convey the function of each control, such as a phone icon for hands-free calling, a music note for music playback, and a navigation arrow for GPS guidance.

(2) **Accessibility:** Our research has shown that accessibility is a key factor in improving the usability and safety of in-car systems. Based on this, we propose the KPI of accessibility, which measures how accessible the in-car system is to users. Factors such as ease of use, reachability, and visibility are important considerations for accessibility. In-car systems can be designed to be easily accessible by positioning controls and displays within easy reach, using large and clear text and icons, and minimizing visual distractions. For example, an in-car system might feature large, easy-to-read displays and controls that are within easy reach of the driver, such as on the steering wheel or dashboard.
(3) **Feedback:** Effective feedback is crucial for improving the usability of in-car systems. Based on our research, we propose the KPI of feedback, which measures how well the in-car system provides feedback to users. This can be visual or auditory and is used to indicate system status or confirm user actions. In-car systems can provide feedback by using visual cues such as progress bars, icons, or color changes, or by providing audible notifications such as beeps or voice prompts. For example, a well-designed in-car navigation system might provide audible directions to the driver while also displaying a visual map on the dashboard display.
(4) **Consistency:** Consistency is a critical factor in reducing cognitive load and improving user experience. Based on our research, we propose the KPI of consistency, which measures how consistent the design and functionality of the in-car system is across different tasks and contexts. In-car systems can be designed to be more consistent by using standardized icons, labeling conventions, and control layouts. For example, a well-designed in-car system might use consistent labeling and iconography for frequently used controls, such as climate control or audio playback, across different car models or brands.
(5) **Hierarchy:** Our research has shown that the organization and prioritization of information and tasks is key to improving the usability of in-car systems. Based on this, we propose the KPI of hierarchy, which measures how well the in-car system organizes and prioritizes information and tasks. In-car systems can be designed to facilitate task completion and reduce user frustration by grouping controls and information in a logical and intuitive manner, and prioritizing frequently used controls and information. For example, a well-designed in-car system might group related controls together, such as climate control or audio playback, and prioritize frequently used controls or information such as speed, fuel level, or trip information.
(6) **Task Completion:** Task completion is the ultimate goal of in-car systems and, therefore, an important KPI for measuring usability. Based on our research, we propose the KPI of task completion, which measures how well users are able to complete tasks using the in-car system. Completion time, error rates, and user satisfaction are important factors to consider when measuring task completion. In-car systems can be designed to facilitate task completion by minimizing the number of steps required to complete

Once the KPIs were established, we proceeded to design the usability evaluation framework. To select applicable evaluation methods for the framework, we considered the following aspects proposed by Stanton and Harvey (2013, p. 55): Context-of-use, Criteria, KPIs, Time and scale of the project, and Resource constraints [31]. We also considered the International Organization of Standardization (ISO) (1998) guideline that there is no universal guideline for selecting or integrating usability evaluation methods. As a result, we designed a usability framework that combines multiple usability methods and also considers the previously stated aspects.

The final framework consists of a two-phased evaluation method. In the first phase, the main goal (eg. Switching on the air conditioner or Turning on the navigation system) is broken down into multiple sub-goals, which are further divided into sub-tasks. In the second phase, all the sub-tasks are evaluated against each of the identified KPIs. Each sub-task is given a score out of 5 and a description is provided for each score. The score ranges from 1 to 5, where 1 stands for failed, 2 for unacceptable, 3 for needs some modification, 4 for acceptable, and 5 for excellent. An individual column is also provided for noting down any information regarding the evaluation, which could also involve potential improvements in the task.

Finally, when every sub-task is evaluated against each KPI, the two-phased evaluation process ends, and the user has a final table where they could identify and gather the results in a qualitative and quantitative format. The data in the table could be analyzed, and each sub-task that had a score below 3 for a KPI could be addressed for improvement.

5.2 The Evaluation Framework

(1) **Phase 1:** Breaking down the goal into sub-tasks.

How to perform this step?

  (a) **Define the goal:** The first step is to define the goal that needs to be evaluated. For example, in the case of a car, the goal could be "Find IUPUI using car's GPS navigation system, set it as destination and start navigation".

