Measuring User Experience of In-Vehicle Infotainment System Software Testing Tool Using a Simple Linear Quantification Model

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Abstract: The In-Vehicle Infotainment (IVI) system replaced traditional car radios, offering a centralized platform with a larger screen and advanced features. Designed by Continental AG multinational corporation specializing in car multimedia systems, modern IVI systems integrate data from various sensors for enhanced functionality. As IVI systems are becoming more complex, their design is also becoming more intricate. Testing tools are crucial for verifying these systems; however, an inadequate understanding of the testing equipment can lead to a rise in user complaints. Therefore, IVI manufacturers must provide testers with user-friendly, effective, and efficient tools for addressing this problem. A survey involving 21 participants, including IVI tool users and resident engineers, was conducted to assess the user experience (UX) regarding the existing tool and the proposed tool. The participants completed two pretesting processes which were meant to evaluate usability, affect, and user value, with a total number of 18 sub-categories. The collected data was analyzed using a simple linear quantification model for UX, with the results indicating that this model could effectively translate UX into a single value. The proposed method highlights the usability and overall value of the IVI testing tools, enabling manufacturers to improve their systems to meet the testers` needs and reduce user complaints.

Keywords: User Experience, Usability, Affect, Value, Quantification Model, IVI System.

1. Introduction

The entire automotive sector is working to create novel technologies that will allow advanced connection options, improve safety, and enhance user experience. The "In-Vehicle Infotainment System" is a key technology that acts as a focal point for all contemporary car systems, combining their functions to operate and monitor them from a single central unit (Choi et al., 2019). Cameras, output speakers, headrest displays, navigation systems, air conditioners, heated seats, thermometers, lighting, and automobile information are all part of the infotainment system. Entertainment refers to various amusements and cultural activities, whereas information refers to the information needed for driving and navigation. Navigation, the digital modulation base (DMB) communication, instrumentation, the radio, multimedia, sensors, and external devices are all included in the IVI system (Choi et al., 2019). Due to space and cost limits, hardwiring became less appealing as the number of Electronic Control Units (ECUs) and their complexity increased, paving the way for advanced in-vehicle networks for Vehicle-to-Sensor (V2S) and multimedia communication. It has fuelled the development of innovative in-vehicle networking systems (Sinha, 2019). As the number of ECUs and their complexity increases, better mechanisms must be used so that each ECU can be monitored and maintained to prevent anything from being wrong. The IVI testing tool is becoming a common experience tool used for testing IVI systems. As a result, user experience is a critical aspect of the tool selection process. The UX idea incorporates a variety of issues that have been missed from a standard HCI standpoint (Hassenzahl & Tracktinsky, 2006). UX can comprise hedonic traits, emotions, and the semantic meaning of experience. As significant research has been conducted to define and identify the characteristics of UX, finding strategies for improving the UX of products or services has been viewed as a significant problem. This process begins with assessing a product or service's current UX condition. Unsurprisingly, most studies consider UX measurement crucial (Law & van Schaik, 2010). The foundation of user experiences inspired UX researchers to create quantitative frameworks for UX. In practice, if the UX of a product or service is measured, decision-makers may readily

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assess or at least comprehend the product's or service's potential worth. The link between UX and its parts should be examined to quantify UX since numerous aspects construct and influence the total UX in each environment. The main goal of this research is to use a quantification model for analysing data gathered from a survey made on the current IVI tool and propose a new tool with UX elements such as usability, affect, and user value. Then, the same survey was conducted on the same participants for the proposed tool, and the results from both surveys were compared to ensure there was a clear improvement regarding the proposed tool. This paper explores the evolving role of In-Vehicle Infotainment (IVI) systems within the automotive industry, highlighting their central function in integrating diverse vehicle features such as navigation, multimedia, climate control, and sensor data. As modern vehicles grow more complex with increasing numbers of Electronic Control Units (ECUs), traditional hardwiring approaches have become inadequate, prompting a shift toward advanced in-vehicle networks. In this context, IVI testing tools have emerged as essential for ensuring system functionality and user satisfaction. The study emphasizes the importance of User Experience (UX) in evaluating and selecting these tools, moving beyond conventional Human-Computer Interaction (HCI) to include hedonic and emotional dimensions. Grounded in prior UX research, this paper applies a quantitative UX assessment framework to compare an existing IVI tool with a newly proposed alternative, using survey-based evaluation to determine improvements in usability, affect, and user value. In summary, the remainder of this paper is structured as follows. Section 2 refers to the challenges related to UX in the current IVI systems, while Section 3 proposes the system framework and design. Section 4 highlights and discusses the outcomes obtained for the proposed model. Finally, Section 5 outlines the conclusion of this paper and possible future research directions.

2. Preliminaries

2.1 Challenges in Standardizing and Testing IVI Systems

An IVI system consists of multiple networks such as CAN (Controller Area Network), LIN (Local Interconnect Network), MOST, and Ethernet. Some IVI providers, such as General Motors, use CAN and LIN, while others, such as Nissan, focus on the CAN bus only. Due to increased data transfer and high-speed processes, future projects like Mercedes cars will focus on ethernet instead of CAN and LIN. The existing IVI system, however, has numerous flaws. According to Perrone (2022), each car manufacturer builds its own unique IVI system, which means devices or components from one brand usually don't work with those from another brand. There's currently no common standard that allows different IVI devices to connect or communicate with each other easily. In addition, as Choi et al. (2019) point out, most existing IVI systems do not consider many different types of communication ports (like USB, HDMI, Bluetooth, etc.) that each device might have. This lack of compatibility and standardization makes integration more difficult and limits flexibility for both developers and users.

