Journal on Interactive Systems, 2026, 17:1
ISSN: 2763-7719 • doi: 10.5753/jis.2026.6743

RESEARCH PAPER

UX on In-Vehicle Infotainment Systems: A Systematic Literature Mapping

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Abstract. An In-Vehicle Infotainment System (IVIS) is an integrated multimedia platform that provides information and entertainment to drivers, offering features such as navigational assistance, vehicle diagnostics, music playback, and smartphone connectivity. The quality of these interactive systems depends largely on Usability and User Experience (UX). However, little research has specifically examined how Usability and UX are evaluated in IVIS. This paper presents a Systematic Literature Mapping (SLM) conducted to answer the research question: "How have studies in the literature approached Usability and UX evaluation in IVIS?" Our results show that studies in the literature evaluate Usability and UX using a combination of different methods, techniques, and approaches, such as NASA-TLX, AttrakDiff, UX heuristics, and questionnaires. The results also indicate several metrics used in these evaluations, including performance, user distraction, and tasks performed in IVIS. Finally, we also highlight emerging research themes such as driver distraction and safety, interface characteristics, and user-centered design.

Keywords: IVIS, Infotainment, UX, Usability, SLM

Edited by: Milene Silveira | **Received:** 24 October 2025 • **Accepted:** 07 April 2026 • **Published:** 21 May 2026

1 Introduction

An In-Vehicle Infotainment System (IVIS) is a car's integrated multimedia computer that provides information and entertainment to the drivers [Reshma and Chetanaprakash, 2020]. IVIS support drivers by offering several features, such as navigational assistance, vehicle health diagnostics [Reshma and Chetanaprakash, 2020], listening to music, and using smartphone apps on the car screen [Ashok and Hallur, 2024]. These features can vary based on several factors, such as the type of vehicle, brand, year, and manufacturer [Quiñones *et al.*, 2024]. Additionally, they can offer various user interaction modes, such as knobs, touchscreens, and voice commands [Reshma and Chetanaprakash, 2020]. Given these diverse characteristics, the quality of IVIS plays a crucial role in user interaction, which, in turn, influences consumers' car selection. This quality refers to the ability to meet the explicit and implicit needs of the customer [Associação Brasileira de Normas Técnicas, 2000], and can be determined by factors such as physical features, appearance, and user satisfaction when using the product.

The quality of interactive systems is strongly shaped by both Usability and User Experience (UX). Usability primarily concerns the pragmatic aspects of interaction, emphasizing the efficiency and effectiveness with which users complete their tasks. In contrast, UX encompasses the hedonic aspects, addressing users' emotional experiences, including affective responses and sensory stimulation during product use [Hassenzahl *et al.*, 2006].

In the literature, there are studies that explore Usability and UX in IVIS. For instance, Quiñones *et al.* [2024] proposes a set of heuristics that incorporate usability and UX attributes with IVIS-specific characteristics to evaluate IVIS. Understanding usability and UX problems in IVIS allows these to be fixed, contributing to the quality of IVIS. Zhou *et al.* [2022] explores how emotional design principles can be integrated into IVIS to enhance the overall user experience. Meanwhile, Berger *et al.* [2021] evaluate UX in an IVIS prototype based on pragmatic and hedonic aspects using specific UX techniques for system products and interviews. Although these studies explore different perspectives of IVIS, providing strategies such as methods and metrics for IVIS evaluation, they do not synthesize the knowledge regarding these strategies, related to the best approaches used to improve Usability and UX in IVIS.

Understanding how Usability and UX are approached in IVIS can help identify the main strategies used for their evaluation, providing insights that can guide researchers and developers to design higher-quality IVIS, thereby improving driving experiences. In the literature, there are already studies synthesizing the main methods of Usability and UX in different contexts [Nakamura *et al.*, 2017; Mortazavi *et al.*, 2024]. Additionally, there are literature reviews that explore IVIS, for example, Lorenz *et al.* [2024] analyzes the current state of the art of computational models for in-vehicle User Interface (UI) design. They perceive that UI evaluation models focus only on small, isolated phenomena, which are disconnected from the needs of automotive UI designers. Also, Reshma and Chetanaprakash [2020] observed the strengths, limitations, and open-ended problems associated with infotainment systems; however, little is explored regarding Usability and UX evaluation in IVIS.

Given this context, we present a Systematic Literature Mapping (SLM) aiming to answer the following research question: *"How have Usability and UX evaluation of IVIS been addressed in the literature?"*. A systematic mapping study offers an objective method for determining the scope and nature of existing research that addresses a specific research question [Fernandez *et al.*, 2011].

Our goal was to provide an overview of the main methods, techniques, and tools used to support the Usability and UX evaluation of IVIS. In addition, we aimed to identify the types of support available in the literature and the challenges involved in conducting such evaluations. Our results highlight the primary studies grouped into eight distinct categories: driving simulators; quantitative and qualitative experiments; user satisfaction surveys; simulation and complexity assessment; empirical and heuristic evaluation of systems; empirical studies on usability and interaction; emerging technologies and AI or gesture-based interactions; and advanced interfaces and interaction designs. We also identified several research themes, such as driver distraction and safety, interface characteristics, and user-centered design, that are emerging in the study of Usability and UX in IVIS. Finally, we summarized the main methods, techniques, and tools that support UX evaluation in infotainment systems.

This paper is organized as follows. Section 2 presents the background related to UX, Usability and IVIS. Section 4 describes our research methodology to map the literature about UX in infotainment systems. In Section 6, we present our results obtained through our SLM. In Section 7, is discussed the main findings found in the results, along with the implications and limitations of the study. Finally, in Section 8, we present the conclusion and future works.

2 Background

In this section, we present the theoretical background necessary for the reader to understand this research. In this sense, we discuss the characteristics and trends related to IVIS. Additionally, we introduce the concepts and key information about Usability and UX.

2.1 In-Vehicle Infotainment Systems (IVIS)

With the advancement of the automotive sector, technologies have been integrated to support drivers in their vehicles. In this context, infotainment systems stand out by providing an interactive interface aimed at helping drivers with their needs. For instance, since smartphones are integrated into users' daily life, their connection with IVIS allows the use of communication apps like WhatsApp or WeChat [Ashok and Hallur, 2024], virtual assistants such as Siri and Google Assistant [Reshma and Chetanaprakash, 2020].

Regarding the user interaction with IVIS, research on IVIS has gained prominence, especially related to design. Jung *et al.* [2021] explored the influence of touch button interface, providing recommendations for the design of such buttons, as touch button shape, edge presence or absence, and color combinations. The touch button affect different interaction modes, including Touchscreen-Based Interaction (TBI), speech-based interaction (SBI), and Gesture-Based Interaction (GBI) [Zhang *et al.*, 2023].

Chen *et al.* [2025] investigated affective technologies and user needs for effective human-vehicle interaction, based on input from users and AI experts. Their findings highlight the need to understand human emotions effectively, consider emotional experiences during early-stage design, and refine in-vehicle systems accordingly. Jiang *et al.* [2025] studied how the interface aesthetics of IVIS affect users' intention to continue using them. The authors emphasize that the design of new IVIS should focus on interface functionality, emotional needs, and ensuring that content is concise and engaging. Quiñones *et al.* [2024] point out that an intuitive interface reduces distractions and keeps the driver focused.

Pettitt *et al.* [2005] state that such distractions occur when an event, object, or person inside or outside the vehicle causes the driver to shift attention away from essential driving tasks, delaying the recognition of important information. This distraction can affect auditory, biomechanical, cognitive, or visual abilities, compromising safe vehicle control. For example, such as taking the eyes off the road to look at the IVIS. Therefore, it is important that these systems provide an interface that minimizes driver distraction.

It is well established that numerous studies in the literature contribute to the design of IVIS. However, pre-market evaluations of these systems are also crucial, as they allow for the identification and correction of issues, as well as potential improvements. Given this context, it is important to understand how UX and usability methods, metrics and techniques can support the evaluation of new systems before market release, since user interaction with IVIS is related to the many features.

2.2 Usability and User eXperience (UX)

Usability is described by 9241-210:2019 [2019] as "the extent to which a system, product, or service can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use." Similarly, Nielsen [2012] defines usability as: "Usability is a quality attribute that assesses how easy user interfaces are to use."

Nielsen [1994] defines usability through five components: (1) learnability, which refers to how easy it is for new users to learn to use the system; (2) efficiency, meaning how quickly experienced users can perform tasks; (3) memorability, or how easy it is to remember how to use the system after not using it for a while; (4) errors, referring to having a low error rate and allowing easy recovery from mistakes; and (5) satisfaction, which concerns how pleasant it is to use the system.

The field of Human-Computer Interaction (HCI) offers various strategies for usability evaluation, among which usability testing and usability inspection stand out. Usability testing involves observing users as they interact with the system, while usability inspection is carried out by a usability expert. One of the most common strategies for inspection is Nielsen's heuristics. Nielsen and Molich [1990] proposed a set of 10 heuristics to guide inspectors in evaluating the usability of a product. These heuristics help identify the main issues that affect the user experience.

The term UX has various definitions across different research fields. In the area of HCI, the most widely accepted definitions in the literature refer to 9241-210:2019 [2019], which describes UX as a "person's perceptions and responses that result from the use and/or anticipated use of a product, system, or service". On the other hand, Norman and Nielsen [2016] argue that UX goes beyond the interface: "User experience encompasses all aspects of the end-user's interaction with the company, its services, and its products."

According to Hassenzahl and Tractinsky Hassenzahl and Tractinsky [2006], UX results from the interplay between the user's internal state, the characteristics of the designed system and the context in which the interaction takes place, such as organizational or social environment. For user's internal state, it includes predispositions, expectations, needs, motivation, and mood. The characteristics of the designed system include complexity, purpose, usability, and functionality.