  (b) **Identify sub-goals:** Next, the evaluator needs to identify sub-goals that are required to achieve the main goal. In the case of previous example, sub-goals could be "Open car's GPS navigation system", and "Set IUPUI as the final destination".

  (c) **Break down sub-goals into sub-tasks:** The evaluator then breaks down each sub-goal into sub-tasks. For instance, the sub-goal "Open car's GPS navigation system" could be broken down into sub-tasks such as "Locate navigation icon in the infotainment system", and "Press the navigation button in the infotainment system". (Refer fig.1)

Why to perform this step?

Breaking down the goal into sub-tasks helps in identifying individual tasks that need to be evaluated for usability. It also provides a detailed understanding of the user's interaction with the system and allows the evaluator to gather more specific information about each task. By breaking down the goal into sub-tasks, the evaluator can identify specific areas that need improvement in the user interface and user experience.

(2) **Phase 2:** Scoring the sub-tasks based on their usability.

How to perform this step?

  (a) **Evaluate sub-tasks against KPIs:** In the second phase, each sub-task is evaluated against key performance indicators (KPIs) such as task completion time, error rate, and user satisfaction. The evaluator assigns a score to each sub-task based on its performance against the KPIs.

  (b) **Provide descriptions for each score:** For each score, the evaluator provides a description that explains why the sub-task received that score. The descriptions should also include any potential improvements that can be made to the sub-task.

  (c) **Note down any additional information:** The evaluator should also note down any additional information that is relevant to the sub-task evaluation. This information could include user feedback or observations made during the evaluation. (Refer fig.2)

Why to perform this step?

Scoring the sub-tasks based on their usability helps in identifying which tasks are performing well and which tasks need improvement. The KPIs provide a standardized way of evaluating each sub-task, which makes it easier to compare the performance of different tasks. The descriptions for each score help in providing a detailed understanding of the sub-task's performance and areas that need improvement. Additionally, noting down any additional information helps in understanding the user's experience and identifying potential areas for improvement in the system.