The IVI is a complicated system, which often leads to design errors, software bugs, communication problems, and poor user interfaces - all of which contribute to user complaints. As a result, IVI testing has become a significant burden for automakers and suppliers. Because of the complexity of the IVI system, the possibility of getting a complaint from an end user is high. However, there are few software tools for verifying the IVI system at the end customer and in the failure analysis lab of the IVI manufacturer. Users' confidence in a system influences UX. It creates an almost insoluble problem for automobile makers. On the other hand, they should design their systems to avoid overconfidence (Frison et al., 2019).

2.2 The UX Challenges in Modern IVI Systems

Previous research indicates that developers often focus on technical aspects rather than on user-centric considerations during the implementation of new technologies or frameworks. Different organizations exhibit varied approaches to UX design, with some establishing dedicated UX design departments, and others implementing UX practices only partially within their development cycles (Nugraha & Fatwanto, 2021). This fragmented adoption has contributed to a lack of confidence among testers using the current IVI (In-Vehicle Infotainment) systems, primarily due to an insufficient emphasis on usability, effectiveness, and user value in the design of testing tools. Park et al. (2013) argue that evaluating UX comprehensively in a single experiment is challenging, as it necessitates a focus on momentary UX within defined contexts.

Recent research has explored user experience (UX) only to a certain extent) using task analysis or quantified models. Law & van Schaik (2010) highlight the importance of defining specific UX metrics and their role in guiding UX design and development, noting that UX evaluation depends on the dynamic interplay of various components. Simple linear models, preferred for their computational simplicity and reduced design flaws, are often used as compensatory models in UX analysis (Shin & Ferguson, 2015). The automotive industry, producing over 70 million vehicles annually and contributing $3 trillion to the global economy (Biz4Intellia, n.d.) has seen a rapid evolution in in-vehicle infotainment (IVI) systems. As the number of vehicles continues to rise annually, the driving behavior analysis has become an important focus of research in the field of public transportation. Yang et al. (2024) introduced a driving behavior recognition model to accurately distinguish various driving behaviors. Such systems have become complex, data-driven platforms prone to design flaws, software malfunctions, and customer dissatisfaction (Wang & Liu, 2019). Integrating Vehicle Driving Behavior Recognition models with In-Vehicle Infotainment (IVI) Systems can significantly enhance both driving safety and user experience. By analyzing real-time driving data, these models can adapt the infotainment system's functionalities to match the current driving context, thereby minimizing distractions and promoting safer driving practices (Wang et al., 2024).

The testing of vehicle equipment has become critical for ensuring safety and functionality, yet an increased vehicle complexity and advanced driver-assistance systems (ADAS) have significantly raised the testing costs (Schwarzl & Herrmann, 2018). A poor UX and software design contribute to malfunctions that can lead to severe consequences, as demonstrated by fatal incidents involving autonomous vehicles like Uber and Tesla (The Economist, 2022). Despite the importance of UX, its integration into software development often lags, resulting in usability and quality issues. Agile development faces challenges incorporating UX due to constraints like limited time for design and testing, conflicts between designers and developers, the lack of a strategic vision, prioritization issues, and inadequate documentation (Curcio et al., 2019). Addressing these barriers is essential for improving software reliability, user satisfaction, and safety in the evolving technological domains.

Certain researchers have explored a few tools for measuring and evaluating user experience (UX) on an application. According to Ntoa et al. (2021), measuring UX becomes significantly more complicated when an innovative environment and all its systems are the interaction target instead of only a single technological tool or application. Based on the research by Ntoa et al. (2021), a framework called User Experience in Intelligent Environments (UXIE) was developed, which creates and assesses intelligent systems, apps, and complete ecosystems with the help of assessment professionals.

To evaluate the user experience from the initial phases of the development lifecycle through the final stages of deployment, the proposed UXIE framework uses an iterative design methodology. It uses the design of intelligent environments and the infrastructure of sensors to identify specific metrics, eliminating the need for observers to keep extensive notes or to address all issues through questions that users must answer. Automated measurements, obtained using the IE, improve measurement objectivity and reduce evaluation labor. This method also offers an alternative to the widespread practice of creating very long surveys by asking people about nearly everything. The suggested approach seeks to evaluate as many topics as feasible using alternative techniques. Other researchers, such as Nascimento et al. (2016) also proposed their way of measuring the user experience (UX), as it is stated in Table 1.

Table 1. Previous studies on User experience (UX)

Authors	Purpose	Application	Methods
Ntoa et al. (2021)	Evaluate user experience in an intelligent environment	UXIE framework	Questionnaire
Nascimento et al. (2016)	Identify and address usability and user experience issues in various applications	Simbora, GRUM, PartyNote, Personal Diet	Task analysis and Questionnaires

According to Nascimento et al. (2016), the Usability approach (Integration of User Experience and Usability) integrates user experience and usability to help researchers in HCI evaluate user experience. The Usability technique was based on two methods: the Expressing Emotions and Experiences (3E) method, which gathers rich data on the emotional response of users, and the Heuristic Evaluation, which is the method most frequently used for conducting usability evaluations.

The Usability technique was created to combine usability evaluation with UX, focusing more on feelings and user experiences. The improvement of evaluation, especially for less experienced evaluators, depends on this integration. However, while analyzing the UX for tools and applications, researchers typically used task performance or task analysis with surveys to understand user experience, but less attention was paid to analyzing the UX for a specific application using quantification models. This study collected and evaluated data based on three UX components and 18 sub-elements. In this paper, the hierarchical dimensions of User Experience are Usability and the dependent variables, namely Simplicity, Directness, Efficiency, Informativeness, Flexibility, Learnability, User Support, Affect and the dependent variables such as Color, Delicacy, Texture, Luxuriousness, Attractiveness, Simplicity and User Value and the dependent variables such as Self-satisfaction, Pleasure, Customer need, Sociability and Attachment, which played a major role in user experience. The essential purpose of this research is to evaluate the quantification model and represent the UX construct as a numerical value for measuring user experience using UX dimensions instead of following other frameworks.