Hassenzahl [2010] points out that UX is a consequence of the user's internal state, the interaction context, and the system's characteristics. Hassenzahl [2010] also characterizes UX into pragmatic aspects, related to the system's functionality, and hedonic aspects, related to the user's emotions and pleasures when interacting with a product.

3 Related Works

In the literature, several literature reviews have been conducted to explore the Usability and UX from different research areas, for example, Perrig *et al.* [2024] conducted a systematic literature review to investigate survey scales in UX research. Their results indicated that the System Usability Scale (SUS), User Experience Questionnaire (UEQ), and NASA Task Load Index (NASA-TLX) were the most popular scales. Also, Graser *et al.* [2024] conducted a literature review to identify methods and techniques for UX evaluation of AR, as well as papers containing AR-specific UX models or frameworks that address the theoretical foundation. The authors identified five AR-specific UX models/frameworks and concluded that most methods and techniques are quantitative. Additionally, Brdnik *et al.* [2022] synthesized the state of the art on Intelligent User Interfaces (IUI). The authors found evaluation tools, methods, and metrics tailored for IUI.

In the IVIS context, several literature reviews have examined various aspects of IVIS, including safety, interaction paradigms, technological advancements, and design approaches. Reshma and Chetanaprakash [2020] provided a review on the advancements of IVIS in the automotive sector, particularly focusing on the integration with vehicular cloud networks. They discussed how vehicular ad hoc networks (VANETs) and cloud computing support the growing complexity and functionality of infotainment systems. The authors also identified challenges related to network capacity, latency, and interoperability. Their review underscores the importance of improving infrastructure to support next-generation infotainment services, which combine information, entertainment, and vehicle diagnostics.

Krstačić *et al.* [2024] conducted a comprehensive SLR on the safety aspects of IVIS, analyzing 96 studies published between 2012 and 2023. Their review identified key safety concerns such as driver distraction, cognitive load, and situational awareness. The study emphasized that certain technologies, such as head-down displays and touchscreens, negatively affect driver safety, whereas speech-based interfaces and Bluetooth integration can improve it. They highlighted the need for better design standards and real-world testing to ensure that future IVIS are both functional and safe.

Lorenz *et al.* [2024] conducted an SLR on the use of computational models for in-vehicle user interface (UI) design. Their study analyzed how computational models can assist in predicting and evaluating driver distraction caused by performing Non-Driving Related Tasks (NDRTs). They found that most existing models focus on isolated phenomena and lack integration into practical design processes. The authors advocate developing computational models that provide detailed, actionable insights for UI designers, thereby enabling safer, more effective IVIS.

Although numerous literature review papers address UX or IVIS, these studies are typically limited to individual topics, they do not satisfactorily address the intersection of IVIS and UX. In this sense, given the lack of literature reviews focusing on Usability and UX, we propose a literature review aiming to identify the main methods, techniques, and tools that have been used to evaluate IVIS.

4 Research Methodology

Our goal is to investigate and synthesize the literature regarding Usability and UX to evaluate IVIS. To achieve this, we aim to answer the following research question: *"How have Usability and UX evaluation of IVIS been addressed in the literature?"*. This will enable us to explore and summarize the existing knowledge on these concepts and identify key gaps in the literature. Since our research question is broad, we have established sub-research questions to explain our results in detail. Table 1 presents the sub-research questions and their motivations.

To execute the SLM, we followed a protocol inspired by the guidelines presented by Kitchenham *et al.* [2015]. An SLM is conducted to answer a research question by identifying and evaluating studies on a specific topic in the literature. The protocol followed three phases: (i) Planning, (ii) Conducting, and (iii) Reviewing. The details of each phase of the protocol are detailed in the following subsections.

4.1 Planning

During the planning phase, we defined the goals and the research protocol. The protocol consists of the following topics: Search String, Selection Criteria, and Search Strategy.

Table 1. Descriptions and underlying motivations of the sub-research questions

ID	Research Question	Motivation
RQ1	Which primary studies have been conducted to evaluate the usability and UX of IVIS?	Analyzing primary studies provides insights into how usability and UX on IVIS have been empirically assessed, highlighting the main focus of these studies.
RQ2	What research topics related to the usability and UX of IVIS have been explored in the literature?	The identification of main themes explored by researchers allows for an understanding of the support available in the literature for this type of evaluation and the main gaps.
RQ3	What techniques, methods, and tools have been proposed for evaluating the usability and UX of IVIS?	The identification of techniques, methods, and tools employed in this context enables a comprehensive understanding of how evaluation practices have been applied.
RQ4	What measures and metrics are used to support usability and UX evaluation of IVIS?	The identification of measures and metrics allows for an understanding of how the quality of the interaction between the user and the IVIS is evaluated.

Table 2. Search string terms from the PICOC Protocol.

Population	"In-vehicle infotainment systems" OR "Infotainment" OR "soft news" OR "IVIS" OR "Driver user interfaces"
Intervention	"Evaluation" OR "Usability Evaluation" OR "UX Evaluation" OR "User experience Evaluation" OR "Heuristics" OR "Heuristic evaluation" OR "Tool" OR "technique" OR "methods"
Context	"User experience" OR "UX" OR "Usability"

4.1.1 Search String

For the structuring of the search string, we based it on the PICOC protocol (Population, Intervention, Comparison, Outcome, and Context) [Keele *et al.*, 2007]:

Population (P) – the analyzed population consisted of IVIS;

Intervention (I) – evaluation procedures proposed, such as methods and techniques;

Comparison (C) – not applied, as we do not seek comparison between studies;

Outcome (O) – not applicable, as we do not aim to compare the efficiency of studies or methods;

Context (C) – in the context of Usability and UX.

To define the search string, we organized the terms used into three groups, as discussed below, aligned with the PICOC protocol. However, the Comparison (C) and Outcome categories were not considered, since we do not seek comparison between studies or compare the efficiency of studies. Table 2 summarizes the specific string terms assigned to each category used, as follows:

- **Group 1 (P)** refers to the terms associated with IVIS, such as In-Vehicle Infotainment Systems, Infotainment, Soft News, and others.

- **Group 2 (I)** refers to the related to techniques, methods, and tools proposed to support the UX of these systems, like heuristic evaluation, usability evaluation, and UX evaluation.

- **Group 3 (C)** represents terms related to Usability and UX.

4.1.2 Search Strategy

To conduct the search for primary studies, the following databases were used in this MSL: ACM Digital Library, El Compendex, IEEE Digital Library and Scopus. We chose these databases because they are the main libraries focused on studies in the field of HCI and Software Engineering. To validate the search string, we initially conducted a manual search to identify the primary studies that would guide the results of our search string. We selected a set of four primary studies. These primary studies represent the accuracy of the results returned by the search string. Table 3 presents the summarized studies and the respective terms associated with these studies.

4.2 Selection Criteria

The scope of the mapping conducted consists of studies that explore UX in IVIS. In this context, inclusion and exclusion criteria were established for the selection of studies returned by the search. The criteria represent the scope of the search and are formulated to identify studies capable of answering the research question. For an article to be selected in the search, it must meet all the following inclusion criteria:

- **IC1.** The article discusses concepts related to UX and Usability of IVIS.
- **IC2.** The article addresses discussions, research challenges, identified problems, and preliminary results regarding on Usability and UX of IVIS.
- **IC3.** The papers addresses primary studies* on Usability and UX of IVIS.
- **IC4.** The article discusses methods, techniques, or tools that support the on Usability and UX evaluation of IVIS.

Studies that meet at least one exclusion criterion were excluded:

- **EC1.** Articles that only deal with IVIS in general.
- **EC2.** Articles that do not meet the evaluation criteria.
- **EC3.** Articles that are not in Portuguese or English.
- **EC4.** Articles that are not available for reading.

5 Conducting

Initially, an initial search was conducted in each of the established search databases to identify the set of studies to be used for the 1st filter. The scope of the search was limited to articles published between 2014 and 2024. We chose this scope (2014–2024) to capture a snapshot of the current landscape of UX in infotainment systems, as these systems began evolving more rapidly with the introduction of Android Auto and Apple CarPlay around 2015 [Shin *et al.*, 2022]. The results of the search string executed for each database can be seen in Table 4. In total, 625 articles were selected for the 1st filter.

Table 3. Primary studies used as parameter to the search

Papers title	Key terms
Mapping the infotainment literature: current trajectories and suggestions for future research	Infotainment, news media, political communication, sensationalization, soft news
User experience heuristics for in-vehicle infotainment systems	In-vehicle infotainment systems, User experience, Evaluation, Heuristic evaluation, Heuristics
A usability evaluation toolkit for In-Vehicle Information Systems (IVISs)	Usability, Evaluation In-Vehicle Information Systems
Evaluation of different interface designs for human-machine interaction in vehicles	Interface design, Infotainment, Free hand, Touchpad, Vehicle, Driving safety, User experience and Usability

Table 4. Initial search results by Digital Libraries

Digital Library	Studies selected
ACM Digital Library	425
El Compendex	54
IEEE Digital Library	71
Scopus	75
Total	625

After the articles returned in the initial search, the 1st filter was applied. The 1st filter consists of selecting studies based on the reading of the title, abstract, and keywords, discarding works that do not meet the Inclusion Criteria. This stage was conducted by 11 researchers. The list of returned studies is divided among the participating researchers, so that each study is reviewed by at least two researchers. In total, 89 studies were selected for meeting the inclusion criteria; 68 studies appeared in more than one source, so only one source was considered; and 468 were rejected.

From the set of returned works, the 2nd filter was applied. The 2nd filter consists of a complete reading of the selected articles, applying the determined inclusion and exclusion criteria again. In this stage, the same 11 researchers reviewed the articles. In total, 45 articles were selected, and then the data extraction stage began. The dataset containing the results of each filter and data extraction is available in the supplementary material [1].

