Strategies to design user-centered Electric Bus Dashboard Interfaces for the Indian context

PhD Dissertation

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by

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Dedicated to my beloved parents, husband and son.

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Abstract

The use of electric buses, or e-buses as they are popularly called, in public transportation is rapidly expanding in India. At the same time, their dashboard user interfaces continue to replicate legacy layouts designed for diesel-based vehicles. As a result, we observe critical information being fragmented across multiple displays and controls. This requires greater cognitive effort and limits effective decision-making during operations on the part of drivers. Industry stakeholders, when probed as part of this research, attribute this to the lack of appropriate knowledge of design strategies amid factors such as cost constraints, reliability concerns, and assumptions about drivers' digital readiness. This knowledge gap corroborates the research literature on e-vehicle interfaces, which is further sparse and underdeveloped regarding the use of e-buses in public transport in developing regions like India.

To address this knowledge gap, focusing on designing e-bus dashboard interfaces for drivers in India, this study adopts a user-centered design research methodology. The study's aim is to systematically investigate existing e-bus dashboard interfaces to generate domain-specific design knowledge that is both useful and valuable to stakeholders, including designers and researchers. The research hypothesizes that dashboard user interfaces, when designed according to the fundamental tenets of user-centered design, will be more effective at enhancing the capabilities of e-bus drivers in the context of public transport in India.

There are four logical milestones in this study's research journey. First, an investigation of existing dashboard interfaces using observation, survey, and interview-based methods with stakeholders. Second, synthesis of the findings from the first stage to generate design insights for research-driven interventions. Third, systematic and iterative design of research prototype(s) and their evaluation with stakeholders in real-world settings. The research prototype(s) integrate key operational modules, including trip management, vehicle status monitoring, alerts, and reporting, within a consolidated interface that reflects electric bus operational workflows. Prototype evaluation is conducted through a field-based usability study with 32 professional bus

drivers. Fourth, the findings from earlier stages are consolidated into domain knowledge that is applicable to stakeholders and positioned within the context of existing literature.

The study contributes to the existing knowledge on e-bus dashboard design by demonstrating that the research prototype(s) significantly outperform existing dashboard interfaces across multiple usability dimensions. Compared to the control dashboard, the proposed interface shows higher perceived usability, lower mental workload, and improved task performance among professional drivers. These improvements are consistently observed across standardized evaluation measures, including task ease, usability, cognitive effort, and system acceptance. The findings further indicate that these gains are primarily driven by the redesigned interaction structure rather than interface language, as no meaningful differences were observed between English and localized versions. In addition, the prototype supports intuitive first-time use with minimal learnability issues and enhances information visibility, diagnostic clarity, and interaction efficiency. Qualitative insights highlight increased driver confidence and acceptance, as well as the role of localization in improving comfort and trust during operation.

Keywords: *Electric bus dashboards; Human–Machine Interface; User-centered design; Usability evaluation; Learnability; Cognitive workload; Multilingual interaction.*

Contents

List of Tables

List of Figures

List of Abbreviations

EV	Electric Vehicle
E-bus	Electric Bus
EVI	Electric Vehicle Interface
EVIS	Electric Vehicle Information System
IC	Instrument Cluster
IP	Instrument Panel
SOC	State of Charge
DTE	Distance to Empty
DDU	Driver Display Unit
OEM	Original Equipment Manufacturer

Chapter 1

Introduction

Electric buses (e-buses) are increasingly adopted within public transport systems worldwide as cities pursue sustainable mobility solutions (Sustainable Bus, 2025). Large-scale deployments are already underway in regions such as China, Europe, and North America (Lipman, 2025; World Resources Institute, 2025, 2024). Existing research in this domain predominantly addresses technical aspects, including battery systems, drivetrains, and charging infrastructure. In contrast, the human–machine interaction (HMI) dimensions of e-bus operation, particularly from the driver's perspective, remain comparatively underexplored (Mandujano-Granillo et al., 2024). Only a limited number of studies examine how drivers interact with dashboard interfaces, interpret new forms of electric-vehicle information, or manage operational safety within these systems (Young et al., 2018).

In this thesis, the term "electric bus (e-bus)" is used to refer to battery-powered public transport buses. For brevity, the term "e-bus" is used throughout the remainder of the document.

The deployment of e-buses has accelerated significantly in recent years, particularly in emerging economies such as India. Under national initiatives such as the Faster Adoption and Manufacturing of Electric Vehicles (FAME II) scheme and subsequent programs like PM e-DRIVE and PM e-Bus Sewa, large-scale electrification of public bus fleets is underway. The FAME II scheme alone supports the deployment of approximately 7,000 electric buses, while the PM e-Bus Sewa initiative targets the introduction of 10,000 e-buses across 116 cities, with over 7,200 buses already sanctioned as of 2026 (Ministry of Heavy Industries, Government of India, 2019; Ministry of Housing and Urban Affairs, Government of India, 2026). These deployments are part of a broader national transition toward electric mobility, with projections indicating substantial growth in e-bus adoption by 2030 (SAREP, 2024; India, 2024). This rapid expansion establishes e-buses as a critical component of urban public transport systems and increases the importance of driver-facing dashboard interfaces.

However, this rapid deployment is not matched by equivalent advancements in dashboard interface design. While battery and powertrain technologies have advanced considerably, many existing dashboard systems continue to be adapted from conventional heavy-vehicle cockpit configurations. As a result, critical operational information is distributed across analog instruments, Intelligent Transport System (ITS) displays, and physical switch panels. Prior studies suggest that such fragmented information presentation can increase visual and cognitive demand, reduce situational awareness, and negatively influence driver acceptance of new vehicle technologies (Strömberg and Karlsson, 2011; Andréasson and Boman, 2022).

From an industry perspective, Original Equipment Manufacturers (OEMs) often cite several constraints that limit substantial redesign of dashboard interfaces. These include limited empirical data on driver requirements, assumptions regarding drivers' digital familiarity, concerns about system reliability, and the perceived cost of interface redesign. As a result, key electric-vehicle–specific parameters, such as State of Charge (SoC), battery health indicators, and pre-trip diagnostic information, are not consistently prioritized in existing dashboards. Human–computer interaction research has previously shown that inadequately structured interfaces can increase cognitive load, contribute to errors, and reduce user satisfaction in safety-critical systems (Szalma, 2014; Zhang et al., 2024).

These observations indicate the need for a systematic understanding of how driver-facing dashboard interfaces support e-bus operation in real-world public transport contexts. In response, this research examines dashboard systems currently deployed in Indian e-buses, focusing on usability, information organization, and driver–system interaction. The study provides an empirical basis for analyzing prevailing interface practices and identifying interaction-related challenges relevant to professional bus drivers. At present, however, existing HMI literature does not sufficiently explain how drivers cognitively manage fragmented dashboard ecosystems across pre-trip, in-trip, and post-trip workflows, particularly within multilingual public transport environments.

From a theoretical perspective, this research is situated at the intersection of Human–Computer Interaction (HCI), cognitive workload theory, and transport ergonomics. It draws on established constructs such as information processing, visual attention, and situational awareness to examine how drivers interpret and act upon distributed dashboard information in safety-critical environments. By extending these theoretical perspectives to professional driving contexts in public transport systems—particularly within multilingual and resource-constrained settings—the study contributes to addressing limitations of existing automotive HCI frameworks, which are largely derived from private vehicle use and controlled environments.

1.1 Context: E-Bus Dashboard

This research is situated within the operational context of electric city buses deployed in Indian public transport systems. Empirical investigations were conducted in collaboration with a major Indian commercial vehicle manufacturer that supplies e-buses to various state transport undertakings. The collaboration provided access to operational vehicles, professional drivers, and real-world driving environments, enabling field-based examination of driver–dashboard interaction under authentic public transport conditions.

This study does not aim to evaluate, compare, or benchmark the product of a specific manufacturer. Rather, the selected vehicles are treated as representative instances of e-bus dashboard configurations currently deployed in India. The analytical focus lies on identifying recurring interaction patterns, information organization practices, and usability implications that arise under shared regulatory, infrastructural, and workforce constraints characteristic of Indian public transport operations.

Within this context, the study documents and analyzes two successive generations of an e-bus dashboard deployed by the collaborating manufacturer: (1) a version deployed operationally, and (2) a version under OEM R&D testing. These dashboard versions are not analyzed as isolated artefacts or indicators of product maturity. Instead, they are used to illustrate how e-bus interfaces in India evolve predominantly through incremental adaptation of conventional heavy-vehicle layouts rather than through purpose-built, electric-specific redesign. The comparison is therefore analytical rather than evaluative, aimed at surfacing persistent interaction constraints and transitional design shifts that inform subsequent user-centered design inquiry.

1.1.1 Dashboard Versions

The e-bus dashboard examined in this study exists in two versions corresponding to different phases of deployment. The first version, introduced in 2019, represents an early-stage adaptation of conventional bus cockpit layouts for electric propulsion systems. It relies heavily on analog instrumentation, discrete mechanical controls, and limited digital integration, mirroring established heavy-vehicle interface conventions.

The second version, developed in 2023 and undergoing OEM R&D testing, reflects a gradual transition toward increased digitalization (see Figure 1.1). It introduces improved color coding, partial information consolidation, and expanded digital displays to accommodate electric-vehicle-specific parameters. However, the overall spatial organization and subsystem separation remain largely consistent with the earlier version. This continuity indicates an evolutionary design approach constrained by manufacturing familiarity, regulatory compliance, and assumptions about driver adaptation, rather than a fundamental rethinking of e-bus interface requirements.

Examining these two versions enables an analysis of how e-bus dashboards are incrementally modified within existing operational and institutional constraints. More importantly, it highlights which usability challenges persist despite digital upgrades, thereby revealing gaps that incremental change alone fails to address (see Figure 1.1).

Both dashboard versions comprise multiple subsystems that collectively support driving operations, monitoring, and control. These include the instrument cluster, ITS (Intelligent Transport System) or DDU (Driver Display Unit), switch panels, gear control, and air-conditioning control. While this modular organization provides functional clarity at a component level, it results in fragmented interaction at the system level. Drivers are required to distribute attention across multiple displays and control locations to interpret vehicle status and operational conditions.

(a) Dashboard Version 1 (2019)   (b) Dashboard Version 2 (2023)

Figure 1.1: Dashboard Versions: (a) 2019 deployed version, (b) 2023 pre-release version (Source: Author's field study, 2023).

This fragmentation is particularly consequential in e-buses, where energy status, system health, and fault conditions demand continuous integration rather than isolated monitoring.

1.1.2 Instrument Cluster

The instrument cluster (IC) serves as the primary information hub of the e-bus dashboard, positioned directly behind the steering wheel. It provides real-time feedback on vehicle performance and system status through a combination of both analog gauges, digital displays, and telltales.

(a) Instrument Cluster Version 1 (2019)   (b) Instrument Cluster Version 2 (2023)

Figure 1.2: Instrument Cluster layouts e-bus: (a) 2019 deployed version, (b) 2023 pre-release version (Source: Author's field study, 2023).

Across the two dashboard versions, the instrument cluster demonstrates a shift toward partial digitalization; however, the underlying interaction logic remains constrained by legacy heavy-vehicle layouts rather than being reorganized around electric driving tasks (see Figure 1.2).

In Version 1 (2019), the instrument cluster follows a conventional bus dashboard configuration comprising six analog dials and a small monochrome LCD. Speed, air pressure, coolant temperature, and battery-related information are presented as separate elements. Eighteen telltales arranged in a single arc use red, amber, and green indicators to communicate basic vehicle alerts. Each gauge operates independently, requiring drivers to shift attention across multiple visual sources to interpret overall system status.

In Version 2 (2023), the layout is partially simplified through information consolidation. The number of analog dials is reduced from six to four, while a larger LCD displays multiple parameters simultaneously. Enhanced color coding, wider navigation buttons, and more consistent iconography improve readability and reduce visual search time. The number of telltales increases to thirty-two, incorporating electric-vehicle-specific alerts such as Vehicle Ready and Charging Status. Despite these upgrades, the subsystems remain visually and functionally distinct, indicating an incomplete transition toward integrated information presentation.

Navigation switches integrated into the instrument cluster enable movement across multiple LCD screens. While these controls support structured access to system information, they also reinforce a menu-driven interaction model in which critical data are distributed across screens rather than presented through a unified, glanceable overview.

1.1.2.1 Speedometer

The speedometer provides real-time feedback on vehicle speed and remains one of the most frequently monitored instruments on the dashboard. In both dashboard versions, it retains a circular analog form to preserve familiarity for drivers transitioning from conventional buses (see Figure 1.3).

In Version 1 (2019), the speedometer uses a traditional black background with white markings, and a red needle, offering visual hierarchy.

In Version 2 (2023), the contrast, illumination, and color accents are improved to enhance readability. The markings are more prominent, and the dial incorporates illuminated ticks for better visibility. The temperature gauge below the speedometer uses a continuous green-to-red color

(a) Speedometer Version 1 (2019)

(b) Speedometer Version 2 (2023)

Figure 1.3: Speedometer layouts in e-bus: (a) 2019 deployed version, (b) 2023 pre-release version (Source: Author's field study, 2023).

band, enhancing quick recognition of thermal limits.

1.1.2.2 State of Charge (SOC) Meter:

The State of Charge (SOC) meter provides the available battery energy and is central to e-bus operation (see Figure 1.4).

In Version 1 (2019), the dial adjacent to the speedometer functions primarily as a power indicator rather than a true SOC display. It follows an E–½–F scale similar to a fuel gauge, with a battery icon used symbolically to represent charge level. This legacy representation ensures visual familiarity for drivers accustomed to conventional heavy-vehicle dashboard layouts but offers limited accuracy and situational awareness.

In Version 2 (2023), the dial is redesigned as a dedicated SOC meter with a numeric scale ranging from 0–100%. The circular gradient ring and white numerals enhance legibility, and the use of blue tones aligns visually with other EV-related indicators. The revised design provides precise and easily interpretable feedback, enabling better estimation of remaining energy. This change marks a conceptual shift from analog fuel-based metaphors to a data-driven electric information model, improving the driver's understanding of vehicle range and energy efficiency.

(a) Power Version 1 (2019)

(b) SOC Version 2 (2023)

Figure 1.4: Layouts in e-bus: (a) 2019 deployed Power dial version, (b) 2023 SOC dial pre-release version (Source: Author's field study, 2023).

1.1.2.3 LCD Display

The LCD display supplements analog gauges by presenting dynamic operational information (see Figure 1.5).

(a) LCD Version 1 (2019)

(b) LCD Version 2 (2023)

Figure 1.5: LCD layouts in e-bus: (a) 2019 deployed version, (b) 2023 pre-release version (Source: Author's field study, 2023).

In Version 1 (2019), the LCD is small, monochrome, and text-dominant. It displays limited information such as odometer reading, gear position, time, and date. Each screen shows only one parameter, requiring manual toggling through navigation buttons. The lack of color, icons, or visual grouping increases cognitive load and slows information retrieval, particularly during driving. EV-specific data such as State of Charge (SOC) or Distance to Empty (DTE) are absent, indicating the display's adaptation from conventional heavy-vehicle dashboard layouts rather than a purpose-built EV design.

In Version 2 (2023), the LCD evolves into a more informative and structured interface. A larger screen integrates multiple parameters simultaneously: SOC (%), DTE (km), air pressure, gear position, and odometer readings. The layout applies grouping and alignment principles to improve scanning and comprehension. The addition of visual dividers and proportional scaling enhances information hierarchy, allowing drivers to access critical data at a glance.

(a)Error diagnostics LCD Version 1 (2019)

(b)Error diagnostics LCD Version 2 (2023)

Figure 1.6: LCD Error versions in e-bus: (a) 2019 deployed version, (b) 2023 pre-release version (Source: Author's field study, 2023).

Error diagnostics for both interface versions are presented in Figure 1.6.

1.1.2.4 Telltales

Telltales provide visual alerts and system status indications, acting as the primary feedback mechanism between the vehicle and the driver (see Figure 1.7). They use color-coded illumination to communicate normal operation, warnings, and critical faults, enabling quick situational awareness.

In Version 1 (2019), the dashboard features 18 telltale indicators arranged in a single horizontal arc above the instrument cluster. These include essential symbols such as parking brake, high beam, low air pressure, and coolant temperature. The color palette consists mainly of red and amber, with a few green indicators for normal status. Illumination is dim and inconsistent, mak-

(a) Telltale Version 1 (2019) (b) Telltale Version 2 (2023)

Figure 1.7: Telltale layouts in e-bus: (a) 2019 deployed version, (b) 2023 pre-release version (Source: Author's field study, 2023).

ing visibility challenging under bright daylight. The set complies with ISO standards but lacks electric-specific indicators, such as Vehicle Ready, Charging, or Regenerative Braking. This configuration mirrors the conventional heavy-vehicle dashboard layout, prioritizing mechanical feedback over electric diagnostics.

In Version 2 (2023), the number of telltales increases to 32, reflecting greater system monitoring capability. The arrangement follows a more compact and balanced arc along the top edge of the instrument cluster. Bright LED backlighting and uniform intensity improve legibility across lighting conditions. The newer layout introduces EV-specific symbols. These include Vehicle Ready, Charging Status, High-Voltage System Fault, and Regenerative Braking. A consistent three-color coding is used, where green indicates information, amber indicates caution, and red indicates critical alerts.

1.1.2.5 Main Coolant Temperature Gauge

The Main Coolant Temperature gauge monitors the temperature of the motor and inverter cooling system (see Figure 1.8). It provides real-time feedback on thermal performance, helping the driver maintain optimal operating conditions and prevent overheating.

In Version 1 (2019), the analog gauge ranges from 0°C to 100°C with discrete green and red segments representing safe and critical temperature zones. The markings are minimal, and the needle contrast is low, making the gauge harder to interpret under glare or low-light conditions. The design provides basic thermal information but lacks a clear visual distinction between normal and warning limits, requiring drivers to focus closely on the dial during operation.

In Version 2 (2023), the gauge retains the same temperature range but adopts a continuous color gradient from green (safe) to yellow (caution) to red (overheat). The bolder markings

(a) Main-coolant Version 1 (2019) (b) Main-coolant Version 2 (2023)

Figure 1.8: Main-coolant layouts in e-bus: (a) 2019 deployed version, (b) 2023 pre-release version (Source: Author's field study, 2023).

and illuminated pointer enhance glanceability and nighttime visibility. A blue accent ring visually aligns the gauge with other EV indicators, creating a cohesive interface aesthetic. The improved color mapping allows faster identification of abnormal temperature levels, supporting more intuitive driver response.

1.1.2.6 Battery Coolant Temperature Gauge

The Battery Coolant Temperature gauge monitors the temperature of the cooling system dedicated to the traction battery (see Figure 1.9). It is critical for maintaining battery health, safety, and performance, as deviations from the optimal temperature range can significantly affect charging efficiency and lifespan.

In Version 1 (2019), the gauge displays a semicircular analog scale ranging from -10°C to 60°C. The dial uses red and green segmented zones, with the green region denoting safe operation. The design provides only a rough indication of temperature conditions. The dense markings and limited color differentiation reduce readability, requiring drivers to focus longer to interpret the data. The battery icon positioned near the dial lacks clear association with the cooling function, reinforcing ambiguity in the displayed information.

In Version 2 (2023), the gauge is refined with a simplified scale (0–50 °C) and a continuous color gradient. The visual range transitions smoothly from green (safe) to amber (caution) to

(a) Battery-coolant Version 1 (2019)

(b) Battery-coolant Version 2 (2023)

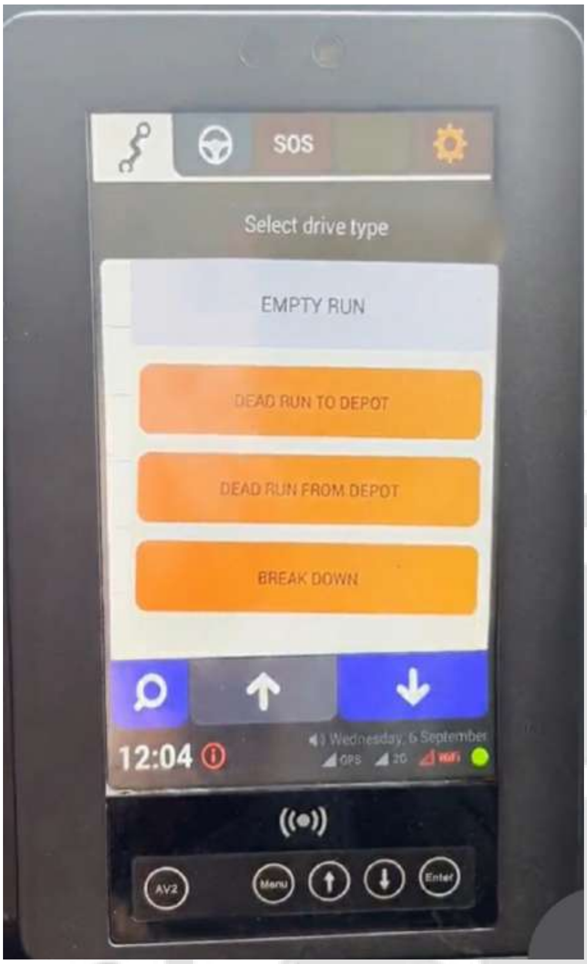
Figure 1.9: Battery-coolant layouts in e-bus: (a) 2019 deployed version, (b) 2023 pre-release version (Source: Author's field study, 2023).

red (critical), improving the perceptual clarity of temperature status. Enhanced pointer contrast and blue accent highlights ensure quick recognition under varying lighting conditions. The improved hierarchy and spacing allow drivers to detect potential thermal risks faster and respond appropriately.

1.1.3 ITS/DDU Display

The Intelligent Transport System (ITS), also referred to as the Driver Display Unit (DDU), is an external, government-mandated device installed primarily for operational monitoring rather than driver assistance. It is not developed or supplied by the vehicle manufacturer (OEM) but procured and managed by the state transport authorities. The ITS unit records route progress, distance travelled, stop adherence, and overspeed events for performance auditing and service regulation.

In Version 1 (2019), the ITS/DDU is mounted on the left side of the driver's seat as an independent third-party device. It displays basic operational data such as route number, start and end points, and trip ID (see Figure 1.10). Drivers manually input route details before starting the trip, and the system continuously tracks kilometers covered and stop-to-stop performance. Overspeed alerts are also issued through visual or auditory signals. However, the unit operates



(a) ITS/DDU Version 1:Drive Type

(b) ITS/DDU Version 1: Route Selection

Figure 1.10: ITS/DDU 2019 deployed version layouts in e-bus: (a) Drivetype, (b) Route Selection (Source: Author's field study, 2023).

completely independently of the main dashboard and vehicle data network, providing no diagnostic or energy-related information. The driver must shift attention between the ITS display and the primary instrument cluster, increasing cognitive load and potential distraction during driving.

In Version 2 (2023), the ITS/DDU maintains its external and regulatory role but introduces a more compact design with larger, high-contrast fonts and improved visibility under varying lighting conditions. Some models include additional features such as stop monitoring, live route updates, or rear camera integration, but each feature is provided on a paid basis, often requiring separate wiring and installation (see Figure 1.11). Due to the high costs, most OEMs only integrate the essential route and distance tracking functions, avoiding the full ITS suite.

(a) ITS/DDU Version 2:Bus parameters

(b) DDU Version 2: External alerts

Figure 1.11: ITS/DDU Version 2 layouts in e-bus: (a) Bus parameters, (b) External alerts (Source: Author's field study, 2023).

1.1.4 Switch Panel

The switch panels are positioned on both sides of the instrument cluster, providing access to essential operational and auxiliary functions. The switches control door operations, driver's cabin light, ventilation fan, hill-hold assist, wipers, and defoggers. Certain functions, such as door opening and closing, are duplicated on both panels for ease of access and redundancy.

The switches are primarily mechanical toggle or push types, arranged in horizontal rows without functional grouping or hierarchy. All switches are uniform in size and color, with limited labeling and low backlight visibility under daylight conditions. As a result, drivers often depend on memorized switch positions during operation. Between Version 1 (2019) and Version 2 (2023), there are no major design or functional changes in the switch panels. The configuration, placement, and wiring patterns remain largely identical, maintaining continuity for operational familiarity but offering limited improvement in usability.

1.1.5 Gear Control

The e-bus replaces the traditional mechanical gear lever with a streamlined electronic gear selection system featuring three push buttons: Reverse (R), Neutral (N), and Drive (D), positioned on the left side of the driver's console (see Figure 1.12). This single-speed configuration transfers torque directly from the electric motor to the wheels, simplifying operations compared to traditional multi-gear systems.

Figure 1.12: Gear mode control panel (Source: Author's field study, 2023).

The gear layout and interface remain unchanged between Version 1 (2019) and Version 2 (2023). Each mode is indicated by a backlit label, but there is no tactile or auditory feedback to confirm selection, occasionally causing uncertainty about the active drive mode. Despite its simplicity, the isolated control placement and lack of visual integration with the main display limit situational awareness during gear shifts.

1.1.6 Air Conditioning (AC) Unit

The air conditioning (AC) control unit is a basic manual block located on the left side of the dashboard, beneath the switch panel (see Figure 1.13).

It consists of a small monochrome display and a single rotary knob for temperature adjustment. The fan is always on full speed. The AC unit in both Version 1 (2019) and Version 2 (2023) remains largely unchanged. This setup offers basic functionality but lacks integration with the main display, limiting visibility of system status during operation, resulting in isolated operation from other dashboard subsystems. Field observations and stakeholder interviews confirmed that the identified interaction patterns, subsystem fragmentation, and information distribution practices are consistent across e-bus fleets operated by different state transport undertakings,

Figure 1.13: AC control panel (Source: Author's field study, 2023).

despite variations in branding and hardware.

The observations documented in this section establish an empirical baseline for analysing how existing e-bus dashboards support or constrain driver interaction, information access, and operational workflows. This baseline informs subsequent problem formulation, derivation of driver information requirements, and evaluation of redesigned dashboard interaction approaches presented in later chapters.

1.2 Problem Statement, Research Gaps, Research Questions, and Hypothesis

1.2.1 Problem Statement

Electric bus drivers in public transport systems are required to manage multiple operational demands, including monitoring vehicle energy status, system health, route adherence, traffic conditions, and passenger interactions. Dashboard interfaces constitute a primary medium through which such information is accessed during driving and therefore play a central role in supporting driver awareness and operational decision-making. Despite the increasing deployment of e-buses in Indian public transport systems, there remains limited empirical understanding of how existing dashboard interfaces support or constrain driver interaction under real-world operating conditions. In particular, it remains unclear whether current interface configurations adequately align with the information needs, workflows, and cognitive demands associated with e-bus operation.

Existing e-bus dashboards in India have largely emerged through incremental adaptation of conventional heavy-vehicle interfaces. As a result, critical operational information related to energy management, diagnostics, and system alerts is often distributed across multiple displays and subsystems. The extent to which such information organization affects driver workload, situational awareness, and decision-making during routine and non-routine operations has not yet been systematically investigated. Furthermore, current literature offers limited guidance on how interaction structures, information organization, and feedback mechanisms should be configured to support professional bus drivers operating electric vehicles in public transport contexts, particularly in developing regions such as India. Much of the existing research on electric vehicle interfaces has focused on private vehicles or controlled laboratory settings, leaving public transport operations and professional driver practices underexplored.

Consequently, there exists a knowledge gap regarding how dashboard interaction practices in e-buses can be empirically understood, evaluated, and informed by drivers' operational experiences. Addressing this gap requires systematic investigation of existing dashboard usage, driver workflows, and information requirements, followed by empirical validation of alternative interaction configurations within realistic public transport settings. This gap is particularly critical in safety-critical public transport systems, where delayed or misinterpreted information can directly impact operational safety.

1.2.2 Research Gaps

The following research gaps are identified through a systematic review of existing literature, detailed in Chapter 2. This review of the literature highlights a number of gaps in our current understanding of electric vehicle dashboard interfaces, particularly when considering public transport systems, professional driving contexts, and developing regions such as India. In particular, while automotive HCI research has extensively examined private vehicle interfaces, its applicability to public transport systems and professional driving contexts remains limited.

1. **Skewed research focus toward private electric vehicles in Western contexts:** Existing automotive HCI research has established substantial knowledge on electric vehicle dash-

boards, particularly in relation to energy visualization, range communication, trust, and cognitive workload in private passenger vehicles (Strömberg and Karlsson, 2011; Lundström and Bogdan, 2012; Khan et al., 2012; Neumann and Krems, 2016; Franke et al., 2015). However, this body of work is predominantly situated in Western contexts and focuses on individual drivers.

In contrast, comparatively little empirical attention has been given to e-buses or public transport vehicles operated by professional drivers (Stahl et al., 2020; Gödker et al., 2018). As a result, the applicability of these established insights to public transport settings remains limited, where operational demands, accountability structures, and driving conditions differ substantially from private vehicle use.

2. **Insufficient understanding of workflow-dependent information needs in public transport driving:** The literature indicates that professional drivers operate within structured workflows involving route adherence, schedule compliance, passenger management, depot communication, and fault handling (Ji et al., 2014). However, these workflow characteristics are rarely integrated into mainstream EV dashboard research, which largely assumes private-car driving scenarios (Jung et al., 2015; Neumann and Krems, 2016). Consequently, existing studies provide limited insight into how dashboard information organization aligns with the temporal phases and decision-making requirements of e-bus trips.

3. **Fragmented treatment of usability, cognitive workload, and information processing in EV dashboards:** A substantial body of work investigates usability, cognitive load, visual complexity, and glance behavior in EV dashboards (Yoon et al., 2015; Feng et al., 2018; Jung et al., 2021). However, these factors are often examined independently or under controlled laboratory conditions. Few studies adopt an integrative empirical approach that examines how information hierarchy, interaction structure, and visual complexity jointly influence workload and situational awareness during real-world e-bus operation (François et al., 2019).

4. **Underexplored applicability of digital and multimodal interaction approaches in e-bus environments:** Recent research on digital clusters, touch-based interfaces, adaptive displays, voice interaction, and multimodal feedback demonstrates potential benefits for usability and workload management in EVs (Jung et al., 2020; Piechulla et al., 2003;

Loehmann et al., 2014; Row and Kim, 2016; Lin et al., 2018). However, their suitability, workload impact, and learnability in safety-critical public bus environments remain an underexplored domain needing systematic research interventions.

5. **Lack of field-based validation of alternative dashboard interaction configurations with professional drivers:** Across the reviewed literature, there is a clear absence of comparative, field-based evaluations of alternative dashboard interaction and information organization configurations involving professional e-bus drivers (Normark, 2015; François et al., 2021). Most proposed interface concepts are assessed through laboratory experiments, short-term simulations, or exploratory studies. This limits the ability to derive empirically validated knowledge that can inform dashboard interaction practices in real-world e-bus operations.

While automotive HCI research has established foundational knowledge on driver interaction, cognitive workload, and interface usability in private vehicle contexts, these insights are not directly transferable to public transport systems. In particular, the operational complexity, shared accountability, and constrained driving environments of e-bus systems introduce distinct interaction challenges that remain insufficiently examined in existing literature.

Taken together, these gaps indicate that while automotive HCI research has established validated principles for dashboard usability, cognitive workload, and information presentation, these principles are largely derived from private vehicle contexts and controlled environments. Their applicability to public transport systems, particularly e-buses operating in developing regions, remains insufficiently examined.

More specifically, existing research does not adequately address the system-level complexity of e-bus dashboards, including fragmented multi-device environments, workflow-driven interaction across operational phases, and integration with depot-level communication systems. In addition, real-world constraints such as multilingual usage, infrastructural variability, and professional driving practices remain underrepresented.

Therefore, the research gap is not simply the absence of new design strategies, but the lack of a contextually grounded and empirically validated understanding of how established automotive HMI principles translate to real-world public transport environments.

1.2.3 Research Questions

RQ1: What are the prevailing practices and limitations of driver-facing dashboard interfaces in e-buses used in public transport?

RQ2: What usability and workflow-related challenges do professional e-bus drivers experience when interacting with existing dashboard interfaces during operation?

RQ3: What information requirements and interaction needs are necessary to support drivers across key operational phases of an e-bus trip?

RQ4: How do empirically examined alternative dashboard interaction and information organization configurations influence usability, mental workload, and acceptance among professional e-bus drivers?

1.2.4 Hypothesis

Electric bus dashboard interfaces, informed by empirically grounded, user-centered investigation of professional driving workflows, multilingual interaction contexts, and safety-critical operational demands, will result in improved usability, reduced mental workload, higher acceptance and better decision making among professional bus drivers in typical contexts, compared to existing dashboard interfaces used in Indian public transport systems.

1.3 Aim, Objectives, and Scope of Research

1.3.1 Aim

To generate empirically grounded knowledge on driver-centered interaction and information organization in e-bus dashboards within Indian public transport systems.

1.3.2 Objectives

[1] To systematically analyze existing dashboard interface configurations and driver experiences to identify recurring interaction patterns and gaps.
[2] To identify and categorize usability and workflow challenges in current e-bus dashboards.
[3] To derive and structure driver information requirements across different operational scenarios in public transport.
[4] To empirically examine alternative dashboard interaction and information organization configurations, instantiated through research prototypes, with professional e-bus drivers to generate evidence-based knowledge on usability, workload, and acceptance in the Indian public transport context.

1.3.3 Scope of Research

The scope of the research is defined across the following dimensions:

1. **Interface Knowledge Scope:** The research focuses on identifying and formalizing driver-centered interaction and information organization strategies related to information prioritization, interaction workflows, and feedback mechanisms in e-bus dashboard interfaces.

2. **System Scope:** The investigation is limited to driver-facing interface components, including the instrument cluster, intelligent transport system displays, switch panels, and associated visual feedback elements. Systems beyond the driver–vehicle interaction layer, such as fleet management platforms, passenger information systems, and policy-level transport planning, are explicitly excluded. Physical ergonomics are considered only insofar as they influence interface usability and interaction.

3. **Methodological Scope:** The study utilizes a user-centered interaction research approach, incorporating field observations, interviews with e-bus drivers and stakeholders, participatory prototyping, and usability evaluations. The methodology is scoped toward understanding experiential, cognitive, and operational aspects of driver–dashboard interaction,

rather than technical performance optimization or hardware-level engineering solutions.

4. **Contextual Scope:** The empirical investigations and validations are conducted within Indian urban electric public bus operations. The research is grounded in real-world public transport environments and driver practices in India.

Hence, the research area lies at the intersection of Human–Computer Interaction (HCI), e-bus technology, and user-centered interaction research (see Figure 1.14). While these domains have been explored independently, their integration toward understanding and improving driver–dashboard interaction in electric public buses remains underexplored. This intersection defines the core scope and contribution of the present research.

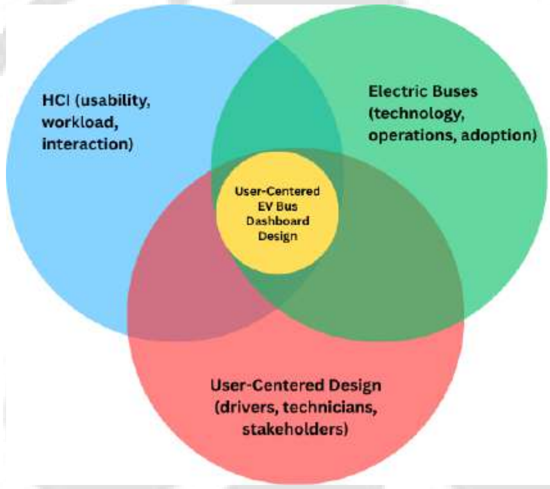


Figure 1.14: Conceptual representation of the research area and its key intersecting domains (Source: Author, 2024).

1.4 Research Contributions

This thesis makes the following key contributions:

1. Provides empirical understanding of driver–dashboard interaction in electric buses through field-based studies with professional drivers in Indian public transport contexts.

2. Identifies workflow-dependent information needs across pre-trip, in-trip, and post-trip phases of e-bus operation.

3. Characterizes key usability challenges related to information fragmentation, cognitive workload, and situational awareness in existing dashboard systems.

4. Develops and evaluates alternative dashboard interaction and information organization configurations through user-centered research prototypes.

5. Extends HCI and automotive interface research to multilingual, safety-critical, and developing-country contexts.

6. Generates practical design guidelines for driver-centered e-bus dashboards, addressing usability, safety, and contextual constraints in public transport systems.

1.5 Organization of the Thesis

This thesis is organized across seven different chapters. Each chapter emphasizes specific aspects of the current research (see Figure 1.15).