2.3 In-Vehicle Infotainment System

In-vehicle infotainment (IVI) is a set of hardware and software that generates video / audio entertainment in automobiles. Unlike older cars with only radios with cassette or Compact disc players, modern vehicles have automotive Navigation system infrastructures, media players, Wi-Fi, USB, and Bluetooth. With their desire to use smartphones and tablets in the car, consumers are pushing familiar technologies into the evolving infotainment market. Users also anticipate that the hearing, speaking, and video experiences in the context of automobiles will be comparable to those in the current consumer space. IVI designs must match a certain audio quality and video resolution for the driver and all passengers. The automotive market requires new, immersive, and demanding automotive and consumer-level applications (Kaprocki et al., 2018). Following this trend, in-vehicle infotainment (IVI) systems have evolved into cutting-edge in-vehicle computer application systems. In today's world, IVI systems go beyond the traditional functions of listening to the radio or watching video entertainment to include various innovative services and applications. So, pursuing this trend, major automotive manufacturers continue expanding the service scope of IVI systems to improve the driving quality and passenger experience (Su et al., 2018). Multiple networks are used in modern vehicles to communicate between modules. These networks include CAN buses for mainstream engine and transmission and body connectivity, a local interconnect network (LIN) for low-cost applications mainly in body electronics, a FlexRay bus for high-speed synchronization when transmitting data by using a sophisticated technology for example to the suspension system, media-oriented systems transport (MOST) for multimedia devices, and other manufacturer-specific networks such as General Motors Local Area Net (GMLAN) (Abbott-McCune & Shay, 2016).

2.4 Criteria Used for Testing the IVI System

Different criteria are frequently the specific standards that something must satisfy to be regarded or qualified for a particular thing. The IVI tester function must serve the standard test, which can test the features of the IVI system. Hence, it is crucial to study the features of IVI and determine the criteria related to the IVI testing tools. The IVI system is part of the radio system. It is a new radio technology that enables all radio functions identical to those of an older radio but adds new features such as GPS, touch screen display, and Bluetooth. It relates to the car system's electronic control unit (ECU). The IVI provider develops a software tool to validate each function and feature in IVI. Hence, there must be criteria for ensuring that the software tools meet the tester requirements and cover the features of IVI.

2.4.1 Bluetooth Connectivity

Bluetooth enables data transfer between devices via radio signals and is a critical feature for IVI users. Gheorghiu et al. (2019) found that Bluetooth is the preferred wireless communication method for connecting smartphones to car infotainment systems. Detecting Bluetooth communications could allow devices to identify vehicles in motion. For IVI testing tools, connecting the tester's phone to the system is essential for evaluating Bluetooth functionality. Common Bluetooth uses include music playback and hands-free calls, but WLAN interference can significantly impact the system's performance. Mourad et al. (2017) highlight that frequency overlap and WLAN transmission levels can cause unstable connections and communication loss. Recent research about automotive infotainment systems highlighted that the implementation of Bluetooth can expose users to privacy attacks. For instance, unauthorized access to personal data such as contacts and messages can occur if developer options are enabled in the IVI unit, allowing attackers to retrieve sensitive information through Bluetooth logs. Certain design assumptions in the Bluetooth protocol can lead to vulnerabilities. For example, the trust model assumes that paired devices are always trustworthy, which may not hold true in multi-user environments like vehicles. This can result in unauthorized data access and privacy breaches (Renganathan et al., 2022).

2.4.2 Audio System

In the early 20-th century, audio technologies focused on enhancing interactivity by doubling the surround channel frequencies. Formats like MP3 and AAC, which are easy to implement on basic embedded systems, remain the standard ones for in-car infotainment. However, with the rise in automotive computing power, the integration of object-based audio technologies is expected soon (Kaprocki et al., 2018). As the demand for advanced in-vehicle entertainment grows, adopting entity-based audio will enhance driving experience. However, resource sharing across various IVI services poses challenges, as even minor disruptions, like losing a single audio sample, significantly impact the sound quality and system reliability (Kaprocki et al., 2018).

2.4.3 Function of Steering Wheel Control

According to recent research, the display is also part of the infotainment systems. However, as the IVI is not placed in front of drivers, the driver needs to move his head to be able to see the IVI display. Furthermore, a sophisticated IVI system provides more information in a context where manual control buttons are used, such as volume tuning and AM/FM radio channel tuning (Jung et al., 2021). The benefit of utilizing the areas such as the left or right spokes of the wheel (horizontal parts where hands usually rest) and Front face or inner thumb area (where thumbs naturally rest when gripping the wheel) on the steering wheel is that the keys or finger wheels are incredibly close to the driver's hand, enhancing safety by eliminating the need for the hand to be moved away from the steering wheel. However, the physical keypad configuration is fixed, and the area for physical buttons is restricted (Döring et al., 2011).

2.4.4 Voice Recognition

Voice recognition (VR) is a powerful feature based on new technology, such as artificial intelligence (AI) and machine learning (ML). VR helps drivers to operate the IVI system. VR not only requires an external source to operate but it has also been used for autonomous voice sources; for instance, VR is used for controlling signals and other functions in the car through IVI. The command given by the driver then activates the ECU to respond accordingly (Divakar et al., 2019). The accuracy of VR systems can suffer in loud environments, which is frequently the case while driving due to the presence of audio/radio media, passenger talk, and ambient noise (Sokol, Chen & Donmez, 2017).