Data extraction was carried out to obtain a set of answers to the predetermined sub-research questions. For each article read, the responsible researcher observed how the answers could be addressed. The data extraction was recorded in a spreadsheet, summarizing the answers for each sub-research question, along with the associated articles.

6 Results

In this section, we present the main results obtained from SLM, such as the main primary studies conducted to evaluate UX, emerging research themes, and specific methods, techniques and tools used in the UX evaluation.

6.1 Data extraction

Regarding the publications selected in the SLM, 33 papers were published in conferences, while 12 were published in journals. Table 5 presents the list of articles published by year. The list of publications is presented in Appendix A. Most articles were published in conferences in 2014 and 2022.

[1]https://doi.org/10.6084/m9.figshare.31502758

Year of publication	Articles
2014	A01, A21, A33, A34, A37
2015	A03, A05, A09, A13, A31
2016	A06, A32, A39
2017	A08, A18, A25
2018	A35
2019	A07, A10, A14, A36
2020	A04, A17, A22, A28, A30,
2021	A12, A20, A24, A45
2022	A02, A15, A16, A29, A43, A44
2023	A11, A19, A26, A27
2024	A23, A42

Table 5. Publications organized by year.

6.2 Primary Studies for IVIS Usability and UX

This subsection presents the results related to the RQ1 - *"Which primary studies have been conducted to evaluate the usability and UX of IVIS?"*. The identified studies were grouped into distinct categories that represent their focus on Usability and UX of IVIS, as shown in Table 6. We discuss the studies in each category as follows.

Study Categories	Articles
Driving Simulator	[A03], [A08], [A09], [A12], [A14], [A24], [A33], [A18]
IVIS Evaluation	[A17], [A34], [A42], [A45]
Usability and Interaction	[A20], [A22], [A25], [A27], [A28], [A44]
Emerging Technologies for Interactions	[A16], [A35], [A38], [A39], [A40], [A41], [A43]

Table 6. Categorization of studies on IVIS usability and UX.

Driving Simulator: Driving simulators are widely adopted in IVIS research to recreate controlled, yet realistic, driving conditions that allow for safe experimentation with interface designs. These settings offer precise control over variables such as speed, road type, or distractions, enabling researchers to study user behavior and system impact without real-world risks.

Five articles (A03, A08, A09, A24, A33) employed driving simulators to conduct controlled experiments replicating real-world interaction with infotainment systems. These studies measured both objective metrics (e.g., driving performance, eye tracking) and subjective perceptions (e.g., workload, usability). Experimental setups allowed comparisons between different interface types, such as gesture vs.

touch, and helped analyze the impact of interaction on safety and efficiency.

Reich and Stark [2015] (A03) evaluated air gesture feedback modalities in a simulator, examining their influence on fixation behavior and task performance through both subjective and objective measures. Similarly, study assessed an augmented reality Heads-Up Display (HUD) using immersive simulation, collecting task performance data and user impressions [Wang *et al.*, 2019](A07).

Shakeri *et al.* [2017] (A08) compared air gestures and direct touch input, evaluating task time, workload and error rate in a simulated driving context. The results indicated no significant compromise in driving performance with gesture input. In Lu *et al.* [2021] (A24), the authors investigated a HUD system using objective metrics (collision avoidance) and subjective assessments (questionnaires), observing a 45% improvement in collision prevention. May *et al.* [2014] (A33) compared laser tracker and touchscreen interfaces, analyzing cognitive load and task selection time, with both interfaces yielding comparable safety and performance outcomes.

Three articles (A12, A14 and A18), focused on interaction complexity, task performance, and user acceptance. Berger *et al.* [2021] (A12) used a pilot simulation to assess user interaction with the InShift system. Galarza and Paradells [2019] (A14) tested an adaptive interface in real vehicles, incorporating complexity estimators and usability feedback. Prabhakar and Biswas [2017] (A18) compared laser tracker and touchscreen inputs in terms of task time, errors, and cognitive load, finding no significant performance degradation from the laser tracker.

IVIS Evaluation : Combining evaluation techniques with empirical data allows researchers to identify usability and UX issues through both expert analysis and real user behavior, improving overall interface assessment. In the context of IVIS, this hybrid approach provides a more comprehensive understanding of interaction patterns and interface flaws, especially when scaled across larger datasets.

Three articles (A17, A42 and A45) presents insight about this category. Čegovnik *et al.* [2020] (A17) compared three infotainment designs using a User Experience Questionnaire (UEQ) to assess usability and safety. Quiñones *et al.* [2024] (A42) proposed and validated the UXH-IVIS heuristic set, which outperformed Nielsen's heuristics in identifying usability issues. Ebel *et al.* [2021] (A45) analyzed over 27,000 real interaction logs from 493 vehicles, deriving insights into usage patterns and improvement opportunities without a formal experimental setup.

Three articles (A10, A13 e A19) utilized structured questionnaires to assess user satisfaction, workload, and interface preferences. These included standardized tools such as NASA-TLX, AttrakDiff, and semantic differential scales. Lagoo *et al.* [2019] (A10) studied gesture-based interfaces in autonomous vehicles, applying NASA-TLX and AttrakDiff to assess perceived workload and user experience. Colley *et al.* [2015] (A13) evaluated an infotainment system from the passenger's perspective using interviews and semantic differentials. Bellani *et al.* [2023] (A19) analyzed a HUD system through pre-test, simulation, and post-test phases, incorporating user feedback on usability and suggestions for improvement.

Usability and Interaction: Structured studies remain the foundation of usability testing, offering concrete evidence through user performance, task completion, and behavioral metrics. This category aggregates studies with real users, measured tasks, and systematic data collection. In IVIS research, such studies allow direct observation of how drivers interact with systems under various cognitive demands.

Jung *et al.* [2021] (A20) evaluated physical button design in infotainment systems, showing that shape, color, and edge attributes affected usability. Young *et al.* [2020] (A22) conducted iterative evaluations of a haptic gesture interface, using online surveys and prototype testing. Wang *et al.* [2017] (A25) assessed the Carpacio system, which accurately detected driver and passenger interactions. Crescenti *et al.* [2023] (A27) performed real-world tests across nine vehicles, collecting eye-tracking data during navigation and multimedia tasks. Kim *et al.* [2020] (A28) applied the Lane Change Task (LCT) along with System Usability Scale (SUS) and NASA-TLX to assess distraction. Alarcón *et al.* [2022] (A44) investigated 13 secondary tasks with 10 participants, analyzing interaction time and workload to generate design guidelines.

Emerging Technologies for Interactions: This category explores emerging interface modalities to enhance user engagement, efficiency, and security in IVIS environments. Moreover, the integration of AI, voice assistants, and gesture-based inputs in IVIS introduces new usability challenges, such as transparency, trust, and adaptability.

Four articles examined such technologies (A16, A34, A37 and A43). Graefe *et al.* [2022] (A16) evaluated user trust in AI-based adaptive interfaces. Wärnestål and Kronlid [2014] (A34) employed the Wizard-of-Oz method to test adaptive speech interaction. Macek *et al.* [2014] (A37) assessed a voice assistant (UMA) with gesture/button controls in static and driving conditions, observing variations in distraction and success rates. Stiegemeier *et al.* [2022] (A43) tested gesture-based controls on a car mockup, finding increased motivation and positive feedback with visual cues and free gestures.

About advanced interface designs, four articles investigated these advanced interface designs (A35, A38, A40 and A41). Xu *et al.* [2018] (A35) compared two IVIS platforms using finger movement and facial expression metrics. Broy *et al.* [2014] (A38) assessed 2D vs. 3D clusters, reporting improved performance with stereoscopic displays. Riegler *et al.* [2020] (A40) explored gaze-based interaction in windshield displays, finding circular feedback to be more user-friendly. Gugenheimer *et al.* [2014] (A41) compared three authentication methods using rotary controls and evaluated usability with NASA-TLX and PSSUQ, identifying trade-offs in visual effort.

6.3 Emerging research themes in Usability and UX of IVIS

In this subsection, we present the results related to the RQ2 - *"What research topics related to the usability and UX of IVIS have been explored in the literature?"*. The Figure 1 present the research themes by number of articles related to that theme. The Table 7 presents the articles associated with

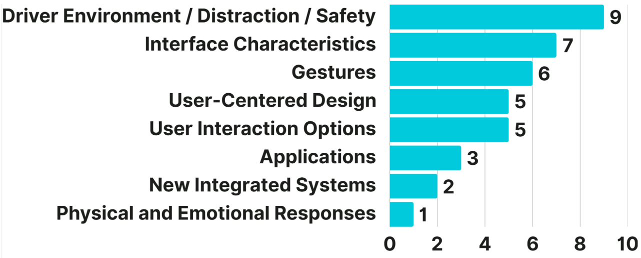

Figure 1. UX research topics vs. number of articles.

each research theme, discussed below.

Distractions and driving safety: According to Wang *et al.* [2017] (A25) and Lu *et al.* [2021] (A24), the UX of IVIS involves a careful analysis of distractions and driving safety, which is hindered by slow responses and poor touch control fluidity, negatively impacting usability and safety.

Safer interaction methods are required to make driving more efficient and intuitive [Farooq *et al.*, 2014] (A21), as touch interfaces are a critical aspect of the automotive experience [Crescenti *et al.*, 2023] (A27). Long journeys can be tiring, increasing driver distraction, especially if passengers, such as children, remain inactive [Wang *et al.*, 2019] (A07), emphasizing the importance of solutions that enhance comfort and satisfaction for all onboard [Quiñones *et al.*, 2024] (A42). Immersive driving environments mentioned by Reich and Stark [2015] (A03) often utilize AR to overlay critical information; this paper indicates that it can reduce cognitive load, allowing drivers to process information more efficiently while maintaining focus on the road.