- **Chapter 1: Introduction** — This chapter introduces the research and establishes its foundation. It outlines the motivation behind the study, defines the research problem, and highlights the existing knowledge gaps. The chapter also presents the aim, objectives, research questions, hypothesis, and scope of the study, followed by the organization of the thesis.

- **Chapter 2: Systematic Literature Review and Theoretical Framework** — This chapter presents a comprehensive review of research on electric vehicles, in-vehicle information systems, dashboard design, and usability challenges, with particular emphasis on public transport applications. It synthesizes insights from prior studies to identify key themes, technological trends, and human–machine interaction issues relevant to e-bus dashboards.

- **Chapter 3: Research Methodology** — This chapter outlines the methodological approaches used in previous studies on electric vehicle interfaces, in-vehicle information systems (IVIS), and dashboard design. Based on the analysis of these methodologies, the present research identifies and adopts a suitable framework to investigate and redesign the dashboard interface for e-buses in India.

- **Chapter 4: Preliminary investigation of electric vehicle interfaces** — This chapter presents the preliminary phase of the research, focusing on identifying usability challenges and functional requirements for e-bus dashboards. It describes early user studies—including surveys, interviews, and contextual inquiries—conducted to understand existing interface issues and user expectations.

- **Chapter 5: Insights from original equipment manufacturer - stakeholders, technicians and drivers of e-buses** — This chapter presents the core user research conducted in two main parts: the stakeholder study and the driver study. It details the methods used to gather design requirements and insights into real-world usage contexts, including field observations, semi-structured interviews, card-sorting exercises, and focus group discussions.

- **Chapter 6: Design and evaluation of research prototype** — This chapter consolidates the finalized user requirements derived from earlier research and translates them into iterative design solutions. It describes the development of both low-fidelity and high-fidelity prototypes used to refine interface layouts and interaction flows. The prototypes are evaluated through pilot testing with design students and domain experts to identify usability issues and areas for improvement. Finally, the chapter presents the comprehensive usability testing conducted with e-bus drivers to assess performance, usability, and overall user experience.

- **Chapter 7: Discussion & Conclusion** — This chapter synthesizes the overall research findings and discusses their implications within the broader context of dashboard design for e-buses. It integrates the study's outcomes with existing literature, highlights key contributions to theory and practice, and presents design recommendations. The chapter concludes by acknowledging the study's limitations and outlining directions for future research.

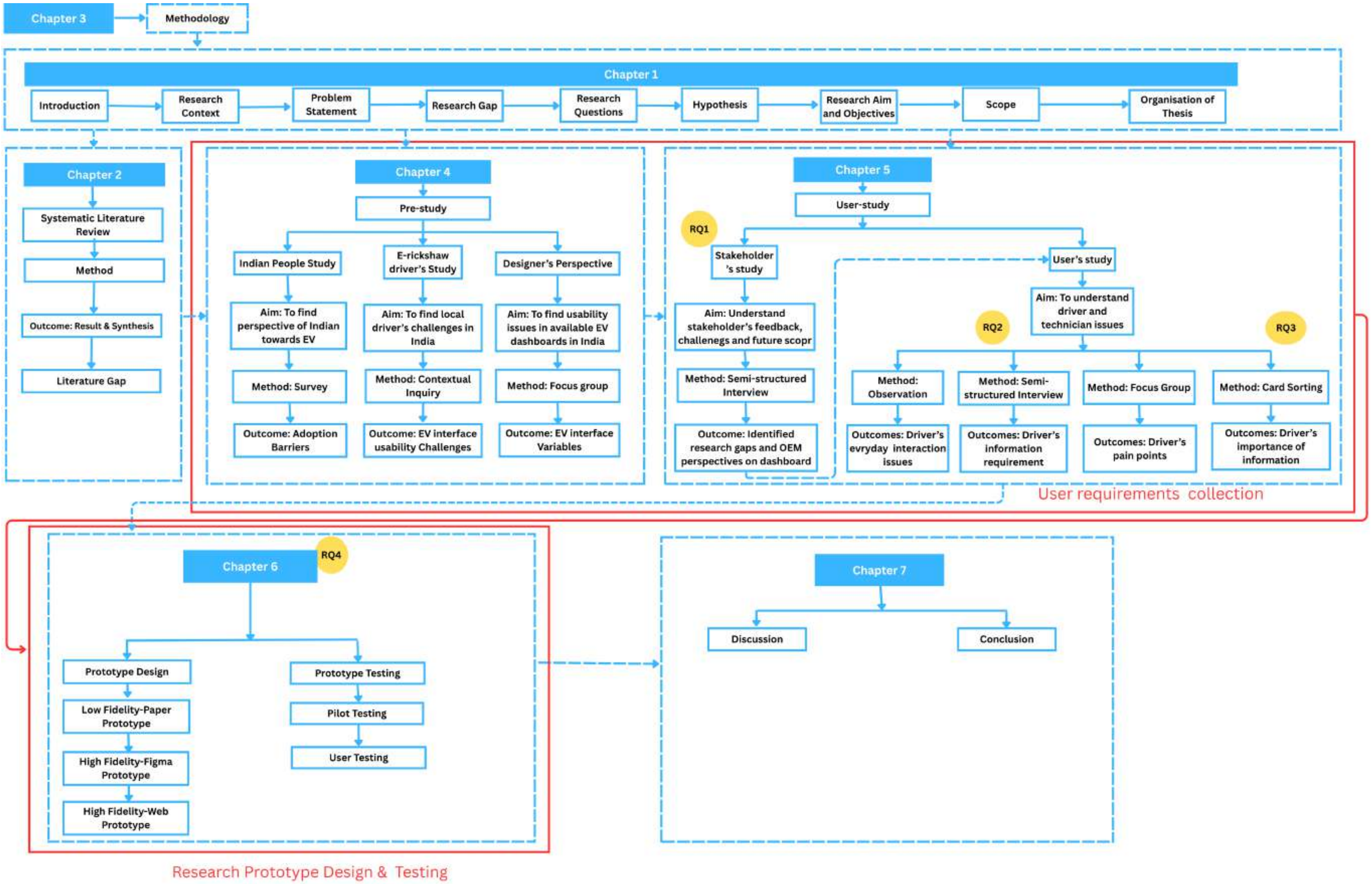


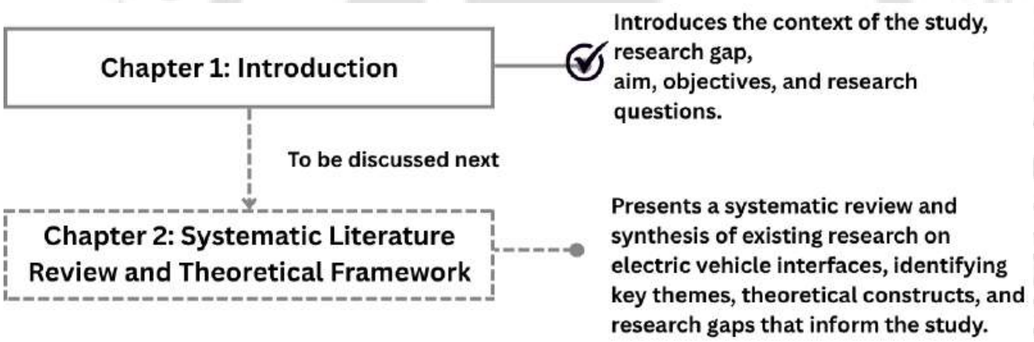
Figure 1.15: Organization of the Thesis.

1.6 Chapter Summary

This chapter establishes the foundation of the research project by introducing the context of e-bus dashboard design in India. It identifies key usability challenges, defines the research problem, and presents the aim, objectives, research questions, hypothesis, and scope of the study. The discussion highlights the need for an evidence-based redesign of e-bus dashboards from the driver's perspective.

Building on this foundation, the next chapter presents the systematic literature review and theoretical framework adopted in this research.

A chapter flow diagram is presented as follows:



Chapter 2

Systematic Literature Review and Theoretical Framework

This chapter presents a systematic literature review of research on driver-facing interfaces, with a focus on dashboards, instrument clusters, and in-vehicle information systems. The review examines prior work on drivers' information needs, usability challenges, and interface design strategies in the context of electric passenger vehicles and professional driving.

The review follows a structured and transparent approach, informed by established systematic review practices such as PRISMA, to ensure methodological rigor in study identification, screening, and synthesis. Furthermore, much of the existing research is concentrated in developed-country contexts, with relatively limited representation of studies from developing regions such as India.

In addition, limited attention has been given to formal standards and ergonomic guidelines. Context-specific interface requirements for public transport systems are also underexplored. To address these gaps, the chapter draws on insights from adjacent domains. These include electric cars, heavy vehicles, and professional driving environments. The findings are then synthesized to identify transferable design principles. They also help reveal domain-specific gaps relevant to e-bus interfaces. Overall, the review provides a theoretical and empirical foundation for the subsequent user research, design, and evaluation phases of this thesis.

2.1 Introduction

The design of user interfaces in electric vehicles (EVs) has received increasing attention due to the critical role dashboards play in supporting energy management, range awareness, system monitoring, and safe driving. As EV technologies evolve, dashboard interfaces serve as the primary medium through which drivers interpret vehicle status and make operational decisions.

In addition to academic research, formal standards and industry guidelines play an important role in shaping in-vehicle interface design. Standards such as ISO 15008 define ergonomic requirements for in-vehicle visual displays, including aspects such as legibility, luminance contrast, color usage, and visibility under varying lighting conditions (iso, 2017). Similarly, transport-oriented guidelines such as TCRP Report 185 emphasize the importance of clear information hierarchy, minimal distraction, and prioritization of safety-critical information in public transport interfaces (TCR, 2016).

Despite growing research on EV interface design, most existing studies are situated in the context of private electric cars. In contrast, the design requirements of e-buses differ substantially due to their operational complexity, including route adherence, passenger management, depot coordination, and fault handling alongside energy-related concerns. This context remains comparatively underexplored in current literature.

This chapter presents a systematic review of existing research on EV dashboard and interface design, with the aim of identifying key design approaches, usability challenges, and research gaps. Particular attention is given to understanding how insights derived from electric car interfaces can be adapted to the context of e-bus dashboards.

2.2 Chapter Objectives

The objectives of this literature review are as follows:

1. To review existing research on user interfaces and dashboards in electric vehicles, with emphasis on usability, information design, and driver cognition.
2. To identify limitations in current literature, particularly the under-representation of e-buses and public transport driving contexts.
3. To examine how user-centered design principles developed for electric car dashboards may be adapted to e-bus interfaces.
4. To synthesize empirical findings into thematic insights relevant to driver information needs, workflows, and interface evaluation.
5. To establish a conceptual and empirical foundation for the user research and dashboard redesign undertaken in later chapters.

2.3 Method

This literature review followed a structured and transparent approach. It is commonly used in HCI, automotive user interface research, and design studies. Rather than aiming for exhaustive statistical aggregation, the review focused on identifying key studies. These studies are influential, methodologically sound, and conceptually relevant. They address EV dashboards, driver interaction, and usability.

2.3.1 Search Strategy

Relevant literature was identified through searches conducted in major academic databases, including IEEE Xplore, ACM Digital Library, ScienceDirect, SpringerLink, and Google Scholar.

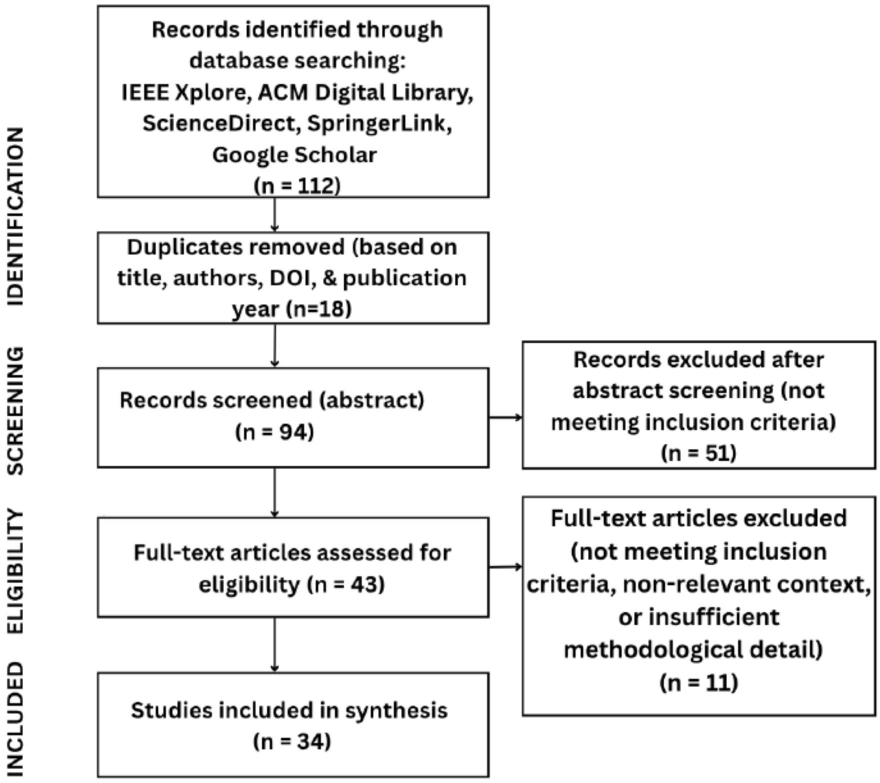


Figure 2.1: PRISMA Flow Diagram

These sources were selected for their coverage of engineering, transportation, ergonomics, and HCI research.

Search queries combined keywords related to electric vehicles, dashboards, and driver interaction. Searches were applied to titles, abstracts, and keywords using Boolean operators. Examples of search combinations include:

- “electric vehicle” AND “dashboard” OR “instrument cluster”
- “human–machine interface” OR “HMI” AND “electric vehicle”
- “usability” AND “in-vehicle information system”
- “electric bus” OR “public transport” AND “driver interface”

The review focused on publications from 2011 to 2025 to capture the emergence and evolution of digital dashboards and EV-specific interface challenges while retaining early foundational studies where relevant.

2.3.2 Study Selection

Identified studies were screened based on relevance to the research objectives. Initial screening was performed using titles and abstracts, followed by full-text review for selected papers.

Inclusion Criteria:

- Peer-reviewed journal articles or full conference papers.
- Studies addressing EV dashboards, instrument clusters, or in-vehicle information systems.
- Research involving usability evaluation, driver workload, trust, information design, or interface interaction.
- Studies conducted in electric cars, e-buses, or professional driving contexts such as buses or trucks.

Exclusion Criteria:

- Studies focused exclusively on battery chemistry, power electronics, or control systems without driver-interface implications.
- Conceptual papers lacking empirical grounding, design rationale, or evaluation.
- Research unrelated to driving or in-vehicle interaction.

2.3.3 Data Extraction and Analysis

For each selected study, key information was extracted, including publication details, vehicle context, study type, interaction modality, participant group, and principal findings related to dashboard usability and information design.

A thematic synthesis approach was used to organize and interpret findings across the selected studies. Rather than treating all EV dashboards as a homogeneous category, the synthesis explicitly distinguished between private car use and professional driving contexts.

2.4 Results and Synthesis

Based on the selection criteria, a total of 34 studies were retained for in-depth analysis (see Table 2.1). The reviewed literature demonstrates strong progress in understanding EV dashboard usability in private cars, particularly regarding energy feedback, range communication, and workload management. The primary themes identified in the literature include:

- Driver-centered dashboard usability and information hierarchy in EVs.
- Visualization of energy, range, and system status and their influence on trust and workload.
- Usability challenges related to visual complexity, glance behavior, and interaction layout.
- Dashboard design and evaluation in professional driving contexts, including buses and trucks.
- Digital and multimodal interaction approaches, such as touch, voice, and tactile feedback.

These themes provided a structured lens for interpreting the literature and for identifying gaps relevant to e-bus dashboard design.

Table 2.1: Final set of studies included in the systematic literature review (aligned with thematic synthesis)

ID	Title	Authors	Year	Source	Vehicle Context	Geographic Context
1	Driver interfaces for electric vehicles	Strömberg et al.	2011	ACM DL	Electric cars	Sweden
2	Designing the HMI to address range anxiety	Khan et al.	2012	IEEE Xplore	Electric cars	Europe
3	BEVs – Implications for the Driver Interface	Neumann & Krems	2016	Taylor & Francis	Electric cars	Germany

ID	Title	Authors	Year	Source	Vehicle Context	Geographic Context
4	Investigating usability of EV interface in simulation	Salmanzadeh et al.	2018	SciTechnol	Electric cars	-
5	Enough power to move: dimensions for representing energy availability	Lundström et al.	2012	ACM DL	Electric cars	Sweden
6	Differentiated Driving Range (Guess-O-Meter)	Lundström et al.	2014	ACM DL	Electric cars	Sweden
7	Getting the message across: energy interface design	Lundström et al.	2015	Springer	Electric cars	Sweden
8	Design to support energy management for EV drivers	Lundström et al.	2017	Springer	Electric cars	Sweden
9	Energy Flow: A Multimodal "Ready" Indication	Loehmann et al.	2014	ACM DL	Electric cars	Germany
10	Heartbeat: Experience the pulse of an electric vehicle	Loehmann et al.	2014	ACM DL	Electric cars	Germany
11	Energy feedback in EVs (multimodal study)	Landau et al.	2014	ACM DL	Electric cars	Germany
12	Advancing EV range displays: trust and adaptability	Franke et al.	2015	SAGE	Electric cars	Germany

ID	Title	Authors	Year	Source	Vehicle Context	Geographic Context
13	Displayed Uncertainty and Range Anxiety	Jung et al.	2015	ACM DL	Electric cars	Germany
14	Understanding range anxiety in EV drivers	Rauh et al.	2015	SAGE	Electric cars	Germany
15	The energy interface challenge	Franke et al.	2019	SAGE	Electric cars	Germany
16	Range InSight: Visualizing range in BEBs	Stahl et al.	2020	SAGE	E-buses	Germany
17	Perceived visual complexity of instrument clusters	Yoon et al.	2015	Taylor & Francis	Passenger cars	South Korea
18	User-centered design criteria in vehicle consoles	Gibson et al.	2016	Elsevier	Passenger cars	USA
19	Effects of interface layout on IVIS usability	Li et al.	2017	Elsevier	Passenger cars	China
20	Button quantity and size effects on glance behavior	Feng et al.	2018	Taylor & Francis	Passenger cars	China
21	Touch button interface usability	Jung et al.	2021	MDPI	Passenger cars	South Korea
22	Touch-based personalizable in-vehicle UI	Normark	2015	Taylor & Francis	Passenger cars	Sweden
23	Gauge design for truck digital clusters	François et al.	2019	Elsevier	Trucks	France
24	Usability of truck dashboards (PD vs UCD)	François et al.	2021	Elsevier	Trucks	France
25	Design of HCI method for intelligent EVs	Ba et al.	2022	MDPI	Electric cars	China

ID	Title	Authors	Year	Source	Vehicle Context	Geographic Context
26	Reducing drivers' mental workload using adaptive HMI	Piechulla et al.	2003	Elsevier	Passenger vehicles	Germany
27	Adaptive HMI for range-anxiety mitigation	Musabini et al.	2020	IEEE Xplore	Electric cars	Europe
28	User perspective on eco-driving HMIs for e-buses	Gödker et al.	2018	ACM DL	Electric buses	Germany
29	Bus drivers' response to real-time schedule adherence	Ji et al.	2014	Elsevier	City buses	China
30	Energy consumption displays in EVs	Gödker et al.	2024	SAGE	Electric cars	Germany
31	Improved eco-driving using consumption displays	Gödker et al.	2024	SAGE	Electric cars	Germany
32	Two types of eco-driving support displays	Gödker et al.	2025	SAGE	Electric cars	Germany
33	Voice + tactile in-vehicle interaction	Jung et al.	2020	ACM DL	In-vehicle systems	South Korea
34	Multimodal EV interaction framework	Jung et al.	2020	ACM DL	In-vehicle systems	South Korea

2.4.1 Theme 1: Electric Vehicle Dashboard Practices and Limitations

Early research on EV dashboards highlights a fundamental gap between technological advancement and interface design maturity. While battery systems, energy management, and vehicle performance have evolved significantly, dashboard interfaces have not progressed at the same pace, leading to persistent usability and comprehension challenges.

A foundational study by Strömberg and Karlsson (2011) demonstrates that even when EV-specific information is accurately presented, drivers struggle to interpret it due to unfamiliar mental models of energy consumption and electrical systems. The study shows that both traditional analogue-inspired layouts and novel digital representations can lead to confusion, indicating that simply introducing new visual formats does not guarantee improved usability. This finding establishes that the core issue lies not in the availability of information, but in its alignment with user cognition.

This limitation is further reinforced by longitudinal work by Neumann and Krems (2016), which examined driver interaction with battery electric vehicle interfaces over extended periods. Their findings reveal that drivers perceive EV dashboard information as only moderately reliable and helpful, and that this perception does not significantly improve with experience. In some cases, trust in displayed information decreases over time, particularly when drivers are unable to relate numerical indicators, such as energy consumption or range estimates, to real-world driving outcomes. These results highlight a critical mismatch between system feedback and user understanding.

Salmanzadeh et al. (2018) highlight that drivers have limited capacity to process in-vehicle information, demonstrating that poorly designed visual and multimodal interfaces can increase cognitive load and reduce usability.

Similarly, Khan et al. (2012) identify that EV dashboards often present complex and highly precise information related to range and energy consumption without adequate contextual support. Rather than reducing uncertainty, such representations can increase range anxiety and cognitive effort. This suggests that current dashboard designs frequently prioritize technical accuracy over interpretability, limiting their effectiveness in supporting driver decision-making.

2.4.2 Theme 2: Energy Representation and Range Communication

Electric vehicles introduce a fundamentally different information paradigm, where energy consumption and driving range are less intuitive compared to conventional fuel-based systems. As a result, the design of energy and range representations has emerged as a critical challenge in EV dashboard interfaces.

Early exploratory studies, such as Landau and Loehmann (2014); Lundström et al. (2012) and Loehmann et al. (2014), investigate alternative representations of EV system states through multimodal and experiential feedback. These approaches highlight the potential of non-traditional representations in improving driver engagement, although their effectiveness in supporting precise decision-making remains limited.

Further extending this line of work, Lundström and Bogdan (2017) emphasize the importance of designing energy interfaces that actively support driver learning and interpretation rather than merely presenting static information. Their findings suggest that interfaces which provide continuous and interpretable feedback enable drivers to better understand the relationship between driving behavior and energy consumption over time, thereby improving both trust and usability.

Early work by Lundström et al. (2012) highlights that drivers struggle to interpret energy availability due to the abstract and non-linear nature of electric energy consumption. Unlike fuel gauges, which are widely understood, EV energy displays often lack clear mental models, making it difficult for drivers to relate displayed information to real-world driving outcomes. This challenge is further emphasized in subsequent work on range visualization, where Lundström (2014) demonstrate that static or overly simplified range estimates can mislead drivers and fail to reflect the dynamic nature of driving conditions.

A significant body of research has therefore focused on improving trust and interpretability of range information. Franke et al. (2015) show that incorporating adaptability and transparency in range displays can enhance user trust, particularly when uncertainty is communicated effectively. Similarly, Jung et al. (2015) demonstrate that explicitly presenting uncertainty in range estimation can improve driver experience and reduce anxiety, as it aligns system feedback with the inherent variability of real-world conditions. Supporting this, Rauh et al. (2015) find that driving experience alone does not eliminate range anxiety, indicating that interface design plays a crucial role in shaping user perception and confidence.

Building on these insights, Franke et al. (2019) conceptualize the “energy interface challenge” as a fundamental issue in EV interaction design, emphasizing the need for interfaces that support users in forming accurate mental models of energy consumption and system behavior. Rather than simply presenting numerical data, effective interfaces must enable drivers to understand how their actions influence energy usage over time.

Complementing these findings, Lundström and Hellström (2015) emphasize that effective EV interfaces must clearly communicate actionable driving possibilities alongside system status, enabling users to relate energy information to real-world driving decisions.

In the context of public transport, these challenges become even more critical. As shown by Stahl et al. (2020), context-aware range representations in electric buses support driver decision-making under operational constraints such as fixed routes and schedule adherence. Their findings suggest that energy displays must be tailored not only to vehicle type but also to the specific demands of professional driving environments.

Collectively, these studies indicate that the effectiveness of EV dashboards depends not only on the accuracy of energy information but on how well that information is communicated, contextualized, and aligned with driver cognition. Addressing these challenges is essential for reducing range anxiety, improving trust, and enabling informed decision-making in electric vehicle operation.

2.4.3 Theme 3: Interaction Design, Cognitive Load, and Usability

A substantial body of research has investigated how interface design parameters influence driver workload, visual demand, and safety. Studies by Yoon et al. (2015) demonstrate that poor typography, dense layouts, and visual clutter significantly increase eyes-off-road time and visual search effort. These findings highlight the importance of clear visual hierarchy and legibility in supporting rapid information perception during driving.

In addition to visual complexity, broader interface design principles also play a significant role in shaping usability outcomes. Gibson et al. (2016) highlight that user-centered design approaches in vehicle consoles improve interaction efficiency by aligning interface structure with user expectations and task flow. Similarly, Li et al. (2017) demonstrate that interface layout organization directly affects both usability and driving safety, with poorly structured layouts increasing interaction time and error rates.

Touch-based interaction has been examined extensively in works by Feng et al. (2018) and Jung et al. (2021). These studies show that increasing the number of interface elements and poor layout organization directly increase task completion time and unsafe glance durations, even when button size is adequate. Importantly, they demonstrate that usability challenges are often driven by task structure and information grouping rather than the interaction modality itself. In touch-based interfaces, the absence of tactile feedback increases reliance on visual processing, further amplifying these effects.

Complementing these findings, Normark (2015) explore touch-based personalizable interfaces, showing that allowing users to adapt interface configurations can improve perceived usability and interaction efficiency. However, such flexibility must be carefully balanced with consistency to avoid increasing cognitive load during driving tasks.

Insights from heavy-vehicle contexts further reinforce these findings. François et al. (2019) demonstrate that even small changes in gauge orientation and pointer design can significantly reduce visual demand. Collectively, these studies establish that interface design decisions directly influence cognitive workload and driving safety, particularly in complex driving environments. Recent work by François et al. (2021) further extends these findings in heavy-vehicle contexts, demonstrating that usability issues in truck dashboards are often linked to a lack of user-centered design processes. Their results reinforce that systematic usability evaluation and iterative design are essential for reducing cognitive demand and improving driver interaction in complex operational environments.

2.4.4 Theme 4: Adaptive and Context-Aware Dashboard Systems

To address the limitations of static information presentation in vehicle interfaces, research has increasingly explored adaptive and context-aware dashboard systems, where displayed information is dynamically adjusted based on driving conditions, task demands, and user state. These approaches aim to reduce cognitive load by prioritizing relevant information and minimizing unnecessary visual complexity.

While adaptive interfaces show strong potential, their effectiveness depends on how well they are integrated with user expectations and driving context. Studies on intelligent EV interfaces, such as Ba et al. (2022), suggest that future dashboard systems must combine adaptability with predictive and context-aware capabilities to support real-time decision-making without increasing cognitive burden.

Early work in this area by Piechulla et al. (2003) demonstrates that adaptive human–machine interfaces can significantly reduce driver workload by selectively presenting information according to situational demands. By aligning interface behavior with driver needs in real time, such systems can improve both usability and safety. Extending this line of research, Musabini et al. (2020) investigate adaptive HMI strategies for mitigating range anxiety in electric vehicles, showing that dynamically tailored information can enhance user confidence and decision-making under uncertain conditions.

Recent studies have begun to explore these concepts in more complex and operationally constrained environments. For instance, as shown by Stahl et al. (2020), context-aware range representations in electric buses can support drivers in managing energy constraints alongside operational requirements such as route adherence and scheduling. Similarly, research in heavy-vehicle contexts highlights the importance of adaptive information presentation and redundancy in improving perception and reducing cognitive effort, particularly in high-demand driving situations.

Despite these advances, the application of adaptive and context-aware interfaces remains largely concentrated in experimental or passenger vehicle settings. Systematic investigation of such approaches in real-world commercial vehicle operations, particularly in e-buses, is still limited. This gap indicates the need for further research into how adaptive dashboard systems can be effectively designed and implemented for professional driving contexts, where task complexity and accountability are significantly higher.

Overall, adaptive dashboard systems represent a promising direction for addressing the challenges of information overload and dynamic driving environments. However, their successful integration requires careful consideration of context, reliability, and user trust to ensure that adaptive behavior enhances, rather than disrupts, driver understanding and performance.

2.4.5 Theme 5: Professional and Public Transport Driver Context

While much EV HMI research focuses on private car drivers, a smaller but crucial body of work highlights the distinct needs of professional drivers. The study by Stahl et al. (2020) is one of the few studies explicitly targeting e-bus drivers. It structured range-related user questions into clusters reflecting operational decision-making rather than personal anxiety, revealing fundamentally different information needs compared to private EV users.

Similarly, Gödker et al. (2018) showed that bus drivers prefer interfaces that confirm whether driving behavior is within acceptable efficiency bounds, rather than highlighting extremes. This contrasts sharply with private-car-focused eco-driving feedback systems that emphasize behavioral nudging.

Studies outside of EVs but within public transport, as cited by Ji et al. (2014), further illustrate that professional drivers actively adapt their behavior based on real-time operational information. These findings collectively demonstrate that dashboard design for e-buses must support workflows such as schedule adherence, depot reporting, and energy-efficient driving in fixed-route areas, which are largely absent from mainstream EV interface research. These requirements are consistent with TCRP Report 185, which emphasizes structured information hierarchy, prioritization of safety-critical alerts, and minimization of driver distraction in public transport interfaces.

2.4.6 Theme 6: Eco-driving Support and Behavioral Feedback Systems

Eco-driving interfaces actively support behavioral adaptation in EV driving. Gödker et al. (2024) introduce the concept of Energy Dynamics Awareness, highlighting how interfaces improve drivers' understanding of energy consumption.

In addition to visual feedback, multimodal interaction approaches have been explored to reduce reliance on visual attention. Jung and Others (2020) propose a combined voice and tactile interaction framework, demonstrating that multimodal systems can mitigate limitations of single-modality interfaces, such as high visual demand or memory load. By distributing interaction across multiple sensory channels, these systems can improve response time and reduce cognitive effort in driving tasks.

Gödker et al. (2024) demonstrate the effectiveness of real-time feedback systems, while Gödker et al. (2025) show that predictive guidance systems further enhance performance in complex scenarios. These studies indicate a shift from passive information display toward interfaces that actively influence driver behavior and decision-making.

2.4.7 Key Inferences

Based on the systematic review and thematic synthesis of the selected studies, the following key inferences are drawn:

- **Dominance of private EV contexts and limited focus on e-buses:** The reviewed literature is predominantly centered on private electric passenger vehicles, with comparatively limited and fragmented attention to e-buses and professional driving contexts. While a few studies address buses and heavy vehicles, these are context-specific and do not comprehensively capture real-world dashboard practices in public transport. This indicates a lack of systematic understanding of existing e-bus dashboard configurations and their operational limitations (RQ1).

- **Challenges in energy representation and range communication:** A substantial body of research highlights that drivers struggle to interpret EV-specific information, particularly related to energy consumption, state of charge, and driving range. The abstract and non-linear nature of electric energy systems, combined with insufficient contextualization, leads to misinterpretation, reduced trust, and range anxiety. Effective dashboard design therefore requires not only accurate data but also intuitive, context-aware representations that align with drivers' mental models (RQ2, RQ3).

- **Impact of interface design on cognitive load and usability:** Interface design parameters, including layout structure, visual complexity, and interaction modality, have a direct impact on driver workload and safety. Poor information hierarchy, cluttered displays, and inefficient interaction design increase cognitive load, task completion time, and eyes-off-road duration. Conversely, well-structured, user-centered interfaces significantly improve usability and reduce interaction effort, emphasizing the importance of cognitive alignment in dashboard design (RQ2).

- **Distinct needs of professional drivers and workflow-oriented interaction:** Professional drivers operate in task-intensive environments that require structured, predictable, and workflow-aligned information. Unlike private users, they prioritize operational clarity, including trip completion, schedule adherence, energy sufficiency, and fault diagnosis. Existing EV dashboard research only partially addresses these needs, indicating a mismatch between current interface designs and the requirements of professional driving contexts (RQ3).
- **Emergence of adaptive, multimodal, and intelligent interface approaches:** Recent studies explore adaptive dashboards, multimodal interaction, and intelligent HMI systems to address information overload and dynamic driving conditions. These approaches demonstrate potential in reducing cognitive demand and improving interaction efficiency by tailoring information presentation to context and user state. However, their application remains largely limited to experimental settings and private vehicle contexts (RQ4).
- **Limited empirical validation in real-world professional contexts:** Although various interface concepts, including eco-driving feedback systems and adaptive displays, have been proposed, most evaluations are conducted in controlled environments using non-professional participants. There is a lack of comparative, real-world validation of dashboard designs involving professional drivers and task-relevant performance measures such as workload, usability, and acceptance. This limits the translation of research findings into deployable solutions for e-bus systems (RQ4).

2.5 Theoretical Background

The present research is grounded in established constructs from HCI and cognitive theory that explain how drivers perceive, interpret, and interact with dashboard interfaces in safety-critical environments. Rather than treating these theories as isolated concepts, this study integrates them to guide both the design and evaluation of e-bus dashboards. These constructs are not independent; rather, they collectively explain how interface design decisions influence cognitive demand, perception, and interaction behavior in driving contexts.

2.5.1 User-Centered Design

User-Centered Design (UCD) provides a conceptual foundation for understanding how interactive systems should be developed in relation to user behavior, context, and task demands. Within human–computer interaction, UCD emphasizes that system usability is not an inherent property of the interface alone but emerges from the interaction between users, tasks, and environmental conditions (International Organization for Standardization, 2019a; Preece et al., 2015). This perspective is particularly relevant in safety-critical domains such as driving, where interface design must align with cognitive processes, situational awareness, and real-time decision-making.

Prior research in automotive HMI demonstrates that interfaces developed through user-centered processes are more effective in supporting driver comprehension, reducing cognitive load, and improving overall interaction quality (Strömberg et al., 2011; Jönsson and Nilsson, 2019). These studies highlight that usability issues often arise not from lack of information, but from poor alignment between system design and driver mental models. UCD therefore provides a framework for interpreting how design decisions influence driver behavior and interaction outcomes.

2.5.2 Cognitive Load Theory

Cognitive Load Theory (CLT) explains how the human brain processes and retains information and emphasizes the importance of managing mental effort during task execution. The theory, first proposed by Sweller (1988), divides cognitive load into three categories: (a) Intrinsic Load: the complexity of the task itself, (b) Extraneous Load: unnecessary information or distractions, and (c) Germane Load: the mental effort that contributes to learning or understanding.

CLT suggests that reducing extraneous cognitive load is essential for effective task performance, especially in high-stress environments like driving. For e-bus dashboards, this means presenting critical information (e.g., speed, battery level) in a clear, concise, and accessible manner. Overloading the dashboard with unnecessary or poorly organized information can distract drivers and increase the risk of errors.

In the context of dashboard design, principles derived from CLT are vital. For example, grouping related information (such as battery level and range estimation) minimizes the intrinsic load, while simplifying navigation reduces extraneous load. Furthermore, visual hierarchies, intuitive icons, and clear feedback mechanisms ensure that the driver can focus on the road without undue mental effort.

2.5.3 Information Hierarchy and Affordance Theory

Information Hierarchy and Affordance Theory are foundational principles in interface design that address how users perceive and interact with information. Affordance Theory focuses on the design cues that inform users about the possible actions they can perform with an object (Gibson, 1966). Information hierarchy, on the other hand, organizes data in a way that prioritizes the most critical elements, ensuring clarity and efficiency in interaction (Norman, 1988).

Affordance Theory posits that well-designed interfaces should inherently communicate their functionality. For instance, a button's shape, size, and placement should indicate that it is clickable. In the context of e-bus dashboards, physical knobs for critical controls (like lights or wipers) provide strong affordances, allowing drivers to quickly perform essential actions without confusion or hesitation.

Information hierarchy ensures that the most relevant information is presented prominently. For example, speed and battery level should be the most visible metrics, as they directly impact driving decisions. Secondary information, such as navigation or air conditioning settings, can be displayed in less prominent areas. Poor hierarchy or unclear affordances can lead to delays in critical decision-making, increasing safety risks.

To systematically translate the identified gaps into a research direction, Table 2.2 presents the alignment between literature gaps, research questions, and expected outcomes.