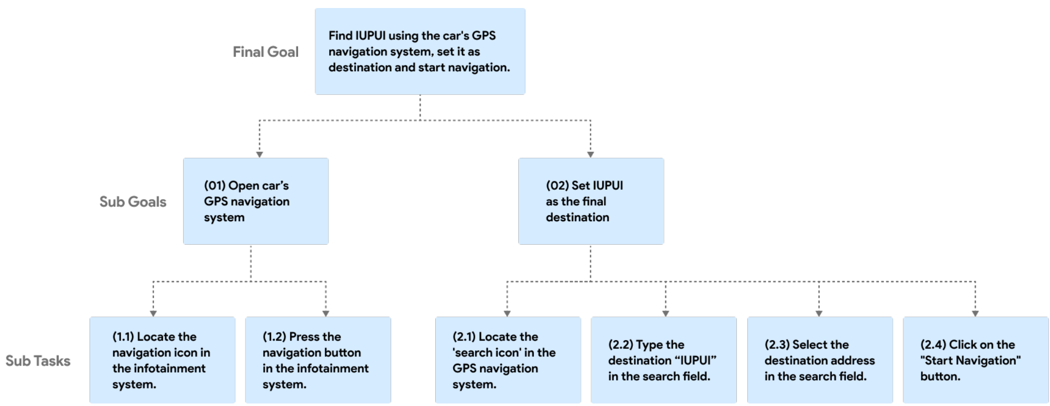

Fig. 1. Goal breakdown with example

List of steps	Self-Identification	Accessibility	Feedback	Consistency	Hierarchy	Task Completion	Notes
List of steps to achieve the goal from the task break-down phase	How is it for users to identify and interact with the different functions and features of the in-car interface?	How it is for users to access and interact with the different features of the EV's in-car interface?	How clear and understandable is the system's responsiveness to user interactions, including providing clear and timely feedback to user actions?	How consistent is the interface across different features and functions, to reduce confusion and increase ease of use?	How well the in-car interface is structured, prioritized, and organized, to allow users to quickly and easily find and use the features they need?	How easily users are able to complete tasks and interact with the in-car functions or features?	Space for recommendations or potential solutions for improvement
1.1	**Score: 5** The navigation icon was easily identifiable with a clear label and appropriate symbol.	**Score: 4** The navigation icon was easily accessible from the home screen of the infotainment system, but required two taps to access.	**Score: 3** The system provided visual feedback by displaying a loading icon, but lacked any auditory or haptic feedback.	**Score: 4** The navigation icon was placed in a consistent location with other infotainment systems in the car.	**Score: 4** The navigation icon was appropriately placed in the first-level menu of the infotainment system, but could be moved to the top-level menu for quicker access.	**Score: 5** The sub-task was completed successfully and accurately.	Provide an audio feedback to indicate users about the navigation icon.
1.2	**Score: 5** The navigation icon was easy to identify as it had a distinct and recognizable image.	**Score: 5** The button is easy to see and reach, and does not require any special skills or knowledge.	**Score: 4** The button provided a subtle haptic feedback when pressed, but there was no on-screen animation or sound effect to confirm the action.	**Score: 5** The icon and placement of the navigation button is consistent with other navigation systems, making it easy for users to find and understand.	**Score: 4** The navigation button was located at a medium level of hierarchy in the infotainment system's menu structure.	**Score: 5** The button performed the intended function of launching the navigation system.	No improvements needed for this sub-task.
2.1	**Score: 4** The search icon was easily recognizable and matched the user's mental model of a magnifying glass icon.	**Score: 5** The search icon was prominently placed on the screen and was easily reachable by the user.	**Score: 4** The icon changed color and displayed a tooltip when hovered over, indicating to the user that it was clickable.	**Score: 5** The search icon was consistent with other search icons in other applications and did not cause any confusion.	**Score: 5** The search icon was appropriately placed in the hierarchy of the navigation system and was easy to find.	**Score: 4** Description: The user was able to locate the search icon with ease and complete the task without any issues.	No potential solutions for improvement identified.
2.2	**Score: 5** The search field was clearly labeled and easy to identify.	**Score: 5** The search field was easily accessible and not obstructed by other icons or elements.	**Score: 2** The system provided auto-suggestions for the address as it was being typed, but did not give any feedback if the address was not found.	**Score: 5** The search field was consistent with the rest of the system in terms of placement and design.	**Score: 5** The search field was clearly positioned as the primary method for inputting the destination address.	**Score: 5** The search field allowed for successful input of the destination address.	Consider adding feedback or error messages if the destination address is not found.
2.3	**Score: 5** The user easily identified the correct address among the search results	**Score: 4** The search results were displayed in a clear and easy-to-read format, and the user was able to select the correct address with ease.	**Score: 5** The system provided clear feedback on the selected address, confirming it was the correct one and displaying the route to the destination.	**Score: 5** The process of selecting the destination address was consistent with the previous steps and followed the expected workflow.	**Score: 5** The destination address was clearly prioritized and easily accessible within the search results.	**Score: 5** The user was able to successfully select the correct address and move on to the next step in the navigation process.	None. No improvements needed.
2.4	**Score: 5** The "Start Navigation" button was clearly labeled and easily identifiable.	**Score: 5** The "Start Navigation" button was easily accessible and required no excessive reaching or stretching.	**Score: 5** The system provided clear and immediate feedback by initiating the navigation process.	**Score: 5** The "Start Navigation" button was consistent with the placement and design of other navigation-related buttons and options.	**Score: 5** The "Start Navigation" button was appropriately placed and emphasized within the navigation process.	**Score: 5** The task was completed successfully without any issues.	None.

Fig. 2. Table for scoring the sub-tasks

Score	Description
5	Excellent
4	Acceptable
3	Needs Some Modification
2	Unacceptable
1	Failed

Fig. 3. Scores and their corresponding descriptions

6 DISCUSSION

Throughout our project, we discovered an important distinction between conducting research to develop a novel methodology and conducting research to solve a problem. Initially, we set out to develop a user-friendly interface for electric vehicles (EVs) to address the pain-points of users and provide a sense of safety, comfort, and satisfaction. However, we soon realized that there was a lack of standard usability frameworks to measure the user experience of EVs, leading us to pivot our hypothesis to introduce a novel usability evaluation framework for EVs. Our insights from secondary research helped us to make this decision, and we began searching for key parameters to include in the usability framework to enable users to examine the complete user experience of the car on a higher level.