As well as cognitive load, it improves the experience and reduces distractions based on user interface design patterns specifically for IVIS [Alarcón *et al.*, 2022] (A44). However, Lagoo *et al.* [2019] (A10) emphasized the use of a HUD with gesture recognition to reduce driver distractions. Kim *et al.* [2015] (A09) addressed the UX in IVIS, proposing a new HMI UI/UX designed for safe and intuitive handling during driving, including speech recognition, gesture recognition, and button manipulation, to enhance the driver's experience without causing distraction. It also highlights the trend of non-touch-based interfaces in IVI systems to improve driver attention and provide a more intuitive UX. Another approach to ensuring user safety is explored by Galarza and Paradells [2019] (A14), emphasizing the importance of designing user interfaces that consider the dynamic nature of driving scenarios to enhance the UX and ensure traffic safety. Finally, the evaluation of Natural User Interfaces (NUIs) demonstrates that intuitive interactions are essential for a smoother and safer UX [Kim *et al.*, 2015] (A09).

UX Research Topics	Articles
Driver Environment / Distraction / Safety	A03, A07, A09, A10, A14, A21, A23, A24, A27, A28, A41, A43
Interface Characteristics	A05, A13, A17, A20, A29, A31, A38
Gestures	A08, A11, A22, A19, A33, A42
User-Centered Design	A04, A06, A16, A36, A35
New Integrated Systems	A12, A30
User Interaction Options	A2, A18, A34, A37
Applications	A1, A39, A40
Physical and Emotional Responses	A44

Table 7. UX Research Topics investigated in Literature.

Interface Characteristics: The user interaction in IVIS involves evaluating interface characteristics available for the users, such as button-based interfaces, hands-free interactions [Čegovnik *et al.*, 2020] (A17), as well as visual aspects such as button shapes, colors, and borders [Jung *et al.*, 2021] (A20).

While some studies explore new approaches and interaction locations inside vehicles [Jansen *et al.*, 2022] (A29), challenges persist with the use of touch screens while driving [Ahmad *et al.*, 2015] (A31), particularly in systems with small screens and no physical keyboards [Smirnov *et al.*, 2015] (A05). Research also compares touch interaction techniques, evaluating the efficiency of using one or multiple fingers [Colley *et al.*, 2015] (A13). Additionally, the application of stereoscopic 3D (S3D) displays in automotive interfaces emerges as an innovation to improve UX, making interaction more immersive and intuitive [Broy *et al.*, 2014] (A38).

Gestures: Gestures have been influenced by various gesture-based interactive approaches. In the study by Stiegemeier *et al.* [2022] (A43), gestural interaction in vehicles was explored, highlighting its impact on UX. However, Bellani *et al.* [2023] (A19) focused on an innovative system for shared autonomous vehicles, enhancing usability without physical contact, utilizing the car's windshield as an interactive display surface for infotainment and integrating two gesture-based interfaces. Meanwhile, May *et al.* [2014] (A33) analyzed multimodal interfaces with air gestures for vehicle menu navigation, and Shakeri *et al.* [2017] (A08) discussed how different feedback modalities influence this interaction. Reyes *et al.* [2023] (A11) highlighted the customization of gestures as an essential factor for improving user trust. Finally, Young *et al.* [2020] (A22) addressed the importance of intuitive gestures aligned with users' familiarity with existing systems, such as mid-air haptic gesture-controlled automotive UI that integrates ultrasonic mid-air haptic feedback technology, contributing to a more natural and efficient experience.

User Interaction Options: Besides the above topic, the types of interaction are also considered. Wärnestål and Kronlid [2014] (A34) addressed adaptive spoken dialogue systems for automotive applications, including traffic and navigation information, aiming to make the interaction more intuitive and efficient. In addition, users' concerns about content discovery when using an interactive assistant for the vehicle manual indicate the need to improve accessibility and usability of these interfaces [Macek *et al.*, 2014] (A37). Riegler *et al.* [2020] (A40) explored UX in gaze-based interactions with Wind Shield Displays (WSDs) in automated vehicles, aiming to enhance the interaction interface. Stampf *et al.* [2022] (A02) emphasized how implicit interaction in highly automated vehicles enhances the UX, allowing gesture- and behavior-based interfaces, reducing explicit commands, and focusing on comfort and personalization. Meanwhile, Prabhakar and Biswas [2017] (A18) introduced an alternative modality known as the Laser-Point Tracker, which can reduce physical tension for drivers.

User-Centered Design: This approach focuses on IVIS. Lamm and Wolff [2019] (A36) discussed HCI methods, emphasizing the importance of usability evaluation through observations and surveys to understand UX in IVIS. Graefe *et al.* [2022] (A16) and Wei *et al.* [2016] (A06) highlighted the need for a user-centered approach in the development of these systems, prioritizing usability and user preferences beyond mere functionality. However, Xu *et al.* [2018] (A35) presented a usability index that considers efficiency and satisfaction, key elements for evaluating the UX in these systems. Finally, Ebel *et al.* [2020] (A04) pointed out the potential of data-driven methods to make IVIS development more user-centered, ensuring a better interactive experience.

New Integrated Systems: Reyes [2020] (A30) addressed IVIS in automated vehicles should be adaptive and intelligent, using sensors and machine learning to personalize it. However, Berger *et al.* [2021] (A12) discussed InShift, an innovative concept that delegates IVIS functions to the co-pilot, making the interaction more creative, practical, and enjoyable, as indicated by a pilot study.

Applications: Articles address applications in the context of IVIS. Gugenheimer *et al.* [2014] (A41) evaluate applications specifically focused on authentication methods, highlighting an innovative approach in which users recreate a tapping rhythm as a password. This method reduces visual demand, enabling users to keep their eyes on the road and thereby enhancing driving safety. Quaresma and Gonçalves [2014] (A01) examine navigation applications, emphasizing that GPS systems must prioritize usability to minimize driver distraction and ensure a safer driving experience. In the domain of engineering-focused applications, Coppola and Morisio [2016] (A39) propose that in-vehicle application design should avoid excessive complexity and consider the suitability of the user interface, ensuring that buttons are easily accessible to drivers.

Physical and Emotional Responses: Articles discuss the interaction under different approaches in the texts. Ebel *et al.* [2021] (A45) proposed a User Behavior Visualization Framework at Multiple Levels to evaluate behavioral data in the use of IVIS. Data was collected from production vehicles, enabling a broad range of user interactions to be captured without a controlled test environment, thereby facilitating a better understanding of UX.

6.4 Methods, techniques and tools to support UX evaluation of Infotainment

This subsection presents the results for the RQ3 - *"What techniques, methods, and tools have been proposed for evaluating the usability and UX of IVIS?"* The Table 8 presents the main methods, techniques and tools applied to Usability and UX Evaluation of IVIS.

Methods, Techniques and Tools applied in UX Evaluation	Articles
Prototype	A10, A22, A34, A35, A37, A40, A43
IVIS specific proposals	A09, A15, A25, A29, A30, A43, A44
Multimodal interface	A03, A08, A13, A21, A23, A28, A33
NASA TLX	A18, A19, A20, A31, A35
Gesture interaction	A08, A11, A22
Wizard-of-Oz	A34
User profile	A32
UX Heuristic	A42
SUS method	A18
AttrakDiff	A19
DX questionnaires	A20

Table 8. Methods, Techniques and Tools obtained by articles.

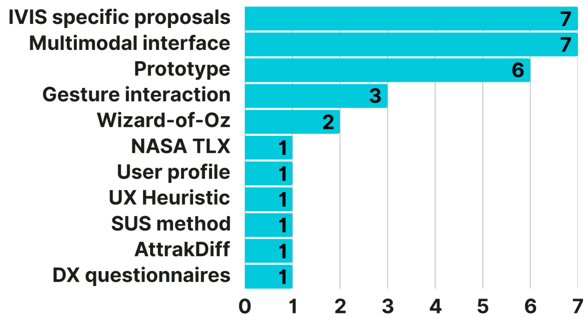

Figure 2. Methods, Techniques and Tools vs. number of articles

6.4.1 *Specific methods, techniques and tools used in the evaluation*

Prototype: Low, medium and high fidelity prototypes have been explored in different experiments with users for researchers to validate proposals related to IVIS. Lagoo *et al.* [2019] (A10), for instance, applied driving simulation for a prototype gesture recognition Head-Up Display (HUD), system aimed at reducing driver distraction caused by multiple IVIS in vehicles. The study involved 20 participants and demonstrated a significant reduction in collision occurrences by 45% when using the HUD compared to traditional head-down display systems.

IVIS specific proposals: We observed different specific proposals for IVIS. Kim *et al.* [2015] (A09) present a multimodal interface-based Human-Machine Interface (HMI) that enhances UX while driving, offering a safer and more efficient alternative to traditional touch-based systems. The methodology involved evaluating the proposed HMI system by measuring driver response times, average driving speeds, and distraction durations using an eye tracker, alongside a comparative analysis of psychomotor workload between the new HMI and a traditional navigation system. The results indicated that the multimodal HMI was preferred over the touch-based system across various evaluation criteria, with a total of 60 testers participating in the simulations.

Ebel *et al.* [2022] (A15) presented ICEBOAT, a tool aimed at automotive UX specialists that uses real driving data to assess user interaction with IVIS. The tool allows for the evaluation of driver interactions with in-vehicle touchscreens and provides insights into user behavior in various driving situations. Future developments for ICEBOAT include enhanced visualizations, the ability to save analyses, and the introduction of additional metrics and filters, with plans for extensive usability studies to evaluate the final tool. Overall, ICEBOAT aims to integrate user behavior analysis into the automotive design process, enhancing the understanding of driver interactions.