Table 2.2: Alignment of SLR gaps, research questions, and expected outcomes

SLR Gap	**Research Question**	**Expected Outcome**
Lack of empirical focus on e-bus dashboards and professional driving contexts	RQ1 – What are the prevailing practices and limitations of driver-facing dashboard interfaces in electric buses used in public transport?	Understanding of existing dashboard systems and identification of key limitations
Mismatch between dashboard interfaces and driver cognition (high cognitive load, poor information structuring)	RQ2 – What usability and workflow-related challenges do professional e-bus drivers experience when interacting with existing dashboards?	Identification of usability challenges such as cognitive load, visibility issues, and diagnostic ambiguity
Insufficient understanding of professional drivers' information needs and workflow requirements	RQ3 – What information requirements and interaction needs support drivers across operational phases of e-bus driving?	Structured and prioritized driver requirements aligned with workflow
Lack of validated dashboard redesigns evaluated with professional drivers in realistic contexts	RQ4 – How do alternative dashboard designs influence usability, workload, and acceptance among professional drivers?	Evaluation of redesigned dashboard and validation of usability improvements

An analysis of the geographic distribution of the reviewed studies (see Table **??**) indicates a strong concentration of research in developed regions, particularly Europe and East Asia. A substantial proportion of the studies on EV interface design and energy feedback systems, including Franke et al. (2015), Lundström (2014), and Gödker et al. (2024), are conducted in European contexts, primarily Germany and Sweden. In addition, several usability and interaction-focused studies, such as Yoon et al. (2015), Feng et al. (2018), and Jung et al. (2021), are situated in technologically advanced environments, including South Korea and China. Contributions from

North America are comparatively limited in the selected dataset.

Most of these studies are conducted in controlled environments such as driving simulators or experimental setups involving private vehicles, reflecting the availability of research infrastructure and the maturity of EV ecosystems in these regions. While a small number of studies extend to heavy vehicles and public transport contexts, such as Stahl et al. (2020), Gödker et al. (2018), and Ji et al. (2014), these are still largely confined to developed-country settings and specific operational scenarios.

In contrast, there is minimal representation of studies from developing countries, including India, where driving conditions, infrastructural constraints, and user diversity differ significantly. This imbalance highlights a critical gap in the literature, as interface design requirements for public transport systems in such contexts remain underexplored and insufficiently validated. Consequently, there is a clear need for context-specific investigations that account for the socio-technical realities of developing regions, particularly in complex domains such as e-bus operations.

2.5.4 Theoretical Basis of Evaluation Instruments

Evaluation of in-vehicle interfaces in automotive HMI research commonly relies on standardized subjective instruments to assess usability, workload, and user acceptance. This is particularly relevant in safety-critical and operational contexts, where controlled experimental measurement may be constrained by ecological validity, safety, and feasibility.

The System Usability Scale (SUS) (Brooke et al., 1996) is widely used to measure overall system usability, capturing perceived ease of use, complexity, and user confidence. In automotive interface research, SUS has been effectively used in controlled and semi-field evaluations to compare alternative dashboard designs and interaction concepts. For example, François et al. (2021) demonstrates that perceived usability scores obtained through standardized scales are strong predictors of driver acceptance and real-world HMI performance in heavy-vehicle contexts.

Task-level interaction experience is commonly assessed using the Single Ease Question (SEQ), which provides a rapid and reliable measure of perceived task difficulty. In driving contexts, such measures are particularly useful for identifying interaction bottlenecks without introducing intrusive instrumentation that may interfere with natural driver behavior. Prior public transport interface studies (Chang and Gunasekara, 2013; Jönsson and Nilsson, 2019) similarly rely on task-level ease and qualitative feedback to evaluate interaction flow and usability in operational environments.

Cognitive workload is typically evaluated using subjective rating scales such as the Rating Scale for Mental Effort (RSME) and the NASA Task Load Index (NASA-TLX). These instruments capture perceived mental effort and attentional demand, which are critical factors in driving performance and safety. Prior research shows that subjective workload measures remain sensitive to interface-induced cognitive demand even in stationary or semi-controlled environments. For instance, Kujala and Sarkar (2025) demonstrate that NASA-TLX can effectively distinguish between baseline driving and interaction-induced workload, even when task structures are not identical.

User acceptance is frequently assessed using the Van der Laan acceptance scale, which measures perceived usefulness and satisfaction. In professional driving contexts, acceptance is closely linked to long-term adoption, trust, and compliance with system feedback. Studies such as Gödker et al. (2018) and Lundström (2014) show that drivers are more likely to adopt systems that enhance situational clarity and reduce uncertainty. The present study shows similar patterns: higher acceptance scores are associated with clearer diagnostic feedback, an improved information hierarchy, and workflow-aligned interaction design.

Although these instruments do not capture fine-grained behavioral metrics such as glance duration or reaction time, they provide a robust and practical framework for evaluation under real-world constraints. As shown in prior studies, including Burns et al. (2010) and Harvey and Stanton (2013), stationary and controlled testing environments can still yield valid insights into interaction demand and usability when supported by structured evaluation metrics.

2.5.5 Theoretical Implications

The theoretical constructs discussed above provide a conceptual understanding of how users interact with complex interfaces in safety-critical environments. The following inferences are derived from these theoretical perspectives:

- User-centered design establishes that usability emerges from the alignment between user characteristics, task requirements, and environmental context. Interfaces that are not grounded in actual operational workflows are likely to result in inefficiencies and interaction challenges.
- Cognitive Load Theory explains that human information processing capacity is limited, particularly in time-constrained environments. Poorly structured or excessive information increases extraneous cognitive load, leading to reduced comprehension and higher mental effort during interaction.
- Information hierarchy and affordance collectively determine how effectively users perceive and act upon interface elements. Clear prioritization of critical information and intuitive design cues enable rapid interpretation and response, while poor structuring leads to delays and errors.
- Task-oriented environments require interfaces that support predictability, clarity, and minimal interaction effort. Users in such contexts rely on structured and workflow-aligned information rather than exploratory or highly expressive interface designs.
- Interaction effectiveness in safety-critical systems is strongly influenced by contextual factors such as attention demands, physical constraints, and task complexity. Usability and workload are therefore dependent on how well interface design aligns with these conditions.

2.6 Chapter Summary

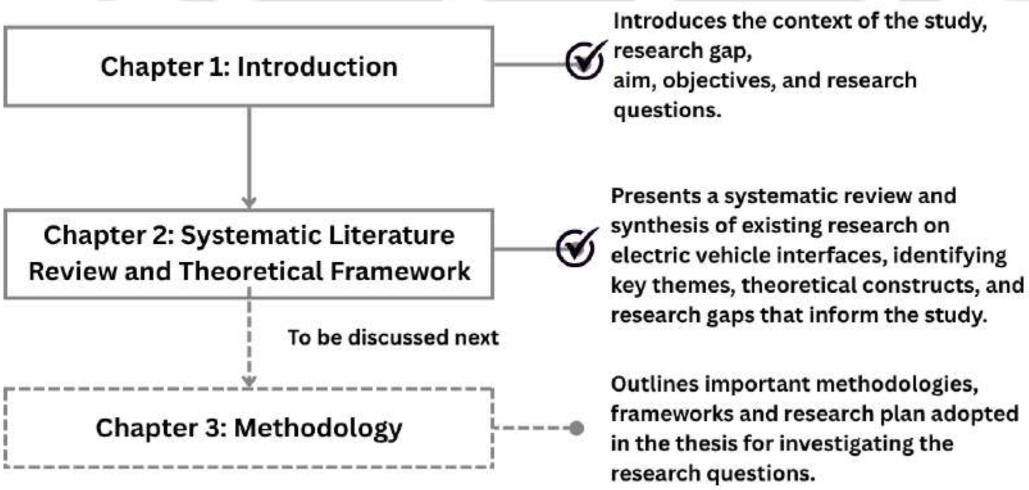
This chapter presents a systematic review of the literature on electric vehicle dashboards and driver–vehicle interaction, with a particular emphasis on usability, information presentation, and driver-centered interface approaches. The review examined studies spanning electric passenger cars, heavy vehicles, and a limited number of public transport applications to understand prevailing interface practices, evaluation approaches, and recurring usability challenges.

The synthesis revealed that existing research largely prioritizes private electric vehicles and Western usage contexts, with comparatively little empirical attention given to e-buses and professional drivers. While prior work demonstrates that dashboard interfaces significantly influence driver trust, workload, and decision-making particularly for energy and range-related information—these insights are rarely adapted to the operational realities of public transport driving. Furthermore, workflow-dependent information needs of professional drivers, such as trip monitoring, schedule adherence, and fault interpretation, remain underrepresented in current EV interface research.

The review also identified limited empirical validation of alternative dashboard interface configurations evaluated with professional drivers in realistic or task-relevant contexts. Most proposed interface concepts are assessed through laboratory studies or short-term simulations, which restrict their applicability to real-world e-bus operations. Together, these findings establish a clear research gap that motivates the present study.

In response, the next chapter outlines the methodological framework adopted to investigate existing e-bus dashboard interfaces, capture driver requirements, and empirically evaluate alternative interface configurations using user-centered methods.

A visual summary of the chapters covered so far is presented as follows:



Chapter 3

Research Methodology

This chapter outlines the methodological approach used to design and evaluate the proposed e-bus dashboard.

3.1 Introduction

The research methodology adopts a mixed-method, design-oriented approach grounded in User-Centered Design (UCD) to investigate and improve driver–dashboard interaction in electric buses (e-buses). The study integrates qualitative methods (contextual inquiry, interviews, and focus groups), quantitative measures (standardized usability and workload scales), and iterative prototyping within a unified framework.

UCD is selected as the primary approach due to the safety-critical and context-dependent nature of e-bus dashboard interaction. It enables iterative development grounded in real user behavior, ensuring alignment with operational workflows, cognitive demands, and environmental constraints. Compared to alternative approaches, UCD provides a structured process that supports both empirical inquiry and systematic design refinement.

The methodology is designed to capture real-world driver behavior, translate insights into interface design, and evaluate usability under operational conditions.

3.2 Chapter Objectives

This chapter has the following objectives:

1. To present the methodological framework adopted for designing and evaluating the e-bus dashboard.
2. To identify and synthesize key methodological patterns from prior automotive HMI and EV dashboard studies.
3. To describe the methods used for data collection, requirement specification, design development, and usability evaluation.
4. To demonstrate the alignment between research questions, methods, and outcomes.

3.3 Methodological Foundations from Prior Research

This section builds on the systematic literature review presented in Chapter 2 and focuses specifically on extracting methodological patterns from prior studies that inform the design of the present research. The focus is on how earlier studies structured data collection, prototyping, and evaluation, and how these methodological approaches can be adapted to the current context of e-bus dashboard design.

A foundational study in this area is that of Burns et al. (2010). Their work validates stationary-vehicle testing as an effective method for evaluating visual–manual in-vehicle interfaces. Their experiment involves 24 licensed drivers aged between 20 and 55. Using a production vehicle interface, participants perform infotainment and control tasks such as menu navigation, temperature adjustment, and address entry. All tasks took place in a parked, instrumented car to remove motion-related effects and to maintain precise control over task timing and visual attention. The researchers measured Static Task Time (STT) and Total Shutter Open Time (TSOT) using the ISO 16673 occlusion method. The participant's view of the display is intermittently blocked to simulate glances away from the road. The researchers compare these measures with on-road glance data, such as total eyes-off-road time and glance duration. The results reveal a strong correlation between static and dynamic metrics, confirming that stationary occlusion testing accurately predicts visual demand and task complexity. The study concludes by emphasizing that early parked-vehicle evaluations allow designers to detect high-demand interactions and refine display layouts before conducting costly field trials.

A subsequent methodological reference is Andersson's thesis, "Redesign of Instrument Cluster" Andersson and Ericsson (2011), conducted at Saab Automobile AB and Chalmers University. Their study focuses on improving the instrument panel cluster (IPC) for Saab's first electric vehicle, the Saab Zero Emission (ZE). Andersson aims to test whether a conventional fuel-based cluster suits an electric vehicle and to identify which gauges, telltales, and feedback elements need redesign for clearer user understanding. The research follows a structured UCD process in two phases. In Phase I, the researcher evaluates the existing IPC using heuristic evaluation, hierarchical task analysis, cognitive walkthroughs, and simulator-based testing with five participants. The researcher uses think-aloud protocols to identify usability problems related to comprehension, errors, and cognitive load. In Phase II, the researcher moves to concept generation, selection, visual redesign, and simulator implementation of a new IPC prototype. The redesigned interface improves the clarity and relevance of feedback for Distance to Empty (DTE), State of Charge (SOC), Auxiliary Load, and Ecometer gauges. Saab integrates this prototype into its full-scale driving simulator for internal testing. Andersson concludes that while the traditional cluster offers familiarity, it misleads users about EV behavior. The study highlights the need for EV-specific feedback and cognitive support. Researcher Helena Strömberg later receives the redesigned prototype and evaluation data for detailed experimental validation.

A direct continuation of Andersson's work is the study by Strömberg and Karlsson (2011). This research builds on the redesigned instrument cluster for the Saab Zero Emission (ZE) vehicle and evaluates it through formal user experiments. The study takes place at Saab Automobile AB's driving simulator facility. Strömberg compares two interface types: (1) a traditional analog cluster and (2) a new digital concept using a between-subject design with twenty participants. Participants are assigned to one of the two interface conditions and complete a simulated electric-vehicle driving scenario that triggers events such as low-battery warnings, "charge now" messages, and performance alerts. The researchers record comprehension accuracy, task completion time, error rate, event recognition, and subjective satisfaction. They collect both objective data, such as reaction time, control actions, and errors, and subjective data from post-task questionnaires, interviews, and think-aloud feedback. The results show that both interfaces communicate essential EV information but differ in usability. The analog layout supports comfort and familiarity, while the digital interface improves accuracy and awareness of energy use. This study demonstrates an early evaluate–redesign–validate process for developing electric-vehicle HMIs, indicating that simulator-based, mixed-method usability testing can yield valid insights when field studies are not feasible.

A distinct line of inquiry is presented in the work of Lundström and colleagues. In a series of three studies, (1) COPE1: Taking Control over EV Range (Lundström and Bogdan, 2012), (2) Enough Power to Move (Lundström et al., 2012), and (3) Differentiated Driving Range (Lundström, 2014). They explore how electric-vehicle drivers perceive and manage range information. The first study Lundström and Bogdan (2012) uses a contextual inquiry approach to understand real-world driving behavior under range limitations. They conduct semi-structured interviews and on-road observations with twelve EV drivers to document how they plan routes, adjust speed, and selectively use vehicle systems to cope with range anxiety and uncertainty. These observations help the researchers uncover key behavioral patterns that reflect how drivers adapt to limited range conditions. Building on these insights, the next study Lundström et al. (2012) transitions from observation to design exploration. Here, eight participants from the earlier phase take part in participatory sessions where they interact with conceptual prototypes. These prototypes show available energy using simple visual cues, such as color gradients and light zones, rather than numbers. The researchers collect qualitative feedback through think-aloud discussions and preference rankings. The findings show that such spatial-ambient displays reduce cognitive load and enhance intuitive understanding of range status. Lundström and colleagues (Lundström, 2014) present the third study in their series, Differentiated Driving Range. In this work, they test how different range displays affect drivers' confidence and decision-making. The researchers developed three visual concepts: reachable, uncertain, and beyond range. Each concept uses color-coded overlays on a navigation map to show how far the vehicle can travel on its current charge. They run the study in a fixed-base driving simulator with real-time battery and route data. Twenty licensed EV drivers take part. Each driver completes three short driving sessions, one for each display type. During the tasks, drivers plan routes, monitor energy use, and decide whether to continue driving or stop for charging. The simulator records objective data such as time to decision, route choice, and number of interface interactions. After each session, drivers fill out short questionnaires to rate their confidence, clarity, and trust in the feedback. The researchers also interview them to understand how they interpret the color-coded range zones. The results show that the differentiated three-zone display increases driver confidence and reduces uncertainty compared to numerical-only range indicators. Drivers report higher trust and faster understanding when visual cues support numerical information.

A further methodological contribution is presented by Harvey and Stanton (2013). In this study, Harvey and his team aim to predict and evaluate touchscreen in-vehicle information systems (IVIS) using Critical Path Analysis (CPA) in a stationary vehicle setup. They involve twenty professional and private drivers who perform fourteen typical infotainment and driving-support tasks. These tasks involve entering destinations, controlling the climate, adjusting audio, and acknowledging messages on a custom touchscreen prototype created using Microsoft Visio and Adobe Flash. The researchers break each task into visual, manual, and cognitive steps and use CPA to model the minimum completion time based on task dependencies. They collect data on task duration, touch count, error rate, and subjective workload ratings while participants perform tasks inside a fixed, non-moving vehicle. The research team then compares CPA-predicted task durations for fast, average, and slow users with the observed median times. They use percentage deviation and correlation analysis to examine the relationship between predicted and actual results. The findings show that CPA predictions stay within 20 percent of the observed task durations. Error patterns also match those found in dynamic driving studies, suggesting that stationary-vehicle testing reliably reflects real driving conditions. The study demonstrates that static evaluations can effectively model both temporal and cognitive aspects of interaction with in-vehicle systems.

An early and methodologically rich example of UCD in public transport comes from the work of Chang and Gunasekara (2013). In this study, the researchers focus on the ITID system, a touchscreen interface within Gothenburg's ITS4Mobility platform used by Volvo Bus Corporation. Their goal is to improve the usability and clarity of real-time driving information for professional bus drivers, specifically features related to route adherence, stop management, and schedule deviation alerts. The researchers begin with contextual inquiry. They observe fifty active bus drivers during their regular service and conduct semi-structured interviews with fifteen of them. These methods help identify major usability problems, including interaction bottlenecks, poor visibility, and high mental workload during driving. Using the insights from this fieldwork, the team develops low-fidelity prototypes with paper and Adobe Flash. They then test these prototypes with seven professional drivers using think-aloud protocols and post-session interviews to gather detailed feedback on usability and comprehension. Analysis of the results reveals four key issues: excessive manual operations, fragmented data layouts, delayed system feedback, and redundant visual layers. To address these issues, the researchers apply Nielsen's usability heuristics and Norman's design principles, with particular focus on visibility, feedback, and consistency. The redesigned prototype features a simplified home screen, contextual alerts, and quick-access shortcuts for timetable adjustments and route communication.

The thesis by Nilsson and Olsson (2014) at Volvo Bus Corporation extends the UCD approach to public transport systems. The study examines how task context and route type shape the design of driver information systems. Nilsson and her team aim to improve information flow and reduce cognitive strain for professional drivers in city, intercity, and tourist operations. They begin with contextual inquiry, combining on-route observations and semi-structured interviews to study how visual overload, alert timing, and information hierarchy affect driver workload. They find that city routes demand rapid attention shifts, while intercity and tourist routes require adaptive feedback and sustained focus. Based on these insights, they design conceptual layouts structured by task segments and adaptive information zones. The team conducts expert walkthroughs and driver feedback sessions to refine the layouts. Drivers assess each version for clarity, error communication, and adaptability. Through these iterations, Nilsson identifies that a modular, adaptive cluster design supports focus and reduces visual strain.

Ordóñez-Hurtado et al. (2018) investigate whether stationary vehicles can serve as effective test platforms for Intelligent Transportation Systems (ITS) and driver–vehicle interface research. They combine field GPS logging with urban-scale simulation using the SUMO traffic model to examine how parked and temporarily stopped vehicles behave in dense city environments. The researchers collect data from a fleet of instrumented vehicles fitted with positioning sensors. They record stationary duration, location stability, and signal accuracy across multiple urban sites. They analyze the data using Gaussian noise modeling and mean absolute error comparisons between static and moving conditions. The results show that parked vehicles remain stationary long enough to ensure stable environmental conditions and repeatable sensor readings. These findings confirm that stationary vehicles provide a reliable, safe, and controllable setting for early testing. From a methodological perspective, the study demonstrates that stationary test setups can yield valid and reproducible data before dynamic or on-road trials.

François and colleagues investigate one of the most comprehensive methodological progressions in heavy-vehicle HMI research. Their studies trace a clear shift from controlled experiments to participatory design and field validation, establishing a foundation for cognitive and perceptual dashboard design. The first study by Francois et al. (2016) examines the transition from analog to digital speedometers through a simulated driving experiment with 18 truck drivers. The participants perform speed-reading and comprehension tasks using analog, digital, and hybrid layouts. The results show that hybrid designs, which combine analog pointers with digital numerals, preserve familiarity while improving reading precision. This study establishes the foundation for examining visual continuity and adaptation during digitalization. This is a key design and evaluation concern also addressed in the present research. The research focuses on transitioning Indian bus drivers from analog to digital dashboards. Building on this François et al. (2017a) conducts a redundant-display study with 20 professional drivers using a simulated truck cockpit. Participants identify visual cues across different workload levels. The study shows that using consistent color, symbols, and spatial cues improves recognition accuracy and decreases mental effort. This insight informs the current research, where multimodal diagnostic feedback aids efficient alert interpretation in high-demand driving environments. François et al. (2017b) expands this work by establishing a participatory co-design framework with 12 professional drivers. They invite drivers to co-create display layouts, express ergonomic priorities, and evaluate early interface sketches. This participatory phase bridges laboratory testing and field reality, demonstrating how iterative driver feedback produces functionally and perceptually grounded display designs. The present study follows this model by integrating feedback loops from e-bus drivers during successive prototype refinements. In a subsequent simulator study, François et al. (2019) evaluates gauge configuration and information density using 22 drivers. Participants perform symbol identification and monitoring tasks, followed by post-task usability scales that measure clarity and cognitive load. The findings show that moderate information density and simplified scaling enhance readability and comfort. This evidence supports the simplified visual structure adopted in the current dashboard prototype and validates the use of subjective usability ratings when field conditions limit objective measurement. The research sequence culminates in François et al. (2021), a comparative usability and acceptance study with 24 professional truck drivers. The participants evaluate three dashboard prototypes in a semi-static cab environment using standardized usability scales. The results show that perceived usability, task clarity, and cognitive comfort predict real-world HMI performance.

Gödker et al. (2018) develop a focused line of research on human–machine interfaces for battery-e-buses (BEBs). Their work pioneers UCD methods designed for professional drivers in public transport. It forms a methodological bridge between private EV interface studies and heavy-vehicle operational contexts, where range perception, workload, and situational clarity are essential for safe and efficient driving. In User Perspective on Eco-driving HMIs for e-buses in Local Transport, Gödker and colleagues conduct a user-centered evaluation of a prototype Eco-Assistant display. The display supports energy-efficient driving through minimal and context-aware feedback. The researchers collect data through semi-structured interviews and post-prototype use discussions with 10 professional bus drivers. They transcribe and analyze the data inductively using in-vivo coding to identify how drivers interpret visual cues and respond to eco-driving feedback. The results show that drivers prefer compact and context-relevant feedback such as green-zone range indicators over abstract or gamified displays. These preferences highlight the importance of perceptually direct and cognitively lightweight information in professional driving contexts.

Another study by Jönsson and Nilsson (2019) also follows a structured UCD process in collaboration with LTG Sweden AB to develop a digital touchscreen interface for public-transport bus drivers. The study aims to simplify operational workflows such as route management, communication, and schedule monitoring within an integrated system. Data collection begins with ethnographic fieldwork, including depot observations, in-cab interviews, and video documentation, to capture authentic task flows and identify sources of cognitive strain during daily operations. Insights from this contextual inquiry inform the creation of task models and information hierarchies that define the prototype structure. The team iteratively refines low-fidelity sketches and wireframes through participatory workshops with drivers and interface engineers. These sessions reveal key design priorities: reducing visual clutter, consolidating key information, and ensuring compliance with safety regulations that restrict interaction while driving. For evaluation, the team conducts usability testing using interactive prototypes. They combine quantitative metrics (task success rate, error count, completion time) with qualitative measures (subjective workload ratings and post-session feedback). The findings lead to several refinements, including improved icon grouping, higher contrast for critical alerts, and a streamlined navigation structure. The thesis demonstrates a comprehensive UCD process, from contextual inquiry to iterative prototyping and empirical validation, applied in a real operational environment. It shows that participatory usability testing and iterative refinement align interface functionality with driver cognition.

A methodological shift appears in the Range InSight study by Stahl et al. (2020). The study extends the earlier Eco-Assistant work by moving from driver-centered evaluation to expert-based modeling of range information for battery-e-bus (BEB) operations. Stahl and colleagues engage 9 domain experts who generate and refine 68 user questions on range estimation, route uncertainty, and feedback reliability. The researchers then organize these questions into four cognitive information clusters that represent distinct mental models of range perception. These clusters guide the design of conceptual display prototypes intended to improve drivers' situation-aware understanding of range dynamics. Methodologically, Range InSight introduces a systematic expert-elicitation framework that translates domain expertise into structured interface concepts through information clustering and conceptual modeling. The study shows how designers transform qualitative expert insights into actionable design parameters.

An additional line of work by Andréasson and Boman (2022) explored the transition from analog to digital interfaces in electric terminal tractors through a UCD process. The study focused on minimizing cognitive friction and legacy bias among professional operators accustomed to traditional dashboards. Data collection started with stakeholder interviews and observations in logistics yards to document habitual control usage, glance behavior, and significant performance pain points during loading and maneuvering. These findings guided the creation of concept sketches and digital mock-ups that preserved familiar analog affordances while introducing digital enhancements for energy and status feedback. Iterative prototype testing was conducted using a combination of heuristic evaluation, think-aloud sessions, and scenario-based walkthroughs, where participants performed standard operational tasks such as docking, reversing, and system monitoring. The results highlighted that visual continuity with legacy interfaces reduced cognitive disruption and improved user acceptance of digital instrumentation. This thesis emphasized the importance of transition-oriented design strategies that connect familiarity and innovation through gradual digitalization.

A related study by Kujala and Sarkar (2025) examines differences in workload between baseline driving and in-car interface conditions. The study assesses driver workload using the NASA Task Load Index (NASA-TLX) while participants complete ten common infotainment tasks, including adjusting the air conditioning, selecting drive modes, entering navigation information, and operating the radio, in two electric vehicles: the VW ID.7 and the Kia EV9. The baseline condition involves driving without any secondary task, representing normal attentive driving. The researchers compare inattentiveness ratios and NASA-TLX scores between baseline and in-car task drives to estimate the additional workload introduced by interface interaction. This study uses uneven task conditions when identical task replication is not feasible in baseline settings.

Table 3.1: Methodological precedents in electric vehicle and public transport HMI research

Author(s) & Year	**Domain / Focus**	**Methods Used**	**Participants / Context**	**Key Measures / Data Collected**	**Methodological Contribution to Current Study**
Burns et al. (2010)	Validation of stationary-vehicle testing for visual–manual IVIS	ISO 16673 occlusion method; measurement of Static Task Time (STT) and Total Shutter Open Time (TSOT)	24 licensed drivers (aged 20–55) performing infotainment and control tasks in a parked vehicle	STT, TSOT, comparison with on-road glance data (eyes-off-road time)	Establishes validity of stationary occlusion testing; supports early-phase usability testing in parked e-buses
Andersson and Ericsson (2011)	Redesign of instrument cluster for Saab Zero Emission (ZE) EV	Heuristic evaluation, Hierarchical Task Analysis, Cognitive Walkthroughs, simulator-based testing	5 participants (Saab Automobile AB simulator)	Usability errors, comprehension, cognitive workload, user feedback	Demonstrates evaluate–redesign–validate UCD process; identifies EV-specific feedback needs (SOC, DTE, ecometer)

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Table 3.1 continued from previous page

Author(s) & Year	Domain / Focus	Methods Used	Participants / Context	Key Measures / Data Collected	Methodological Contribution to Current Study
Strömberg and Karlsson (2011)	Evaluation of redesigned instrument cluster concepts for EVs	Between-subject simulator study; mixed-method usability evaluation	20 participants (10 per interface condition)	Task completion time, error rate, comprehension, satisfaction	Validates redesigned concepts via simulator testing; exemplifies mixed-method analysis for EV HMI evaluation
Lundström and Bogdan (2012)	COPE1 – Coping mechanisms for EV range anxiety	Contextual inquiry, semi-structured interviews, on-road observation	12 EV drivers (mixed gender, ages 25–60) participated in interviews and drive-along contextual observations.	Qualitative insights on coping strategies (route planning, speed control)	Provides contextual foundation for understanding range behavior in EVs

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Table 3.1 continued from previous page

Author(s) & Year	Domain / Focus	Methods Used	Participants / Context	Key Measures / Data Collected	Methodological Contribution to Current Study
Lundström et al. (2012)	Enough Power to Move – Conceptual representation of energy availability	Conceptual prototyping and participatory evaluation sessions using visual and ambient range cues (e.g., color zones, light gradients)	8 participants from prior COPE1 phase	Qualitative feedback collected through think-aloud discussion and preference ranking.	Shows transition from qualitative insight to concept-based design using participatory evaluation to ground abstraction in driver cognition.
Harvey and Stanton (2013)	Prediction and evaluation of touchscreen IVIS using CPA	Stationary vehicle testing, Critical Path Analysis, quantitative comparison	20 professional/private drivers performing 14 infotainment tasks	Task duration, error rate, touch count, subjective workload ratings	Validates stationary testing for estimating dynamic task patterns; supports task-time comparison for EV bus dashboards

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Author(s) & Year	**Domain / Focus**	**Methods Used**	**Participants / Context**	**Key Measures / Data Collected**	**Methodological Contribution to Current Study**
Chang and Gunasekara (2013)	Usability of ITID system (Volvo Bus) for public-transport drivers	Field observation, semi-structured interviews, low-fidelity prototyping, usability testing	50 observed, 15 interviewed, 7 tested bus drivers	Task performance, visibility, mental workload, interaction bottlenecks	Demonstrates heuristic-based redesign from field data; parallels participatory testing of EV bus dashboards
Lundström (2014)	Differentiated Driving Range – Categorization of range feedback	Iterative UCD with simulator-based evaluation	20 licensed EV drivers participated in simulator-based evaluation of the three range prototypes.	Driver confidence, decision-making, usability feedback	Demonstrates iterative validation of conceptual range feedback models
Nilsson and Olsson (2014)	Context-specific redesign of bus driver interfaces (Volvo Bus)	Contextual inquiry, route-based observation, expert walkthroughs	10 professional bus drivers + 3 expert walkthroughs (5–6 drivers/workshop)	Cognitive load, alert timing, information hierarchy	Establishes task-segmented interface design; supports adaptive dashboard layouts

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Table 3.1 continued from previous page

Author(s) & Year	Domain / Focus	Methods Used	Participants / Context	Key Measures / Data Collected	Methodological Contribution to Current Study
Francois et al. (2016)	Transition from analog to digital truck speedometers	Simulator-based experiment (speed reading, comprehension)	18 professional truck drivers	Reading accuracy, response time, comprehension rate	Establishes analog–digital adaptation benchmark; supports gradual dashboard transition
François et al. (2017a)	Redundant information display for truck dashboards	Simulator cockpit testing under varying workload	20 professional drivers	Recognition accuracy, mental effort, visual redundancy benefit	Demonstrates redundancy improves recognition and reduces cognitive strain
François et al. (2017b)	Participatory co-design of heavy-vehicle HMIs	Driver workshops and co-design sessions	12 professional drivers	Ergonomic priorities, interface sketch evaluation	Illustrates participatory co-design framework linking drivers with prototype generation

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Author(s) & Year	Domain / Focus	Methods Used	Participants / Context	Key Measures / Data Collected	Methodological Contribution to Current Study
Ordóñez-Hurtado et al. (2018)	Validation of stationary vehicles as test environments for ITS	GPS data logging, SUMO simulation, Gaussian noise modeling	Fleet of parked and moving vehicles in urban networks	Stationary duration, signal stability, mean absolute error (MAE)	Confirms parked vehicles as stable, low-risk, repeatable usability test contexts
Gödker et al. (2018)	Eco-Assistant HMI for battery-e-buses (BEBs)	Prototype interaction, semi-structured interviews, inductive in-vivo coding	10 professional bus drivers	Driver interpretation of visual feedback, preferences, qualitative coding	Defines qualitative, early-stage evaluation framework for professional driver HMIs; informs stationary prototype testing
François et al. (2019)	Gauge layout and information density optimization	Simulator comparison study	22 drivers	Symbol identification accuracy, clarity ratings, cognitive load	Identifies optimal information density for readability; supports visual simplification

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Author(s) & Year	Domain / Focus	Methods Used	Participants / Context	Key Measures / Data Collected	Methodological Contribution to Current Study
Jönsson and Nilsson (2019)	Digital touch-screen interface for bus drivers (LTG Sweden AB)	Contextual inquiry, participatory workshops, iterative prototyping, usability testing	Bus drivers in depot and route contexts	Task success rate, error count, completion time, workload ratings	Demonstrates full UCD process; bridges field observation with iterative refinement; aligns with EV dashboard usability evaluation
Stahl et al. (2020)	Range InSight – expert elicitation for range feedback design	Expert workshops, question generation, information clustering, conceptual modeling	9 BEB domain experts	68 elicited questions, four cognitive clusters of range perception	Introduces structured expert-elicitation approach; supports domain-informed concept modeling for dashboard design

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Table 3.1 continued from previous page

Author(s) & Year	Domain / Focus	Methods Used	Participants / Context	Key Measures / Data Collected	Methodological Contribution to Current Study
François et al. (2021)	Comparative usability and acceptance of truck dashboards	Semi-static cab evaluation with standardized scales	24 professional drivers	SUS, acceptance scores, perceived usability	Establishes validated subjective evaluation model balancing realism and control
Andréasson and Boman (2022)	Transition from analog to digital interface in electric terminal tractors	Contextual observation, stakeholder interviews, heuristic evaluation, think-aloud, scenario walkthroughs	8 professional operators in logistics yards	Task completion, usability feedback, acceptance ratings	Demonstrates transition-oriented UCD; supports incremental digitalization approach in EV bus dashboards

3.3.1 Key recommendations and Inferences

1. A common methodological pattern observed in earlier automotive HMI and EV dashboard studies is the reliance on a structured, UCD process. Research across passenger cars, heavy vehicles, and buses demonstrates that effective interfaces emerge from real driver practices rather than speculative design (Strömberg et al., 2011; Lundström, 2014; Gödker et al., 2018; Jönsson and Nilsson, 2019). These studies employ a systematic methodology, involving contextual inquiry and field observations to identify operational needs, followed by iterative prototyping and refinement informed by driver feedback (Lundström and Bogdan, 2012; Nilsson and Olsson, 2014; Chang and Gunasekara, 2013). This suggests that future dashboard studies should begin with direct engagement with drivers and their actual operating context. Additionally, these patterns emphasize the importance of allowing user data to inform the structure and content of subsequent interface prototypes, rather than treating prototyping as a purely creative exercise.

2. A further inference emerges from studies that employ stationary or semi-field evaluations with professional drivers. Research by Burns et al. (2010), Harvey and Stanton (2013), and Ordóñez-Hurtado et al. (2018) shows that parked-vehicle or controlled-lab setups can still capture meaningful information about visual demand, perceived workload, and usability while maintaining safety and logistical feasibility. This indicates that dashboard evaluations do not always require full driving simulators or on-road trials, provided that posture, reachability, and context are reasonably preserved.

3. Earlier work also illustrates the value of subjective evaluation instruments. Many studies combine system usability and workload ratings with acceptance judgments to obtain a richer picture of driver experience (Franke and Krems, 2013; Jung et al., 2015; François et al., 2021). Standardized scales, such as the SUS, SEQ, RSME, the Van der Laan Acceptance Scale, and NASA–TLX, are frequently used for this purpose, demonstrating that subjective measures alone can form a structured and comparable assessment framework when objective performance logging is constrained.

4. Finally, there is an important methodological lesson regarding uneven task structures. Kujala and Sarkar (2025) compare a simple baseline driving condition with multiple, more

complex infotainment tasks in production EVs, and then use NASA–TLX to quantify the added workload of each in-car task relative to baseline. Their work shows that baseline and interaction phases do not need to be structurally identical for meaningful workload comparisons; what matters is that the baseline represents attentive driving and the in-car condition represents realistic interface use. This provides a clear precedent for using uneven task conditions to estimate the incremental workload, ease of use, and mental effort introduced by an in-vehicle interface.

This integrated methodological approach is particularly relevant in the Indian public transport context, where operational variability, infrastructural constraints, and driver diversity necessitate flexible and context-sensitive evaluation approaches. The present research extends this trajectory to the Indian e-bus context, combining exploratory inquiry, iterative prototyping, stationary field testing, and uneven task-based workload evaluation within a unified UCD framework. This ensures that the developed dashboard is operationally effective, cognitively efficient, and grounded in authentic driver experience while meeting international HMI evaluation standards.