2.5 Current IVI Testing Tools

Testing is an essential aspect of the development process in the automotive area to ensure that software performs as planned. A high-quality test case definition ensures that testers comprehend, execute, and use the test cases precisely as intended by the test designer. Since each participant frequently has a distinct understanding of the system being tested or a set of presumptions, or varying experiences with the testing methodologies and processes, this can be challenging. According to recent research, operators respond that there are defective test cases, and that the quality of test case specification is low. For example, a significant communication effort owing to testers' inquiries regarding ambiguity in test case specification or improperly built test cases may suggest this. A defective test specification results in excessive testing time, and resource consumption due to ambiguities or redundancies in test descriptions, failing to detect any defects at all (e.g. when test cases are implemented incorrectly or do not align with the actual system behavior) (Juhnke et al., 2020). Since the IVI testing instrument is confidential, only four existing IVI testing tools will be discussed in the next subsection due to time and resources constraints.

2.5.1 Bluetooth Scanner

The Bluetooth scanner is a tool for testing Bluetooth functionality in IVI systems. As vehicle entertainment systems are increasingly incorporating smartphone connectivity via Bluetooth, detecting this wireless communication could provide insights into the vehicle. Gheorghiu et al. (2019) predict that as phone integration progresses, the Bluetooth-enabled devices detection rates will improve. However, the tool is currently limited to Bluetooth testing and does not cover the full scope of IVI functions. Future advancements in autonomous vehicles may introduce more reliable wireless communication systems for evaluating vehicles within road networks. Speech recognition (SR) is another emerging feature that allows drivers to perform hands-free tasks. Divakar et al. (2019) developed a tool using Google Voice Assistant to control vehicle turn indicators via a system integrating Arduino, a microphone, and voice commands. This approach demonstrates the potential of SR in enhancing driver convenience and safety.

2.5.2 Speech Recognition-based Turn Indicator

Speech Recognition (SR) is a new feature that helps drivers perform any task without needing to do it manually. For instance, this tool developed by Divakar et al. (2019) used Google Voice Assistant to control the left and right vehicle turn indicators. Figure 1 illustrates the architecture of this system using three main components: Arduino, a Microphone, and a voice integrated with Google Voice Assistant (Divakar et al., 2019).

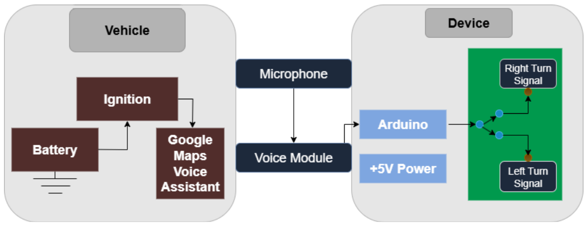

Figure 1. Speech Recognition System Architecture

2.5.3 Blaubox Tools

The Blaubox is a 19-inch testing unit for electrical devices like IVIs, instrument clusters, and ECUs. It supports power management, input signal testing, and measurement output with standard protocols such as CAN, SPI, I2C, and UART. Key internal measures include current consumption, the audio system, and GPIO. Low-level protocols are implemented in C/C++ on a specialized CPU, with Linux-based software communicating via a 1.5Mbaud UART. Blaubox is managed through the Blaukit application, initially developed in Visual Basic and later in C# for improved usability. However, the UI remains challenging due to a lack of usability studies, causing testers to avoid it as they do not want to face customer complaints. Instead, they replace parts directly or send them to the factory for analysis.

2.6 Measuring UX: Methods and Models

User Experience (UX) encompasses the interaction between users and a system, focusing on meeting user expectations and delivering meaningful experiences (Hassenzahl & Tracktinsky, 2006). Rooted in Human-Computer Interaction (HCI), UX design has evolved from usability and user-centered design to a holistic approach emphasizing usability, accessibility, aesthetics, functionality, and user-centeredness. These elements collectively drive user satisfaction and engagement. A recent review for the period 2000–2019 highlights questionnaires as the most frequently employed UX evaluation method (Inan Nur et al., 2021). Usability, central to effective tool development, emphasizes simplicity and ease of use, as defined by ISO 9241-11: achieving goals efficiently, effectively, and satisfactorily (ISO, 2018). For In-Vehicle Infotainment (IVI) systems, usability ensures seamless driver-vehicle interaction (Jung et al., 2021). Beyond usability, user value and affect - emotional responses and intrinsic associations with a product - contribute to the hedonic aspects of UX. These factors collectively shape a product's overall value (Aydin & Burnaz, 2016). Quantifying UX is vital for assessing product potential, requiring an analysis of its components' interplay (Park et al., 2013). Practical UX assessment employs traditional methods like surveys and adapts to context-specific needs (Law & van Schaik, 2010). Models for UX quantification fall into two categories: Compensatory Models (e.g. simple linear, polynomial models) which address multiple factors and are modular and interpretable and Non-Compensatory Models (e.g. the conjunctive model), which focus on specific criteria (Elrod et al., 2004). The simple linear model, preferred for IVI system studies, balances predictive accuracy with practical simplicity (Molnar, 2023). However, research shows that simplifying models frequently results in more exact models. If there are various models with a comparable predictive potential, the simplest one should be selected since it is more likely to be the best regression model (Frost, 2023). This structured understanding of UX highlights its evolving nature, the importance of usability, and practical approaches to evaluation, guiding future HCI-focused studies. The Simple Linear Model is expressed in equation (1):

$$Y = \sum_{i=1}^{n} \omega_i X_i \tag{1}$$

where X_i is the i-th element in the target construct and ω_i is the weight of each element. The user experience (UX) related to an application, product, or website aims to express the user's success, happiness, or enjoyment. Additionally, the characteristics of UX could change depending on the application type. This study did not primarily focus on users with disabilities; however, the accessibility phase of the IVI system design involves addressing a wide range of needs, including visual, physical, hearing, speech, and cognitive impairments. UX is a vague and abstract concept that can be understood and measured using a hierarchical structure. Scholars have yet to examine such hierarchical UX elements. To evaluate UX succinctly, Hassenzahl & Tracktinsky (2007) presented hedonic and practical judgments on product features. This study examined the following three UX elements that have the greatest impact on an individual's experience, namely usability, affect, and user value. These factors are also referred to as the primary UX aspects regarding the hierarchical dimensions of UX (Park et al., 2013). To explain and comprehend the user experience (UX) related to a particular system or product, these UX elements typically cover all the fundamental user experience components (as child attributes). Table 2 includes the expectations from a product or service related to each child attribute mentioned above.