Wang *et al.* [2017] (A25) present Carpacio, a system that differentiates whether a driver or passenger touches the screen in a car by measuring the parasitically coupled signal from the screen. The authors evaluated Carpacio in eight cars and five mobile devices and found that it correctly detected over 2600 touches with an accuracy of 99.4%. According to the authors, manufacturers can easily incorporate Carpacio into vehicles since the included seat occupancy detection sensor or seat heating coils can be used as the seat electrode.

Jansen *et al.* [2022] (A29) present AutoVis, a mixed-immersion analysis tool that integrates an immersive VR view with a synchronized non-immersive desktop view, aimed at analyzing automotive user interface (AUI) studies. This tool allows analysts to re-experience interactive recordings of original studies in a virtual environment while also enabling aggregated data analysis on the desktop. The results indicate that AutoVis can effectively facilitate the analysis of AUI interactions, bridging immersive and non-immersive environments, and enabling collaborative analysis.

Crescenti *et al.* [2023] (A27) propose a test protocol and evaluation method for assessing the ergonomics of IVIS interfaces, particularly focusing on the impact of touch interaction on driver safety. The results indicated that the data collected was representative but not statistically valid due to the limited number of tests conducted.

Alarcón *et al.* [2022] (A44) present a collection of nine user interface design patterns specifically for IVIS, aimed at addressing driver distraction during secondary tasks while driving. The patterns were developed based on an exploratory test involving ten users aged 18 to 29, which identified recurrent problems and behavioral patterns related to driver interaction with infotainment systems. The main objective of these patterns is to reduce interaction time, interaction cost, and perceived mental workload for drivers, thereby contributing to a decrease in driver distraction. The results indicated that the developed design patterns effectively met three main criteria: they are supported by robust theories, logically coherent, and contribute new insights rather than duplicating existing models.

Ebel *et al.* [2021] (A45) present a Multi-Level User Behavior Visualization Framework aimed at enhancing the evaluation of IVIS by providing effective visualizations of user behavior data collected via telematics from production vehicles. This framework addresses the complexity of modern IVIS and supports UX experts in designing systems that meet customer needs and ensure safety while driving. A study was conducted to evaluate how these visualizations helped in generating insights into driver interactions with IVIS. The results indicate that the visualizations were effective in helping UX experts identify potential problems and understand user interactions.

Multimodal interface: Multimodal Interface is defined as a system that combines various methods of interacting, such as speech, touch, and others. We noticed different research focused on how users have been interacting with IVIS, as various sensory channels and input/output methods. Reich and Stark [2015] (A03), for instance, investigates the influence of immersive driving environments on user interaction with navigation systems, focusing on three modalities: touch, spin controller, and free-hand gestures, across two levels of immersivity (low and high) with a total of 20 participants involved in the study. Results indicated that high immersive driving environments provided advantages in situational awareness and perception when interacting with a navigation system, with significant differences in cognitive workload based on interaction modality.

NASA-TLX: NASA Task Load Index (NASA-TLX) is a questionnaire for assessing subjective mental workload, which measures the level of six dimensions (mental demand, physical demand, temporal demand, effort, performance, and frustration) and determines an overall workload rating. Each dimension is evaluated on a scale of 0 to 100. These measures are discussed in Subsection 6.5. Ahmad *et al.* [2015] (A31) evaluate the effectiveness of an intent-aware display solution for in-vehicle touchscreens, demonstrating significant improvements in UX. The results indicate that the average overall workload score, measured by the NASA TLX, is reduced from 58 to 29.5 when prediction is enabled, effectively halving the workload.

Gesture interaction: Gesture interaction involves using hand gestures to control and manipulate digital interfaces. Shakeri *et al.* [2017] (A08) investigated the effects of different feedback modalities on mid-air gesture interaction for infotainment systems in cars, aiming to reduce driver distraction caused by visual demands. It highlights that non-visual feedback, such as auditory and tactile cues, significantly reduces eyes-off-the-road time, suggesting that these modalities are promising for enhancing driving safety. Overall, the findings emphasize the need for designing efficient mid-air gestures that minimize cognitive load and enhance user interaction in vehicles.

User profile: A user profile is a collection of information and data about a specific user, or a group of users, to understand their needs, behaviors, and preferences. For instance, Tobias [2016] investigated the usability of vehicle navigation map concepts, focusing on how age impacts map reading performance among younger and older participants while driving in a simulator. The methodology involved 31 participants (18 males and 13 females) who drove in a simulator, interpreted maps, and answered questions while their eye gaze behavior was recorded using an eye tracker. The study measured response time, accuracy of map interpretations, self-reported difficulty, and eye behavior. Results indicated that older participants had significantly longer response times (M = 6.71 seconds) compared to younger participants (M = 5.12 seconds) and glanced at the maps about twice as often. The findings suggest that older adults may require more visual information retention, which could impact their navigation performance.

UX Heuristics: Heuristics are general principles or guidelines that experts use to evaluate a product. Quiñones *et al.* [2024] (A42) discusses the development of a new set of UX heuristics for IVIS, named "UXH-IVIS," which aims to enhance the user experience while ensuring road safety. The study emphasizes the importance of designing IVIS that are intuitive and user-friendly to prevent distractions while driving. The proposed set of 12 heuristics was validated and demonstrated its effectiveness in identifying significant UX issues within IVIS. The findings indicate that while the UXH-IVIS set is useful, further refinements and validations are necessary to improve its effectiveness across different contexts. The paper also highlights the need for ongoing research to adapt the heuristics based on user expectations and advancements in IVIS design.

6.4.2 Combined methods in the evaluation

In our analysis, we notice that the research has combined methods and techniques to provide precise insights into UX evaluations. This is especially interesting, as the actual approaches were not enough to evaluate IVIS or highlight different dimensions. The NASA-TLX was the primary method used alongside other methods, such as SUS, AttrakDiff, DX questionnaires, and prototypes.

NASA TLX and SUS: System Usability Score (SUS) method is a simple, ten-item scale giving a global view of subjective assessments of usability. Prabhakar and Biswas [2017] (A18) propose a new interaction device using a Laser pointer for automotive environments, aiming to reduce cognitive load while allowing drivers to interact with secondary task systems without physical contact with a display. Regarding cognitive load, it was measured by NASA TLX, and system usability was measured by the SUS method. The methodology involved testingLaser-point Tracker's performance against a touchscreen under various luminance conditions, adjusting parameters such as room luminance, display brightness, and camera exposure, and analyzing the accuracy and processing time across different color spaces.

NASA TLX and AttrakDiff: AttrakDiff is a standardized test that evaluates the user's experience based on Hedonic, Pragmatic, and Attractive qualities [Hassenzahl, 2004]. Bellani *et al.* [2023] (A19) conducted a study with 20 participants who interacted with two gesture-based interfaces integrated into the car's windshield, allowing for IVIS and real-time environmental information. Participants completed tasks while their performance and physical fatigue were monitored, and they filled out standardized questionnaires (NASA-TLX and AttrakDiff) to assess workload and interaction experience.

NASA TLX and DX questionnaires: Driving Experience (DX) questionnaires are instruments designed to gather information about drivers' behaviors, perceptions, and experiences behind the wheel. These questionnaires can explore a wide range of topics, including driving habits, attitudes towards traffic rules, and emotional responses during driving situations. Jung *et al.* [2021] (A20) investigated the impact of various touch-button interface factors, including shape, color combination, and edge presence, on the usability of IVIS. NASA-TLX and Driving Experience (DX) questionnaires were used for the survey items. The main conclusions suggest that effective combinations of button shape, and color can enhance user satisfaction and task performance, providing a basis for future research in IVIS design.

NASA TLX and Prototype: Ahmad *et al.* [2015] (A31) present a pilot study with 18 participants that investigated workload associated with interacting with the in-vehicle touchscreen using the NASA TLX method. It was based on a developed prototype of the system. The results of this pilot study show that an intent-aware display significantly reduces the workload and time of executing on-screen selection tasks.

Wizard-of-Oz and Prototype: Wizard of Oz Prototyping allows a design team to fake features so that the user thinks that the responses are computer-driven when they are actually human-controlled. Wärnestål and Kronlid [2014] (A34) present a set of design principles for traffic information and navigation based on a qualitative analysis of driver interactions with an adaptive speech prototype, explored in driver interviews. A prototyping solution was designed as a Wizard-of-Oz (WOZ), which allows for simulating complex dialogue and system behavior, and generates data on the interaction between a partially implemented system and its users.

Category	Measurements x Publications
Performance	Perceived Workload [A3], [A8], [A14], [A16], [A20], [A31], [A33], [A38], [A43] Perceived Driving Performance [A3], [A10], [A15] Authentication Time [A41] Primary Task Performance [A14], [A28], [A31], [A32], [A33], [A38] Secondary Task Performance [A8], [A10] Driver Response Time [A9], [A35] Average Driving Speed [A9], Driving Performance Metrics [A18] Mean Task Completion Time [A17] Task Completion Time [A20], [A33], [A35]
User distraction	Driver Distraction Metrics [40] Visual Distraction Percentage [A24] Dwell Time [A24] Average Glance Time [A20], [A24], [A32] Distraction Levels [A27] Manual Distraction [A28]
Tasks performed in IVIS	Number of Errors [A20], [A33] Touch Accuracy [A25] Touch Categories [A25], [A26] Completeness [A35]
Perceived user experience	Autonomy [A42] Competence [A42] Intention to Use [42] Facial Features [A2]
IVIS Data Collection	Collision Occurrences [A9], [A10] Gaze Direction [A2]

Table 9. Measurement Categories by article

Xu *et al.* [2018] (A35) conducted an exploratory study about interaction design techniques for human-vehicle interactions, such as scale scenarios, WOZ, and prototypes. According to the authors, video prototypes can be set in various environments. This is important in terms of contextual elements such as different driving situations. As a result, the vehicle interaction is necessarily evaluated concerning its context, which is especially important in the driving context.