3.4 Researcher Positionality

This study was conducted in collaboration with an Original Equipment Manufacturer (OEM), Ashok Leyland, a leading manufacturer of electric buses in India. This collaboration provided access to domain knowledge, operational context, and relevant stakeholders. It helped in understanding real-world dashboard requirements and enabled field-based data collection.

The study maintained independence in research design, data collection, analysis, and interpretation. The UCD approach was followed. Design decisions were based on data from drivers, technicians, and other stakeholders, not organizational preferences.

To reduce bias, multiple methods were used, including observations, interviews, participatory tasks, and surveys. This allowed triangulation of findings. Feedback was collected from different participant groups across roles and contexts.

The researcher acted as an independent investigator within an applied setting. The study balanced industry access with systematic and unbiased research practices.

3.5 Methodology for Current Research

This study adopts a UCD approach to investigate and improve driver–dashboard interaction in e-buses. The methodology integrates contextual data collection, iterative prototyping, and field-based evaluation, following the human-centered design principles outlined in International Organization for Standardization (2019b).

UCD is selected as the primary framework due to its strong emphasis on iterative development grounded in real user interaction, which is critical in safety-sensitive and context-dependent environments such as public transport. Alternative approaches, such as Design Science Research, focus primarily on artifact development, while Participatory Action Research emphasizes collaborative change processes. These approaches are less suited to structured usability evaluation and iterative interface refinement under operational constraints. In contrast, UCD provides a balanced framework that supports both empirical inquiry and systematic design iteration.

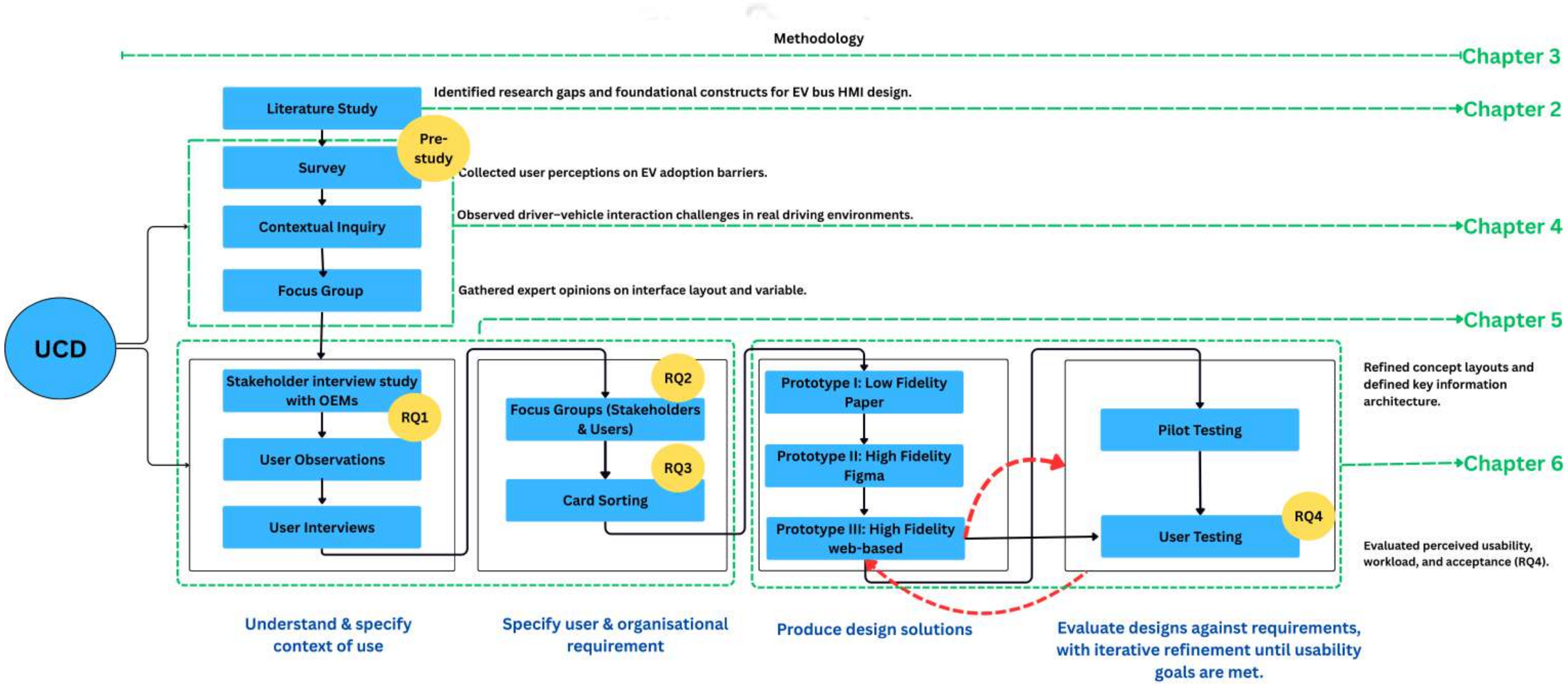

Figure 3.1: Overview of the UCD-based research methodology adopted in this study (Source: Author, 2023).

The research is structured into four sequential phases: (1) understand and specify the context of use, (2) specify user and organizational requirements, (3) produce design solutions, and (4) evaluate designs against requirements, with iterative refinement until usability goals are met (see Figure 3.1). Each phase employs specific methods aligned with its objective, enabling a systematic progression from empirical data collection to prototype development and usability evaluation.

3.5.1 Understand and specify the context of use

This phase establishes the contextual and behavioral foundations for designing the e-bus driver interface. A mixed-method approach was employed to capture behavioral, cognitive, and perceptual aspects of driver–dashboard interaction. Contextual inquiry was used to observe real-world driving behavior and environmental constraints that cannot be reliably captured through self-report methods. Interviews were conducted to explore drivers' cognitive interpretation of dashboard information and decision-making processes. Focus groups enabled the identification of system-level issues and communication gaps across different stakeholders. Participatory tasks (card sorting) were used to externalize drivers' mental models and prioritize dashboard information. Quantitative surveys were administered to validate qualitative findings through structured usability and perception measures. This combination enabled methodological triangulation.

The study comprised both a pre-study and a main user study to understand how professional drivers, technicians, and depot staff interact with existing dashboard systems under real operational conditions. These investigations provided a grounded understanding of user tasks, environmental constraints, and cognitive challenges that shape dashboard interactions in public transport settings.

3.5.1.1 Pre-study: Establishing Context and Design Foundations

The pre-study forms the foundational phase of this research, providing empirical grounding for the subsequent user study. It ensures that the research questions and methods align with real-world driver experience and current design practice. The pre-study is organized into three complementary strands to capture behavioral, contextual, and design perspectives relevant to e-bus dashboard interaction.

1. **Survey to understand behavioral and perceptual responses toward EV adoption:** A structured survey was conducted to examine Indian users' attitudes toward electric mobility and identify behavioral and perceptual factors influencing interaction with EV systems. This method was selected to capture broader user perceptions and expectations that inform dashboard design requirements.

2. **Contextual inquiry with e-rickshaw drivers:** Direct observations were conducted with public-transport e-rickshaw drivers in urban and semi-urban routes to study real driving behavior, visual attention patterns, and interaction with existing EV indicators. This method was chosen to capture real-world operational behavior and environmental constraints that cannot be obtained through self-reported data.

3. **Focus group with interface designers:** A focus group was conducted with professional automotive and interface designers to explore dashboard layout, information organization, and design considerations for EV systems. This method was selected to incorporate expert perspectives and translate domain knowledge into actionable design variables.

The pre-study establishes the empirical foundation for the main user study by refining research scope, informing method selection, and identifying key behavioral and contextual variables relevant to dashboard design.

3.5.1.2 User study

This phase investigates how professional drivers and operational staff interact with existing e-bus dashboards to identify usability challenges and design requirements. The study captures behavioral, cognitive, and operational aspects of dashboard interaction in real working conditions using multiple complementary methods.

1. **Semi-structured interviews:** Interviews were conducted with drivers and stakeholders to understand how dashboard information is interpreted and used in decision-making. This method was selected to capture cognitive processes and usability issues that are not directly observable.

2. **Focus groups:** Group discussions were held with drivers, technicians, and depot supervisors to examine workflow challenges and system-level usability issues. This method was chosen to identify shared problems and inconsistencies across different user roles.

3. **Participatory tasks:** Card-sorting and clustering exercises were conducted to understand how drivers prioritize and organize dashboard information. This method was selected to externalize users' mental models and inform interface structure.

4. **Quantitative surveys and comprehension tests:** Standardized questionnaires (e.g., SUS, Telltale Knowledge Test) were administered to assess usability, comprehension, and satisfaction. These measures were selected to provide quantitative validation of qualitative findings.

3.5.2 Specify user and organizational requirement

The specification of user and organizational requirements was derived through the integration of five complementary methods, each contributing a distinct layer of insight:

1. **Field observations** documented drivers' naturalistic behaviors, visual attention shifts, and ergonomic challenges in operational settings. This method was essential to identify real-world constraints and understand how drivers prioritize information under dynamic conditions.

2. **Semi-structured interviews** explored the cognitive and motivational factors underlying dashboard use, including interpretation of indicators and decision-making strategies. This method was selected to capture reasoning processes and identify perceived usability gaps that are not directly observable.

3. **Focus groups** facilitated cross-role discussions among drivers, technicians, and depot supervisors. This approach enabled the identification of system-level issues, workflow inconsistencies, and communication gaps across stakeholders.

4. **Participatory tasks** (card sorting and clustering) translated tacit driver knowledge into explicit prioritization of dashboard elements. This method was used to externalize mental models and inform the structuring of dashboard information.

5. **Quantitative surveys and comprehension tests** (e.g., SUS, Telltale Knowledge Test) provided measurable indicators of usability, comprehension, and satisfaction. These measures were used to validate qualitative findings and support requirement prioritization.

To ensure methodological rigor, the study addressed multiple forms of research validity:

- **Construct validity:** All instruments were aligned with constructs of usability, workload, and comprehension. Pilot testing ensured clarity and consistency.
- **Internal validity:** The sequential method design (observation → interviews → focus groups → participatory tasks → surveys) minimized bias and reinforced convergence across data sources.
- **External validity:** Participants were selected from multiple depots and routes to capture diverse operational conditions.
- **Ecological validity:** Data were collected in real or simulated bus environments, preserving contextual realism such as posture, lighting, and interaction constraints.
- **Reliability:** Standardized protocols were used for data collection, and qualitative coding was validated through inter-rater agreement. Survey instruments were pre-tested for consistency.

This sequential mixed-method approach enabled both qualitative depth and quantitative validation. The triangulation of behavioral, cognitive, and perceptual data ensured that the derived requirements were robust, contextually grounded, and directly informed the subsequent design and prototyping phase.

3.5.3 Produce design solutions

The prototyping phase translates empirical findings from the user study into concrete interface decisions. This is done through an iterative refinement process. Observations revealed fragmented access to information, high visual search time, and difficulty interpreting diagnostic alerts. These issues informed the restructuring of the dashboard layout and interaction flow.

Prototyping was used not only to explore design alternatives but also to address these usability challenges. It enabled continuous validation of design decisions through feedback from drivers and domain experts.

The process progresses through three fidelity levels: paper, Figma, and web-based prototypes. Each level serves a distinct role in the design process and responds to findings from the user study:

- **Paper prototyping:** Low-fidelity sketches were used to explore layout alternatives and user flows. This stage addressed the fragmented information structure observed during contextual inquiry. It enabled rapid testing of multiple layouts before detailed implementation.
- **Figma prototyping:** Medium-fidelity interactive prototypes were developed based on paper prototypes. This stage focused on refining navigation, information grouping, and visual hierarchy. It addressed issues related to icon comprehension and interaction flow identified during interviews and focus groups.
- **Web-based prototyping:** A high-fidelity interactive dashboard was developed for final evaluation. This stage simulated realistic interaction, system feedback, and visual behavior. It enabled usability testing under conditions close to actual operation.

This multi-level approach supported progressive refinement from concept to functional validation. Early stages enabled rapid iteration and structural correction. Later stages supported realistic interaction testing. This ensured that the final design remained grounded in empirical findings, user requirements, and operational constraints.

3.5.4 Evaluate designs against requirements

Evaluation was conducted in a stationary e-bus parked at the depot during post-route sessions. This setup was selected to balance safety with ecological validity, allowing drivers to interact with the prototype in a realistic cockpit environment while avoiding risks associated with on-road testing.

The in-bus setting preserves key contextual factors such as seating position, reachability, and visual attention demands, which are critical for evaluating in-vehicle interfaces. Laboratory-based testing was not adopted due to its limited ability to replicate these conditions and the practical constraints of recruiting active e-bus drivers for controlled experiments.

Testing was carried out in three sequential phases:

1. **Pilot Study:** An initial evaluation was conducted with expert designers and HCI researchers to identify early usability and interaction issues. This stage was used to detect structural problems in layout, feedback, and information hierarchy before involving end users, enabling efficient early refinement.

2. **Field Testing with Drivers (Usability Evaluation):** The prototype was evaluated with professional e-bus drivers performing scenario-based tasks within the stationary bus environment. This method was selected to assess usability under realistic operational conditions, capturing both performance and user experience through standardized measures and observational feedback.

3. **Cognitive Walkthrough (Learnability Evaluation):** A cognitive walkthrough was conducted with expert designers and HCI researchers to evaluate the learnability of the interface by analyzing how a first-time user would understand and navigate the system. This method was used to identify potential usability barriers related to task flow, action visibility, and feedback interpretation.

This multi-stage evaluation approach enabled progressive refinement, combining expert review, real-user interaction, and analytical assessment. It ensured that the final design was both functionally effective and aligned with real-world driver requirements.

3.5.4.1 Task Design and Evaluation Conditions

Usability tasks were designed to reflect authentic e-bus operations while accounting for functional differences between the existing analog dashboard and the proposed digital prototype. The analog system lacks features such as dynamic alerts, trip logging, and performance visualization, making direct task equivalence infeasible.

To address this, a differentiated task framework was adopted, structured into three operational phases: *pre-trip*, *in-trip*, and *post-trip*. The pre-trip phase included tasks common to both systems (e.g., routine checks and setup), enabling baseline comparison. The in-trip and post-trip phases focused on dynamic, system-supported functions available only in the digital interface, such as responding to alerts, monitoring energy usage, and reviewing trip data.

This uneven task design was a deliberate methodological choice. It allows each system to be evaluated within its functional capabilities rather than forcing artificial equivalence. Imposing identical tasks on dissimilar systems would lead to invalid comparisons and misrepresent actual usability performance. All participants were professional e-bus drivers with prior route experience. Testing was conducted in a stationary bus environment, ensuring realistic interaction conditions while maintaining safety. Familiarity with the operational context minimized learning effects and ensured that responses reflected interface usability rather than environmental adaptation. This approach prioritizes functional validity and contextual realism, ensuring that evaluation outcomes accurately represent real-world usage conditions.

3.5.4.2 Selection of Evaluation Metrics

The evaluation focused on subjective measures of usability, workload, and acceptance, rather than objective performance metrics such as task completion time or error rate.

This decision was based on three methodological considerations:

1. **Ecological validity and safety:** Testing was conducted in a stationary bus within an operational depot. Instrumentation required for objective measures (e.g., gaze tracking or precise timing) would interfere with natural interaction and reduce realism.

2. **Professional driver context:** Participants were active e-bus drivers with fixed schedules. Minimizing instrumentation ensured natural behavior and reduced observer-induced bias.

3. **Feasibility of field-based evaluation:** Under real-world constraints, subjective measures provide a practical and reliable means of assessing usability, workload, and acceptance without compromising safety or context.

Evaluation sessions were conducted after regular driving shifts, allowing participants to base their responses on recent operational experience.

Four standardized instruments were used:

- **System Usability Scale (SUS)** — overall usability
- **Single Ease Question (SEQ)** — task-level ease
- **Rating Scale for Mental Effort (RSME)** — cognitive workload
- **Van der Laan Acceptance Scale** — perceived usefulness and acceptance

These measures provided a structured and context-appropriate evaluation framework. Although objective metrics were not collected, the approach ensures reliable assessment under real-world operational constraints while maintaining safety and ecological validity.

In summary, the research methodology follows a structured, mixed-method UCD approach that integrates contextual inquiry, participatory methods, iterative prototyping, and field-based evaluation within a single coherent framework. Each phase builds on the previous one, ensuring that design decisions are grounded in empirical evidence and real-world driver experience.

The methodology is specifically adapted to the constraints of public transport environments, where safety, operational feasibility, and ecological validity are critical. Methodological choices such as stationary field testing, differentiated task design, and the use of subjective evaluation metrics reflect a deliberate balance between experimental rigor and real-world applicability.

This approach not only enables the development of a usable and contextually relevant e-bus dashboard but also demonstrates a practical framework for evaluating in-vehicle interfaces under operational constraints. The resulting design is therefore grounded in user needs, validated through iterative refinement, and aligned with the realities of professional driving contexts.

The alignment between research questions, objectives, methods, and outcomes is summarized in Table 3.2, demonstrating the coherence and traceability of the research design.

Table 3.2: Alignment of research questions, objectives, methods, and outcomes

Research Question	**Objective**	**Methods Used**	**Outcomes**
RQ1 – What are the prevailing practices and limitations of driver-facing dashboard interfaces in e-buses used in public transport?	RO1 – Examine existing practices and limitations	Literature review, field observations, stakeholder interviews	Documentation of current dashboard architectures, legacy design constraints, and OEM and depot perspectives
RQ2 – What usability and workflow-related challenges do professional e-bus drivers experience when interacting with existing dashboard interfaces during operation?	RO2 – Identify usability and workflow challenges	Contextual inquiry, semi-structured interviews with drivers and technicians, KJ–severity analysis	Identified challenges including high visual and cognitive workload, fragmented information access, unclear diagnostics, reliance on mobile phones, and language-related barriers
RQ3 – What information requirements and interaction needs are necessary to support drivers across key operational phases of an e-bus trip?	RO3 – Derive driver-centered information and interaction requirements	Focus groups, card sorting, participatory design workshops	Prioritized information and interaction requirements across pre-trip, in-trip, and post-trip phases (e.g., SoC, DTE, speed, alerts, route context, diagnostics, reporting)

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Table 3.2 continued from previous page

Research Question	Objective	Methods Used	Outcomes
RQ4 – How do empirically examined alternative dashboard interaction and information organization configurations influence usability, mental workload, and acceptance among professional e-bus drivers?	RO4 – Design a consolidated dashboard prototype RO5 – Evaluate the prototype	Iterative prototyping (low- to high-fidelity), pilot study (heuristic evaluation), field usability testing with drivers (SUS, SEQ, RSME, Van der Laan Acceptance)	Validated dashboard prototype demonstrating improved usability, reduced mental workload, and higher acceptance compared to existing systems

Methodologically, this study contributes a field-grounded, mixed-method UCD framework tailored to e-bus dashboard design in the Indian public transport context. It integrates contextual inquiry, participatory design, iterative prototyping, and stationary field evaluation within a coherent pipeline. The study further demonstrates how differentiated task structures and subjective evaluation metrics can be effectively applied under real-world operational constraints.

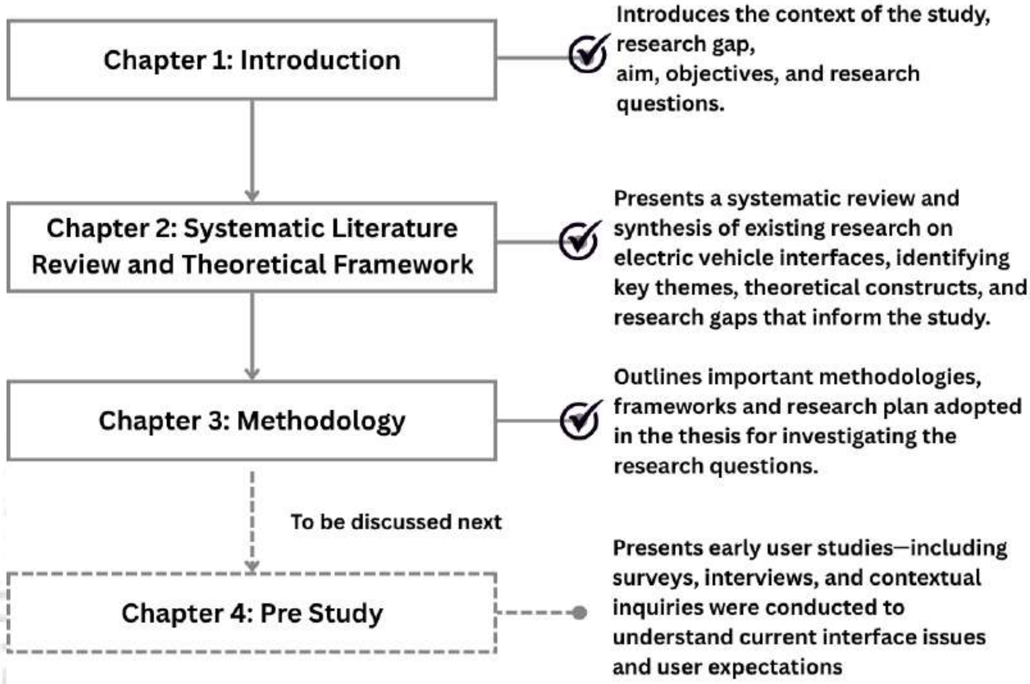
3.6 Chapter Summary

This chapter outlines the research methodology used to design and evaluate an e-bus driver dashboard in the Indian public transport context. The study follows a structured, mixed-method approach that integrates contextual inquiry, participatory methods, iterative prototyping, and field-based evaluation.

The methodology progresses through four stages: understanding the context of use, specifying user and organizational requirements, developing design solutions, and evaluating the prototype. Key methodological decisions include the use of stationary field testing to balance safety and realism, differentiated task design to account for functional differences between systems, and the use of subjective evaluation metrics under operational constraints.

Overall, the chapter establishes a coherent and contextually grounded framework that supports both the development and validation of the proposed dashboard design.

A visual summary of the chapters covered so far is presented as follows:



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Chapter 4

Preliminary Investigation of Electric Vehicle Interfaces

This chapter investigates the key challenges affecting the adoption of electric vehicles (EVs) in the Indian context and examines the usability aspects of EV dashboards through three exploratory pre-studies, each addressing user needs, real-world driving contexts, and interface design perspectives.

4.1 Introduction

This chapter builds on the literature review in chapter 2. It focuses on direct user evidence to understand how people in India perceive EVs, how drivers use dashboards, and how designers view existing EV interfaces. Three pre-studies form the foundation of this research. Each addresses a distinct level of user understanding within the UCD process: user perception, operational context, and interface evaluation.

4.2 Chapter Objectives

1. Identify user requirements and adoption challenges related to electric vehicles (EVs) in India.
2. Examine real-world dashboard use and information needs of drivers in their operational context.
3. Identify and analyze key dashboard variables and usability patterns in current EV interfaces.

4.3 Pre-study 1: Understanding Indian Users' EV Adoption Mindset

This study investigates Indian users' requirements, expectations, and preferences related to EVs. It focuses on understanding how lifestyle, occupation, and technical familiarity shape user attitudes toward EV adoption. The findings provide a grounded understanding of user expectations and inform the design direction of EV interfaces. The focus is on creating intuitive and context-appropriate designs, particularly for public transport systems.

4.3.1 Method

4.3.1.1 Participant Recruitment

Participants aged 18–65 years from different regions of India took part in the study. Participants were required to be Indian citizens and possess a valid driving license. Recruitment was carried out through online channels (email and social media) as well as in-person outreach at academic institutions and public spaces. All participants provided informed consent prior to participation.

4.3.1.2 Survey Instrument

A structured 20-item questionnaire captures demographic information, personality traits, daily routines, vehicle usage, fuel expenses, expectations from EVs, and level of technical familiarity (see Table 4.1). The survey includes both open- and closed-ended questions. It is available in English and Hindi to ensure accessibility for participants with different language backgrounds.

Table 4.1: Persona development questionnaire used for capturing demographic, behavioral, and contextual user attributes (Source: Author, 2021).

Sl. No.	Questions
1.	What is your name?
2.	What is your gender?
3.	What is your age?
4	What is your occupation?
5.	Where do you locate?
6.	What is your personal goal?
7.	How many members are there in the family?
8.	What is your typical day routine (morning to night)?
9	Which factors improve your productivity?
10	Which factors diminish productivity?
11	Which factors give you moments of delight?
12	Which factors give you moments of frustration?
13	Do you drive a vehicle?
14	If yes, mention the name of the vehicle and the purpose to use it.
15	How often does your fuel consumption impact your expenses?
16	Would you prefer an electric vehicle?
17	What would be your expectations from an electric vehicle?
18	How do you measure your technology exposure (e.g., use of Android mobile phone)?
19	Remarks, if any?
20	Contact (Email or Mobile Number)

4.3.1.3 Procedure

The survey was administered using both online and offline modes. Online responses were collected through Google Forms distributed via email and messaging platforms, while offline responses were gathered through in-person interactions at selected locations. The data collection process lasted eight weeks.

4.3.1.4 Data Collection and Analysis

All responses were cleaned and compiled prior to analysis. Quantitative data were analyzed using descriptive statistics. Open-ended responses were analyzed using a two-stage affinity mapping process. In the first stage, three researchers independently identified preliminary themes related to EV expectations and user contexts. In the second stage, a different set of three researchers re-coded the data to validate the themes. Inter-rater reliability was assessed using Cohen's Kappa (Fleiss and Cohen, 1973). Discrepancies were resolved through discussion, and similar themes were merged into final categories. These categories were subsequently used to develop representative user personas.

4.3.2 Results

The survey received responses from 205 participants across India (mean age = 33.49 years, SD = 9.61; male = 152, female = 53). Participants were drawn from multiple regions in India, including metropolitan cities such as Mumbai, Delhi, and Bangalore (Tier-1), developing urban centers such as Guwahati and Bhubaneswar (Tier-2), and smaller towns such as Jajpur and Bhadrak (Tier-3). Respondents represented different city tiers, with 20% from Tier-1 cities, 42% from Tier-2 cities, and 38% from Tier-3 cities, reflecting a mix of urban, semi-urban, and smaller-town contexts. Participants' ages ranged between 18 and 65 years. Occupationally, 36.7% were in the service sector, 26.1% were researchers, 13.5% were business professionals, 11.6% were homemakers, 5.8% were teachers, 3.4% were drivers, and 2.9% were retirees. However, as the sampling approach was convenience-based, the sample does not represent a statistically balanced national population.

Demographic Attributes Male participants (61%) and female participants (63%) showed a positive inclination toward EV adoption. In terms of location, 66% of participants from Tier 1 cities and 65% from Tier 2 cities expressed higher interest, followed by 62% from Tier 3 cities. Among age groups, individuals aged 51–65 years exhibited the strongest willingness to adopt EVs (71%), followed by participants aged 18–30 years (64%). Regarding occupation, service-sector professionals were the most interested group (72%), followed by teachers (67%), business professionals (64%), and homemakers (62%). Drivers showed the least interest (29%).

Distinguishable Attributes Participants with prior driving experience showed a higher positive response (68%) toward EV adoption, while those without experience reported 59% agreement. Participants with medium fuel expenditure indicated the highest positive response (75%), followed by high (68%) and low (67%) expenditure groups. Respondents with high technology exposure demonstrated the greatest enthusiasm for EVs (79%), while medium and low exposure groups showed 63% and 64% interest, respectively. Respondents were further analyzed based on six distinguishing variables to understand their behavioral patterns and EV adoption outlook (see details in Table 4.2).

Table 4.2: Distinguishing variables and their operationalization used for participant profiling (Source: Author, 2021).

Variable	**Operational Measure**	**Response Scale**
Driving Experience	Do you drive a vehicle?	Yes / No
Vehicle Type	Which type of vehicle do you use?	Two-wheeler / Three-wheeler / Four-wheeler
Fuel Cost Sensitivity	What are your fuel expenses?	High / Medium / Low
EV Adoption Intention	Would you prefer an EV?	Yes / No / Maybe
EV Expectations	What are your expectations from EVs?	Performance / Range / Service / Charging / Hybrid / Environment
Technology Familiarity	How do you rate your technical exposure?	High / Medium / Low

Indian user's requirements and expectations from EVs The survey participants' expectations and requirements are categorized into seven factors namely Economy, Performance, Charge, Service, Environment, Range, and Hybrid (refer to Figure 4.1). The most important factor was economy (40.9%), followed by performance (38.6%), charging infrastructure (36.8%), service availability (13.4%), environmental benefits (11.1%), range (5.3%), and the availability of hybrid options (1.2%). Notably, the significance of economy, charging infrastructure, and performance is quite similar, implying these three factors present major requirements of the user. The study also reveals that the demand for hybrid options is the lowest among the seven categories.

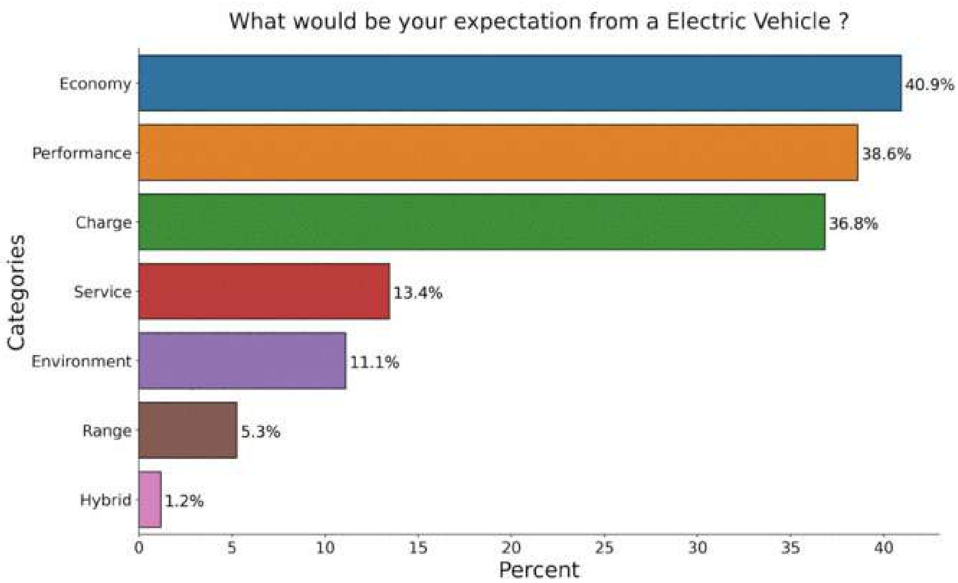

Figure 4.1: Key requirements of electric vehicle users in the Indian context, identified through the pre-study (Source: Author, 2021).

4.3.3 Implications for the Main study

The survey findings provide a broad understanding of how Indian users perceive EVs and the factors influencing their adoption. Affordability, performance, and charging accessibility emerged as key priorities, indicating that users evaluate EVs primarily through economic and practical considerations, with a tendency toward shared or public transport options, particularly in urban and semi-urban contexts. As the study was conducted in 2021, the findings reflect early-stage user perceptions and should be interpreted as indicative insights that informed the subsequent investigation of driver interaction with EV dashboards.

4.4 Pre-study 2: Drivers' Dashboard Interactions

This study investigates the usability challenges and informational needs of public vehicle drivers. As few private users in India currently own electric vehicles, it was not possible to derive meaningful dashboard insights from general users. Therefore, we moved into a real driving context to observe how professional drivers interact with EV dashboards in their daily operations.

We selected electric rickshaw (e-rickshaw) drivers for this study. E-rickshaws have rapidly become a common mode of public transport in Indian cities. Studying these drivers allowed us to examine dashboard usage, information-seeking behavior, and pain points in actual operating conditions.

4.4.1 Method

4.4.1.1 Participant Recruitment

The e-rickshaw drivers were conveniently sampled from the population available at College Square Chouk, North Guwahati, Assam. Participants were required to be active drivers with a minimum of six months of driving experience and regular daily operation within the city area. Drivers who owned or operated an e-rickshaw as their primary occupation were included in the study.

4.4.1.2 Procedure

The study followed the contextual inquiry framework as described by Holtzblatt and Beyer (1998). This method emphasizes observing users in their natural work environment, asking clarifying questions, and collaboratively interpreting behaviors to uncover usability challenges that may not surface through interviews or surveys.

The contextual inquiry was conducted at College Square Chouk, North Guwahati, where e-rickshaw drivers routinely operate. Observations were carried out in the drivers' natural work setting to understand their interaction with dashboard elements during real driving conditions. Researchers initially observed driver behavior, glance patterns, and dashboard use. Drivers who were available and willing to participate during their idle time were then invited to take part in the study.

Each selected participant was observed during a regular trip to capture real-time dashboard interactions. Two researchers accompanied the driver, one observed the operational and behavioral aspects, while the other maintained detailed field notes. After the trip, a brief discussion was conducted to clarify observed behaviors and understand drivers' perceptions, informational needs, and challenges related to dashboard use.

4.4.1.3 Data Collection and Analysis

Video data were recorded using a GoPro camera during each observation session, while audio interviews were recorded using a mobile device. Verbal consent was obtained from all participants before data collection. Confidentiality and anonymity were maintained by assigning pseudonyms during transcription and analysis.

The collected video, audio, and field notes were transcribed into Microsoft Word documents. All transcripts were systematically reviewed to identify recurring actions, behaviors, and statements related to dashboard use. The data were then coded and grouped into thematic categories reflecting patterns of dashboard preference, battery monitoring practices, and usability challenges. The resulting themes provided the basis for interpreting drivers' real-world interaction patterns and information needs.

Although this study focuses on e-rickshaw drivers, the context shares several operational characteristics with e-bus driving, including continuous vehicle operation, real-time monitoring of system status, and interaction under dynamic traffic conditions. E-rickshaws provide a practical proxy for studying electric vehicle interaction in public transport settings, particularly in the absence of accessible e-bus driver populations during early stages of this research.

4.4.2 Results

A total of fifteen e-rickshaw drivers participated in the study. Participants operated a range of vehicle models, which included both analog and digital dashboards. Seven vehicles featured analog gauges, while eight used digital dashboards equipped with LED screens.

Drivers typically charge their e-rickshaws overnight for 8–10 hours. A full charge allowed them to operate for approximately 8–9 hours during the day, covering 70–80 km. Due to limited public charging infrastructure, operations were confined within a 4–5 km radius of their homes. Some drivers recharged during lunch breaks at home. Charging exclusively at home resulted in monthly electricity bills ranging from Rs. 1,200 to Rs. 2,000. Despite these expenses, drivers earned approximately Rs.500 to Rs. 700 per day. The maximum speed of the e-rickshaws was between 30–35 km/h. The dashboard information included speedometer readings, battery levels, and odometer readings. Analog dashboards displayed battery levels using circular meters, while digital dashboards used vertical or horizontal battery icons resembling those on mobile devices. Additional features included directional indicators (left/right) and auditory feedback for horn usage and reverse gear engagement.

4.4.2.1 Thematic Summary of Findings

Analysis of the interviews identified drivers' needs, barriers, and facilitators related to dashboard usage in daily operations. These findings are summarized in Table 4.3. The interface characteristics identified in this study serve as usability facilitators, supporting effective interaction and reducing cognitive effort during driving.

Table 4.3: Needs, barriers, and facilitators were identified in e-rickshaw dashboard usability through qualitative analysis (Source: Author, 2022).