Our study uncovered some unexpected insights that challenged our assumptions. Through our survey we found that only 11% of users felt range anxiety, a type of anxiety related to EV car charging. We also discovered that novice users tended to place undue emphasis on charging infrastructure, while experienced users didn't find such issues. These findings emphasize the need for targeted evaluation focused for various user groups to ensure a comprehensive understanding of EV usability. Our usability framework primarily focuses on task-based user experience and evaluates the usability score for specific features of the EV. However, we also identified a significant opportunity to develop a framework that measures the user experience and learnability for first-time and frequent users. Therefore, one of our design recommendations for designers and researchers who want to explore this field further is to create a more inclusive usability framework that measures the car experience for new users versus frequent users.

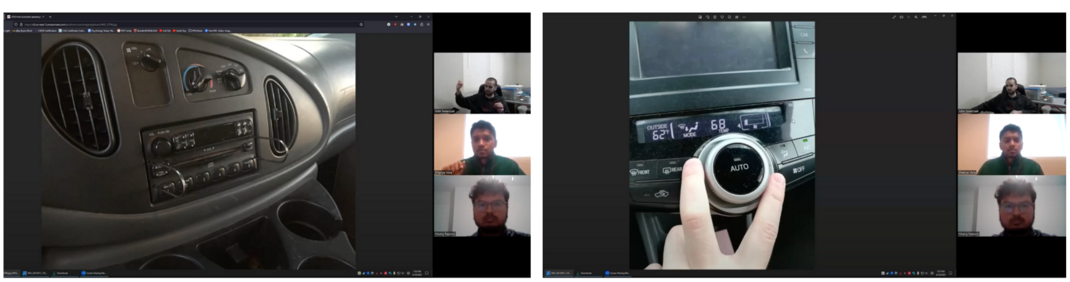

Fig. 4. Participant explaining different modes of interaction for the same feature during user interview

Additionally, our research uncovered a discrepancy between user preferences for interaction methods in the car. In our survey, 53% of users indicated a preference for a touchscreen interface, while in our user interviews, frequent drivers expressed difficulty with the touchscreen, noting that it can be distracting and require visual attention that should be focused on driving. They suggested that a combination of touchscreen and physical buttons could offer a more user-friendly and safe interaction experience. This highlights the importance of considering not just user preferences, but also human factors and safety in the design of car interfaces. Our recommendation for designers working in this domain is to carefully consider the most appropriate interaction method for each feature or task, based on user needs and human factors considerations. This presents a significant opportunity for further research and innovation in this area.

7 CONCLUSION

In summary, our research project aimed to bridge the gap in the current usability framework available for assessing the usability of Electric Vehicles (EVs). Through our research, we identified key usability factors and developed a framework that enables car manufacturers to evaluate the usability of their vehicles. By addressing usability challenges associated with electric vehicles, we expect to improve the usability and user experience of EVs, making them more attractive and adaptive to potential users. This, in turn, can enhance safety, reduce user errors, and increase the adoption of electric vehicles, ultimately contributing to the transition towards a sustainable transportation system.

The broader impact of our research is significant. By increasing the adoption of electric vehicles, we can reduce dependence on fossil fuels and help in mitigating climate change. Our research contributes to this transition by addressing the usability challenges that have hindered the adoption of electric vehicles. The current trend towards electric vehicles in the automotive industry highlights the importance of our work. Many countries and regions are implementing policies to incentivize the adoption of EVs, such as subsidies and tax breaks, to reduce carbon emissions and air pollution. However, despite the benefits of electric vehicles, the adoption rate is still relatively low due to usability challenges.

Our proposed usability framework can help to address these challenges and provide the consumer with confidence in their purchase decision, ultimately leading to increased adoption of electric vehicles. By improving the usability and user experience of EVs, our research can make a significant contribution to the growth of this market and the transition towards a sustainable transportation system.