2.7 Extent of UX Usage for the Current IVI Testing Tools

Although various UX frameworks have been developed so far, none of them are tailored to the IVI Testing tool for the automotive sector. In this regard, Table 2 also includes the current IVI testing tools with UX usages.

With modern features like GPS, touch screens, Bluetooth, and connectivity to the automotive system's electronic control unit (ECU), IVI is a new radio technology that enables all radio functions identical to those of an older radio. The IVI supplier creates a software tool to validate each of those functions and features. Testing is a crucial part of the development process in the automobile industry for software to function as intended. Four features were selected for this study: Bluetooth, audio system, steering wheel

Table 2. Overview of Existing Tools with UX Usage

Tool	Function	A possible issue
Blaubox	To perform a functional testing of the complete IVI system	No study has been conducted before designing the UI
Resident Engineer Test Kit	To perform a basic functional test for the complete IVI system	UI is not user-friendly and is complicated to understand
Bluetooth Scanner	To test Bluetooth functionality in the IVI system	The tool tests only the Bluetooth function, not the entire IVI system
Speech-Based Turn Indicator	Using Google Voice Assistant to control turn signals	Specifically, controlling the left or right indicators

Table 3. Previous study on User experience (UX)

Feature	Criteria	A possible issue	Reference
Bluetooth connectivity	The possibility of establishing a Bluetooth connection	Unstable communication may disconnect Bluetooth	(Gheorghiu *et al*.,2019) (Mourad *et al*., 2017)
Audio System	Providing the best driving experience to consumers in terms of audio quality	The utilization of resources across various IVI services may disrupt the behavior of audio systems	(Kaprocki *et al*., 2018)
Steering Wheel Control	The possibility to adjust the volume up/ down for media	The physical button is small and hard to press	(Döring *et al*., 2011) (Jung *et al*., 2021)

control (SWC), and voice recognition. Hence, the IVI testing tool criteria were developed based on these features as per Table 3.

The scarcity of studies on UX causes this tool to be challenging to understand and not user-friendly. Research based on the UX model focused on usability or system quality and most HCI researchers used a linear compensatory quantification model. Several researchers have looked at the hierarchical aspects of UX. Even though user experience affects many aspects of everyday life, it can only be defined as what happens when a person interacts with a product or service. The UX component addresses certain aspects of using a product or service.

3. The Proposed Method, Framework, and Design

Research design refers to the overall framework that outlines the methods and techniques selected to ensure the research approach aligns effectively with the study's objectives and topic. The quantitative research method is concerned with quantifying and analysing variables to obtain results (Apuke, 2017), while the qualitative method uncovers and helps to interpret the chosen topics extracted. In this research, the design steps, as per Figure 2, are included below. Each step is well-defined to ensure this paper fulfils the goal of the research. Details are discussed in the following subsections.

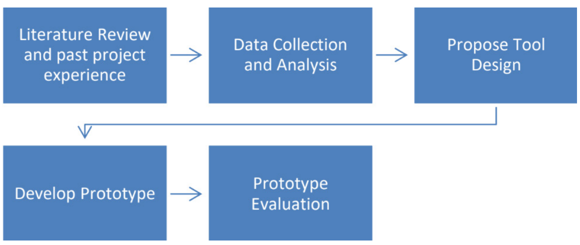

Figure 2. Stages of research design

Each user should have basic knowledge and expertise regarding the IVI testing tool. The length of the work experience was also a selection criterion, with at least five years of working in that related field (Bukhari et al., 2019). The participants in the study which was carried out were involved regarding both the existing and proposed tools. Since some participants were outside the study area, email questionnaires and video chats were the instruments used for data collection.

3.1 The Proposed Tool Design

At this stage, the results of the data collection based on the literature review, as well as the result of the first evaluation and analysis using the quantification model were used to develop a framework related to the design and development guidelines for developing the digital content creating tool prototype for the IVI tester, to increase its usage among IVI testers. For the development of the testing tools Visual Studio was used as an IDE to create the framework and C# programming as a primary language. The IVI tool was developed to integrate the hardware and software (one can refer to Table 4 and Figure 3 for details). Object-oriented programming (OOP) was employed in this research to clarify and strategize the tool design. Moreover, OOP simplifies how a program works by combining data and its behaviour (or function) into a single image. An OOP use case diagram and an activity diagram were used in this research. The use case diagram was employed to record the requirements for the systems being designed or considered, describe the functionality provided by those systems, and ascertain the demands those systems place on their surroundings. UML use case diagrams depict actors, their relationships, and their use cases (Stransky, 2021). As the activity diagram is concerned, it includes activities, states, and transitions between the respective activities and states. According to Cvetković & Cvetković (2019), evaluating the activity diagram may find the underlying system paths and test each one at least once. Activity diagrams highlight system-accessible loops as well as control structures. Therefore, activity diagrams are suitable for testing control structures and system loops.