Theme	**Observation / Insight**	**Illustrative Quote / Supporting Statement**
	Needs	

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Table 4.3 continued from previous page

Theme	**Observation / Insight**	**Illustrative Quote / Supporting Statement**
Accurate Battery Information	Drivers required clear and consistent indicators to estimate remaining charge and plan trips effectively.	*"It's important to have a clear idea of the battery level, especially for longer trips."*; *"I can plan my charging better when I know how much charge remains."*; *"I get confused because the information is not consistent before starting and during driving. The battery percentage suddenly shows much less than what I see at the start."*
Timely Low-Battery Alerts	Early and reliable alerts were needed to prevent unexpected stops during service hours.	*"I need timely low-battery alerts."*; *"If the warning comes early, I can avoid sudden breakdowns and keep driving smoothly."*
	Barriers	
Language and Symbol Comprehension	Technical terms and English labels limited understanding for low-literate drivers.	*"I find it hard to read the words on the dashboard."*; *"Most of the information is in English, so I cannot understand everything easily."*
Inadequate Visibility	Dim lighting, glare, or reflections hindered clear readability, especially in outdoor or varying weather conditions.	*"The battery meter lights are not bright enough."*; *"I can't see them clearly when sunlight falls on the dashboard."*
Technological Complexity	Overly complicated digital interfaces demanded training or prior exposure, challenging less tech-savvy drivers.	*"I find it hard to understand some of the icons and menu options in the new dashboards."*
Lack of Standardized Layout	Inconsistent dashboard layouts and differing icon positions across models led to confusion for drivers switching vehicles.	*"Every rickshaw shows the dashboard differently. I take time to get used to each one."*

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Table 4.3 continued from previous page

Theme	Observation / Insight	Illustrative Quote / Supporting Statement
Inadequate Feedback	Dashboards provided limited or unclear feedback on how driving behavior affects battery use.	*"I don't know if my driving style affects the battery."*; *"There is no signal or indicator that shows how my driving changes the battery use."*
Facilitators (Interface Characteristics)		
Digital Dashboards	Provided clearer and more precise information (e.g., battery percentage and speed), which supported better decision-making and planning during trips.	*"I like seeing the battery percentage and speed clearly on screen."*;*"The display gives me clear information."*; *"With precise feedback, I can plan my charging better."*
Analog Dashboards	Familiar layout and simple visual representation enabled quick glance-based monitoring, reducing cognitive effort during driving.	*"I can easily see the charge on the analog dashboard with just one glance."*; *"It feels familiar, so I don't need to concentrate much while checking it."*

These findings can be interpreted through established HCI principles. Issues related to visibility and readability reflect the principle of perceptual clarity, while challenges in understanding symbols and layout relate to cognitive load and learnability. The need for timely alerts and consistent feedback aligns with feedback and system status visibility, which are critical for supporting decision-making in dynamic driving environments. These interpretations help translate observed usability challenges into higher-level design considerations for subsequent interface development.

4.4.2.2 Preliminary Insights

Based on the contextual inquiry, the following preliminary insights are categorized according to their evidential basis. This distinction clarifies which insights are directly grounded in empirical observations from the field study and which represent interpretive or forward-looking design recommendations derived from these findings.

1. **Enhance Clarity and Visibility** Utilize high-contrast color schemes and increase LED brightness to improve visibility under various lighting conditions. *(Evidence-based: derived from observed issues related to glare, low brightness, and poor readability)*

2. **Implement Real-Time Battery Monitoring** Ensure dashboards display accurate, real-time battery percentage information to aid in trip planning. *(Evidence-based: supported by drivers' need for consistent and reliable battery information)*

3. **Simplify Dashboard Information** Focus on essential information such as battery percentage and speed, avoiding unnecessary technical details. *(Evidence-based: derived from challenges related to cognitive load and difficulty understanding technical indicators)*

4. **Ensure Accurate Low-Battery Warnings** Implement timely and precise low-battery alerts to prevent unexpected vehicle shutdowns. *(Evidence-based: supported by driver demand for early and reliable alerts)*

5. **Standardize Dashboard Layouts** Promote consistency in layout and icon placement across different vehicle models. *(Evidence-based: derived from confusion caused by inconsistent layouts across vehicles)*

6. **Incorporate Auditory Feedback** Add auditory cues for key system states such as gear changes or warnings. *(Interpretive: inferred from limited feedback mechanisms and absence of non-visual cues)*

7. **Provide Range and Charging Information** Include estimated range and information about nearby charging stations to support route planning. *(Interpretive: inferred from range anxiety and lack of charging awareness)*

8. **Facilitate User Training and Onboarding** Provide training or onboarding support for drivers unfamiliar with digital dashboards. *(Interpretive: inferred from observed difficulties with technological complexity)*

9. **Support Context-Specific Driving Information** Include adaptive features such as terrain-sensitive battery feedback (e.g., for uphill driving). *(Interpretive: forward-looking recommendation based on contextual driving conditions)*

10. **Design for Model Flexibility** Develop adaptable dashboard systems that can accommodate variations across vehicle types. *(Interpretive: generalized design recommendation based on diversity of vehicle models)*

4.4.2.3 Limitations

This study was conducted with a small sample of 15 e-rickshaw drivers from a single location (College Square Chouk, North Guwahati). Therefore, the findings are context-specific and should be interpreted as preliminary insights rather than generalizable conclusions. However, the study provides valuable real-world observations that informed subsequent stages of the research.

It is important to note that e-rickshaws differ from electric buses in terms of vehicle scale, interface complexity, and operational demands. Bus drivers typically manage more complex dashboards, higher speeds, and greater cognitive load due to route planning, passenger management, and traffic conditions. Therefore, the findings from this study are not directly transferable but are interpreted as foundational insights into basic driver–dashboard interaction patterns, such as glance behavior, information prioritization, and battery awareness.

4.4.3 Implications for the Main Study

These insights are abstracted at a conceptual level to inform the design of e-bus dashboards. Rather than directly translating interface features, the study contributes to understanding fundamental interaction principles such as clarity of information, visibility under varying conditions, and the need for timely system feedback. These findings informed the main study in the following ways:

1. They emphasize the need to balance familiarity with technological advancement when designing digital interfaces for public vehicles.
2. They indicate that real-time, reliable battery feedback and timely alerts are central to driver trust and efficiency.
3. The contextual evidence supports the user-centered design approach by grounding future interface development in real-world operational challenges.

Together, these observations and insights informed the design direction of the main dashboard prototype, ensuring that the design remains grounded in real-world operational contexts.

4.5 Pre-study 3: Identifying EV Interface Variables

This study investigates usability issues and interface variables in existing electric-vehicle (EV) instrument clusters. It explores design challenges and opportunities for improvement through group discussions with interaction designers and researchers. Insights from this study help define the core variables for redesigning digital dashboards in the main study.

We recruited interaction designers with driving experience. All participants had formal education in interface design and usability evaluation. Their experience supports a detailed analysis of interface principles, feedback mechanisms, and information hierarchy. The focus-group format enables collaborative reflection on design consistency, visual clarity, and driver interpretability, helping to identify key variables that shape the usability of dashboards.

We used electric car interfaces as stimuli for this study. Car dashboards are selected because they represent the most advanced form of EV interface research and industry practice. They integrate real-time energy feedback, range estimation, and multimodal alerts features not yet common in public transport EVs such as buses or e-rickshaws. Studying these interfaces provides a comprehensive view of current design directions and usability issues in EV human–machine interaction.

4.5.1 Method

4.5.1.1 Participant Recruitment

The participants were recruited through a snowball sampling process from the authors' institute. They were required to have a formal bachelor's education in design and at least two years of driving experience with a valid license.

4.5.1.2 Procedure

The focus group discussion (FGD) method was used to collect participants' perspectives on usability issues in existing electric vehicle (EV) interfaces. Sessions were conducted in a controlled laboratory setting.

A total of 55 cluster images were initially gathered from online sources using the keywords "EV dashboards" and "electric vehicle instrument clusters." After screening for clarity, completeness, and resolution, 18 representative car interfaces were finalized as visual stimuli. Each image was anonymized to remove brand identifiers (see Figure 4.2). The selected interfaces represented major EV models commonly available in India and abroad, including the Audi e-tron, BMW i3, Tata Nexon EV, Nissan Leaf, and Tesla Model 3.

The moderator introduced the participants, explained the objectives, and briefed them on HCI challenges related to EVs. Each participant evaluated three randomly assigned interface images using a laptop, noted perceived usability issues, and shared them during group discussions. The moderator summarized and ranked these issues collectively on a whiteboard. All sessions were recorded and transcribed. Each FGD lasted approximately 45 minutes. The time allocation for each task is illustrated in Figure 4.3.

4.5.1.3 Data Collection and Analysis

All focus group sessions were video recorded and later transcribed verbatim. To ensure participant anonymity, all personal identifiers were replaced with pseudonyms during transcription.

The qualitative data were analyzed using MAXQDA 2020 software following a conventional

Figure 4.2: Example of electric vehicle interface stimuli used in the pre-study for participant evaluation (Source: Author, 2022).

Figure 4.3: Timeline of the focus group discussion conducted during the pre-study phase (Source: Author, 2022).

content analysis approach. In the first step, key concepts were identified from the transcripts. Related code segments were then grouped based on content or contextual similarity to form higher-level categories and themes.

During coding, recurring and unique viewpoints were noted across groups. To maintain analytical balance, only one representative opinion per unique point was considered rather than counting repetitive statements. Finally, distinct and insightful quotations from the discussions were retrieved and included in the results to support thematic interpretation.

4.5.2 Results

A total of thirty-one participants took part in the focus group discussions. All were master design students with valid driving licenses and at least two years of driving experience. Participants were divided into seven focus groups, each consisting of four to five members. The discussions focused on evaluating the usability and design characteristics of eighteen distinct electric car interfaces, which represented both Indian and international EV models.

It is important to note that participants in this study are trained designers rather than professional drivers. Therefore, the findings are interpreted as expert-derived interface variables and design perspectives, rather than direct representations of driver needs. These insights complement user and contextual findings by contributing a structured understanding of interface design principles.

4.5.2.1 Thematic Summary

Analysis of the focus group discussions revealed six primary themes reflecting participants' perceptions and experiences with existing EV instrument clusters (EVIs) and their expectations for future designs.

Table 4.4: Key themes, participant insights, and illustrative quotations from focus group discussions on EV instrument cluster design (Source: Author, 2022).

Theme	**Observation / Insight**	**Illustrative Quote / Supporting Statement**
User Perceptions and Trust		

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Table 4.4 continued from previous page

Theme	**Observation / Insight**	**Illustrative Quote / Supporting Statement**
Trust, Usability, and Safety Concerns	Participants expressed hesitation in adopting EVs due to lack of clear information about charging station availability and uncertainty about vehicle feedback. Silent operation raised additional safety concerns, particularly in urban or crowded areas.	*"I cannot trust EVs for adventurous travel due to the lack of charging station information." (P_02)*; *"I have to stay extra careful on busy roads because it's silent." (P_11).*
Interface Preferences and Design Expectations		
Battery Information Display Preferences	Familiar Mobile-Style Battery Icons were perceived as intuitive and easy to interpret. Numeric percentage indicators were preferred over abstract visual icons. Overly large or central placements were seen as distracting.	*"It's easy to read battery percentage when it looks like a mobile battery." (P_23)*; *"The battery shouldn't be in the center of the screen." (P_19)*; *"The remaining charge should be written in percent." (P_13).*
Range Display: Distance vs. Map Visualization	Two key formats were preferred for range display distance in kilometers and visual maps. The map-based display reduced range anxiety and aided route planning.	*"Maps are a great advantage. At least they show where we can go and return." (P_09)*; *"For range, an accurate distance in kilometers is fine." (P_02).*

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Table 4.4 continued from previous page

Theme	**Observation / Insight**	**Illustrative Quote / Supporting Statement**
Speedometer Design: Familiarity and Centrality	Participants favored analog-style or hybrid speedometers due to their familiarity and reduced cognitive effort. Central placement of the speedometer was preferred for better glance accessibility.	*"I like a clock-like meter for power and speed." (P_09)*; *"The position should be in the center. It takes time to get used to new ones." (P_13)*; *“Meters should be simple, preferably one." (P_03).*
Information Hierarchy and Clutter	While detailed information was valued, cluttered layouts and poor hierarchy created confusion. Participants suggested prioritizing key data (battery, range, speed) and simplifying technical terms like kW and A.	*"Too cluttered display—it’s hard to focus on what’s important." (P_07)*; *"The most important information should be front and center." (P_11)*; *"I don’t understand ‘kW’. It should be in simple terms." (P_10).*
Alerts and Feedback Mechanisms		
Effectiveness of Alerts and Notifications	Visual-only alerts caused confusion, especially for "Ready" or low-battery states. Text color and size were criticized for poor visibility. Participants deemed touch-based acknowledgment unsafe during driving.	*"What is ‘Ready’? How will I know my vehicle is in start mode?" (P_08)*; *"I cannot touch the interface while driving—it’s risky." (P_14)*; *"The color of the query text is too bright and distracting." (P_02).*

4.5.2.2 Quantitative Findings: Interface Performance and User Preferences

The quantitative analysis complements the qualitative insights by providing numerical data on EVI variables and participant ratings of specific interfaces.

EVI Variable Frequency Analysis An analysis of the focus group transcripts identified key EVI variables and their discussion frequency (see Figure 4.4). The term "Battery" was the most frequently mentioned word, underscoring its centrality to the user experience. "Information" ranked second, reflecting a consistent focus on the data displayed on the dashboard. Other frequently discussed variables included the speedometer, alerts, range, modes, color, power, and energy flow. Figure 4.5 presents a detailed breakdown of the positive and negative feedback frequencies associated with these variables.

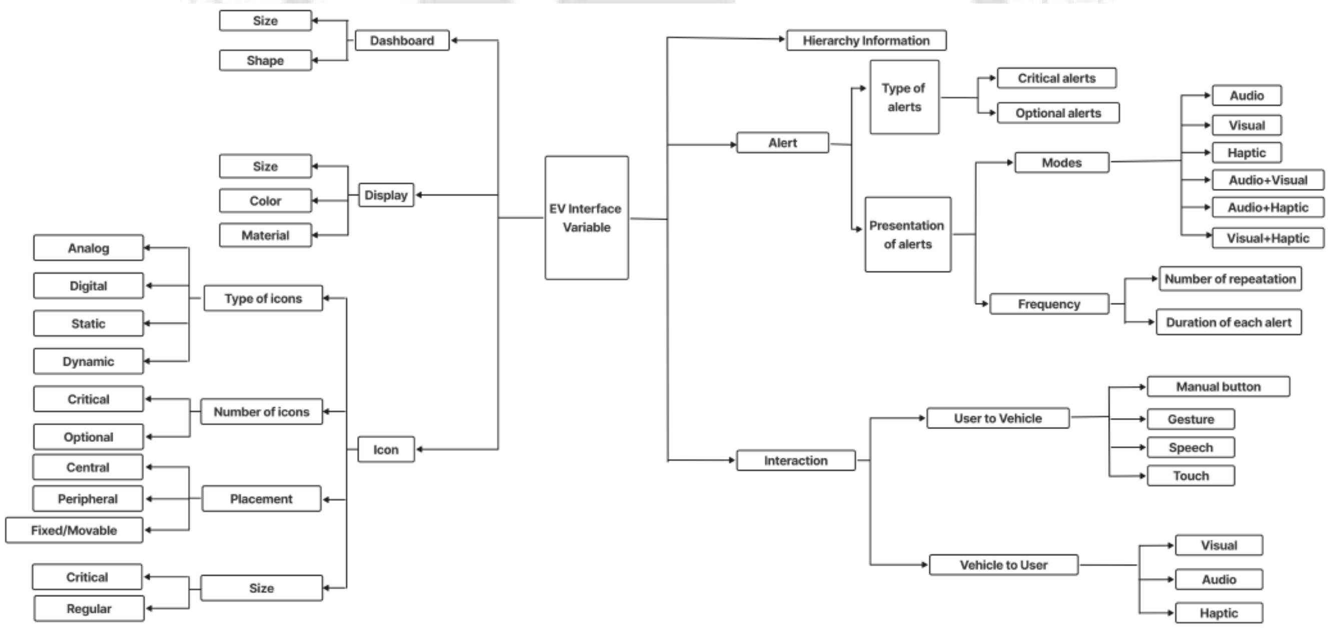


Figure 4.4: Key variables of the electric vehicle interface considered in the pre-study (Source: Author, 2022).

EVI Interface Ratings Participants rated various car interfaces based on specific design factors, with each interface receiving 12 to 13 ratings. Figure 4.6 illustrates the overall sentiment towards each interface. Sti16 consistently received the highest amount of positive feedback, suggesting its design aligns well with user preferences across multiple factors. In contrast, Sti15 garnered the most critical feedback, indicating significant areas for improvement in its

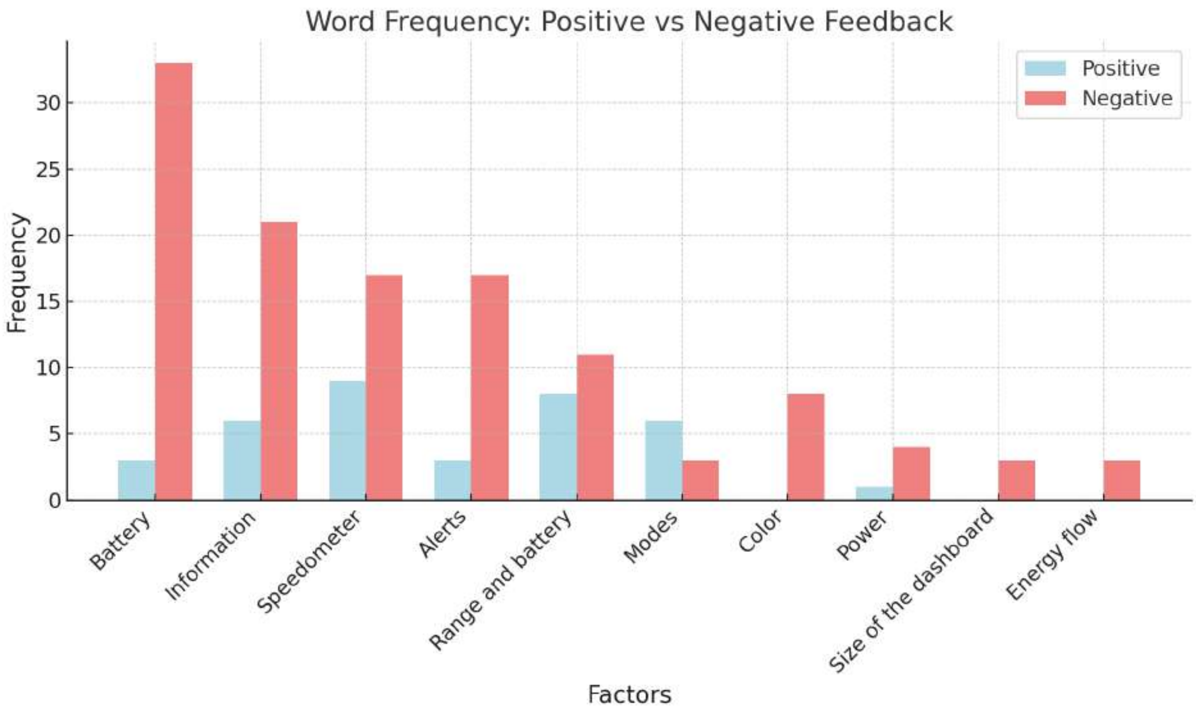


Figure 4.5: Word frequency distribution of positive and negative feedback from the pre-study (Source: Author, 2022).

usability and design from a user perspective.

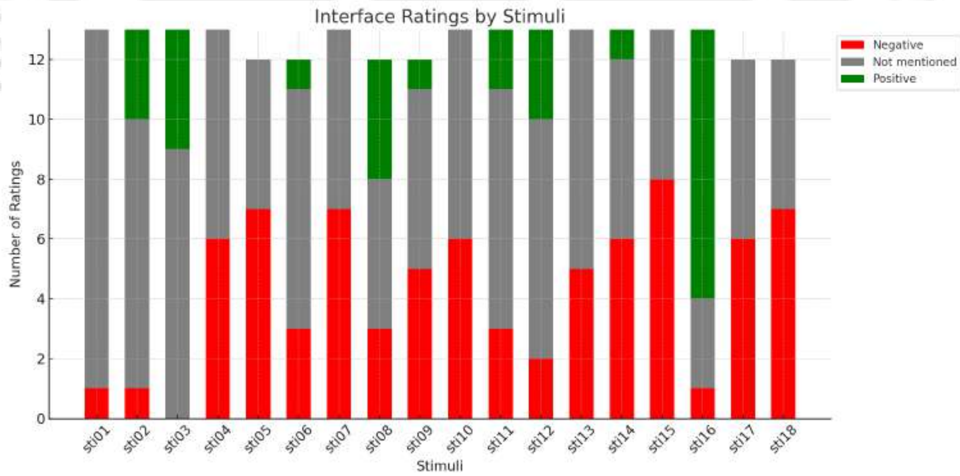


Figure 4.6: Participant ratings of electric vehicle interface stimuli obtained during the pre-study (Source: Author, 2022).

4.5.3 Implications to Main Study

This study provides structured input to the main research on e-bus dashboard design. It explores how interface designers and researchers perceive usability challenges in current EV instrument clusters and identifies key variables influencing driver interaction and interface performance.

The findings underscore the importance of clarity, consistency, and familiarity in digital dashboard design. Analog-style layouts and hybrid meters were preferred for their intuitive readability, while digital-only displays required greater visual effort. Clear battery visualization and standardized color codes emerged as essential for improving situational awareness and reducing range anxiety. Participants also emphasized the importance of a balanced information hierarchy, ensuring that critical elements such as range, battery, and speed remain visually prioritized.

These insights inform the main study in three ways:

1. They help define core interface variables, battery indicators, range displays, mode visibility, and speedometer layout for dashboard redesign.

2. They underscore the necessity of harmonizing technical accuracy with user familiarity to enhance usability and driver confidence.

3. The focus group evidence supports a systematic translation of qualitative feedback into measurable design parameters for prototype development.

Together, these findings bridge expert perception with user-centered needs, guiding the main study toward developing adaptive, accessible, and cognitively efficient digital dashboard interfaces for electric public vehicles.

4.6 Chapter Summary

This chapter synthesizes insights from three pre-studies that collectively informed the main study on designing a user-centered digital dashboard for e-buses in India. The user survey (Pre-study 1) identified core motivations and adoption challenges among Indian EV users, highlighting the need for economic efficiency, charging convenience, and performance clarity. The

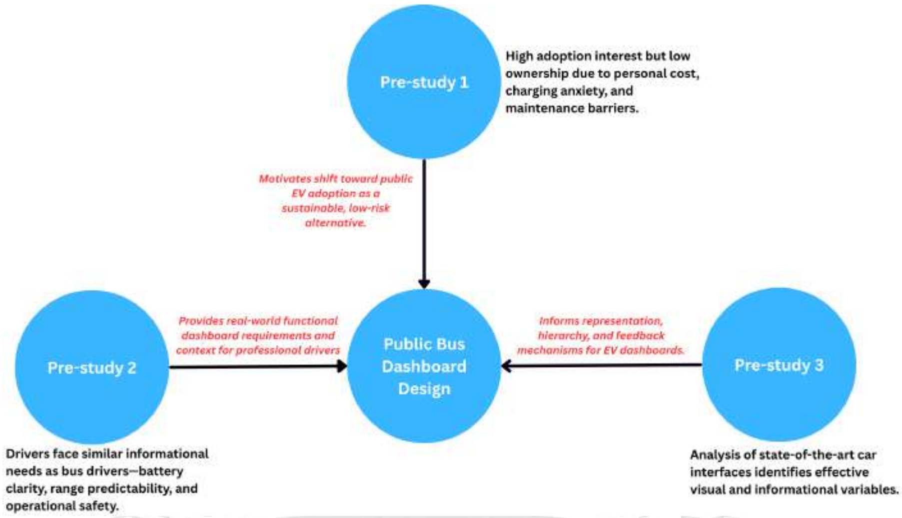


Figure 4.7: Flow diagram illustrating how the three pre-studies contribute to the main study (Source: Author, 2022).

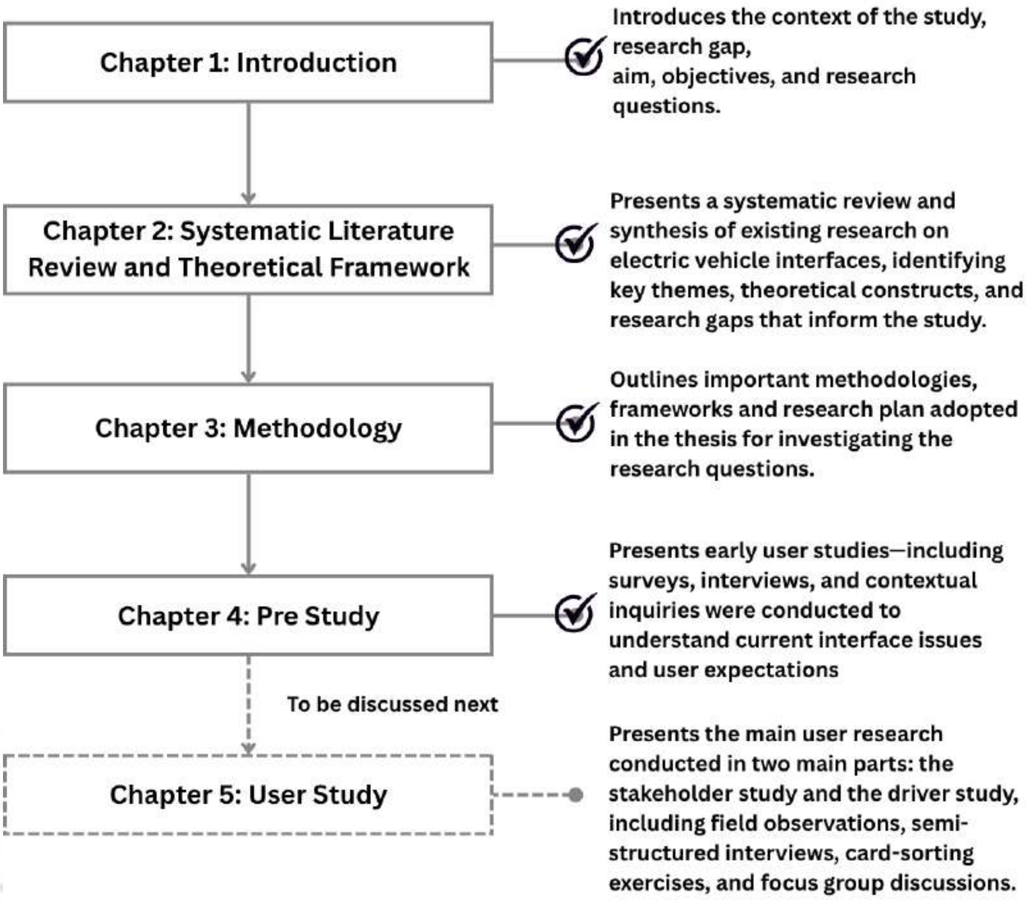
contextual inquiry (Pre-study 2) with e-rickshaw drivers revealed real-world usability gaps such as inconsistent battery feedback, poor visibility, and limited interaction cues, emphasizing the importance of clarity and trust in operational dashboards. The focus group study (Pre-study 3) with interaction designers analyzed existing EV interfaces, defining essential design parameters such as analog-digital balance, hierarchy, readability, and range visualization that enhance usability and reduce cognitive load. Together, these studies establish a strong empirical foundation for the main research, ensuring that the final EV bus dashboard design is grounded in user experience, contextual realities, and validated interface principles relevant to India's evolving public transport ecosystem (see Figure 4.7).

Table 4.5: Synthesis of pre-studies and their contribution to EV dashboard design variables

Pre-study	**Study Focus**	**Key Findings / Insights**	**Derived Design Variables**
Pre-study 1: EV Adoption Survey	Understanding user expectations and adoption factors	Importance of economy, performance, and charging infrastructure; influence of technology familiarity and usage context	Cost awareness, range visibility, charging information, simplified interface for diverse users
Pre-study 2: E-rickshaw Drivers	Real-world dashboard interaction in operational context	Need for clear battery indicators, low-battery alerts, minimal cognitive load, visibility under varying conditions	Real-time battery feedback, alert systems, glanceable interface, visual clarity, standardized layout
Pre-study 3: Design Students (FGD)	Expert evaluation of EV interface design and usability	Preference for familiar layouts, importance of hierarchy, clarity in icons and alerts, avoidance of clutter	Information hierarchy, icon clarity, layout consistency, multimodal feedback, interface simplification

This synthesis shown in Table 4.5, demonstrates how diverse data sources, including user perceptions, real-world observations, and expert evaluations, collectively informed the identification of core design variables for the main study.

A visual summary of the chapters covered so far is presented as follows:


Chapter 1: Introduction
Introduces the context of the study, research gap, aim, objectives, and research questions.
Chapter 2: Systematic Literature Review and Theoretical Framework
Presents a systematic review and synthesis of existing research on electric vehicle interfaces, identifying key themes, theoretical constructs, and research gaps that inform the study.
Chapter 3: Methodology
Outlines important methodologies, frameworks and research plan adopted in the thesis for investigating the research questions.
Chapter 4: Pre Study
Presents early user studies—including surveys, interviews, and contextual inquiries were conducted to understand current interface issues and user expectations
To be discussed next
Chapter 5: User Study
Presents the main user research conducted in two main parts: the stakeholder study and the driver study, including field observations, semi-structured interviews, card-sorting exercises, and focus group discussions.

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Chapter 5

Insights from original equipment manufacturer - stakeholders, technicians and drivers of E-buses

This chapter investigates the perspectives of original equipment manufacturer (OEM) stakeholders, e-bus technicians, and drivers to identify operational challenges, usability issues, and dashboard-related requirements in e-buses. It analyzes how existing interface layouts and information structures influence driver performance, situational awareness, and decision-making during real-world operations. Based on these insights, the chapter derives key user requirements and interface variables to inform the design of an effective, user-centered e-bus dashboard for the Indian public transport context. Unless stated otherwise, the term *dashboard* in this chapter refers to the combined driver-facing information system, comprising the instrument cluster (IC), LCD display, and the digital Driver Display Unit (DDU).

5.1 Introduction

This chapter presents two empirical studies conducted to obtain user-centered data for the design and usability assessment of e-bus dashboards. The first study (Study-1 in Section 5.3) involves stakeholders from an OEM based in Chennai and focuses on product development processes, design rationale, and feedback mechanisms guiding current and future dashboard systems. The second study (Study-2 in Section 5.4) involves professional e-bus drivers from Ahmedabad, the first Indian city to deploy e-buses in 2019. These participants possessed long-term driving experience and provided detailed accounts of operational difficulties, interface usability concerns, and information requirements encountered during daily driving.

The findings from the two studies are first analyzed independently and then examined together to identify areas of convergence and complementarity between design-side and use-side perspectives. This integrative approach enables a more comprehensive understanding of e-bus dashboard requirements than either perspective alone. The synthesized insights provide evidence-based guidance for refining dashboard information architecture, interaction logic, and interface layout, and directly inform the design phase of the research prototype, ensuring alignment with both real-world operational needs and industrial constraints.

5.2 Chapter Objectives

1. Identify key stakeholders involved in e-bus dashboard development and document their roles, responsibilities, and perspectives on design challenges and opportunities.

2. Identify the evolution of existing e-bus dashboards by mapping changes in interface elements, design rationale, and alignment with usability and safety standards.

3. Examine manufacturer priorities related to technical performance, functionality, integration, and cost constraints that influence dashboard design decisions.

4. Document the design principles and ergonomic guidelines currently applied to enhance information accessibility, task efficiency, and driver convenience.

5. Assess the training structure for drivers and technicians in dashboard operation, including selection criteria, methods, and effectiveness.
6. Investigate driver experiences with e-bus dashboards, focusing on workload, comfort, situational awareness, and adaptation to digital interfaces.
7. Synthesize stakeholder and user insights to establish evidence-based recommendations for future dashboard design and improvement.

5.3 Study-1: Stakeholder Study

This study investigates the design rationale, development priorities, and usability considerations that shape the dashboard systems of e-buses from the perspective of original equipment manufacturer (OEM) stakeholders. It examines how organizational decisions, technical constraints, and regulatory standards influence the design and implementation of information systems in public transport vehicles. In India, dashboard design is primarily guided by engineering, cost, and compliance requirements, while direct user feedback plays a limited role in the development process. To understand this imbalance, the study analyzes how manufacturers conceptualize and develop dashboard systems. It also examines how usability considerations are integrated into the product development cycle.

The study was conducted at the product development and manufacturing facility at one of India's earliest OEMs to design and deploy e-buses. Semi-structured interviews were held with key personnel involved in dashboard development, including program managers, vehicle architects, styling designers, hardware and testing engineers, advanced engineers, and both diesel and electric test drivers. The findings provide insight into how industrial and organizational priorities define what eventually reaches the driver's interface. These insights establish the foundation for the next phase of research, which investigates the driver's perspective through real-world operational studies.

5.3.1 Method

This study followed a qualitative inquiry-based approach to obtain detailed stakeholder perspectives on the evolution, functionality, and usability of e-bus dashboards. The procedure aligns with the formative phase of the overall research framework (*Stage 1: Understand & specify context of use* from Chapter 3), aimed at establishing an empirical understanding of design rationale and technical constraints prior to intervention development (see Figure 5.1).

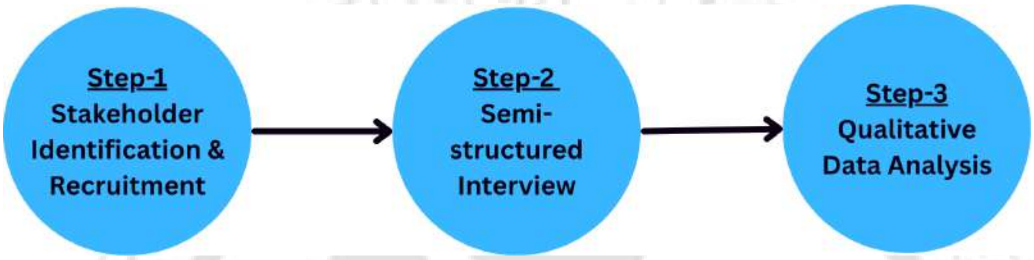

Figure 5.1: Overview of the stakeholder study method employed in the main study (Source: Author, 2023).

The methodological structure aligns with established qualitative research in mobility and transport studies (Bryson, 2004; Patton, 2014; Braun and Clarke, 2013). This study followed frameworks commonly used in stakeholder-based mobility research, consisting of four interconnected stages: stakeholder identification and recruitment, semi-structured interviews, thematic analysis, and systems interpretation.

5.3.1.1 Participant recruitment

Participants were recruited purposively to represent design, engineering, testing, and program management domains. Purposive and snowball sampling ensured a balance between high-level decision-makers and technical contributors (Bryson, 2004). Recruitment continued until thematic saturation was achieved.

5.3.1.2 Procedure: Interview Protocol

The interviews were conducted on-site at the OEM's product development facility in Chennai. Each session took place in a private meeting room to maintain confidentiality and minimize workplace disturbance. The process followed a structured and sequential protocol developed in line with qualitative inquiry standards (Patton, 2014).

Step 1: Recruitment and Scheduling: Participants were contacted through official communication channels and provided with an information sheet outlining the study objectives, confidentiality policy, and participation requirements. Interview schedules were confirmed based on participant availability.

Step 2: Introduction and Consent: At the beginning of each session, the researcher introduced the study's purpose, explained the procedure, and obtained verbal and written consent for participation and audio recording.

Step 3: Context Establishment: Participants were asked to briefly describe their professional role and involvement in e-bus dashboard design, testing, or management. This established the operational context for subsequent discussion.

Step 4: Interview Execution: The researcher followed a semi-structured interview guide consisting of open-ended questions on dashboard evolution, usability challenges, technical constraints, validation practices, and driver training mechanisms. Probing and follow-up questions were used to clarify or deepen responses when necessary.

Step 5: Session Closure: At the end of each interview, the researcher summarized the discussion, invited participants to verify or elaborate on key points, and thanked them for their contribution.

5.3.1.3 Data Collection and Analysis

All interviews were audio-recorded. Recordings were transcribed verbatim in Microsoft Word and were imported into MAXQDA for analysis.

The analysis followed Braun and Clarke (2013) seven-stage framework for thematic analysis: (1) transcription, (2) reading and familiarization, (3) coding, (4) searching for themes, (5) reviewing themes, (6) defining and naming themes, and (7) writing and final analysis. A combined deductive–inductive coding approach was adopted to capture both predefined design considerations and emergent stakeholder perspectives.

To ensure reliable analysis, two researchers independently coded 25% of the transcripts and compared their results using Cohen's kappa coefficient. The inter-coder reliability value of $\kappa = 0.82$ indicates *substantial agreement* (Landis and Koch, 1977). Discrepancies were discussed and resolved collaboratively before applying the final codebook to the full dataset.

5.3.1.4 Ethics and Confidentiality

Participants were informed about the study's purpose, data use, and their right to withdraw at any time. Verbal and written consent were obtained prior to participation. No personal identifiers or confidential company information were disclosed in any report or publication. All data were anonymized and stored securely in accordance with institutional data management guidelines.