8 FUTURE SCOPE

As we have acknowledged, the user experience of electric vehicles can vary based on many factors. Therefore, we anticipate that car manufacturers may customize our framework in the future to meet their specific needs and goals. This could involve adding more metrics or features to improve the accuracy and comprehensiveness of the usability assessment. Furthermore, integrating the framework with other data sources can provide a more complete view of customer needs and preferences, leading to better usability and increased adoption of electric vehicles.

One limitation of our framework is that it requires manual assessment by humans, which can be prone to errors. In the future, it may be beneficial to explore the use of emerging technologies such as artificial intelligence and machine learning to analyze data collected through the framework. This could lead to more efficient and effective insights generation, enabling car manufacturers to improve the usability of their vehicles and enhance the overall user experience.

We have also identified that psychological and behavioral factors play a significant role in the usability of electric vehicles. As a result, we recommend that car manufacturers collaborate with human factors engineering and user experience design experts to gain a deeper understanding of these factors. This collaboration can lead to the development of more innovative and user-centric vehicle designs that take into account the psychological and behavioral factors that affect the usability of electric vehicles. By doing so, we can further improve the usability and user experience of electric vehicles, making them more attractive and adaptive to potential users, and ultimately contributing to the transition towards a sustainable transportation system.

9 REFERENCES

(1) The road ahead for e-mobility (mckinsey.com)

(2) ACES 2019 survey: Can established auto manufacturers meet customer expectations for ACES? (mckinsey.com)

(3) How automakers can drive electrified vehicle sales and profitabilitymck.ashx (mckinsey.com)

(4) Zimm, C. (2021) “Improving the understanding of electric vehicle technology and policy diffusion across countries,” Transport Policy, 105, pp. 54–66. Available at: https://doi.org/10.1016/j.tranpol.2020.12.012

(5) Egbue, O. and Long, S. (2012) “Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions,” Energy Policy, 48, pp. 717–729. Available at: https://doi.org/10.1016/j.enpol.2012.06.009

(6) Ullah, A., Aimin, W. and Ahmed, M. (2018) “Smart Automation, customer experience and customer engagement in Electric Vehicles,” Sustainability, 10(5), p. 1350. Available at: https://doi.org/10.3390/su10051350

(7) Ullah, A., Zhang, Q. and Ahmed, M. (2021) “The impact of smart connectivity features on customer engagement in Electric Vehicles,” Sustainable Production and Consumption, 26, pp. 203–212. Available at: https://doi.org/10.1016/j.spc.2020.10.004

(8) Strömberg, H. et al. (2011) “Driver interfaces for electric vehicles,” Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications [Preprint]. Available at: https://doi.org/10.1145/2381416.2381445

(9) Charissis, V. et al. (2021) “Employing emerging technologies to develop and evaluate in-vehicle intelligent systems for Driver Support: Infotainment Ar Hud Case Study,” Applied Sciences, 11(4), p. 1397. Available at: https://doi.org/10.3390/app11041397

(10) Wolf, J. et al. (2021) “HM INFERENCE: Inferring multimodal HMI interactions in automotive screens,” 13th International Conference on Automotive User Interfaces and Interactive Vehicular Applications [Preprint]. Available at: https://doi.org/10.1145/3409118.3475145

(11) Risk and safety issues related to use of electric and hybrid vehicles. Available at: https://stumejournals.com/journals/tm/2017/1/37.full.p

(12) Fröhlich, P. et al. (2010) “Augmenting the driver’s view with realtime safety-related information,” Proceedings of the 1st Augmented Human International Conference [Preprint]. Available at: https://doi.org/10.1145/1785455.1785466

(13) Svangren, M.K., Skov, M.B. and Kjeldskov, J. (2017) “The connected car,” Proceedings of the 19th International Conference on Human-Computer Interaction with Mobile Devices and Services [Preprint]. Available at: https://doi.org/10.1145/3098279.3098535

(14) Strömberg, H. et al. (2011) “Driver interfaces for electric vehicles,” Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications [Preprint]. Available at: https://doi.org/10.1145/2381416.2381445