6.5 Measures and Metrics used in usability and UX evaluation of IVIS

This subsection present the results related to the RQ4 - *What measures and metrics are used to support usability and UX evaluation of IVIS?* Regarding our results from analysis, we synthesized the metrics in five categories: Performance, User distraction, Task performed in IVIS, IVIS Data Collection and Perceived User Experience. Most of the measures and metrics evaluated are related to the assessment of Performance that analyzes primary aspects related to driving and secondary aspects related to interaction with infotainment systems; User distraction which quantifies distractions caused during the user interaction with IVIS, followed by analyses carried out through Tasks Performed in IVIS by users, Perceived UX and IVIS Data Collection that provides information that directly influences UX. The Table 9 presents the main measures by categories. The Figure 3 present frequency of the measures by use. All our findings are described as follows:

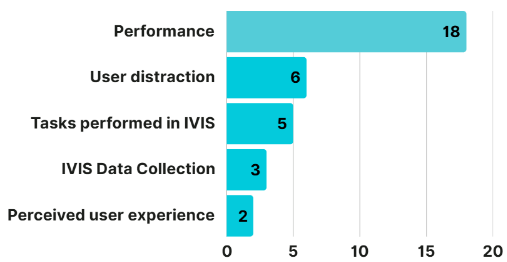

Figure 3. Measurements Applied for UX

Performance: *Perceived Workload* - this has been evaluated with support of NASA-TLX method through six subjective measures, such as:

Mental Demand - How much mental and perceptual activity was required? Was the task easy or demanding, simple or complex?

Physical Demand - How much physical activity was required? Was the task easy or demanding, slack or strenuous?

Temporal Demand - How much time pressure did you feel due to the pace at which the tasks or task elements occurred? Was the pace slow or rapid?

Own Performance - How successful were you in performing the task? How satisfied were you with your performance?

Effort - How hard did you have to work (mentally and physically) to accomplish your level of performance?

Frustration Level - How irritated, stressed, and annoyed versus content, relaxed, and complacent did you feel during the task?

Perceived Driving Performance - Self-assessment questionnaire with eight items measuring aspects like tracking, maintaining speed, and overall judgment, providing a score that reflects self-estimated driving performance. [3]

Authentication Time - The time taken for successful logins was recorded, revealing significant differences between standing and driving conditions.

Primary Task Performance - These include lateral control, steering wheel pattern, longitudinal control, speed maintenance, brake pedal pattern, and distance from other cars, which are essential for assessing driving performance while interacting with infotainment systems.

Secondary Task Performance - Accuracy and time required to complete tasks, utilizing techniques like detection response time and peripheral detection task to evaluate cognitive load and attentional effects

Driver Response Time - This measurement captures the time taken from the initiation of a command to the corresponding action, comparing the performance of the proposed multimodal interface against the touch-based interface.

Average Driving Speed - How driving speed varies while interacting with different HMI systems.

Driving Performance Metrics - Included the arithmetic mean of deviation, speed, and steering angle from a reference path, which were compared to assess the impact of the secondary task on driving performance.

Mean Task Completion Time - The efficiency of different input designs was assessed by measuring task completion times for secondary tasks and cognitive workload, indicated by changes in pupil size during interactions with the infotainment system.

Task Completion Time – It explored by automatically saving the pressed button and the time it was pressed, allowing for the calculation of mean task completion time for each button operation.

User distraction: *Driver Distraction Metrics* - Measurements included headway deviation in seconds and lane distance deviation in meters, which were analyzed to assess the impact of authentication tasks on driving performance.

Visual Distraction - This indicator measures the frequency of glances during the tasks.

Dwell Time - This is defined as the total time a driver spends looking away from the virtual road to the interior of the car. It is a critical measure of visual distraction during secondary tasks.

Average Glance Time - This is calculated by dividing the total dwell time by the visit count, providing insight into how long drivers are distracted on average.

Distraction Levels - Drivers' gaze data to estimate distraction levels while using various infotainment systems, providing insights into how different interface designs impact driver focus.

Manual Distraction - This was measured by counting the number of times drivers removed their hands from the steering wheel while interacting with the interface, highlighting the level of distraction caused by different modalities.

Tasks performed in IVIS: *Number of Errors* - Errors were defined as the number of incorrect taps, which help assess user accuracy and interaction effectiveness.

Touch Accuracy - This distinguishing between touches by the driver and passenger.

Touch Categories - Four types, such as tap, tap and hold, swipe, and multi-touch hold, allowing for a detailed analysis of user interactions.

Completeness - This measurement indicates whether a task was completed successfully, typically represented in a binary format (1 for completed, 0 for failed).

Perceived UX : *Autonomy* - Assessed using six items on a 5-point Likert scale, focusing on the freedom of interaction with the system.

Competence - Evaluated through seven items, measuring the successful completion of tasks using the system.

Intention to use - Assessed with three items on a 5-point Likert scale, measuring users' willingness to continue using the system.

Facial features - Recognition of facial expressions and head pose can provide insights into a user's emotional state and driving capability, which are important for assessing the user experience in infotainment contexts.

Regarding the findings, Performance and User Distraction, for instance, Kim et al. [28] considered *visual distraction*, the time driver had the eye off the road, the *perceived workload* to complete a task and the *manual distraction* – time participants had the hands off the whell (as they were instructed to keep it a the whell all the time). Moreover, NASA-TLX was used to measure *perceived workload*.

7 Discussion

This SLM analyzed how Usability and UX are addressed in the context of IVIS, identifying the most common evaluation methods, tools, and challenges. In this section, we reflect on the evidence found, gaps in the literature, and future directions for UX evaluation in IVIS.

7.1 Challenges in In-Vehicle Infotainment Systems

By synthesizing findings from this body of research, to better understand the challenges identified across the 45 articles focused on IVIS, we aim to provide a comprehensive overview of the key challenges.

7.1.1 Driver Distraction and Safety

Our findings show that reducing driver distraction to enhance safety requires integrating multiple interaction modes, such as head-up displays, gesture recognition, voice commands, and eye-tracking to minimize the cognitive and visual demands on the driver.

Additionally, real-time monitoring of driver attention is crucial for managing distraction levels. Thus, designing multimodal, adaptive systems that maintain usability while keeping the driver focused on the road remains a key and ongoing challenge in this field.

Reducing driver distraction is a critical challenge in infotainment systems, as discussed by several authors. Lagoo *et al.* [2019] (A10) emphasizes the importance of systems such as head-up displays and gesture recognition to keep the driver focused on the road, minimizing distraction. Kim *et al.* [2020] also points out that integrating multiple modes of interaction, such as gestures and voice, can significantly reduce the cognitive and visual tasks required of the driver, improving safety without compromising usability [Lu *et al.*, 2021]. Crescenti *et al.* [2023] (A27) supports this idea, highlighting that eye-tracking techniques are essential for analyzing how driver distraction can be monitored and controlled in real-time.

However, these multimodal systems depend on how well they balance the trade-off between information richness and cognitive load. While integrating voice and gestures reduces physical effort, an excess of simultaneous inputs may lead to sensory's saturation. As observed in our results, the goal is not just to provide more interaction channels, but to ensure they are context-aware.

7.1.2 Multimodal Interaction (Touchscreen, Gestures, Haptics)

The use of multimodal interaction, such as gestures and haptic feedback, is a key solution to improve the user perception. Shakeri *et al.* [2017] (A08) suggests that interfaces utilizing air gestures and haptic feedback can reduce the need for physical interaction with the screen, providing a smoother and safer experience. Young *et al.* [2020] (A22) argues that combining air gestures with haptic feedback creates a more intuitive sense of control without overloading the driver with excessive physical tasks. Similarly, Bellani *et al.* [2023] (A19) investigates how windshield gestures can improve user engagement in autonomous vehicles, providing a touch-free interface that preserves safety and facilitates navigation.

Studies suggest that combining air gestures with haptic feedback can reduce the reliance on touchscreens, creating a smoother and safer user experience without overwhelming the driver. Additionally, innovative approaches such as windshield gestures offer touch-free control options that enhance user engagement and support safe navigation, especially in autonomous vehicles. Therefore, developing interaction methods that provide effective control and feedback without increasing cognitive or physical load remains a critical challenge for IVIS design.

7.1.3 Personalization and Adaptation

Personalizing interfaces is seen as an important solution to meet the individual needs of drivers and passengers. Berger *et al.* [2021] (A12) proposes a system that adapts the infotainment design based on collaboration between the driver and co-driver, aiming for a more intuitive and personalized experience. Similarly, Reyes [2020] (A30) explores how user-profile-based personalization can improve the experience by offering interfaces that adjust to individual behaviors and preferences, increasing efficiency and user satisfaction. Graefe *et al.* [2022] (A16) discusses how explainable interfaces, which adapt to user behavior, can improve system understanding, promoting more intuitive and safe use in intelligent vehicles.

A significant challenge for user interaction with IVIS is creating adaptive and personalized interfaces that respond to both individual users and collaborative contexts, such as between driver and co-driver. Designing systems that dynamically adjust to user profiles and behaviors can enhance usability, efficiency, and satisfaction. Additionally, incorporating explainable interfaces that help users understand system responses is crucial for fostering intuitive and safe interactions. Thus, developing IVIS that effectively balance personalization and transparency remains a key challenge in improving user perception and safety.