5.3.2 Results

A total of 14 stakeholders participated in the interviews (13 males, 1 female; mean age = 33.2 years). The participants represented diverse roles across the organization, including four managers, three engineers, one vehicle architect, one instrument cluster styling designer, one test EV engineer, one EV driver trainer, and four test drivers (see details in Table 5.1).

Table 5.1: Profile and professional background of stakeholders interviewed in the study (Source: Author, 2023).

Code	Profile	Exp (yrs)	Responsibility
S1	Manager (Electronics Hardware cockpit)	35	Designs and develops cockpit electronic components, ensuring safety, performance, and quality.
S2	Engineer (Electronics Hardware cockpit)	4	Designs circuits, including instrument clusters, displays, control modules, and diagnostics.

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Table 5.1 continued from previous page

Code	Profile	Exp (yrs)	Responsibility
S3	Manager (Program-Ebus)	30	Coordinates e-bus implementation in cities, manages resources, and oversees strategic objectives.
S4	Engineer (Advanced EVs)	20	Conducts EV R&D to explore new technologies, materials, and methods.
S5	Vehicle Architect (Bus Aggregate)	15	Integrates vehicle aggregates according to specifications, e.g., selecting appropriate motors.
S6	Manager (IC-Styling)	18	Manages design costs, leads projects, and interacts with clients.
S7	Designer (IC-Styling)	8	Selects size, color, arrangement, semantics, and grouping of instrument cluster information.
S8	Manager (EV-Quality)	22	Uses driver and customer feedback to improve product quality and experience.
S9	EV Driver Trainer	4	Assesses driver performance during training to ensure safe and confident operation.
S10	Engineer (Diesel/CNG Testing)	11	Conducts performance tests, analyzes data, and resolves issues.
D0	Test Driver	20	Evaluates e-bus performance, safety, and efficiency; provides feedback to improve design and functionality.
D1	Test Driver	30	Evaluates e-bus performance, safety, and efficiency; provides feedback to improve design and functionality.
D2	Test Driver	15	Evaluates e-bus performance, safety, and efficiency; provides feedback to improve design and functionality.

Continued on next page

Table 5.1 continued from previous page

Code	Profile	Exp (yrs)	Responsibility
D3	Test Driver	25	Evaluates e-bus performance, safety, and efficiency; provides feedback to improve design and functionality.

Interview transcripts were analyzed through a hybrid thematic analysis in MAXQDA, combining deductive codes derived from the interview guide and prior EV usability literature with inductive codes emerging from stakeholder narratives. The coding framework was refined iteratively until consensus was achieved between two researchers, ensuring analytical rigor and consistency.

Thematic analysis of the stakeholder interviews yielded five major themes and several sub-themes, representing the interconnected socio-technical dimensions of e-bus dashboard design and operation (see Table 5.2). These themes were *(1) Fleet Operations & Charging Infrastructure, (2) Maintenance & Technical Challenges, (3) Driver Experience & Adaptation to EVs, (4) Dashboard Design & Human–Machine Interaction,* and *(5) Safety Features & Driver Support Systems*. These reflect both organizational priorities and real-world challenges encountered during e-bus deployment.

Table 5.2: Key themes and associated sub-themes identified through thematic analysis (Source: Author, 2023).

Theme	Sub-themes
Theme 1: Fleet Operations & Charging Infrastructure	Fleet monitoring; Whole-night depot charging and mid-day opportunity charging; Route-based charging coordination between OEMs and authorities; Charging cost variation across cities and its operational implications.
Theme 2: Maintenance &	Routine maintenance and diagnostics;

Continued on next page

Table 5.2 continued from previous page

Theme	**Sub-themes**
Technical Challenges	Driver-reported feedback (*"Driver's Voice"*) integration; Lack of skilled technicians and limited service network; Environmental and electrical sensitivity affecting e-bus reliability.
Theme 3: Driver Experience & Adaptation to EVs	Enhanced driving comfort due to reduced noise and vibration; Challenges in interpreting digital interfaces and diagnostic codes; Increased cognitive load from frequent alerts and telltales; Language barriers and the need for multilingual feedback systems.
Theme 4: Dashboard Design & Human–Machine Interaction	Prioritization of essential driving and safety information; Simplified hybrid analog–digital layout and adaptive visibility; Context-aware display hierarchy and minimal visual clutter; Preference for larger screens and reduced manual switches.
Theme 5: Safety Features & Driver Support Systems	Preventive maintenance alerts and feedback loops; Centralized ADAS and warning information placement; Integration of ITS and auxiliary systems into unified console; Preservation of manual redundancy for emergency controls.

Each theme and its associated sub-themes are elaborated below, supported by illustrative quotations from the participants to highlight distinct perspectives and recurring patterns.

5.3.3 Theme 1: Fleet Operations and Charging Infrastructure

E-buses require a well-coordinated fleet management system to optimize their operations, ensure efficient charging, and prevent disruptions due to low battery levels.

5.3.3.1 Fleet Monitoring

Fleet monitoring emerged as a central operational theme, highlighting how digital connectivity supports efficient supervision of e-bus systems. Stakeholders described the OEM control center as the "nerve hub" of operations, where telemetry platforms continuously monitor vehicle location, performance, and charging status (refer to details in Figure 5.2). The system provides live visibility of every bus, enabling coordination between fleet owners, engineers, and service teams through a unified cloud interface.

"Every bus is tracked in real time so we can see its route, charge level, and issues from the control room." — Participant S3

"If anything goes wrong on the route, the control team identifies it immediately and contacts the driver." — Participant S8

This continuous monitoring allows rapid intervention and data-driven maintenance planning. Telemetry dashboards consolidate key parameters such as battery health, energy consumption trends, trip reports, and diagnostic alerts. Stakeholders emphasized that these systems have streamlined communication, reduced downtime, and improved operational reliability. This observation aligns with prior findings on how centralized digital monitoring enhances efficiency and decision-making in electric fleet management (Farahpoor et al., 2023).

5.3.3.2 Charging infrastructure, range anxiety, and operational adjustments

Charging infrastructure strongly influences route planning, operational confidence, and cost-effectiveness of e-buses. Stakeholders described a depot-based overnight charging strategy supplemented by opportunity (fast) charging during service intervals. Routes are planned to align with charger locations and depot capacity, but operational disruptions still occur when delays, high loads, or degraded battery health accelerate energy consumption.

"Each bus goes for full charging at night in the depot, and we do fast charging after every trip." — Participant S5

Despite planning, range anxiety persists. Participants reported mid-day trip cancellations or dynamic reassignment when remaining state-of-charge (SOC) fell below operational thresholds. Control-room monitoring and on-the-fly bus rotation reduce service impact but do not eliminate

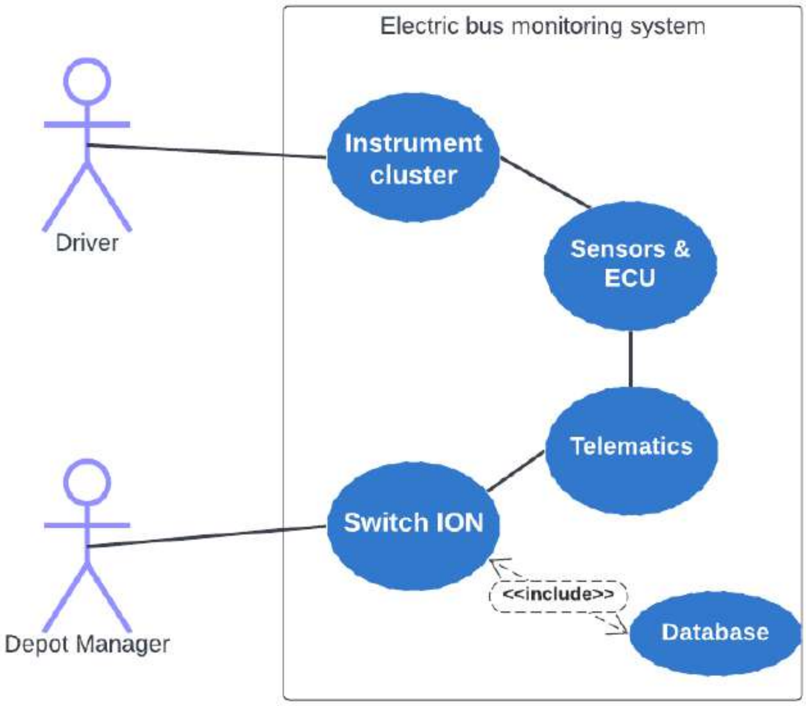


Figure 5.2: Schematic representation of the e-bus monitoring system and its key components (Source: Author, 2023).

the underlying constraints, which are exacerbated on hilly routes or during peak congestion. These operational impacts are particularly acute for older vehicles with reduced battery efficiency.

Regional electricity tariffs further affect viability. Stakeholders noted wide variation in charging costs across states, which alters per-kilometre economics and influences deployment decisions.

"Charging costs differ from less than 5*/kWh to nearly* 11*/kWh across states, which significantly changes running costs per kilometre."* — *Participant S3*

Together these findings indicate that improving predictive energy-management, increasing opportunity-charger availability, and accounting for local tariff regimes are necessary to reduce operational anxiety and improve fleet reliability (Barbosa, 2024; Zhao et al., 2020).

5.3.3.3 Charging Cost Variations Across Cities

Charging cost considerations emerged as a major determinant of large-scale e-bus adoption. Stakeholders consistently emphasized that high capital investment and uneven charging tariffs across Indian states constrain operational scalability and financial planning.

The initial procurement cost of e-buses remains substantially higher than that of diesel or CNG models, primarily due to battery expenses, which account for nearly half of the total vehicle cost.

"An e-bus today costs nearly twice that of a diesel one because the battery alone makes up around 50% of the total price. Operators have to plan carefully before committing to large EV fleets." — Participant S3

Beyond procurement, regional disparities in electricity pricing significantly affect running costs. Charging tariffs vary widely across states, shaping the economic feasibility of EV fleet operations.

"For example, charging costs differ from less than 5 per kWh in Delhi to almost 11 in Tamil Nadu. Since a bus consumes roughly 1 kWh per kilometer, that means 4 per km in Delhi but 11 in TamilNadu almost equal to diesel costs." — Participant S3

Stakeholders reported that such cost discrepancies influence where fleets are deployed and how charging schedules are planned, often discouraging operation in high-tariff regions. These findings reflect broader patterns noted by Nehiba (2024), who observed that inconsistent energy pricing structures remain a significant barrier to sustainable EV fleet expansion and long-term financial optimization.

5.3.4 Theme 2: Maintenance and Technical Challenges

Maintenance emerged as a critical operational domain in which e-buses differ substantially from their conventional counterparts. While both follow structured daily, weekly, and monthly inspection cycles, stakeholders emphasized that e-buses demand more comprehensive and frequent checks due to their electrical and software subsystems. The diagnostic process involves monitoring of battery health, insulation resistance, cooling systems, and high-voltage components to prevent thermal or mechanical failures.

"During night shifts, all the inspections take place. The technicians check specific e-bus requirements like insulation, charging connectors, and battery temperature." — Participant S3

This aligns with Wang et al. (2022), who emphasize preventive maintenance strategies as essential for EV fleet reliability.

In addition to scheduled servicing, the Original Equipment Manufacturer (OEM) has institutionalized a practice known as the *Driver's Voice*. Each driver reports operational anomalies or performance concerns after completing their route such as abnormal noise, vibration, or dashboard warnings. These firsthand inputs are logged digitally and reviewed during the nightly maintenance cycle.

"When the buses return to the depot, drivers share any issues they noticed during the trip. Those reports are recorded and checked by the maintenance team." — Participant S8

This bottom-up feedback mechanism strengthens real-time monitoring and reduces fault-resolution time, reflecting a hybrid model of *user-informed preventive maintenance*. Together, these practices ensure continuous operational readiness and support adaptive improvements in e-bus reliability and performance.

5.3.4.1 Diagnostic Alerts and Driver Response Protocols

Diagnostic alerts serve as the primary interface for real-time fault detection in e-buses. Stakeholders highlighted that the dashboard communicates system errors through multimodal cues combining visual and auditory signals to ensure prompt driver awareness.

"For any alert, we have two features: a telltale with a buzzer and an LCD pop-up." — Participant S5

These alerts are integrated with the onboard diagnostic (OBD) system, allowing drivers to identify potential malfunctions related to battery temperature, motor torque, insulation faults, or high-voltage disconnects. As noted by Astrain et al. (2021), multimodal feedback significantly improves driver response time in high-risk operational contexts.

Upon receiving an alert, drivers immediately report the issue to the shift-in-charge through digital communication channels. Each driver was equipped with a smartphone and typically captures the telltale display using the camera, forwarding it via encrypted messaging applications such as WhatsApp. The shift-in-charge then relays the diagnostic information to the maintenance technician for remote assessment and action coordination. This rapid information loop ensures minimal downtime and informed decision-making during on-route incidents.

Safety response protocols are also standardized across depots. Drivers undergo structured training modules to ensure proper response during diagnostic alerts, particularly in high-voltage or thermal warning scenarios.

"Drivers are trained to park the bus safely, clear passengers, and mark the vehicle's location before contacting the control room." — Participant S3

Such standardized procedures align with the human–machine interaction frameworks discussed by Mohammed et al. (2021), emphasizing the integration of driver behaviour, interface clarity, and safety compliance in EV fault management. These coordinated protocols ensure passenger safety, reduce operational risk, and facilitate efficient fault rectification (see Figure 5.3).

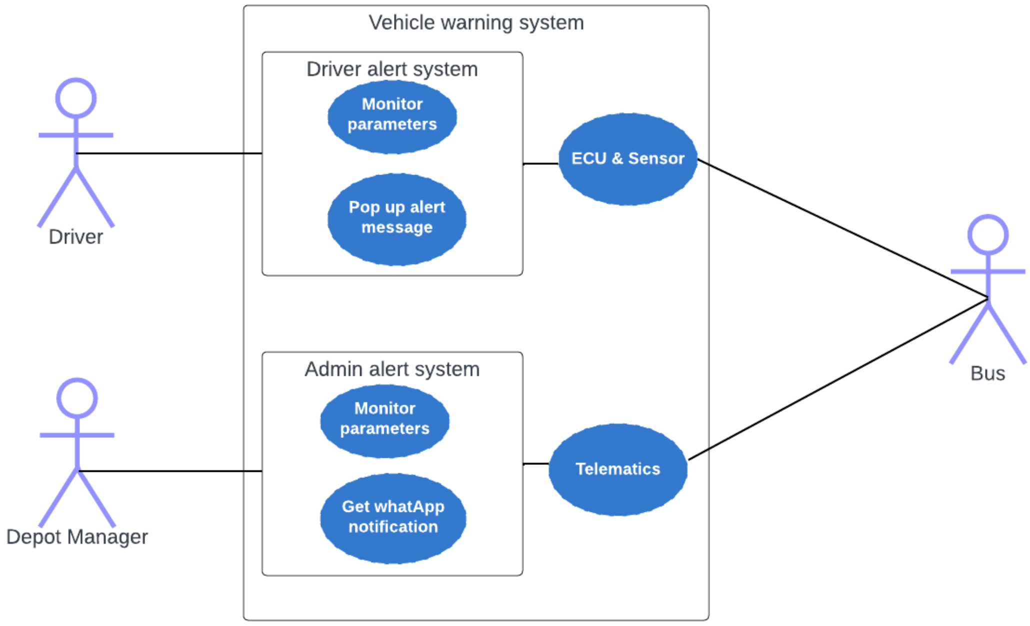


Figure 5.3: Use-case workflow illustrating a city bus diagnostic alert and the corresponding driver response (Source: Author, 2023).

5.3.4.2 Lack of Skilled Technicians

A recurring operational challenge identified by stakeholders was the shortage of skilled technicians capable of diagnosing and repairing e-bus faults. Unlike conventional systems, e-buses integrate complex electrical architectures, high-voltage circuits, and software-dependent diagnostic mechanisms. Stakeholders explained that because electric drivetrains contain fewer mechanical components, physical inspection offers limited insight making the system appear as a "black box." In such cases, diagnostic errors trigger an automatic safety shutdown, requiring specialized intervention.

"Due to the reduced number of mechanical parts, conducting a physical checkup becomes challenging. Consequently, the vehicle can be perceived as a black box. Any diagnostic error triggers an automatic shutdown of the bus, requiring resolution by trained professionals. Unfortunately, the service locations lack adequately skilled experts, which contrasts with the presence of dedicated roadside breakdown services for other fuel vehicles." — Participant S3

This shortage of trained personnel limits the responsiveness of service teams and prolongs vehicle downtime. It also underscores the dependency of e-bus operations on a smaller pool of EV-certified technicians, a finding consistent with Taylor et al. (2025), who emphasized the urgent need for targeted vocational programs in electric mobility maintenance.

Beyond technical staff shortages, stakeholders noted difficulties in recruiting and training qualified drivers. Operating an e-bus requires proficiency in regenerative braking systems, digital instrument clusters, and high-voltage safety protocols skills not commonly found among conventional drivers. The limited availability of structured EV training programs further constrains workforce readiness.

"Recruiting new drivers for the e-bus system is challenging due to the need for specific skills and training. Additionally, the less developed service network for EVs compared to diesel vehicles poses maintenance and servicing challenges." — Participant S4

Together, these workforce and infrastructure gaps highlight the transitional strain in India's e-bus ecosystem, where rapid technological advancement outpaces institutional capacity building. Expanding technical education and creating standardized EV maintenance certifications are thus critical to ensuring sustainable fleet operations and service reliability.

5.3.4.3 Environmental and Electrical Sensitivity

Environmental conditions emerged as a critical contextual factor influencing the performance and reliability of e-buses in India. Stakeholders emphasized that while electric mobility faces technical challenges worldwide, India's climatic and infrastructural diversity marked by high ambient temperatures, monsoon flooding, and pervasive dust introduces additional operational risks that are less common in temperate regions.

"When connectors are repeatedly engaged, they develop scoring marks that lead to oxidation and blackening. This causes resistance and overheating during charging. The issue has become more frequent in recent years, especially due to India's dusty environment." — Participant S3

Such particulate contamination degrades electrical contact efficiency and accelerates connector wear, increasing the probability of thermal failure. Consistent with Shao et al. (2020), stakeholders noted that environmental particulates and humidity are among the leading causes of reliability degradation in high-voltage EV systems.

In addition to dust, high humidity and extreme seasonal variation affect electrical insulation and cooling performance. Stakeholders described that monsoon flooding in particular poses acute risks to system safety. Because e-buses operate at voltages up to 650V, even minimal water ingress can trigger automatic shutdowns through insulation monitoring software designed to prevent electrical hazards.

"The EV interface is highly sensitive. If it detects even a small current leak, it shuts down automatically to protect passengers. During monsoon, when the underbody is wet, even a drop of water on a connector can trigger a short and stop the bus. The system cannot always distinguish between a small leak and major submersion." — Participant S3

These environmental interactions illustrate a key constraint in adapting EV technologies designed for Western climates to Indian operating conditions. The combination of high dust exposure, variable humidity, and uneven road surfaces amplifies maintenance demands and requires localized engineering strategies such as enhanced connector sealing, humidity-resistant insulation, and improved diagnostic calibration. Addressing these environmental sensitivities is therefore essential not only for operational continuity but also for ensuring driver trust and system dependability in diverse Indian contexts.

5.3.5 Theme 3: Driver Experience and Adaptation to EVs

The transition from conventional diesel and CNG buses to e-buses has transformed the driving experience, offering distinct ergonomic and cognitive implications. Stakeholders and drivers described this shift as both liberating and demanding, combining enhanced comfort with new technological challenges.

5.3.5.1 Improved Driving Comfort

Drivers with prior experience operating diesel or CNG fleets emphasized the substantial comfort benefits of e-buses. The absence of engine vibration, heat, and gear-handling fatigue has improved perceived driving quality and reduced physical strain. The automatic transmission system further simplifies control, enabling smoother operation and longer driving endurance.

"Driving an e-bus is an easy and stress-free experience. There is no sound or vibration, resulting in a smoother ride. Unlike diesel/CNG, e-buses come with automatic transmission, eliminating the need for a clutch. With just an accelerator, and a brake, and the addition of power steering, driving becomes even simpler and more enjoyable." — Participant D0

This finding reflects with Jiang et al. (2021), who noted that the elimination of noise and vibration enhances occupational comfort and reduces driver fatigue in electric fleet operations. However, comfort improvements are accompanied by new cognitive demands. Frequent diagnostic alerts and system notifications require drivers to maintain constant dashboard awareness, increasing mental workload.

"In diesel buses, there are no error codes, but with electric, I have to keep an eye on the dashboard every ten minutes, or else the buzzer will sound repeatedly." — Participant D0

5.3.5.2 Challenges in Learning Digital Interfaces

While the adoption of digital dashboards introduces modern control interfaces, it also presents a steep learning curve for drivers transitioning from analog systems. Stakeholders highlighted that limited familiarity with digital readouts and diagnostic codes often forces drivers to relied on workarounds such as visual documentation or assistance from technicians.

“Reading and understanding error messages is challenging, so I take a photo and send it to the engineer for guidance.” — Participant D1

Although adaptation improves over time, the initial transition phase is marked by uncertainty and dependency on support systems.

“Initially, it might be new to the drivers. However, as time goes by, the driver’s familiarity with digital clusters may improve.” — Participant S7

A recurring concern among stakeholders was the excessive number of telltales and warning symbols, which overload drivers with information and hinder rapid prioritization during operation.

“Some drivers struggle to comprehend the severity of situations conveyed through telltales, resulting in potential financial losses. Critical telltales related to parameters like soot and exhaust are sometimes misunderstood or ignored.” — Participant S10

Language barriers further exacerbate comprehension difficulties, as many drivers lack fluency in English, making text-based alerts on LCD screens less effective.

“I have difficulty reading detailed error messages and usually rely on the feel of the vehicle or telltale indicators.” — Participant D3

These findings echo Wei et al. (2020), who advocate for multilingual, icon-based, and context-sensitive human–machine interface (HMI) designs to improve inclusivity and reduce cognitive load. Collectively, these insights reveal that while e-buses enhance physical comfort, they simultaneously demand higher digital literacy and situational awareness, necessitating redesigned dashboard systems that are intuitive, multilingual, and adaptive to drivers with varying technical proficiency.

5.3.6 Theme 4: Dashboard Design and Human–Machine Interaction

Dashboard design emerged as a central theme connecting technology, usability, and safety. Stakeholders consistently highlighted the need for interfaces that balance information density with simplicity, enabling drivers to interpret critical vehicle data efficiently under varying operational conditions.

5.3.6.1 Critical Information Visibility

Stakeholders emphasized that the instrument cluster must prioritize key operational metrics such as speed, odometer, motor temperature, chiller temperature, and State of Charge (SOC). The presentation of this information should be unambiguous and immediately accessible, particularly for indicators affecting vehicle safety and energy management.

"The dashboard should prioritize battery charge and electric-related functions." — Participant S3

In alignment with Schwambach Costa (2020), participants advocated for adaptive display hierarchies that dynamically highlight the most relevant information based on driving context. Reducing visual clutter and isolating critical alerts were seen as vital to minimizing distraction and cognitive overload.

"For example, if the driver is driving in a city, for him, for that particular moment, he just wants to see the route of the path only the map could be displayed." — Participant S7

Such adaptive visibility supports context-aware interaction, ensuring that essential driving information remains foregrounded while secondary data recedes from view.

5.3.6.2 Instrument Cluster Layout Preferences

The OEM design team emphasized a minimalist approach to reduce the number of physical controls and promote intuitive interaction. Instead of distributing functions across separate dials and switches, stakeholders proposed consolidating all essential indicators and settings within a unified digital interface. This hybrid approach retains analog familiarity while leveraging digital flexibility.

"The instrument cluster should have a complete LCD display with gauges positioned on the edges and telltales placed on the top. This arrangement allows for easy visibility and access to essential information. By combining digital gauges with traditional telltales, drivers can get a comprehensive overview of their vehicle's status." — Participant S2

This preference for structured digital layouts suggests a gradual design transition, preserving the legibility of analog systems while incorporating adaptive digital features that can evolve with driver familiarity and technological maturity.

5.3.6.3 Need for Larger Screens and Touch-Free Controls

Stakeholders further emphasized the role of display size and visual ergonomics in supporting situational awareness and reducing fatigue. Larger, high-resolution screens were viewed as essential for presenting layered information (route maps, system diagnostics, charge status) without crowding the interface or requiring physical navigation.

"With bigger screens, you can get more information without needing physical switches. The screen can display the route, vehicle performance, speed, charge, etc." — Participant D0

Participants also suggested bringing multiple systems, such as air conditioning, fire alarms, and emergency switches, into a single digital console. They felt this would help drivers stay focused and reduce the need to monitor fragmented interfaces.

"Various essential systems, including the AC system, fire detection alarms, and emergency switches, are in place. We aim to streamline the interior design, minimizing distractions for optimal focus and functionality." — Participant S5

Beyond efficiency, aesthetic and experiential aspects were also recognized as influencing driver satisfaction. Stakeholders proposed the use of Thin Film Transistor (TFT) displays, which offer higher data density, lower maintenance, and better visual appeal compared to traditional analog clusters.

"The biggest solution is that with the screens, you get more information but don't require more infrastructure." — Participant S5

Collectively, these insights underscore the growing movement toward integrated, context-aware, and ergonomically optimized dashboard systems. Such designs not only improve information access and task efficiency but also contribute to a more engaging and less stressful driving experience for professional e-bus operators.

5.3.7 Theme 5: Safety Features and Driver Support Systems

Safety-related systems formed a recurring concern among stakeholders, who emphasized that the reliability of dashboard alerts and control interfaces is vital to maintaining passenger and driver safety. Their discussions centered on three dimensions: preventive maintenance feedback, the integration of Advanced Driver Assistance Systems (ADAS), and the prioritization of safety-critical controls in interface design.

5.3.7.1 Preventive Maintenance and Dashboard Alerts

Stakeholders consistently underscored the importance of preventive maintenance notifications to sustain the operational safety and reliability of e-buses. Several participants noted that interface failures often occurred due to improper servicing, such as disconnected connectors or incomplete diagnostics. They felt that clearer in-vehicle alerts and maintenance prompts could have helped prevent these issues.

"Getting preventive maintenance notifications through the interface would help ensure proper maintenance during service, which is crucial for the safety and reliability of e-buses. There have been several instances where the EV interface failed due to improper maintenance, such as disconnected connectors affecting performance. It would be better if the operations and service teams took appropriate actions based on dashboard system alerts." — Participant S3

This feedback echoes with research emphasizing the role of automated alert systems in reducing maintenance-related downtime and safety risks (Astrain et al., 2021). Stakeholders further advocated for stronger coordination between service and operations teams to ensure timely response to system warnings and fault codes.

5.3.7.2 ADAS and Safety Information Placement

Beyond maintenance feedback, participants discussed how digital interfaces can support driver awareness through the placement and presentation of safety information. TFT-based digital clusters were seen as advantageous for visualizing real-time alerts, pollution checks, and ADAS feedback. Although cost was identified as a barrier, stakeholders believed that the long-term benefits of reliability and reduced maintenance justify the investment.

"Implementing a digital instrument cluster might initially be costly. Once it becomes a practice, it will reduce. Eliminating switches and dashboards can reduce production and maintenance costs." — Participant S6

Several participants stressed that ADAS alerts should occupy central positions within the instrument panel to ensure immediate visibility and quick driver reaction during high-demand situations.

"It is important to place vital Advanced Driver Assistance System (ADAS) information in the center of the instrument panel so drivers can promptly access alerts and warnings for enhanced safety and decision-making." — Participant S2

These perspectives echoes the findings of Jiang et al. (2021), who demonstrated that centralized ADAS displays reduce visual search time and improve response accuracy in public transport contexts.

5.3.7.3 Prioritizing Safety Over Non-Essential Data

A prominent consensus among stakeholders was that safety-critical controls must always remain accessible, redundant, and independent of digital interfaces. They emphasized the need for a unified yet modular console design that brings together key systems such as air conditioning, emergency communication, and ITS. At the same time, they stressed that physical controls should be retained for life-safety functions.

"Our goal is to establish a single and integrated digital console that can support various technologies, such as air conditioning controls and ITS. This design strategy will minimize distractions and focus the driver's attention on safety-critical controls." — Participant S4

In particular, participants warned against over-digitization of safety elements. Manual overrides for emergency exits, alarms, and passenger doors were considered indispensable for ensuring reliability during hardware or software failures.

"Essential safety components such as isolators, fans, and emergency alarms should always be situated outside the digital dashboard and given priority over other information. To maintain reliability, safety-critical controls should never be installed on a touchscreen or console." —

Participant S5

Stakeholders also suggested that during emergencies such as electrical leakage or fire, the dashboard should automatically suppress non-essential information and display only critical alerts. This design principle was viewed as essential for maintaining driver focus and ensuring swift, appropriate action.

"In critical situations, the dashboard should prioritize safety-related information, overriding non-essential details. This ensures drivers are promptly alerted to urgent issues like leaks or fires." — Participant S6

"If a leak or fire is detected, all other dashboard information should be overridden to display only the warning." — Participant S5

These insights collectively reinforce the argument that digitalization in heavy-vehicle dashboards should progress carefully. Automation and richer information can be introduced, but redundancies for safety-critical control and communication systems must be preserved.

Taken together, Study-1 explains how e-bus dashboards are designed from the OEM perspective. Design decisions are shaped by technical constraints, safety requirements, and operational priorities. These findings reflect how manufacturers expect drivers to read alerts, respond to warnings, and manage the vehicle. However, this perspective does not capture how drivers actually experience and use the dashboard during daily operations. To address this gap, Study-2 examines e-bus dashboards from the drivers' point of view, focusing on real-world use, usability challenges, and on-road decision-making.

5.4 Study-2: User Study

This study investigated how bus drivers interact with the dashboard of electric city buses during regular operations. It examined how they monitored information, manage vehicle controls, and respond to different driving situations in real-world conditions. The dashboard functions as the driver's central interface with the vehicle, influencing decision-making, performance, and safety. In India, dashboard development is often guided by engineering and regulatory priorities rather than by drivers' actual experiences. As a result, important usability challenges remain undocumented. This study addresses that gap by directly engaging drivers to investigate their routines, behaviors, and challenges when using existing dashboard systems.

This study was conducted at the Electric Bus BRTS depot, Ahmedabad, India. Through field observations and semi-structured interviews conducted at public transport depots, the study analyzes how drivers perceive dashboard information and manage operational tasks. The findings identify critical usability issues, cognitive demands, and ergonomic concerns that affect driving performance and satisfaction. These insights contribute to the development of a driver-centered design framework that aims to improve usability, safety, and overall operational efficiency in electric public transportation systems.

5.4.1 Method

This study adopts a mixed-methods approach to investigate how bus drivers interact with the dashboard of electric city buses during regular operations. It builds on insights from the preceding Stakeholder Study and extends the formative phase of the overall research framework (*Stage 1: Understand & Specify Context of Use,* Chapter 3). Together, these two studies complete the foundational stage by combining manufacturer perspectives with real-world driver experiences (see Figure 5.4).

The methodological structure follows established practices in human-centered transport and usability research. Consistent with mixed-methods principles, the study integrates qualitative and quantitative strands to obtain a comprehensive understanding of dashboard usability and driver experience.

The qualitative phase comprises field observations, semi-structured interviews, focus group discussions, and participatory design tasks that capture contextual evidence of driver routines, challenges, and preferences. The quantitative phase includes the System Usability Scale (SUS) and a Tell-tale Knowledge Survey, providing measurable indicators of usability and comprehension. The integration of both strands enables data triangulation and a balanced interpretation of subjective insights and objective performance, thereby completing the contextual understanding required for subsequent design development.

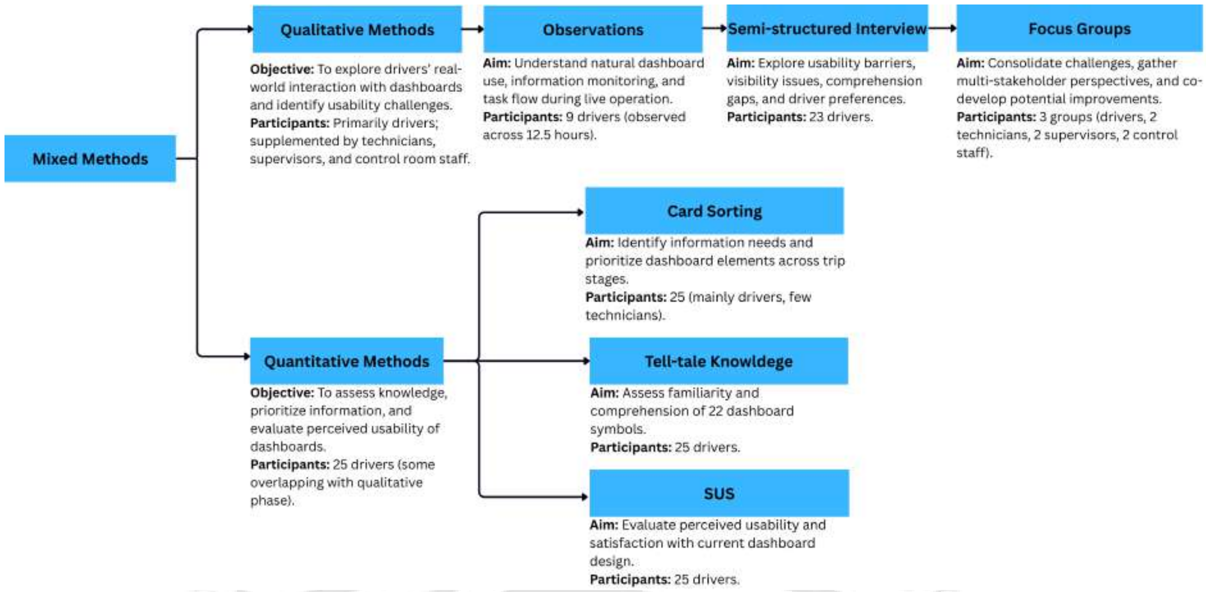


Figure 5.4: Overview of the mixed-method user study adopted for the driver study (Source: Author, 2023).

5.4.1.1 Participant recruitment

We used purposive and convenience sampling to include both newly trained and experienced e-bus drivers, as well as depot staff, including technicians, supervisors, and control room operators. All participating drivers hold valid commercial licenses and are actively employed in city bus operations. Drivers with less than one year of experience are classified as newly trained, while those with more than three years are considered experienced. Participants took part in one or more study components depending on availability. Each participation was documented separately for its corresponding component.

5.4.1.2 Data Collection

Data collection was organized in sequential phases, with each method designed to build upon insights obtained from the first study (see Figure 5.3). The process began with field observations that aimed to understand how drivers interact with the dashboard during real-world driving conditions. Based on these observations and the earlier study, a semi-structured interview guide was developed. The interviews were conducted individually with drivers to explore usability challenges and operational difficulties. The findings from these interviews were discussed in focus group sessions with drivers, technicians, and supervisors to identify recurring issues and possible improvements. Participatory card-sorting tasks were also conducted to prioritise drivers' information needs across different trip stages. Finally, quantitative evaluations using the Tell-tale Knowledge Test and the System Usability Scale (SUS) were carried out to assess drivers' comprehension and overall satisfaction. This sequential mixed-methods process provided comprehensive insights and ensured validity through methodological triangulation.

Observation: Field observations were conducted to document how drivers interact with the dashboard during regular shifts. A total of 12.5 hours of observation covered morning, mid-day, and evening operations. The observations focused on how drivers monitor dashboard parameters, respond to warnings, and adjust their behaviour according to the displayed information. Data were recorded through field notes, photographs, and short video clips.

Semi-Structured Interviews Individual interviews were conducted with drivers to examine usability barriers, comfort issues, and preferences related to dashboard features. Each session lasted between 30 and 45 minutes and followed a semi-structured guide (see Appendix A). All interviews were audio-recorded with participant consent for later analysis.

Group Tasks (Participatory Design) Participatory group sessions were conducted to examine drivers' priorities and preferences for dashboard information. A total of 35 dashboard attributes were identified from the existing e-bus interface (see Appendix B). Each attribute was presented on an individual card to enhance visibility and facilitate interaction during the task.

During the sessions, to understand the driver's mental model, we conducted group tasks with three to five participants. Below are the three structured tasks:

- Rate the importance of each element on a 1–9 scale (Ouwehand et al., 2021; De Meyer et al., 2019).
- Classify items as "All-Time," "Occasionally," or "Never" used.
- Categorise the dashboard elements into trip phases: *Pre-Trip*, *In-Trip*, and *Post-Trip*.

These participatory exercises capture how drivers perceive and prioritise dashboard information in real operational contexts.