Table 4. Hardware and software for the proposed IVI testing tool

	Name	Description
Hardware	Arduino Uno	For interfacing the IVI device with C# software
Software	Arduino IDE	For programming the Arduino
	Visual Studio C#	For UI development and communication with Arduino

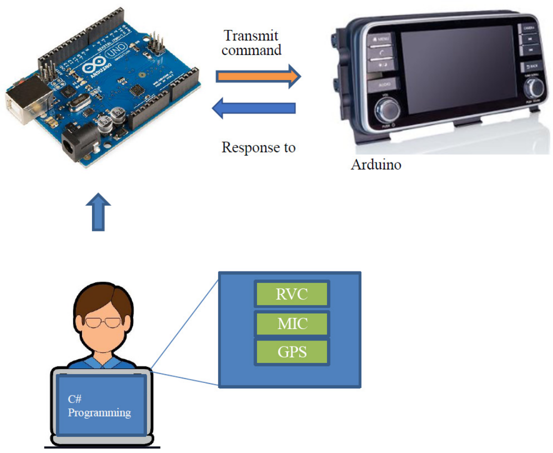

Figure 3. Use Case for the Proposed Tool

Suggestions provided in the context of the study which was carried out to improve Usability, Affect, and User Value (UV) for the proposed tool's user interface (UI) are summarized as follows:

a. Increasing the size of the operating elements is a priority for improving usability;

b. Improving the color, button size, and clue image for each function on the button of the toolbox;

c. Providing instant and easily understandable feedback triggered when users input the data.

3.2 Prototype Development

The development of the suggested application prototype included using the framework built during the third phase of the design process. The completion of this step resulted in the creation of a prototype that was tailored specifically for the IVI tester. At the beginning of this process, it was intended that the prototype be produced using the technologies employed by the IVI system.

3.3 Prototype Evaluation

The prototype created in the fourth stage of the design process was shared among IVI testers using an online survey Google form because the participants were located at different locations, some of them outside the study area. Online surveys are convenient in several ways. They reduce the expenses associated with logistics, questionnaire design, and administration, making data collecting more inexpensive than it once was (Van Quaquebeke et al., 2022). Some online surveys allow respondents to start answering a question and come back to it later. A prototype was shown to an IVI tester during a video conference before conducting a survey to get the data for the evaluation using a simple linear quantification model. Video conferencing is a good alternative to face-to-face communication. The selected simple linear quantification model was used for UX evaluation after the video and survey were conducted.

3.4 Preliminary Questionnaire

The purpose of the preliminary questionnaire is to learn more about:

a. The position of the IVI Tester;

b. The most tested brand in the context of IVI tools;

c. The type and name of the tools for testing the IVI system;

d. The focus criteria and function are to be tested using IVI tools.

3.5 System Framework and Design

The proposed testing tool framework includes four types of testers, namely the Lab Technician, Lab Engineer, Resident Engineer and Test Engineer. For all the users the same features or items were tested, namely login, performing functional testing (Bluetooth, Audio, Reverse Camera, Read DTC and phone) and generating the test report.

The components of the system framework are a synthesis of the elements from other frameworks related to the existing tools. To understand the functionalities, this subsection discusses the overall framework and each part of it. Figure 4 shows each module of the system framework for developing the proposed testing tool to test the IVI system.

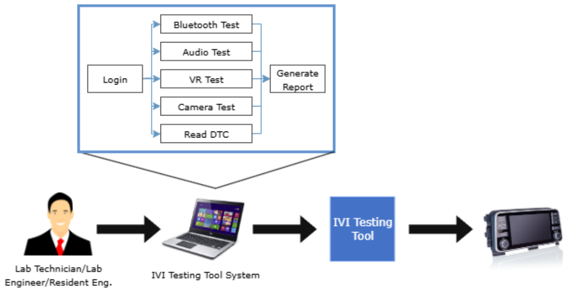

Figure 4. IVI Tool Framework

3.6 Functional Testing

As it was previously mentioned, this paper covers five functional testing tools: Bluetooth, Audio, Voice Recognition, Reverse camera, and reading diagnostic trouble code (DTC). This system provides instructions on launching the testing and delivering the anticipated results similarly with the IVI display. As a result, it is simpler for the user to comprehend how the IVI behaves during testing.

3.7 The Proposed System

The IVI testing tool was established and developed based on IVI functionality and a system framework (as it can be seen in Figures 5, 6, 7, 8, 9 and 10) aimed to increase system efficiency and improve the testing experience among IVI testers. However, in relation to the proposed tool, an experiment was conducted to obtain user feedback

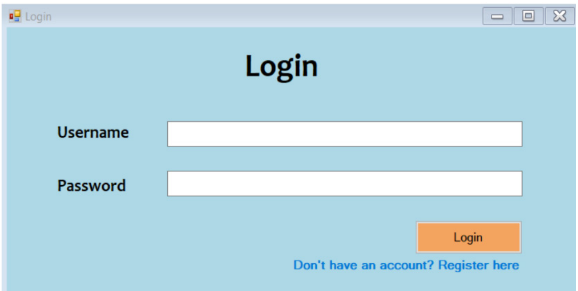

Figure 5. Login UI

Figure 6. Main page UI

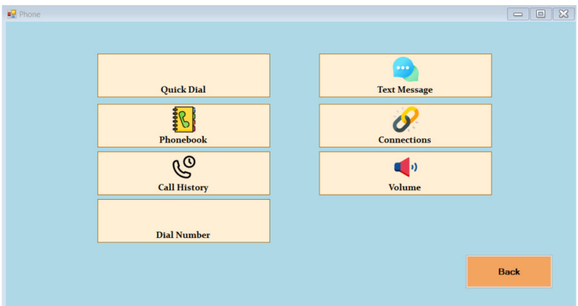

Figure 7. Phone Use Case UI

Figure 8. Phone Use Case UI (Continuation)

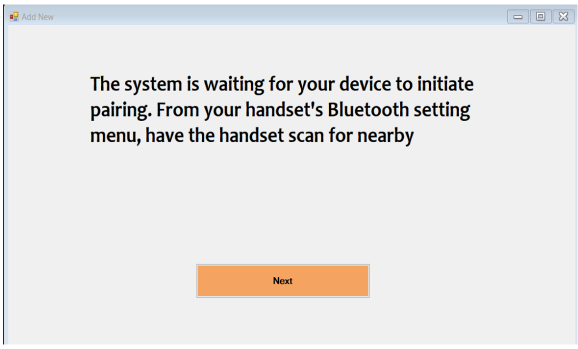

Figure 9. Add New Device UI

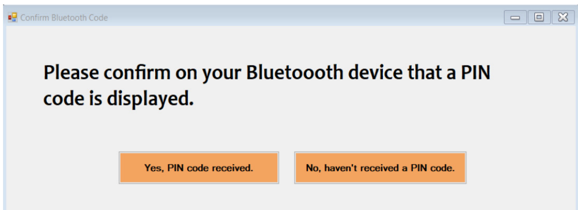

Figure 10. BT Confirmation UI

for determining whether this new proposed tool with a new UI will improve system efficiency and performance or not.