7.1.4 Intelligent Interfaces

The evolution of interfaces in autonomous vehicles requires a focus on intelligent technologies that interact more seamlessly with users. Reich and Stark [2015] (A03) highlight how immersive driving environments can enhance driver evaluation, providing a more integrated experience adapted to the dynamics of the autonomous vehicle. Bellani *et al.* [2023] (A19) discusses how gesture-based interactive systems can be employed to increase passenger engagement in autonomous vehicles, helping them communicate with the infotainment system without interruptions. Galarza and Paradells [2019] (A14) reinforces the idea that autonomous vehicles require dynamic and contextually adaptive interfaces to ensure safety and a more personalized user experience.

Developing intelligent, dynamic, and context-aware interfaces is crucial for enhancing user engagement in autonomous vehicles. Such systems must adapt to the specific requirements of autonomous driving by offering immersive environments and gesture-based controls that facilitate seamless passenger interaction without distractions.

7.1.5 Feedback Systems and System Performance

The technical performance and feedback of IVIS systems are essential for creating an effective user experience. Wang *et al.* [2024] (A23) analyzes how software and hardware performance directly impact the user experience, highlighting the importance of optimizing chips and systems to reduce latency and improve responsiveness. Prabhakar and Biswas [2017] (A18) also suggests that the technical performance of interfaces should be balanced with ease of interaction, using devices like laser pointers to improve accuracy and system response. Ebel *et al.* [2021] (A45) explores how behavioral analytics can help refine feedback systems and optimize interface performance in real-time, providing a faster and more efficient experience.

Ensuring high technical performance and effective feedback is critical for creating seamless and responsive IVIS interactions. Optimizing hardware and software to reduce latency, balancing precision with ease of use, and utilizing behavioral analytics for real-time feedback adaptation are essential strategies to enhance user experience and system efficiency.

7.2 New Approaches for Evaluating UX in IVIS

Based on our results, we observed the use of specific approaches for UX evaluation in IVIS. In particular, the studies highlight several key directions: integrating user feedback and involving users in the development process; proposing UX evaluation methodologies and models, especially due to the lack of standard protocols; creating UX design databases and using data-driven support in the design process; establishing objective testing methods; developing new sets of heuristics; and creating effective visualizations of user behavior data. In this section, we provide more details about the approaches identified in our findings.

Among the articles analyzed, three address the integration of user feedback, including customers in the development process. The importance of understanding user interactions and usability through real-world scenarios is highlighted by Wei *et al.* [2016] (A06), suggesting that current methods may need to be revised or improved. Furthermore, Galarza and Paradells [2019] (A14) agree that it is essential to consider user feedback as a means to improve the model, highlighting the emphasis on user experience.

The theme of improving UX evaluation methodology and models through the standardization of protocols and approaches is mentioned in two articles. Galarza and Paradells [2019] (A14) highlighted the need for new proposals to improve the methodology and model developed to evaluate usability and UX of IVIS. They suggested that incorporating a greater number of variables, such as traffic density and user interaction with the infotainment system, could improve the monitoring and evaluation process. Due to the lack of standard protocols and methodologies for the objective evaluation of infotainment systems in vehicles, a test protocol and an evaluation method based on eye-tracking technology are proposed by Crescenti *et al.* [2023] (A27) to address this gap.

These findings suggest that the transition from subjective feedback to objective, data-driven metrics is not merely a trend, but a necessity for the safety-critical nature of IVIS. While user feedback provides valuable insights into emotional satisfaction, it often suffers from recall bias. By integrating real-time variables such as traffic density and eye-tracking, as proposed by Galarza and Paradells [2019] (A14) and Crescenti *et al.* [2023] (A27), researchers can move toward a holistic evaluation framework.

The proposed UX design database for data-driven support in the design process is also mentioned in two articles. Wei *et al.* [2016] (A06) highlights the need for UX design, indicating a demand for new proposals in this area. In addition, Ebel *et al.* [2021] (A45) highlights the need for data-driven support in automotive UX design due to the complexity of designing in-vehicle information systems (IVISs) and the unique challenges they present compared to web or app development.

This shift towards data-driven support, as argued by Ebel *et al.* [2021] (A45), reflects the growing complexity of IVIS, where traditional 'trial and error' design is no longer viable. The creation of specialized UX databases allows for a more predictive approach, where designers can consult previous interaction patterns to avoid known distraction triggers.

The need to establish a set of objective testing and performance evaluation methods for IVIS is emphasized. The purpose is to provide objective side-by-side comparison data for automotive companies. Wang *et al.* [2024] (A23) proposes a semi-automatic performance testing method to better evaluate the response time of IVIS, which could contribute to the evaluation of the user experience.

The theme of developing a new set of heuristics addresses the fact that existing heuristics may not effectively evaluate IVIS due to their unique characteristics, highlighting the need for a tailored approach. Proposed by Quiñones *et al.* [2024] (A42), the new set, named 'UXH-IVIS', was designed to address specific IVIS related issues and improve the user experience. This set consists of 12 heuristics and was developed using an 8-stage methodology.

The development of the UXH-IVIS represents a significant shift from general usability principles to context-specific requirements. Standard heuristics often overlook critical automotive factors, such as physical safety, driver distraction, and varying environmental conditions. In this sense, researchers and designers can now evaluate interfaces through a lens that accounts for the 'secondary task' nature of IVIS, ensuring that the cognitive load remains within safe limits.

7.3 Research Topics for Future Work on UX in IVIS

We analyzed the future work proposed of the 45 articles and identified seven distinct categories, as follow.

7.3.1 User Survey and Data Collection

Given the variety of scenarios and approaches for evaluating IVIS, it becomes necessary to explore new data collection strategies, as current methods may not accurately reflect users' perceptions. In this regard, the reviewed studies suggest conducting real-world driving experiments to validate findings and highlight the potential of using Augmented Reality (AR) and Virtual Reality (VR) simulations as alternative evaluation environments [Reich and Stark, 2015] (A03). Other authors propose incorporating additional data and more diverse participant profiles to improve model accuracy [Galarza and Paradells, 2019] (A14), expanding user trials to obtain more detailed data and statistical validity, and addressing external validity by testing systems in real driving conditions [Reyes *et al.*, 2023] (A11).

These perspectives suggest a growing need for new evaluation strategies in IVIS, particularly those that incorporate context-aware data and methods. For example, Crescenti *et al.* [2023] proposed a protocol and model for the objective assessment of IVIS, responding to the current lack of standardized evaluation methods. They plan to extend their research with a larger participant pool and more complex driving scenarios. Similarly, Reich and Stark [2015] (A03) analyzed how immersive environments affect user interaction with navigation systems. Understanding the experiential characteristics of AR and VR can help shape new evaluation tools, especially when considering the contextual factors unique to IVIS. Therefore, it is essential to examine each evaluation scenario in depth to support the development of more appropriate and effective UX assessment instruments for IVIS.

Ergonomics is also a key factor to be explored in future research. For example, Colley *et al.* [2015] (A13) proposed as further research on the ergonomic positioning to determine the optimal screen angles and positions for user interaction. Similarly, Prabhakar and Biswas [2017] (A18) proposed as future work to test the LPT under varied parameters to validate performance consistency and refine its ergonomic design to reduce cognitive demand. In the context of HCI, ergonomics primarily impacts physical, cognitive, and organizational aspects and can be studied to improve IVIS design. In line with this, our findings also highlight ergonomic design as a relevant direction for future work. Bellani *et al.* [2023] (A19) proposed optimizing ergonomics to improve user comfort and acceptance of touchless systems. Likewise, Jung *et al.* [2021] (A20) proposes as future work to explore different shapes, symbols, and color schemes to further improve IVIS usability. Finally, Xu *et al.* [2018] (A35) performed a usability test comparing two IVIS and proposed exploring the relationship between user multilevel tasks interaction and interface usability.

These future works can drive researchers and developers to enhance the UX and usability of IVIS systems, and advance the knowledge in the HCI and Software Engineering (SE) area. While HCI worries about user interaction, design process, and engagement, the SE can support the development process. Also, we pointed out the lack of literature review analysis from the SE perspective, aiming at the requirements elicitation, architecture, and tests.

7.3.2 Multimodal User Interaction

Our results highlighted the necessity of investigating several multimodal interactions. Multimodal interaction represents many ways to interact with a system. In this sense, future works related to multimodal interactions present the need to optimize and integrate recognition methods, refine feedback mechanisms, and evaluate hybrid multimodal interactions to create solutions surpassing single-modality systems' limitations. For example, Stampf *et al.* [2022] (A02) proposed to evaluate, adapt, and extend current state recognition methods to address gaps in implicit interaction within HAVs. Kim *et al.* [2015] (A09) highlights as future work, integrating gesture recognition in multimodal Human-Machine Interface (HMI), and improving interaction with the driver's statement recognition system. Meanwhile, Farooq *et al.* [2014] (A21) proposes refinements to generate oriented tactile feedback using systems as Pressure-Sensitive Waveform (PSW) and Low-Amplitude Tactile Signal (LATS) systems. The variety of future works on multimodal user interaction highlights how much this area still needs to be explored. This is largely driven by rapid technological innovation, which continues to expand the possibilities for interaction and testing in IVIS.

Currently, the authors are expanding the multimodal perspective context, for example, Kim *et al.* [2020] proposes the controlled driving simulations to capture detailed distraction characteristics and explore user-defined cascaded multimodal interfaces tailored to different traffic conditions. Jansen *et al.* [2022] Reyes [2020] investigated the customization of human-machine interfaces (HMIs) in IVIS and proposed that future research analyze driver-specific behavioral determinants influencing HMI adaptation efficacy and the development of algorithmic adaptation mechanisms that integrate identified behavioral factors to enhance interface personalization.

All these future works highlight the main opportunities to improve the multimodal interaction on IVIS and should be explored by researchers.