Focus Groups Focus group sessions were conducted with drivers, technicians, supervisors, and control room staff. The discussions explored daily challenges, dashboard visibility, symbol comprehension, and suggestions for interface improvement. Each session was audio-recorded, and summaries were prepared to identify recurring themes and shared concerns.

Quantitative Surveys Two short surveys complement the qualitative findings:

- The System Usability Scale (SUS) measured perceived usability of the dashboard using a 10-item Likert questionnaire (see Appendix P).
- The Tell-tale Knowledge Survey evaluated drivers' familiarity with 22 dashboard telltale symbols through multiple-choice questions scored for accuracy (see Appendix E).

These quantitative assessments provided measurable indicators of usability and comprehension, supporting triangulation with qualitative results.

5.4.1.3 Data Analysis

The qualitative materials, including interview transcripts, observation notes, and focus-group discussions, were analyzed thematically using a combination of deductive and inductive coding. Deductive codes draw on the research questions and interview framework, while inductive codes develop from patterns that appear repeatedly in drivers' accounts. All coding was managed in qualitative analysis software, which helps maintain consistency and provides an auditable record of decisions.

Data from the card-sorting exercise included both qualitative explanations and quantitative counts. Item placements across the three trip stages (*Pre-Trip*, *In-Trip*, and *Post-Trip*) are tabulated and summarized descriptively to identify the attributes that drivers prioritize most often. Mean importance ratings on the 1–9 scale indicate relative significance, and frequency counts group elements as *"All-Time," "Occasionally,"* or *"Never"* used. Notes and comments recorded during the sorting sessions are reviewed thematically to understand the reasoning behind participants' choices and any points of divergence.

Quantitative results from the System Usability Scale (SUS) were calculated using the standard SUS scoring formula. The telltale knowledge survey was conducted using an offline response sheet (see Appendix E). Each driver identified the meaning of 22 dashboard telltale symbols commonly used in e-buses. The collected responses were independently reviewed and graded by an expert technician using a five-point accuracy scale: A (Correctly Identified), B (Partially Correct), C (Wrong), D (I don't know), and E (No response given).

Finally, insights from all sources of data, including observations, interviews, participatory sessions, and surveys, were integrated to achieve triangulation and build a comprehensive picture of how e-bus dashboards support or hinder driver performance.

5.4.1.4 Ethics and Confidentiality

All participants were briefed on the purpose of the study, the nature of the data collected, and their right to withdraw at any stage without consequence. Both verbal and written consent were obtained before participation. To protect privacy, no personal identifiers or confidential organizational information appear in any transcript, report, or publication. All datasets were anonymized and stored securely, following institutional guidelines for research ethics and data management.

5.4.2 Results

A total of 80 unique participants took part in Study 2, all of whom were male. Of these, 74 were professional e-bus drivers and 6 were depot staff, including technicians, supervisors, and control room personnel.

The professional drivers ($n = 74$) ranged in age from 25 to 58 years ($M_{\text{age}} = 36.8$ years, $SD = 7.9$). Their total professional driving experience ranged from 5 to 30 years ($M = 14.6$ years, $SD = 6.3$), while experience specifically with e-buses ranged from 6 months to 4 years ($M = 2.1$ years, $SD = 1.1$). This range ensured representation of both newly trained and highly experienced drivers, capturing diverse usability, safety, and adaptation challenges.

Depot staff participants ($n = 6$) were included to provide contextual and system-level perspectives on diagnostics, maintenance workflows, and operational coordination, but were not included in driver-specific demographic or usability statistics.

Figure 5.5: Photo taken during driver's observation in actual driving condition (Source: Author's fieldwork, 2023).

Drivers participated in one or more study components depending on availability and task relevance. Specifically, 9 drivers participated in on-route observations, 23 in semi-structured interviews, and 25 in participatory card-sorting activities.

All 6 depot staff members participated in focus group discussions to provide complementary perspectives on system-level operations.

5.4.2.1 Theme 1: Dashboard Interaction Patterns and Information Needs

In the observations, we found that participants' e-bus driving followed a structured and safety-oriented workflow (see Figure 5.5). All the observed drivers systematically performed pre-trip checks involving the Driver Display Unit (DDU), mirrors, dashboard indicators, and door operations (see Figure 5.6).

Dashboard monitoring formed a central part of the observed driving routine. Drivers engaged most actively with the instrument cluster at transition points—when starting the bus, approaching stops, or resuming motion after passengers board. They frequently leaned forward or adjust their posture to read dashboard readings, particularly in bright sunlight or when exposed to glare, suggesting a suboptimal display angle and visibility. In several instances, drivers also used the DDU or mobile phone during brief halts to cross-check route or diagnostic information. These behaviours illustrated a multitasking environment where drivers balance vehicle control, monitoring, and passenger interaction simultaneously.

The interview data corroborated these observation patterns (see Figure 5.7). Six drivers reported continuous or near-continuous monitoring, keeping the dashboard "always in front of

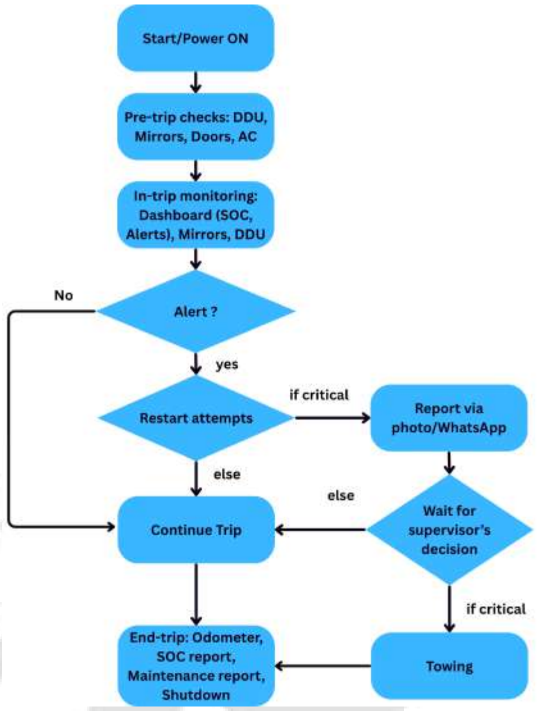


Figure 5.6: Observed driver action flow illustrating the typical sequence of pre-trip checks, in-route monitoring, stops, alert handling, and end-of-shift docking (Source: Author, 2023).

their eyes” as part of their constant visual awareness. Five drivers described context-based checking, mainly at traffic signals or bus stops. Four drivers reported monitoring the dashboard primarily when auditory or visual alerts occurred, indicating a more reactive engagement style. The remaining participants described mixed or situational monitoring strategies that did not fall clearly into a single category.

Figure 5.7: Photographs captured during driver interviews conducted as part of the field study (Source: Author’s fieldwork, 2023).

These variations indicated that dashboard monitoring was not uniform but adaptive, shaped by each driver’s workload, perceived system reliability, and environmental conditions. The overall trend suggested a high frequency of interaction, reinforcing the dashboard's role as a central reference point in e-bus driving routines.

> *"It is in front of my eyes. So I often look into it. All the time you can say." — Participant U–D03*

> *"I look at the dashboard continuously. In each 5–7 minutes. Whenever there is a stoppage, I see the dashboard." — Participant U–D06*

> *"Twice or thrice in 30 minutes." — Participant U–D12*

> *"Whenever there is any stoppage, I find a chance to look at the dashboard to see if there is any problem." — Participant U–D07*

> *"Whenever there is an issue, alert sound would come. Then I see the dashboard." — Participant U–D16*

Interview data revealed a clear hierarchy of information that drivers monitored while operating e-buses. All participants reported the State of Charge (SOC) as their primary reference point, using it to estimate range and maintain confidence during trips. Participants described cross-checking SOC on both the analog meter and LCD screen to confirm accuracy. Battery temperature was identified as a critical indicator by 19 of the 23 drivers, followed by main coolant temperature, mentioned by 15 drivers. These thermal parameters were closely associated with safety and the risk of overheating. Drivers reported maintaining constant vigilance over temperature readings, explaining that sudden increases could lead to bus malfunction or, in extreme cases, fire-related incidents.

Air pressure was continuously monitored by 14 drivers, while warning telltale symbols were emphasized by 17 drivers, as both signal immediate issues related to braking performance or system faults. Several participants noted that the bus cannot be operated safely if air pressure drops below six bars. Speed was monitored by 17 drivers, primarily to ensure compliance with the 40 km/h speed limit on downhill sections and during late-night operations. Odometer and Distance-to-Empty (DTE) readings were mentioned by 12 drivers, mainly at the start and end of trips for reporting remaining charge and distance to depot supervisors. A smaller subset of

8 drivers reported checking contextual indicators such as time, gear mode, or air-conditioning controls, which were considered secondary and situation-dependent.

This pattern suggests that drivers do not casually glance at the cluster but follow a purposeful, and safety-oriented scanning sequence. Their attention centers first on energy and thermal indicators, followed by mechanical and diagnostic cues. The dashboard thus serves as both a performance monitor and a reassurance interface, enabling continuous situational awareness throughout the route.

> *"When I start, I see the battery percentage first because issues in battery occur frequently." — Participant U–D09*

> *"Chiller temperature, coolant temperature, and SOC are the most important features of the bus. If these parameters go up, then the bus will catch fire. So I keep an eye on battery and chiller temperature." — Participant U–D13*

> *"Air pressure gives real power to the bus. If it goes below six, braking will not work." — Participant U–D18*

> *"In every signal post, I press the button to know diagnostic info, SOC, and odometer. By seeing the LCD, I find motor, door, or chiller temperature issues myself." — Participant U–D20*

> *"My default screen shows SOC in percentage and DTE in km. These two I keep in front of my eyes." — Participant U–D22*

> *"While going down from the bridge, our bus catches speed. We have to monitor not to cross 40 kmph." — Participant U–D15*

> *"During going from depot and coming to depot, they ask to say the SOC and km." — Participant U–D10*

> *"Whenever any symbol pops up, I see. When there is an issue, alert sound would come." — Participant U–D16*

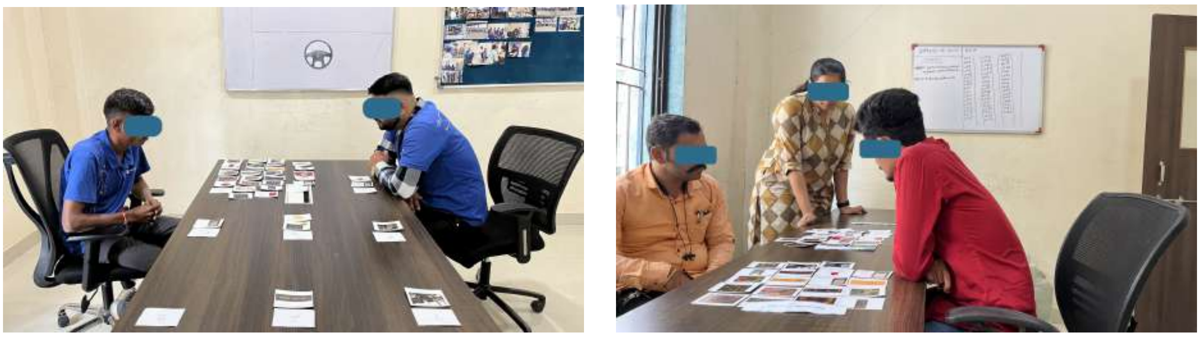


Figure 5.8: Photographs captured during card sorting activity task (Source: Author's fieldwork, 2023).

To examine how these observed monitoring behaviours translate into explicit information priorities, three card-sorting tasks were conducted. In the first task, we investigated the types of information bus drivers considered essential at different stages of a trip and how they prioritize various dashboard attributes. The findings were based on group activities, card-sorting tasks, and participatory discussions with drivers and technicians. These activities revealed clear distinctions between the information required *before*, *during*, and *after* trips, as well as preferences for how often certain parameters should remain visible. The six groups were formed during participatory card-sorting sessions, with each group comprising 3–5 drivers; importance ratings were first discussed within groups and then averaged across groups to reduce individual bias and capture collective prioritization.

Importance ratings of dashboard attributes Drivers rated the perceived importance of 35 dashboard parameters using a 9-point Likert-type importance scale (1=Not important at all, 9=Absolutely essential). Mean scores were calculated for each parameter across all six participant groups. The six groups represented participatory discussion groups (3–5 drivers each), not independent samples. Table D.1 summarizes the results, showing the mean, standard deviation, and rank for each parameter. These parameters achieved complete agreement across all six groups, resulting in zero variance at the group level.

As presented in Table D.1 and Figure 5.9, participants demonstrated clear consensus regarding the hierarchy of dashboard information importance. Rank 1 included sixteen parameters that received perfect agreement across all six groups (Mean = 9.00, SD = 0.00). These were: Speedometer, SOC Meter, Main Coolant Temperature, Battery Temperature, DTE (Distance to Empty), Air Pressure, Battery Percentage, Time, Route Information, Telltales, Message Alerts

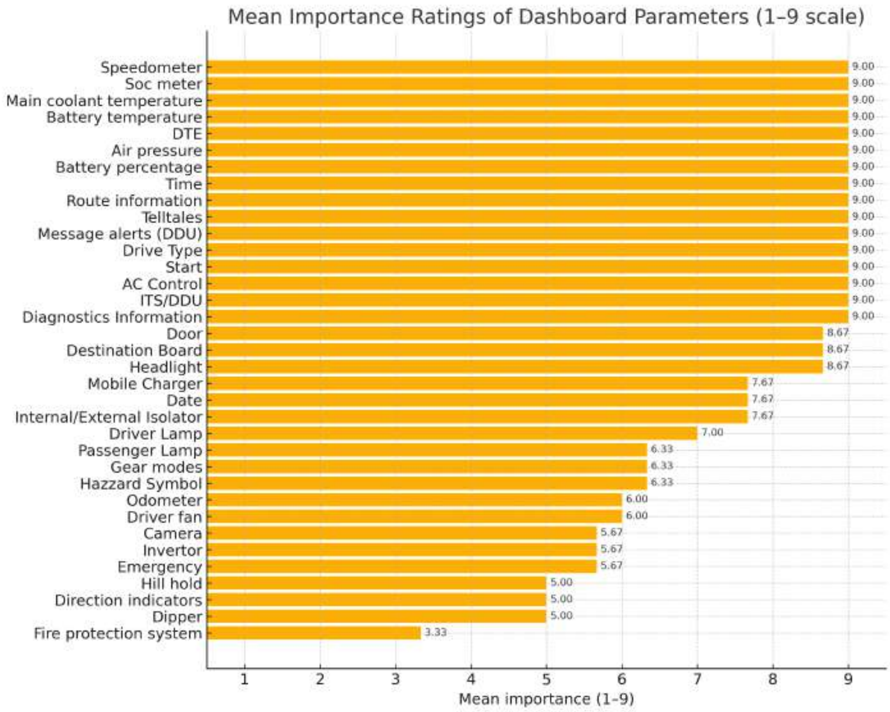


Figure 5.9: Mean importance ratings (on a 1–9 scale) for dashboard parameters across six participant groups; values above the bars indicate mean scores (Source: Author, 2023).

(DDU), Drive Type, Start, AC Control, Diagnostics Information, and ITS/DDU. These elements represented core operational and feedback indicators, perceived as absolutely essential for real-time monitoring during driving. Rank 2 comprised Headlight and Destination Board (Mean = 8.83, SD = 0.37). These were considered high-priority visual communication elements, required primarily during low-visibility or route-display situations. Rank 3 was occupied by Door (Mean = 8.67, SD = 0.47), which drivers associated with passenger safety and boarding control. Rank 4 included Internal/External Isolator and Mobile Charger (Mean = 7.67), representing supportive yet safety-linked controls. Rank 5 was assigned to Driver Lamp (Mean = 7.33), reflecting moderate relevance, mostly used in nighttime or depot operations. Rank 6 included Odometer, Gear Modes, and Passenger Lamp (Mean 6.00–6.33), which drivers viewed as situationally useful rather than continuously monitored. Rank 7 comprised Camera (Mean = 5.67, SD = 0.52), regarded as a supplementary aid for parking or reversing rather than for dynamic driving. Rank 8 contained parameters such as Hill Hold, Inverter, Dipper, Emergency, Driver Fan, and Hazard Symbol (Mean = 5.0–6.3). These received high variability (SD up to 3.5), indicating differing familiarity or perceived relevance across operating contexts. Rank 9 consisted solely of Date (Mean = 7.67, SD = 0.82), viewed as non-operational but still useful informational content. Rank 10, the lowest, included Fire Protection System (Mean = 3.33, SD = 1.49) and Direction Indicators (Mean = 5.00, SD = 1.41), suggesting that although these features are critical for safety, drivers consider them automatic or always-on functions rather than manually monitored parameters. Overall, 45.7% of all parameters (16 of 35) achieved the maximum mean rating, indicating strong agreement on a core information set essential for effective e-bus operation. The remaining elements displayed greater variability, largely corresponding to auxiliary or infrequently accessed functions.

Frequency of information use The results from the two participating technicians indicate that all dashboard attributes are functionally relevant, with no parameters classified under the "Never needed" category. The technicians classified 19 parameters as continuously required, 16 as occasionally required, and none as unnecessary (see Table 5.3). The following frequency classification reflects the technical assessment of depot technicians and is presented as an expert validation of dashboard relevance rather than direct driver behaviour.

Table 5.3: Technicians' assessment of dashboard attribute usage frequency, categorized by perceived operational necessity (Source: Author, 2023).

Usage Category	Number of Attributes	Representative Parameters
Need it all the time	19	Speedometer, SOC Meter, Main Coolant Temperature, Battery Temperature, DTE, Air Pressure, Gear Modes, Battery Percentage, Time, Route Information, Telltales, Drive Type, Start, Door, Driver Fan, Emergency, Destination Board, Inverter, Internal/External Isolator.
Need it occasionally	16	Direction Indicators, Odometer, Date, Camera, Message Alerts, AC Control, Passenger Lamp, Hill Hold, Mobile Charger, Dipper, Driver Lamp, Hazard Symbol, ITS/DDU, Headlight, Diagnostics Information, Fire Protection System.
Never needed (Can be hidden)	0	— None reported —



Figure 5.10: Information needs identified across pre-trip, in-trip, and post-trip stages based on the main field study (Source: Author's field study, 2023).

Trip-wise information requirements From the observations and interviews, we found that driver participants have different needs of information throughout the stages of the trip. To further investigate the required need for information, we conducted a card sorting task. The participants were asked to categorize thirty-five dashboard attributes according to three trip stages: *Pre-Trip*, *In-Trip*, and *Post-Trip* (see Figure 5.11).

The pre-trip analysis identifies the information drivers and technicians prioritise before beginning the journey. Out of 35 parameters, 18 were categorised as *highly recommended* (endorsed by four or more groups), including Air Pressure, Battery Temperature, Battery Percentage, Gear Modes, Diagnostics Information, ITS/DDU, and Start—representing essential checks for vehicle readiness and system status. Ten parameters were classified as *moderately recommended* (three groups), such as Fire Protection System, Headlight, and Isolators, reflecting their conditional relevance during inspection.

The in-trip analysis revealed that most driving-time information requirements focused on continuous monitoring of system performance and safety. Out of 35 parameters, 20 were categorised as *highly recommended* (endorsed by four or more groups), including Battery Temperature, Speedometer, Direction Indicators, Camera, Headlight, and Message Alerts. These parameters represent the core set of information drivers relied on for operational awareness while driving. Nine parameters were marked as *moderately recommended* (three groups), including DTE, Gear Modes, and Hazard Symbol, indicating secondary relevance depending on route and vehicle condition.

The end-of-trip activity highlights parameters essential for completing operational tasks and verifying post-trip vehicle status. Out of 35 dashboard elements, only 8 were categorised as *highly recommended* (endorsed by four or more groups), including Battery Percentage, Destination Board, SOC Meter, Time, and Odometer—primarily those related to trip summary and final checks. Twelve parameters were marked as *moderately recommended* (three groups), such as Battery Temperature, Direction Indicators, and Gear Modes, indicating selective relevance for shutdown and reporting operations.

Figure 5.11: Word clouds representing dashboard information relevance across pre-trip, in-trip, and post-trip stages (left to right). Larger words denote higher consensus among participant groups(Source: Author's field study, 2023).

5.4.2.2 Theme 2: Usability Challenges and Adaptive Strategies in Existing Bus Dashboards

Field observations revealed recurring ergonomic and visibility challenges during dashboard interaction. Drivers frequently leaned forward or adjusted their posture to read LCD text or interpret instrument readings, particularly under conditions of daylight glare. These behaviours suggest visibility constraints and increased visual effort during driving. To further examine these issues, drivers' perceived ease of reading and understanding dashboard information was assessed during interviews using a 7-point Likert scale (1 = Very difficult, 7 = Very easy), followed by open-ended questions.

Although participants rated their overall comfort with dashboard information relatively high (mean = 6.0), qualitative responses revealed several usability barriers in real-world driving contexts. Drivers reported difficulty when monitoring multiple display locations simultaneously, including the analog cluster, LCD screen, and Driver Display Unit (DDU). This distributed information layout increased visual effort and occasionally led to delayed awareness of updates during traffic operations.

Visibility and Ergonomic Challenges Consistent ergonomic limitations were observed during driving. Participants frequently leaned forward or altered their posture to view dashboard readings, particularly the LCD panel, which was often affected by steering-wheel obstruction and glare. These actions indicated a misalignment between drivers' eye position and instrument placement.

> *"The dashboard behind the steering wheel is difficult to see. I have to bend every time to read the LCD." — Participant U–D02*

> *"There are lighting issues in daytime. I have to bend and see the LCD information." — Participant U–D18*

Small text size and limited contrast further reduced legibility, especially in bright conditions. Several drivers reported visual strain resulting from the need to attend to three separate display zones: the analog cluster, LCD, and DDU. Drivers also described the need to divide attention between dashboard elements, mirrors, and physical switches, increasing visual and cognitive effort.

> *"I have to see three different places — it's not easy to monitor." — Participant U–D07*

Language and Comprehension Barriers Interview data indicated that all participating drivers reported fluency in Gujarati and Hindi, while a substantial proportion reported difficulty understanding English-language messages on the dashboard (approximately 61%). As a result, drivers often struggled to interpret diagnostic text displayed exclusively in English, leading to delayed problem reporting and reliance on supervisors for clarification.

> *"I can read the text, but I don't understand the meaning in English. I take a photo and send it to the supervisor." — Participant U–D14*

> *"When I don't understand the message, I take a photo and send it to the supervisor. They tell me what to do next." — Participant U–D16*

Although some buses provided bilingual labels or symbolic cues, technical fault messages such as "HV Battery Fault" or "Motor Error" were still difficult for drivers with limited English proficiency to interpret quickly. Consequently, drivers relied more heavily on color, icon shape, and auditory alerts than on textual descriptions for immediate decision-making.

Information Comprehension and Diagnostic Interpretation While routine operational information was generally well understood, difficulties emerged in interpreting diagnostic text and symbol meanings. Small icon sizes and ambiguous terminology slowed comprehension and response time.

> *"I can read the English text but cannot explain it properly when I report the issue." — Participant U–D16*

Participants reported that color-coded indicators helped signal severity, but some fault messages lacked clarity regarding required action.

> *"The colors show seriousness, but when 'motor error' comes, the bus stops completely. I had to restart two or three times." — Participant U–D15*

Concerns regarding display reliability also influenced driver trust. Several drivers mentioned inaccurate or fluctuating SOC and air-pressure readings, prompting them to cross-check information across screens.

> *"Sometimes the air-pressure meter shows wrong readings. In some buses, the SOC meter also does not work properly." — Participant U–D20*

Adaptive and Coping Strategies To manage these usability limitations, drivers developed several adaptive strategies. Physical adjustments, such as leaning forward or altering steering position, were commonly used to improve visibility. Drivers also adopted sequential scanning patterns, checking dashboard information primarily during traffic signals or bus stops.

> *"I check the dashboard at signals or stoppages. I go through each screen one by one." — Participant U–D11*

When comprehension was limited, most drivers relied on supervisors via phone or WhatsApp, often sharing photographs of diagnostic messages.

> *"If I don't understand the English message, I send a photo to the supervisor." — Participant U–D16*

With experience, some drivers reported increasing reliance on vehicle feel, sound, and performance cues, reducing exclusive dependence on visual dashboard information.

> *"I mostly understand problems from the driving feel and sound, not only from the screen." — Participant U–D12*

Table 5.4: Summary of usability issues reported by drivers during field evaluation, indicating prevalence and nature of observed problems ($n = 23$) (Source: Author, 2023).

Issue Type	**% of Participants Mentioning (Approx.)**	**Nature of Problem Observed / Reported**
Visibility / Readability	≈52% (12 of 23)	Small font size, glare, and steering obstruction requiring posture adjustment to read LCD information.
Multi-display Monitoring Load	≈39% (9 of 23)	Need to attend to multiple display zones (analog cluster, LCD, DDU), increasing visual effort.
Language and Comprehension Barriers	≈35% (8 of 23)	Difficulty interpreting English diagnostic messages; reliance on supervisors for clarification.
Symbol Interpretation Issues	≈30% (7 of 23)	Small or unclear telltales; ambiguity in icon meaning and perceived severity.
Display Reliability Issues	≈22% (5 of 23)	Inconsistent SOC or air-pressure readings; occasional display malfunction.

Continued on next page

Issue Type	% of Participants Mentioning (Approx.)	Nature of Problem Observed / Reported
Situational Constraints	≈17% (4 of 23)	Passenger crowding, vehicle vibration, and daylight reflections affecting readability.

Overall, visibility limitations and comprehension challenges emerged as the most prominent usability concerns, followed by the cognitive demands associated with monitoring multiple display elements during operation.

5.4.2.3 Theme 3: Diagnostic Practices and Communication

Building on the usability constraints described in Theme 2, this theme focuses specifically on diagnostic detection and communication. Diagnostics emerged as a critical information requirement for e-bus drivers, directly influencing operational decisions, safety responses, and communication with depot staff. This theme examines how drivers detected faults, interpreted diagnostic feedback, and communicated issues during routine operations.

The focus of this theme is on documenting existing diagnostic and communication practices as they currently occur in daily operations.

Issue Detection and Interpretation All interviewed drivers ($n = 23$) identified the instrument cluster as the primary source for detecting vehicle faults. Issue recognition typically began with a visual or auditory cue, such as a telltale symbol or chime, followed by reference to diagnostic text on the LCD display. Drivers relied heavily on color-coded alerts to judge severity, with red indicators prompting immediate attention.

> *"First I check the symbols. The color of the symbol helps me identify the fault. Then I read the LCD diagnostic information." — Participant U–D09*

More experienced drivers also reported identifying problems through changes in vehicle behaviour, including reduced pickup, abnormal vibration, or altered braking response, sometimes before a dashboard alert appeared.

"When the bus slows down or the pickup changes, I can tell something is wrong even before the symbol appears." — Participant U–D12

Critical alerts such as *"Vehicle Not Ready," "Emergency Off," "Motor Error,"* and *"Chiller Temperature High"* were consistently recognized as high-risk conditions requiring immediate action. Eight of the 23 drivers rated the diagnostic system as highly effective, while the remaining drivers described it as only moderately helpful or confusing. Drivers further reported that fault messages were often vague, delayed, or difficult to interpret, particularly when presented only in English.

Fault Handling and Immediate Response Once an issue was identified, drivers typically attempted first-level verification through the dashboard interface. Common actions included restarting the vehicle, checking air pressure, and monitoring trends in State of Charge (SOC) and temperature.

"When I see a symbol, first I check the screen, then restart the bus once or twice to see if it clears." — Participant U–D15

SOC information strongly influenced trip-level decisions. Several drivers reported modifying routes or returning early to the depot when SOC fell below critical thresholds.

"If SOC drops below 15%, I inform the manager and may skip stops to return to the depot." — Participant U–D22

These behaviours indicated that drivers acted as first-level diagnosticians, stabilising situations before seeking external assistance.

Communication and Reporting Practices After confirming a fault, drivers reported issues to supervisors or control room staff using mobile phones, most commonly via WhatsApp. The typical workflow involved photographing the dashboard display and sending the image for confirmation and instruction.

"When I don't understand the message, I take a photo and send it to the supervisor. They tell me what to do next." — Participant U–D16

Figure 5.12: Photographs captured during focus group discussions conducted as part of the user study (Source: Author's fieldwork, 2023).

While this practice ensured visual accuracy, drivers noted delays in receiving responses, particularly during peak operational hours. In some cases, drivers continued operation or made independent decisions when guidance was not immediately available.

> *"Sometimes the supervisor replies late, so we have to decide ourselves whether to continue or stop." — Participant U–D13*

Drivers also expressed increased stress during roadside breakdowns, especially when managing passenger reactions without on-site support.

> *"When the bus stops in traffic, passengers start shouting. I have to manage them and call the control room at the same time." — Participant U–D09*

Validation from Depot Stakeholders Focus group discussions with depot staff, including technicians, supervisors, and control room operators, confirmed that fault communication is fragmented and difficult to manage (see Figure 5.12). Control room staff reported challenges in tracking multiple simultaneous messages and linking reports to specific vehicles.

> *"Messages come from many drivers at once. It's difficult to track who reported first or which bus it belongs to." — Technician U–M02*

Stakeholders highlighted the absence of automated alerts or centralized dashboards for real-time fault monitoring, which increases reliance on manual coordination.

Table 5.5: Drivers' perceived effectiveness of diagnostic feedback provided by the instrument cluster ($n = 23$) (Source: Author, 2023).

Aspect	**Percentage**	**Summary**
Instrument cluster as primary diagnostic source	100%	Symbols, chime, and LCD text used for fault detection
Comfort with diagnostic information	Mean = 5.4 / 7	Moderate to high comfort with comprehension challenges
Reliance on color-coded telltale symbols	91%	Immediate recognition of alert severity
Reliance on English text messages	35%	Many drivers reported difficulty understanding text
Reported delayed or false alerts	26%	Delayed motor or battery warnings reported
Dependence on supervisors for clarification	43%	Use of WhatsApp images and calls

Overall, diagnostic practices in e-bus operations relied on a hybrid system of dashboard alerts, driver experience, and informal communication channels. While drivers demonstrate strong adaptive competence in fault detection and first-level response, the absence of structured in-dashboard reporting and automated escalation increases cognitive load and operational risk for both drivers and depot staff.

5.4.2.4 Theme 4: System-Level Design Requirements

Participants provided extensive recommendations on how the dashboard and diagnostic system could be enhanced for better usability, visibility, and operational efficiency. These recommendations emerge directly from the usability challenges and diagnostic practices documented in Themes 2 and 3, and therefore represent user-informed design priorities rather than speculative solutions. Their suggestions indicated that drivers do not seek more data but desire timely, integrated, and intelligible feedback in a form that reduces confusion, manual reporting, and physical strain. The recommendations, supported by focus group discussions, are summarized below.

Unified Digital and Numeric Display Multiple participants from the focus group and interview suggested a consolidated dashboard interface with a fully digital, numeric display for battery percentage, temperature, air pressure, and door status.

> *"One display, all data. Speedometer and SOC should be in digits so we can say the exact value." — Participant U–D09*

> *"The tick mark in temperature is not helpful. If I could see the number, I could tell the technician exactly what it is." — Participant U–D19*

Several drivers also noted that numeric temperature and SOC values would improve precision when explaining faults to technicians. This preference reflects drivers' need for precision and communicability rather than increased information density.

Improved Visibility and Ergonomic Positioning Visibility challenges emerged as a major usability limitation. Drivers suggested repositioning the dashboard or instrument cluster higher, improving brightness, and enlarging telltale symbols and text for better readability, particularly under daylight glare.

> *"Change the instrument cluster location a bit higher. The steering comes in between, and we can't see it clearly." — Participant U–D11*

> *"I feel difficulty seeing the dashboard. The bonnet should be a little lower so I can see both the dashboard and the road." — Participant U–D13*

> *"Make the LCD bigger with large text size and clear black-and-white colors." — Participant U–D17*

These suggestions highlight a misalignment between display placement and drivers' natural line of sight under real-world driving conditions.

Audio Feedback and Predictive Alerts Participant drivers advocated for more context-sensitive alerts that provide timely warnings without causing distraction. They recommended short, adjustable sounds for specific SOC levels, temperature issues, or motor faults.

> *"Add sound at 30% and 20% SOC to alert early, but not continuously. There should be a stop button." — Participant U–D10*

> *"Announce diagnostic issues like battery or motor problems with chime or voice. Volume control should be given to the driver." — Participant U–D13*

> *"The chime for low battery is fine, but it irritates when I return with 15%. A stop button is needed." — Participant U–D08*

Drivers emphasized selective and controllable audio feedback, indicating a desire for anticipatory alerts without increasing distraction.

Early and Automated Fault Detection Participants strongly emphasized the need for earlier alerts and automatic fault communication between the bus and control room. Such integration would minimize time delays and reduce reliance on mobile phones.

> *"If the issue could be detected by the control room and they notify us with the next steps, that would be faster." — Participant U–D06*

> *"The management should be proactive. The person who receives the call should be connected directly to a technician. If the dashboard could send messages itself, it would save time." — Participant U–D15*

> *"Automatic diagnostic messages to the technician will save time. Now it depends on when the mechanic replies." — Participant U–D16*

This reflects drivers' desire to shift from reactive, driver-initiated reporting to system-driven fault awareness and response.

Local Language and Accessible Feedback Drivers expressed a need for bilingual support (Gujarati and Hindi) or audio feedback to quickly interpret diagnostic text, thereby improving communication accuracy with technicians and managers.

> *"Feedback should be in local language with sound. I can read English but cannot explain it correctly to the technician." — Participant U–D18*

> *"Make the LCD text in English, Hindi, or Gujarati — whichever is comfortable." — Participant U–D21*

Contextual and Safety Enhancements Some participants proposed additional interface features to support energy efficiency and operational safety. These included tire pressure icons, AC fault indicators, speed limit markings, and prompts for eco-driving behavior.

> *"Add tyre puncture and AC issue symbols. Notify the driver to do less braking and accelerating to save battery." — Participant U–D12*

> *"Add speed limit mark on the speedometer dial to avoid fines." — Participant U–D20*

> *"Use of camera for safety and to see door status clearly should be in the dashboard itself." — Participant U–D09*

Process and Coordination Efficiency While Theme 3 documented how diagnostic communication currently occurs through informal and mobile-based channels, this subsection captures participants' suggestions for how coordination and response could be improved at a system level. A small group highlighted the necessity of institutional coordination, recommending quicker control room decision-making and direct communication with skilled technicians to shorten response times.

> *"The person whom we call should be connected to an experienced technician. Others don't understand the situation, and it delays everything." — Participant U–D15*

Taken together, these suggestions highlight a consistent set of design priorities centered on clarity, integration, and timely feedback. Drivers emphasized the need for a unified digital display that reduces visual fragmentation and supports quick interpretation under real driving conditions. Early, automated, and language-accessible diagnostic feedback was viewed as essential for reducing cognitive load and dependence on external communication tools. Visibility, ergonomic placement, and selective audio cues emerged as critical enablers of safer and less stressful driving. Collectively, these priorities underscore the importance of a dashboard that supports how drivers make decisions, manage faults, and maintain safety during daily e-bus operations.

5.4.2.5 Theme 5: Telltale Comprehension and Symbol Usability

Interview data indicated that all driver participants underwent mandatory training before being assigned to operate e-buses. The duration of this training ranged from 4 to 15 days, depending on prior experience and learning pace. Training combined classroom instruction with supervised field practice, introducing drivers to battery management principles, dashboard interpretation, telltale recognition, and basic e-bus operations. During field sessions, drivers practiced starting, braking, docking, and responding to diagnostic alerts on test tracks under supervision.

Drivers reported that during training they were instructed to photograph any unfamiliar telltale or diagnostic message appearing on the dashboard and send it to a supervisor via mobile phone for clarification. For many participants, this practice became the default strategy for handling uncertainty during later operations.

> *"They trained us about new telltale symbols and how to start or stop the e-bus. We also learned to check the dashboard for battery percentage and air pressure before trips." — Participant U-D21*

This reliance on external validation indicated that telltale meanings were not always sufficiently self-explanatory at the point of use, requiring drivers to seek confirmation rather than relying solely on in-situ comprehension.

As drivers transitioned to real-world operations, learning continued beyond the formal training period. Through repeated exposure, drivers gradually connected dashboard feedback with vehicle behaviour such as changes in vibration, sound, or pickup. Over time, this experiential learning contributed to greater confidence and intuitive understanding. Informal peer mentoring also emerged at depots, with experienced drivers supporting newer colleagues.