(15) Daramy-Williams, E., Anable, J. and Grant-Muller, S. (2019) “A systematic review of the evidence on plug-in electric vehicle user experience,” Transportation Research Part D: Transport and Environment, 71, pp. 22–36. Available at: https://doi.org/10.1016/j.trd.2019.01.008

(16) Franke, T. et al. (2015) “Advancing Electric Vehicle Range displays for enhanced user experience,” Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications [Preprint]. Available at: https://doi.org/10.1145/2799250.2799283

(17) Colley, A., Väyrynen, J. and Häkkilä, J. (2015) “In-car touch screen interaction,” Proceedings of the 4th International Symposium on Pervasive Displays [Preprint]. Available at: https://doi.org/10.1145/2757710.2757724
(18) Ullah, A., Zhang, Q. and Ahmed, M. (2021) “The impact of smart connectivity features on customer engagement in Electric Vehicles,” Sustainable Production and Consumption, 26, pp. 203–212. Available at: https://doi.org/10.1016/j.spc.2020.10.004
(19) Cocron, P. et al. (2011) “Methods of evaluating electric vehicles from a user’s perspective – the mini E field trial in Berlin,” IET Intelligent Transport Systems, 5(2), p. 127. Available at: https://doi.org/10.1049/iet-its.2010.0126
(20) Charissis, V. et al. (2021) “Employing emerging technologies to develop and evaluate in-vehicle intelligent systems for Driver Support: Infotainment Ar Hud Case Study,” Applied Sciences, 11(4), p. 1397. Available at: https://doi.org/10.3390/app11041397
(21) Usability Evaluation Framework for Ubiquitous Computing Device. Available at: https://ieeexplore.ieee.org/document/4682020
(22) de Souza Filho, J.C., Brito, M.R. and Sampaio, A.L. (2020) “Comparing heuristic evaluation and MALTU model in interaction evaluation of Ubiquitous Systems,” Proceedings of the 19th Brazilian Symposium on Human Factors in Computing Systems [Preprint]. Available at: https://doi.org/10.1145/3424953.3426639
(23) Karvonen, H. and Kujala, T. (2022) “Designing and evaluating Ubicomp characteristics of intelligent in-car systems,” AHFE International [Preprint]. Available at: https://doi.org/10.54941/ahfe100765
(24) Zhang, D. and Adipat, B. (2005) “Challenges, methodologies, and issues in the usability testing of mobile applications,” International Journal of Human-Computer Interaction, 18(3), pp. 293–308. Available at: https://doi.org/10.1207/s15327590ijhc1803_3
(25) Meschtscherjakov, A. et al. (2013) “Computerized experience sampling in the car,” Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications [Preprint]. Available at: https://doi.org/10.1145/2516540.2516565
(26) Ziefle, M. et al. (2014) “Public perception and acceptance of electric vehicles: Exploring users’ perceived benefits and drawbacks,” Design, User Experience, and Usability. User Experience Design for Everyday Life Applications and Services, pp. 628–639. Available at: https://doi.org/10.1007/978-3-319-07635-5_60
(27) Osswald, S. et al. (2013) “HMI development for a purpose-built electric taxi in Singapore,” Proceedings of the 15th international conference on Human-computer interaction with mobile devices and services [Preprint]. Available at: https://doi.org/10.1145/2493190.2494089
(28) Egbue, O. and Long, S. (2012) “Barriers to widespread adoption of electric vehicles: An analysis of consumer attitudes and perceptions,” Energy Policy, 48, pp. 717–729. Available at: https://doi.org/10.1016/j.enpol.2012.06.009
(29) BURNETT, G.A.R.Y.E. and MARK PORTER, J. (2001) “Ubiquitous computing within cars: Designing Controls for non-visual use,” International Journal of Human-Computer Studies, 55(4), pp. 521–531. Available at: https://doi.org/10.1006/ijhc.2001.0482
(30) Kalakanti, A.K. and Rao, S. (2023) “Computational challenges and approaches for electric vehicles,” ACM Computing Surveys [Preprint]. Available at: https://doi.org/10.1145/3582076
(31) Harvey, C., and Stanton, N. A. (2013). Usability evaluation for in-vehicle systems. https://doi.org/10.1201/b14644