7.3.3 Contextual and Cultural Design

Our results highlighted the need to consider the context and cultural design, as the IVIS can be different in each country. May *et al.* [2014] (A33) recommends replicating the experimental protocol with diverse demographic sampling to evaluate cross-cultural validity and accessibility to enhance the generalizability of the results. Also, incorporating factors such as accessibility and cultural influences on driver experience, and to further validate the design patterns through empirical testing [Alarcón *et al.*, 2022] (A44). In this sense, user interaction would change from each culture; the design of interfaces, UX, usability, and several other factors can differ. Understanding different driving scenarios can help to reach more general results. Future works should examine the variations in interaction preferences across manual, semi-automated, and fully automated driving scenarios, and extend these findings by exploring additional design features and application contexts [Stiegemeier *et al.*, 2022] (A43).

These future works highlight a shift toward more adaptive, inclusive, and user-aware design practices. It shows that the field is moving beyond general usability to consider contextual and cultural nuances, which is essential for creating IVIS that serve diverse users in real-world conditions.

7.3.4 Systematic UX Evaluation

The reviewed studies presented several tools to support IVIS evaluation, including analytical frameworks, heuristic methodologies, and immersive visualization technologies. These tools are valuable for enabling systematic evaluation, optimization, and validation of user experience. For example, Ebel *et al.* [2021] (A45) developed ICEBOAT, an interactive analytical tool developed to evaluate user interactions with IVIS. The future work for ICEBOAT includes improved visualizations, functionality for saving analyses, the addition of new metrics and filters. Jansen *et al.* [2022] (A29) presented AutoVis, a mixed-immersion analytical tool combining immersive virtual reality (VR) and synchronized non-immersive desktop views. As future work, the authors will focus on developing novel 2D and 3D features and visualizations for both desktop and VR environments.

The emergence of specialized tools like ICEBOAT and AutoVis signifies a move towards hybrid evaluation environments, where the precision of quantitative data meets the context of qualitative user behavior. By integrating immersive VR with analytical dashboards, these tools allow researchers to replicate complex driving scenarios that would be too dangerous or costly to perform in real-world settings.

These findings reinforce the importance of continued research into adaptive, context-aware systems that evolve with user behavior and expectations, pointing toward several promising directions for future work.

7.3.5 AI and Connected Ecosystems

Recently, Artificial Intelligence (AI) has become a major topic in academic research, and the automotive field is no exception. Several studies explore the potential of AI in IVIS, proposing features for next-generation systems such as adaptive AI-driven interfaces, interoperable communication protocols, and context-aware data processing. Smirnov *et al.* [2015] (A05) introduces an intelligent driver support system that utilizes advanced technologies including context-based collaborative recommendation systems, proactive information support, smart space concepts, and vehicle-to-vehicle (V2V) communication. These capabilities illustrate how AI can integrate multiple sources of contextual information to improve the relevance of information delivered to the driver.

Similarly, Ahmad *et al.* [2015] (A31) empirically validated an intent-aware touchscreen interface and future work proposes the development of advanced predictive algorithms. Artificial intelligence can enhance IVIS interaction by enabling personalized and context-aware interfaces. The future works focused on AI should support the driver by adapting content and interaction modes based on the driver's preferences. Also, the connected ecosystems should be further explored, for example, Coppola and Morisio [2016] (A39) analyzed the transformative role of connected vehicles within IoT-enabled vehicular ecosystems, emphasizing their capacity for real-time data acquisition, internet connectivity, and bidirectional communication with smart devices. The author's future work includes evaluations of user experience frameworks for integrated IoT-vehicle ecosystems.

Overall, the literature indicates that AI will play a crucial role in the evolution of IVIS, particularly in enabling adaptive, predictive, and interconnected systems. Nevertheless, challenges remain regarding the design of user-centered AI interfaces, the management of large volumes of contextual data, and the evaluation of user experience in highly connected vehicular environments.

7.4 Main Findings and Research Gaps

The studies identified span a wide range of UX evaluation approaches, including empirical studies with users, simulation-based testing, heuristic evaluations, and hybrid methods. The results presented several research gaps to further explore.

Driving simulators, for instance, were commonly used to simulate real-world conditions safely. However, most studies were conducted in controlled environments, which may not reflect real driving behavior. More realistic environments are necessary to simulate the IVIS, providing more immersion and involvement. Recently, Reich and Stark [2015] (A03) investigated immersivity within driving environments while interacting with a navigation system. The authors concluded that immersive driving environments are useful in the automotive context, as they increase situation awareness, presence, and immersive tendency. Currently, the immersion in simulated environments is still being explored. In this sense, VR has been investigated to simulate in-vehicle utilizing 3D avatars, motion trajectories, and aggregated visualizations embedded in virtually replicated environments [Jansen *et al.*, 2023]. The authors pointed the field remains unexplored,

We observed a lack of standardization in UX evaluation protocols. While tools like NASA-TLX, SUS, AttrakDiff, and user-centered heuristics are commonly used, few studies have proposed integrated frameworks that combine objective and subjective data to comprehensively assess the user experience. Current tools provide some support for UX evaluation; however, they have a limited scenario and do not address the specific UX dimensions unique to IVIS. In this sense, there are no UX evaluation frameworks specifically designed for the nature of IVIS. It is important to consider the development of dedicated tools that support UX evaluation while taking into account the context of use, system features, screen size, and the specific IVIS model of each brand, as car interfaces often follow different design patterns.

Additionally, there is little consensus on which metrics best represent UX in IVIS, especially regarding performance, user satisfaction, distraction, and adaptability. General UX metrics may not fully represent unique aspects. Therefore, developing or adapting metrics for the specific context helps ensure that evaluations reflect real user experiences, improving the accuracy and relevance of the results.

Moreover, many studies focus on specific IVIS features or technologies (e.g., gesture-based interfaces, head-up displays), making it difficult to generalize results across systems. This fragmentation reveals a need for unified models and best practices for UX evaluation in this domain. Future research should explore different models, aiming to find ways to generalize the results.

Our main findings and research gaps can drive the future of IVIS, and researchers can use them as an opportunity to advance the knowledge on HCI and SE. More investigation are still necessary to improve the UX on IVIS.

Threats to validity

To avoid potential threats to validity during the review process, we followed an established protocol that is widely used in the field for conducting literature reviews. This protocol was validated through meetings and discussions with the involved researchers to reduce potential research bias. One possible threat to study selection is the inclusion of relevant publications. To address this, we used digital libraries that index major conferences and journals in software engineering and HCI. In addition, a set of key papers was defined to guide the search strategy. Another threat to validity concerns which studies should be included. To mitigate this, we defined clear inclusion and exclusion criteria that helped guide the researchers throughout the review process.

Additionally, to minimize bias during the selection and extraction of studies, the authors participated in a training session. During this training, they practiced classifying studies using a sample set, applying the inclusion and exclusion criteria. Afterwards, a second training session was conducted to align the data extraction process. In this session, the data extraction form template was presented along with practical examples to ensure consistency among researchers.

We developed the review protocol to ensure the quality of the results. The protocol was also designed to support the replication of the findings.

8 Conclusion

This paper aims to understand how Usability and UX are addressed in IVIS. To achieve this, we conducted a systematic mapping study to answer five research questions. We presented the current state of the art based on 45 primary studies. Although there are similar mapping studies in the field, none of them specifically explored UX in IVIS.

Our results summarize the main studies that explore UX evaluation in IVIS and can help guide researchers in developing better UX evaluation strategies to support IVIS design. This work provides an overview of the key methods, techniques, and tools used in this evaluation process. As presented in Section 6, although several techniques already exist for evaluating UX, only a few are specifically tailored to the IVIS context, which may limit their ability to reflect the user's real experience. IVIS systems offer different interaction designs, such as button-based interfaces and hands-free interactions. Therefore, developing UX evaluation techniques specifically for IVIS can contribute to improving user experience by taking into account these various interaction models.

Additionally, our results emphasize the importance of considering Usability and UX throughout the design process, particularly regarding interface characteristics. They highlight the need for user-centered approaches that take into account user observations, needs, limitations, and satisfaction with the product. Moreover, our findings point to several challenges and future research topics related to the UX of IVIS. These challenges can help expand the study of IVIS within the fields of HCI and Software Engineering, not only by offering new ways to evaluate UX but also by serving as a foundation for developing models and frameworks to improve these systems, ultimately contributing to the overall quality of IVIS.

As future work, we intend to investigate specific UX topics in IVIS, particularly by exploring how other evaluation techniques can help improve IVIS quality. In addition, we aim to use the results of this systematic mapping study to support the interaction design of IVIS, with the goal of expanding this topic within the HCI field.

Declarations

Acknowledgements

The authors would like to acknowledge that this research was developed within the scope of Research and Development (R&D) projects funded under the Informatics Law and managed by the Superintendence of the Manaus Free Trade Zone (SUFRAMA). We also gratefully acknowledge the support provided by the Eldorado Research Institute, which contributed to the successful execution of this work.

Funding

The research focused on Research and Development (R&D) projects funded by the Informatics Law and managed by the Superintendence of the Manaus Free Trade Zone (SUFRAMA). This research was also funded by the Eldorado Research Institute.

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Competing interests

There is no competing financial and/or non-financial interests in relation to the work described.

Availability of data and materials

The extracted and analysed data are available at: https://doi.org/10.6084/m9.figshare.31502758 (access on 21 May 2026). The list of articles returned as results are listed on the Appendix bellow.

Further relevant information

The authors acknowledge that, during the preparation and revision of this article, artificial intelligence tools (specifically OpenAI's GPT-4o model, Gemini 2 and Copilot) were used to assist with translation, grammar correction, and occasional text restructuring. In all instances, the resulting content was carefully reviewed and appropriately revised by the authors. The final manuscript is entirely original and reflects the authors' own work.

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A Appendix

In this section, we present the list of articles returned as results of SLM.

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