3.8 Modeling and Quantifying User Experience

The quantitative models for this investigation were first constructed using the multiple regression technique. As mentioned earlier, the employed model is a simple linear model. Each UX component and its related sub-elements are meant to measure the UX and perform the simple linear model calculation. The relationships between each element and its sub-elements were evaluated independently based on a hierarchical framework. In this study the stepwise regression technique was employed, which includes carrying out a series of tests (such as F-tests and t-tests) to pinpoint a group of independent factors significantly affecting the dependent variable. A simple linear compensation model was chosen for assessing the user experience. Apart from simple linear models, there are many other models, such as the S-shaped, conjunctive, and polynomial models. However, a polynomial model, for instance, is more intricate than a simple linear model. Also, because cubic or biquadratic equations have too many components to implement the all-possible regression approach, quadratic equations were used in this investigation (Park et al., 2013). Table 5-7 below show the modelling results for the usability, affect, and user value UX components for the existing tool and the proposed tool. The data was collected from twenty-one participants using the current tool and the proposed tool. The equations below show the adjusted coefficient of determination (R^2) and maximum variance inflation factor (VIF), which were calculated using SPSS software.

According to Table 5, the average adjusted coefficient of determination (R^2) and the average maximum value of the simple linear model for usability for the current tool were 0.93 and 14.29, respectively. For the proposed tool, the obtained values were only 0.22 and 1.28, respectively.

According to Table 6, the average adjusted coefficient of determination (R^2) and the maximum value of the simple linear model for affect were 0.67 and 3.03, respectively, for applying the existing tool. For the proposed tool, however, the obtained values were only 0.5 and 2.00, respectively.

Table 7 shows that, using the available tool, the average adjusted R^2 value and the maximum value of the simple linear model for user value were 0.87 and 7.69, respectively. However, the values obtained by applying the proposed tool are 0.5 and 2.00, respectively.

This section of the paper proposed a user-cantered IVI testing tool prototype for addressing usability and standardization issues in current systems. Using a quantitative approach and a simple linear UX model, the tool was developed with Visual Studio C# and Arduino, focusing on core IVI functions like Bluetooth and voice recognition.

Table 5: Modeling results for Usability

	Model Equation	Result	Adj. R^2	Max. VIF
Current Tool	$U = -0.38 + 0.674 \times U2 + 0.417 \times U4$	$U = -0.38 + 0.674 \times 4 + 0.417 \times 4 = 3.98$	0.93	14.29
Proposed Tool	$U = 2.40 + 0.43 \times U4$	$U = 2.40 + 0.43 \times 5.5 = 4.77$	0.22	1.28

The symbols U, U2, and U4 denote usability, directness, and informativeness, respectively

Table 6: Modeling results for Affect

	Model Equation	Result	Adj. R^2	Max. VIF
Current Tool	$A = 0.37 + 0.64 \times A4 + 0.25 \times A2$	$A = 0.37 + 0.64 \times 4.05 + 0.25 \times 4.14 = 4.00$	0.67	3.03
Proposed Tool	$A = 0.56 + 0.64 \times A2$	$A = 4.04$	0.5	2.00

The symbols A, A2, and A4 denote affect, luxuriousness, and simplicity, respectively

Table 7: Modeling results for User Value

	Model Equation	Result	Adj. R^2	Max. VIF
Current Tool	$V = 0.14 + 0.49 \times V4 + 0.48 \times V2$	$V = 0.14 + 0.49 \times 4.52 + 0.48 \times \mathbf{4.43 = 4.48}$	0.87	7.69
Proposed Tool	$V = -0.28 + 0.67 \times V2$	$V = -0.28 + 0.67 \times 5.48 = 3.39$	0.5	2.00

The V, V2 and V4 symbols denote user value, pleasure, and sociability, respectively

The evaluation carried out with experienced testers showed an improved usability and a reduced multicollinearity, confirming that a UX-driven design enhances tool effectiveness and user satisfaction.

4. Results and Discussion

The current IVI testing equipment UI had issues related to its usability and complexity perspectives, as shown by the different results obtained in the context of two evaluations - for the existing tool and for the proposed tool. So, using technical tools for implementing a smooth testing process is a good idea, however, these tools need to be clearly designed, as the previous framework faced problems due to a lack of focus on usability. The following three research objectives of this paper have been met:

a. The primary goal was identifying the testers' requirements and expectations for the IVI testing tool. Researchers offered diverse perspectives on the appropriate criteria for creating a successful tool, with the key features identified through the literature review, including Bluetooth connectivity, an audio system, steering wheel control (SWC), and microphone functionality. The survey data revealed that over 85% of participants prioritized the implementation of Bluetooth audio tests for the IVI tool;

b. Understanding user behavior is crucial for developing a robust IVI testing tool. A survey involving 21 experienced testers, focusing on tools like Blaubox, identified key testing criteria such as Bluetooth, audio, microphone, and steering wheel controls. The participants highlighted the deficiencies related to usability, affect, and user value (UV). Based on this data, a new tool was proposed for addressing these gaps and enhancing the testing experience;

c. The suggested measurement models incorporate the essential elements related to user experience into a single metric, and the best-fit models have been determined based on their adjusted coefficient of determination (R^2). The selected usability, effect, and user value models are displayed in equations (2)-(7). This study discovered that the proposed model performs better in terms of usability in comparison with the current tool based on a simple linear calculation in the context of the two evaluations below:

The first evaluation

The current Tool Modelling results summary *(the Simple Linear model) is as follows:*

$$U = -0.38 + 0.647 \times U2 + 0.417 \times U4 = 3.98 \quad (2)$$

$$A = -0.37 + 0.64 \times A4 + 0.25 \times A2 = 4.00 \quad (3)$$

$$V = -0.14 + 0.49 \times V4 + 0.48 \times V2 = 4.48 \quad (4)$$

The second evaluation

The proposed Tool Modelling results summary (*the Simple Linear model*) *is as follows:*

$$U = 2.40 + 0.43 \times U4 = 4.77 \quad (5)$$

$$A = 0.56 + 0.64 \times A2 = 4.04 \quad (6)$$

$$V = -0.28 + 0.67 \times V2 = 3.39 \quad (7)$$

The primary focus in the field of human-computer interaction (HCI) has shifted from usability construction to a much broader definition of user experience (UX), where users' feelings, affects, motivations, and values are taken into consideration at least as much as the ease of use, learning curve, and fundamental subjective satisfaction (Law & Abrahão, 2014). In the same way, it was considered that simplicity, directness, and efficiency were mutually exclusive sub-elements of usability. The multiple regression technique also needs variables that are not related. Correlation, causation, and hierarchy can be examined using structured equation modeling (SEM) or any other regression technique. The findings of the survey demonstrate the necessity of including all modules, particularly the UI, in developing the IVI testing tool. Experimentation and assessment using a quantification approach helped create a strong IVI testing tool architecture. This research covers all the aspects of UX that were previously mentioned, and it is in line with the service design cycle. Different UX techniques may keep product development efforts on track and in line with the actual user demands rather than fictitious ones at every level of the design process.

For usability, as compared with user value and affect, issues were identified from users' responses in the survey. According to the research literature review, usability is crucial in making software more efficient and user-friendly. Moreover, based on ISO 9241-11, usability increases efficiency and makes a tool more efficient. In contrast to the results from the literature review, data from the survey revealed that only 9.5% of the participants strongly agreed that the current tool, Blaubox, is user-friendly and less complex. In contrast to that, the survey revealed that 52% of participants strongly agree with the proposed tool. Further on, Tables 9 and 10 show that the proposed testing tool increases the user`s level of satisfaction as affect and user value elements are concerned.

Table 8. Usability - Strongly agree results

Usability	Strongly Agree (%)	
	Current Tool	Proposed Tool
U1	9.5	57.1
U2	9.5	61.9
U3	9.5	57.1
U4	14.3	61.9
U5	4.8	47.6
U6	4.8	61.9
U7	4.6	47.6

Table 9. Affect - Strongly agree results

Affect	Strongly Agree (%)	
	Current Tool	Proposed Tool
A1	0	42.9
A2	4.8	57.1
A3	4.8	61.9
A4	0	57.1
A5	9.5	57.1

Table 10. User Value - Strongly agree results

Usability	Strongly Agree (%)	
	Current Tool	Proposed Tool
V1	14.3	42.9
V2	14.3	47.6
V3	9.5	57.1
V4	19	61.9
V5	9.5	61.9

In addition, based on the data on literature reviews and surveys found usability is important when developing a new product and for product improvement. This study addresses the usability and user experience (UX) limitations of current In-Vehicle Infotainment (IVI) testing tools by developing and evaluating a new, user-centered prototype. Through a survey of 21 experienced testers and a comparative UX quantification model, key features such as Bluetooth, audio, microphone, and steering wheel controls were prioritized. The proposed tool showed significant improvements in usability, affect, and user value in comparison with the existing tools like Blaubox.

5. Conclusion

This paper presented a simple linear model for quantifying the UX for the current and proposed IVI testing tools. The employed model, a compensatory model, transformed survey data into linear relationships to estimate the R^2 and Max VIF coefficients via multiple regression using a SPSS software, yielding several models with adjusted R^2 values. While the research focused on a specific user group and a single company, the simple linear model demonstrated its potential for assessing immediate UX for IVI tools, with improvements in terms of usability and affect noted for the proposed tool in comparison with the current tool (Blaubox). Despite its effectiveness, the tool presented in this study has several limitations. The simple linear model employed in this paper may not encompass all future strategies for UX quantification, and alternative models may offer additional insights.

Additionally, the survey revealed that the testers faced difficulties understanding Bluetooth testing steps, indicating a need for more precise guidance. Another limitation consists in the fact that this system is currently tailored to a single company; however, it may have a broader application for other IVI manufacturers. To that, the proposed model, focused on simple linear quantification, did not address the VIF values beyond a threshold of ten, limiting the exploration of multi-collinearity impacts. Moreover, alternative methods such as the Analytic Hierarchy Process (AHP) could determine the weighting of elements, offering flexibility in integration with various modeling approaches, like multiple linear regression, fuzzy logic, and neural networks. Such combinations could enable richer insights and broader applications beyond this study's constraints. On the other hand, other UI types for various tools could be assessed using the quantification approach as part of the ongoing research. Future testing must consider various tester viewpoints, such as expanding the functional testing scope to include GPS and artificial or machine learning techniques to comprehend tester needs. A study of the benefits and drawbacks of quantification techniques could also be carried out to provide more alternatives for research studies about the quantification of user experience. Also, the quantification method may be used for analyzing different applications instead of IVI testing tools. Further on, this study assumed that customers were in the post-use phase, which should be further addressed. Finally, by offering designers input on their ideas, the study's findings are anticipated to aid in the beginning phases of product or service development.

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