> *"When new drivers face a problem, they call me or show me the photo of their dashboard. I tell them which issue it is and what to do next." — Participant U-M01*

Despite these adaptive learning patterns, several participants noted that the short duration of formal training limited deeper understanding of dashboard functions, particularly for drivers with less exposure to digital interfaces. Many continued to relied on peers or technicians during their initial months of service.

As discussions progressed, drivers consistently highlighted challenges related to telltale comprehension. Many reported that symbols were too small or densely packed, making rapid recognition difficult during driving. Some also noted that alerts disappeared too quickly to allow identification or documentation.

> *"Feels difficult in recognising telltale symbols due to small size." — Participant U–D19*

> *"The size of the telltale symbols are very small. The symbol should remain on the screen so I can take the photo." — Participant U–D08*

Although most participants understood the basic red–yellow–green severity hierarchy, inconsistent color usage reduced clarity. The same indicator occasionally appeared in different colors or lacked sufficient contrast under daylight conditions.

> *"Sometimes the meter is incorrect. Different color sometimes confuses." — Participant U–D10*

Several drivers acknowledged that certain telltales remained unfamiliar even after months of operation. These symbols often appeared briefly, offering limited opportunity for interpretation.

> *"There are some telltale symbols that I don't know. While running it shows up but I don't know what it is for." — Participant U–D16*

Drivers also identified gaps in the existing telltale set, requesting additional indicators for conditions such as tyre puncture, air-conditioning malfunction, and speed-limit awareness.

> *"Add tyre puncture and AC issue symbols. Also show speed limit in the dashboard."*
> *— Participant U–D15*

At the same time, participants acknowledged that when color coding was applied consistently, it supported rapid prioritisation and decision-making.

> *"The colors (green/yellow/red) are helpful to identify how serious the issue is." — Participant U–D13*

To further examine telltale comprehension, a brief survey was conducted to assess how accurately drivers could identify existing telltales on the instrument cluster.

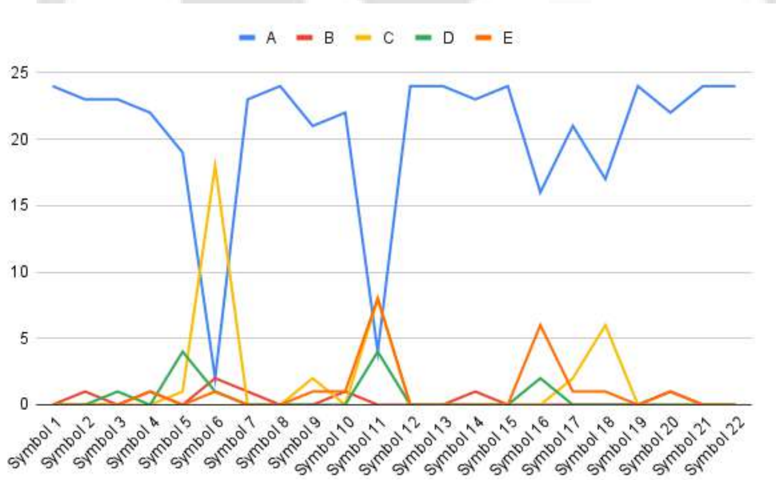


Figure 5.13: Knowledge of dashboard telltale indicators among drivers (Source: Author, 2023).

Approximately 75% of telltales received "A" ratings, indicating strong familiarity with standard indicators such as State of Charge, headlight status, and speed-related telltales. However, Symbols 6 and 11 showed the lowest recognition accuracy, with frequent C–E responses, suggesting unclear visual representation or limited exposure during training. Symbols 16–18 demonstrated moderate recognition, indicating partial comprehension gaps.

Taken together, these findings indicated that telltale comprehension depends on both driver experience and symbol design quality. While consistent color coding supported rapid prioritisation, small icon sizes, brief display duration, inconsistent color use, and incomplete EV-specific telltale sets continued to hinder effective interpretation. The telltale knowledge survey further confirmed that standard indicators were well understood, whereas EV-specific telltales exhibited lower recognition accuracy. These results highlighted the need for clearer, more persistent, and semantically transparent telltale design to support safe and confident e-bus operation.

5.4.2.6 Theme 6: User Acceptance and Redesign Preferences

This theme synthesizes findings from the usability evaluation and interviews to understand how drivers perceive the existing e-bus instrument cluster and what forms of dashboard design they prefer for future systems. It integrates quantitative results from the System Usability Scale (SUS) with qualitative insights from drivers' everyday experiences, highlighting how usability constraints shape comfort, satisfaction, and expectations for redesign.

System Usability Scale (SUS) Results Usability of the existing e-bus dashboard interface was assessed using the System Usability Scale (SUS), administered to 25 drivers. The SUS was conducted after participants completed representative interaction tasks on the dashboard interface in a controlled setting, ensuring that responses were based on direct usage experience.

The mean SUS score of 59.16 indicates moderate usability of the current dashboard system. While this score falls within the 'Marginal–OK' range based on general SUS benchmarks, its interpretation must be contextualized within automotive and in-vehicle interface systems. In such safety-critical environments, usability scores are often lower than those of consumer applications due to divided attention, safety requirements, and system complexity.

Therefore, the obtained score reflects a dashboard interface that is functionally usable but suboptimal, with notable limitations in visibility, information organization, and language comprehension, indicating clear scope for improving interaction efficiency and reducing cognitive load during driving.

Interview responses helped contextualize these quantitative results. Drivers frequently described the dashboard as functional but not optimally designed for quick comprehension under time pressure.

> *"The dashboard works fine, but some information is too small or hidden behind menus. I can't always find what I need quickly." — Participant RD*

"Some messages appear suddenly in English, and I have to stop and think what it means." — Participant SP

These accounts suggest that usability limitations stem less from missing information and more from how information is presented—through small text, layered menus, or unfamiliar language. Together, the SUS scores and interview data identify key usability bottlenecks that inform the need for redesign.

Dashboard Type Preferences In the interview, drivers were also asked about their preferred dashboard type for future e-buses. Among interviewed drivers ($n = 23$), sixteen (69.6%) preferred a fully digital dashboard, four (17.4%) preferred a traditional analog layout, and three (13%) favored a hybrid configuration (see Figure 5.14).

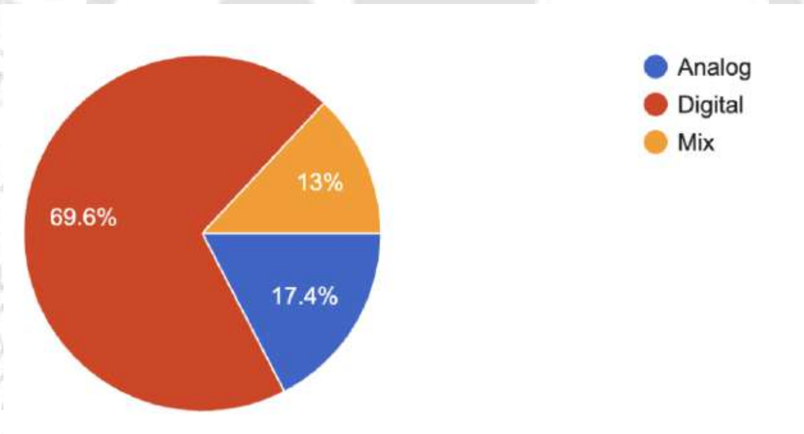


Figure 5.14: Drivers' preferences for digital and analog dashboard types (Source: Author, 2023).

Drivers who preferred digital dashboards associated them with clarity and consolidation, noting that multiple parameters could be viewed simultaneously on a single screen.

"At a time, all information should be visible on one screen—battery, temperature, and door issues together." — Participant U-D09

More than 80% of drivers reported prior experience using smartphones for periods ranging from one to fifteen years. This familiarity contributed to relatively smooth interaction with the touchscreen-based Driver Display Unit (DDU), which several drivers compared directly to mobile phone interfaces.

"I like the DDU the most. It feels like using a mobile. I can touch, select routes, and even adjust speaker volume." — Participant U-D23

"For me, the DDU is simple because it works like a mobile. I log in, select my route, and adjust the volume. But for new drivers, it takes time to remember which button does what." — Participant U-D04

A smaller group of senior or less digitally familiar drivers expressed a preference for analog dashboards, citing their simplicity, perceived reliability, and resemblance to conventional fuel-bus systems. Even within this group, however, drivers emphasized the need for larger dials, improved lighting, and clearer markings to enhance visibility under daylight conditions.

Overall, the findings indicate that while digital dashboards are widely preferred, successful redesign must account for varying levels of digital familiarity. Usability improvements should therefore focus not only on digitization but also on clarity, accessibility, and ergonomic presentation to support drivers across experience levels.

5.5 Analysis of Study 1 and Study 2

This section presents the combined analysis of data from the Stakeholder Study (see Section 5.3) and the User Study (see Section 5.4). From these two studies, we developed the bus-driver user journey (Appendix F) and the driver persona (Appendix G), which guided the later stages of research prototype development. Along with this a total ninety-one quotations were extracted and compiled for systematic analysis (Appendix C). To interpret this large qualitative quotes, we used two complementary methods: **(i)** the KJ (Affinity) Analysis to group related observations and uncover major patterns (Scupin, 1997), and **(ii)** a Severity Evaluation based on Nielsen (1994) to assess how critical each identified issue is for real-world driving tasks. Together, these methods provide a clear, evidence-driven picture of the recurring usability challenges and design opportunities that shaped the dashboard requirements.

The interpretation process involved both researcher-led and expert-supported review sessions. The initial grouping of quotations in the KJ analysis was conducted by the primary researcher and validated through two independent reviewers with backgrounds in human–computer interaction and transportation design. To ensure reliability, any disagreements in cluster assignment were discussed until a consensus was achieved. For the severity evaluation, three usability experts independently rated the identified issues and positive features using Nielsen's (1994) 0–4 scale, after which the mean score across raters was used to determine the final severity level for each cluster. This multi-rater approach strengthened the analytical rigor and minimized individual bias in interpretation.

5.5.1 Triangulated Interpretation of Findings

To strengthen the validity of the findings, results from the Stakeholder Study (Study 1) and the User Study (Study 2) were triangulated through systematic comparison and integration. The two studies offered complementary perspectives: Study 1 captured design rationales, technical constraints, and system-level intentions from manufacturers and depot stakeholders, while Study 2 documented how these design decisions manifest in real-world driving practices, usability challenges, and adaptive behaviours of e-bus drivers.

Triangulation revealed strong convergence across both datasets on several critical issues, including diagnostic clarity, information visibility, alert timing, and communication gaps between drivers and depot staff. While stakeholders described intended dashboard functions and safety mechanisms, drivers' accounts exposed mismatches between these intentions and operational realities, such as delayed alerts, fragmented displays, and reliance on informal communication channels. These convergences indicate that the identified issues are not isolated user complaints but systemic design limitations.

At the same time, the two studies provided complementary insights. Stakeholder inputs clarified why certain design trade-offs were made (e.g., limited display space, regulatory constraints), whereas driver data highlighted how these trade-offs affect workload, trust, and decision-making during live operations. This integration enabled a holistic understanding that neither dataset could provide independently.

The triangulated findings were used to construct the bus-driver user journey (Appendix F) and the driver persona (Appendix G), which together represent a synthesized model of driver needs, constraints, and interactions across operational contexts. These artefacts directly informed the subsequent design and evaluation phases.

To interpret the large volume of qualitative data generated through triangulation, two complementary analytical methods were applied: **(i)** KJ (Affinity) Analysis to identify recurring design-relevant patterns across stakeholder and driver perspectives, and **(ii)** Severity Evaluation to prioritise issues based on their impact on safety, performance, and usability in real-world driving conditions.

5.5.2 KJ (Affinity) Analysis

The KJ Method, developed by Jiro Kawakita, was applied to organize the qualitative findings into coherent design-focused themes (Scupin, 1997). A total of ninety-one quotations, extracted from the thematic analysis, were treated as individual data labels representing driver or stakeholder observations related to dashboard usability. Using iterative grouping and reflection, conceptually similar quotations were clustered until stable categories emerged. This inductive process emphasized intuitive association rather than formal coding, allowing patterns to surface naturally.

5.5.2.1 Procedure of KJ Analysis

The analysis began with repeated review of the quotation set to ensure familiarity and contextual understanding. The quotations were then grouped based on conceptual similarity, forming initial clusters without predefined categories. These clusters were iteratively refined through multiple rounds of grouping, reorganizing, merging, and reassigning quotations to improve internal consistency and reduce overlap between groups. The process continued until stable and coherent clusters were achieved. To ensure consistency in interpretation, the clustering outcomes were reviewed and discussed with two independent domain experts. Any ambiguities or disagreements in cluster assignment were resolved through discussion until a consensus was reached. Finally, each cluster was assigned a descriptive label representing its underlying design concern, which informed the subsequent severity evaluation and design implication development.

5.5.2.2 Results of KJ Analysis: Emergent Design-Focused Clusters

The affinity analysis of the combined dataset produced ten major thematic clusters, representing recurring usability and design concerns. Individual quotations could appear in more than one cluster when they expressed multiple ideas; therefore, cluster frequencies represent mentions rather than unique items. Table 5.6 summarizes the ten clusters and their respective quote frequencies.

Table 5.6: Mapping of coded participant quotations to KJ clusters, indicating cluster-wise distribution and frequency of mentions (Source: Author, 2024).

SN	Cluster Name	Quote IDs	No. of Mentions
1	Diagnostic Clarity	Q9, Q16, Q17, Q19, Q20, Q47, Q48, Q50, Q52–Q58, Q61–Q64, Q73–Q75, Q81, Q83, Q85, Q87, Q88	19
2	Contextual Feedback	Q34–Q38, Q40–Q41, Q44–Q46, Q49, Q51, Q55, Q56, Q60	15
3	Layout and Visibility	Q23, Q31–Q33, Q39–Q43, Q65–Q67, Q82, Q84, Q89	14
4	Alert Timing and Attention	Q68–Q71, Q86, Q10, Q18, Q24, Q26, Q28	11
5	Safety and Oversight	Q31–Q33, Q40–Q41, Q46, Q55, Q56, Q60, Q77	12
6	Maintenance Information	Q1–Q2, Q8, Q59–Q61, Q72–Q74	10
7	Localization and Language	Q75, Q76, Q83, Q85, Q88	9
8	Interaction and Touch Usability	Q22, Q24–Q26, Q28, Q90–Q91	8
9	Eco-Driving and Efficiency Support	Q21, Q40, Q44, Q77, Q78	6
10	Aesthetic and Interface Acceptance	Q23–Q26, Q30, Q87, Q90–Q91	7

The results show that clusters such as *Diagnostic Clarity*, *Contextual Feedback*, and *Lay-*

out and Visibility contain the highest number of mentions, reflecting their prominence in user discourse. *Safety and Oversight* and *Maintenance Information* highlight operational reliability and control-room coordination as significant factors. Meanwhile, *Localization and Language*, *Eco-Driving Support*, and *Aesthetic and Interface Acceptance* reveal evolving expectations for adaptive, efficient, and culturally resonant digital interfaces. Together, these clusters form the basis for subsequent severity assessment.

5.5.3 Severity Evaluation

Based on the clusters derived from the KJ analysis, a severity evaluation was conducted to prioritize usability issues according to their impact and frequency. Following the thematic synthesis, both usability problems and positive interface features were rated for their relative criticality using Nielsen's severity evaluation framework (Nielsen, 1994). This stage translated descriptive findings into a diagnostic hierarchy, prioritizing issues for redesign and identifying valuable features worth preserving.

Each item was evaluated along two dimensions: *(a)* frequency of occurrence: how many users were affected, and *(b)* impact on performance: the extent to which the issue influenced task success or safety. Both were rated on an integer scale from 0 to 4:

- 0 = Not a usability issue or no observable effect
- 1 = Cosmetic issue; fix if time permits
- 2 = Minor problem or low-benefit feature
- 3 = Major problem or important feature
- 4 = Critical problem or essential feature

Table 5.7 presents the high-priority usability problems identified across the ten clusters.

Table 5.7: Severity assessment of usability problems identified through KJ cluster analysis, indicating issue frequency and assigned severity levels (Source: Author, 2024).

Issue / Cluster	**Representative Observation**	**Frequency (Participants)**	**Severity (0–4)**
Diagnostic Clarity	Drivers unable to interpret system faults or connect warning telltale symbols with actual faults.	12	4
Contextual Feedback	Pop-up alerts disappear quickly; lack of consistent auditory confirmation.	10	3
Layout and Visibility	Small fonts, poor contrast, and steering obstruction reduce readability.	11	4
Alert Timing and Attention	Sudden short alerts distract or confuse drivers during operation.	8	3
Safety and Oversight	Inadequate indication of propulsion or brake system state; low visibility of safety icons.	9	4
Maintenance Information	No automatic fault transfer to control room; manual reporting delays repairs.	7	3
Localization and Language	English-only text causes confusion for local drivers.	6	3
Interaction and Touch Usability	Inconsistent touch response and unclear menu structure increase task time.	6	3

Issue / Cluster	Representative Observation	Frequency (Participants)	Severity (0–4)
Eco-Driving and Efficiency Support	Lack of feedback on regenerative braking or energy efficiency.	5	2
Aesthetic and Interface Acceptance	Overly cluttered display; low contrast in bright conditions.	4	2

Issues scoring 4 (*Diagnostic Clarity*, *Layout and Visibility*, *Safety and Oversight*) are classified as critical and demand immediate redesign attention. Issues with scores of 3 represent major but manageable concerns, to be addressed in the next design iteration.

Table 5.8: Prioritization of positive usability features derived from KJ cluster analysis, showing feature importance, participant frequency, and assigned priority levels (Source: Author, 2024).

Feature / Cluster	Representative Observation	Frequency (Participants)	Priority (0–4)
Diagnostic Clarity	Color-coded telltale symbols and sound cues aid quick fault identification.	10	4
Contextual Feedback	Sound confirmations for alerts and pop-ups enhance awareness.	9	3
Layout and Visibility	Familiar circular gauges for SOC and speed improve comfort.	8	3
Safety and Oversight	Audible chime for low battery warning effectively attracts attention.	6	3
Maintenance Information	Real-time air-pressure gauges and service reminders are useful.	6	3

Feature / Cluster	Representative Observation	Frequency (Participants)	Priority (0–4)
Localization and Language	ISO-compliant telltale symbols are easy to recognize across languages.	5	2
Interaction and Touch Usability	Touch layout familiar from mobile use allows quick access to menus.	6	3
Eco-Driving and Efficiency Support	DTE gauge effectively support range estimation.	7	4
Aesthetic and Interface Acceptance	Clean digital layout improves overall appeal.	8	3
Alert Timing and Attention	Persistent visual cues (e.g., low-battery icon) support vigilance.	5	2

This evaluation distinguishes between issues requiring correction and features worth retaining. High-priority features such as *clear color coding*, *effective DTE visualization*, and *sound-based alerts* are existing strengths that should be preserved and refined in the redesign phase.

5.5.4 Compilation of Statistical Findings

To integrate findings from the KJ and severity analyses, we conducted a Pareto assessment to identify which clusters contribute most significantly to usability concerns. The number of participants mentioning issues in each cluster (from Table 5.7) was converted into percentage values and arranged cumulatively to produce a Pareto distribution (Figure 5.15).

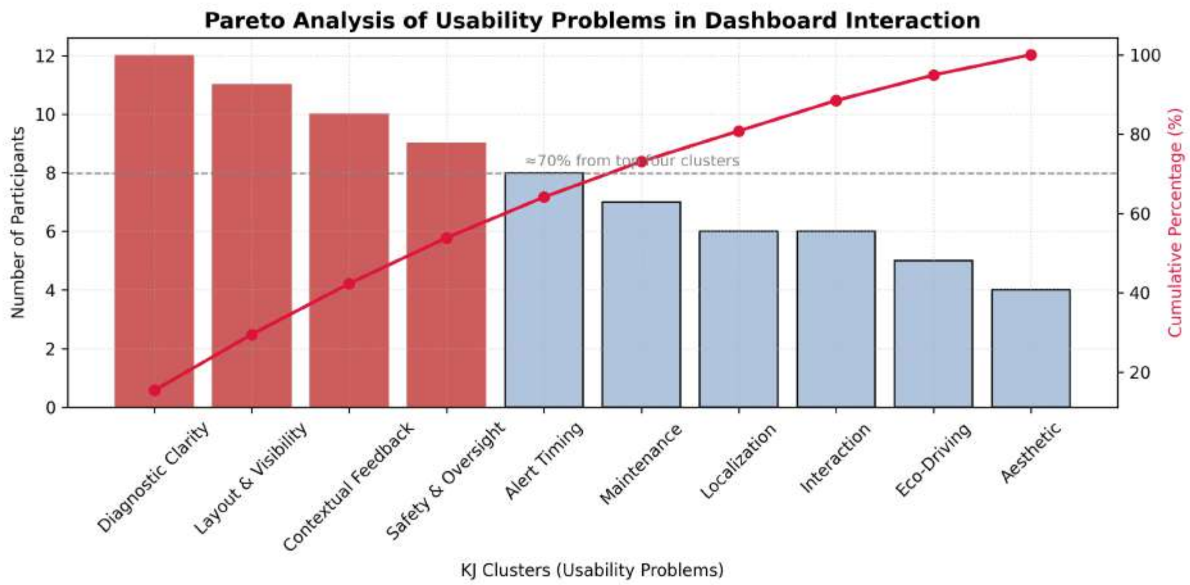


Figure 5.15: Pareto analysis of usability problems identified from KJ clustering during the main study (Source: Author, 2024).

The Pareto distribution shows that the four clusters: *Diagnostic Clarity*, *Layout and Visibility*, *Contextual Feedback*, and *Safety and Oversight* account for the majority of reported difficulties (approximately two-thirds of all mentions). This indicates that driver performance and trust depend primarily on clear fault representation, legible information layout, consistent multimodal feedback, and prominent safety cues.

5.5.5 Design Implications Summary

The analysis identified four key areas for dashboard redesign: *Diagnostic Clarity*, *Layout and Visibility*, *Contextual Feedback*, and *Safety and Oversight*. These areas affect how drivers understand, monitor, and react during operation.

The design implications are prioritized based on three criteria: (i) frequency of occurrence across participants, (ii) severity of usability issues identified through evaluation, and (iii) convergence of evidence from both stakeholder and driver studies (see Table 5.9). These criteria combine evidence from KJ affinity clustering (frequency of mentions), participant-level impact, and severity ratings based on Nielsen's framework.

1. **Diagnostic Clarity:** Show faults clearly with numeric data and color-coded symbols. Automate fault messages and send them directly to the control room.

2. **Layout and Visibility:** Use large text, clear contrast, and an unobstructed screen. Keep important data visible and easy to read in all light conditions.

3. **Contextual Feedback:** Provide short, meaningful alerts. Combine sound, visuals, and icons in local language to aid quick understanding.

4. **Safety and Oversight:** Keep physical controls for safety features. During faults, highlight only critical alerts and hide non-essential data.

Table 5.9: Prioritization of design implications based on frequency, severity, and evidential convergence from stakeholder and driver studies

Design Area	**KJ Frequency (Mentions)**	**Participants Affected**	**Severity (0–4)**	**Priority Level**
Diagnostic Clarity	19	12	4 (Critical)	High
Layout and Visibility	14	11	4 (Critical)	High
Contextual Feedback	15	10	3 (Major)	Medium
Safety and Oversight	12	9	4 (Critical)	High

As shown in Table 5.9, Diagnostic Clarity, Layout and Visibility, and Safety and Oversight are identified as high-priority design areas due to their high frequency and critical severity. In contrast, contextual feedback is categorized as a medium priority due to its comparatively lower severity and impact. These prioritized implications collectively inform the subsequent design phase, ensuring that critical usability and safety concerns are addressed systematically in the proposed dashboard solution.

Design Scope. Based on stakeholder insights and driver familiarity patterns, the redesign focuses on developing a *digital dashboard for EV-specific information* rather than modifying the existing instrument cluster (IC). The current IC, which contains analog indicators for speed and telltales, is retained to preserve driver familiarity, minimize retraining, and maintain cost efficiency. Both drivers and stakeholders emphasized that the primary usability challenges such as diagnostic clarity, contextual feedback, and digital communication are associated with the

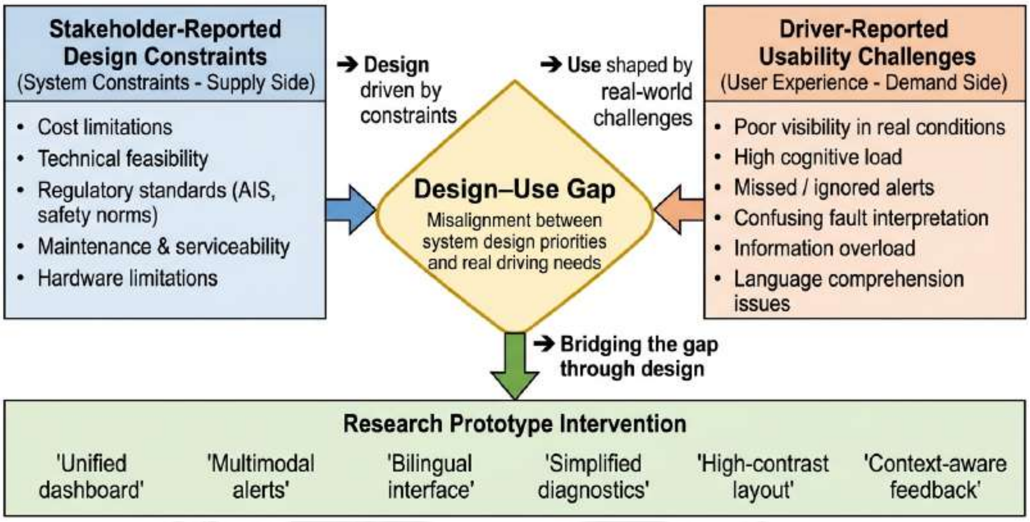


Figure 5.16: Conceptual illustration of the design–use gap, showing how stakeholder-reported design constraints (supply-side) and driver-reported usability challenges (demand-side) create a misalignment in system design, motivating the development of the proposed research prototype intervention.

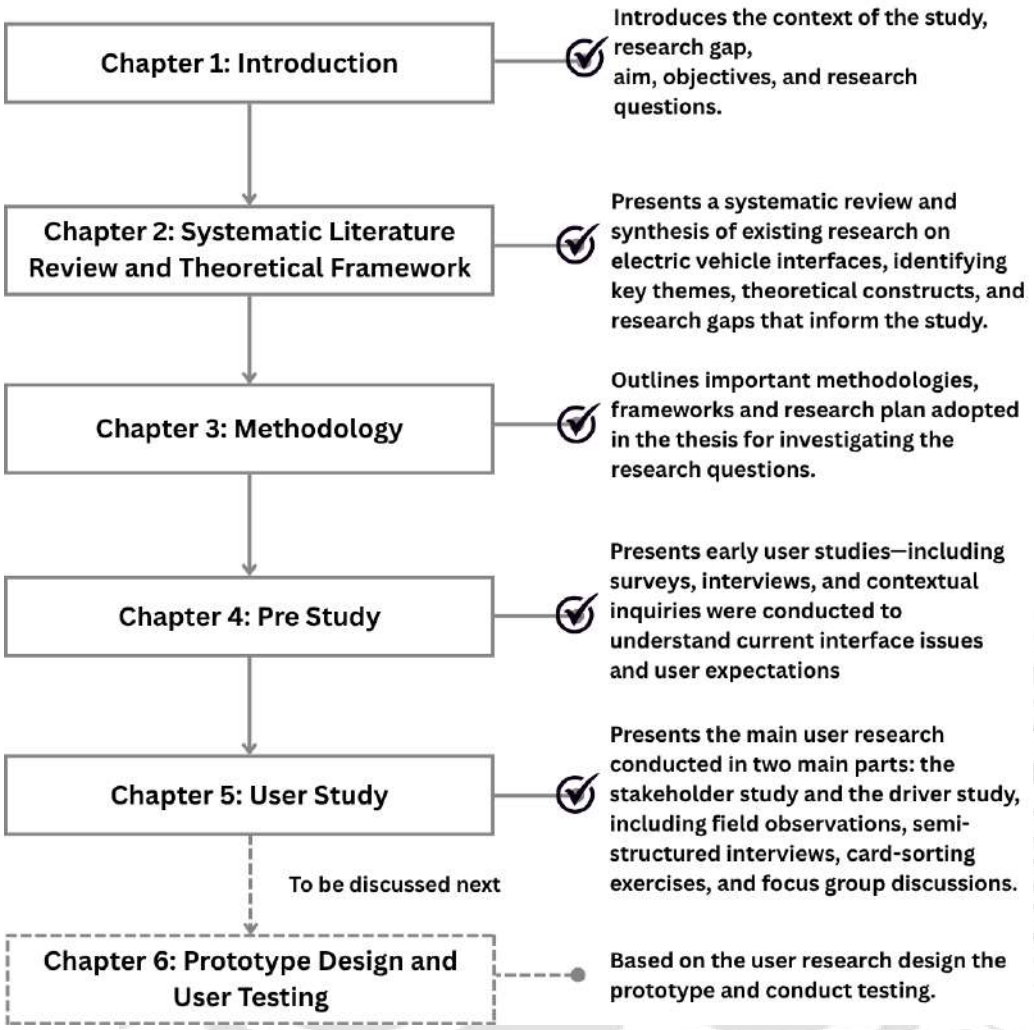
electronic information layer rather than the mechanical cluster. Therefore, the subsequent prototyping and testing phases concentrate on creating and evaluating this digital dashboard that integrates EV-specific data, alerts, and communication features into a unified interface for operational decision support.

We have drawn a diagram to show how system constraints and real driving challenges create a design–use gap, which the prototype addresses (see 5.16).

5.6 Chapter Summary

This chapter synthesises insights from the stakeholder and driver studies to establish concrete user requirements for the e-bus dashboard redesign. Along with analysing ninety-one quotations, the chapter also developed the driver persona and user journey, which informed the contextual understanding of real driving workflows. Using KJ Affinity Analysis integrates insights from both stakeholder and driver studies to derive actionable user requirements for the redesign of the e-bus. These evidence-based insights form the foundation for the research prototype design in the following chapter.

A visual summary of the chapters covered so far is presented as follows:



Chapter 6

Design and evaluation of research prototype

The previous chapter consolidated insights from stakeholders and users to define key usability challenges and functional requirements for the e-bus dashboard. Building on these findings, this chapter translates the identified requirements into tangible design concepts for the e-bus dashboard. The goal is to design and test the research prototype.

6.1 Introduction

This section outlines the development and evaluation of the e-bus research prototype based on the refined user requirements. The objective is to translate these empirically derived needs into a functional, driver-centered research prototype and evaluate its usability in an operational context. The chapter is divided into two sections: Prototype Design and Prototype Testing.

The research prototype design section outlines a structured method for transforming design implications into actionable solutions, adhering to Jesse James Garrett's five UX planes. The research prototypes were developed in stages, starting with low-fidelity paper sketches, then moving to high-fidelity Figma designs, and finally resulting in an interactive web-based research prototype for user testing.

The research prototype testing section explains the usability evaluation of the developed research prototype conducted in three stages. These included a heuristic evaluation using Nielsen's ten heuristics, a user test based on usability and acceptance frameworks, and finally, a cognitive walkthrough conducted with design experts to assess first-time learnability from an expert inspection perspective.

6.2 Chapter Objectives

This chapter has two main objectives:

1. To translate and refine the set of user requirements and expert-validated design guidelines from the previous chapter into a functional user-centered research prototype.
2. To test and validate the developed research prototype in a real depot setting under operational conditions, assessing its usability, clarity, and contextual applicability for professional drivers.

6.3 Prototype Design

The design focuses on creating a separate digital dashboard for EV-specific information. The analog instrument cluster is retained to preserve driver familiarity. The research prototype design process followed Jesse James Garrett's five UX planes: *strategy*, *scope*, *structure*, *skeleton*, and *surface* (see Figure 6.1). This structure supports traceability from user requirements to the final interactive dashboard, which is explicitly demonstrated in the following subsection. Each plane builds upon the insights established in the previous chapter. It systematically translates qualitative findings from stakeholder and driver studies into tangible interface solutions.

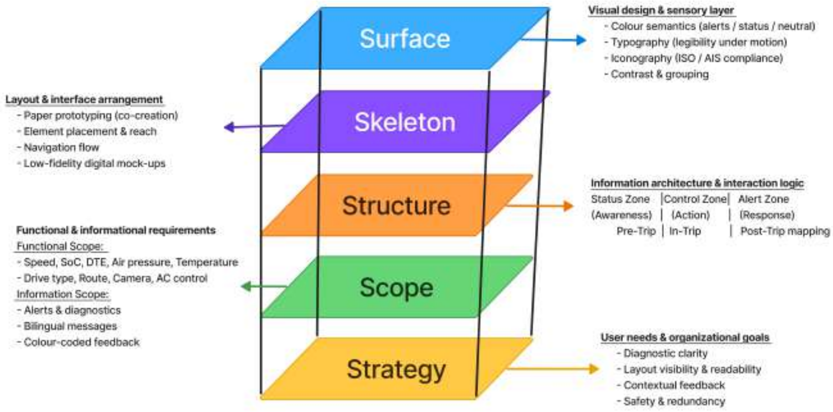


Figure 6.1: The five planes of user experience proposed by Jesse James Garrett (2000), redrawn by the author.

6.3.1 Strategy Plane

At the most abstract level, the *Strategy Plane* defines the foundational intent of the research prototype. It balances driver needs with organizational goals such as safety, efficiency, and reliability. User needs were derived from recurring pain points identified through the KJ Analysis and Severity Evaluation in Chapter 5. Four key user-centered priorities guided the strategic intent:

1. **Diagnostic Clarity:** Show faults clearly through numeric data, color-coded icons, and automated depot fault reporting.

2. **Layout and Visibility:** Use large, high-contrast typography and decluttered screens for easy readability across lighting conditions.

3. **Contextual Feedback:** Provide multimodal (visual, and auditory) alerts that perceived reduction in cognitive load during driving.

4. **Safety and Oversight:** Preserve physical redundancy for safety-critical functions while prioritizing essential alerts during high-risk conditions.

These strategic objectives collectively guided the research prototype design, ensuring alignment with real driver behaviors, contextual constraints, and stakeholder expectations for safety and operational clarity. In contrast to existing dashboards, which distribute information across multiple displays and physical controls, the proposed design consolidates key functions into a unified interface, thereby reducing visual scanning and interaction complexity.

6.3.1.1 Traceability from Empirical Findings to Design Decisions

To ensure transparency in the design rationale, the empirical findings from Chapter 5 were explicitly mapped to corresponding design implications and their implementation in the research prototype. This mapping establishes a clear traceability between identified usability challenges and the resulting interface features, demonstrating how each design decision is grounded in user and stakeholder data rather than abstract assumptions.

Table 6.1: Traceability from empirical findings to prototype design features

Empirical Finding	**Design Implication**	**Prototype Implementation**
Drivers struggled to interpret faults and system status clearly (KJ Analysis, Severity Ranking – Chapter 5)	Diagnostic Clarity	Numeric SOC display, simplified fault codes, color-coded alerts, automated depot reporting
Poor visibility under varying lighting conditions (Contextual Inquiry, Field Observations – Chapter 5)	Layout and Visibility	High-contrast interface, large typography, centralized information layout
Drivers missed or ignored alerts during operation (Interviews, Focus Groups – Chapter 5)	Contextual Feedback	Multimodal alerts (visual + auditory), simplified icons, bilingual messages
High cognitive load during fault situations (Interviews, Severity Analysis – Chapter 5)	Safety and Oversight	Priority-based alert filtering, suppression of non-critical information, retention of physical controls

This traceability ensures that each design decision can be directly traced back to empirical evidence, thereby reducing subjectivity in the design process.

6.3.2 Scope Plane

The *Scope Plane* translates strategic goals into specific functional and informational deliverables. It defines what the dashboard must *do* (functional scope) and what it must *communicate* (informational scope).

The initial EV interface variables were identified in Pre-study 3. These included battery, range, speed, alerts, temperature, and drive mode. They were identified during a focus group with interface designers. These variables represent established usability conventions across EV systems. They ensure conceptual continuity between car and bus interfaces. This set formed the foundation for defining the e-bus dashboard's content structure.

Following Garrett's model, two complementary specifications were created:

- **Functional Specifications:** The dashboard enables monitoring of key vehicle parameters (speed, State of Charge, Distance-to-Empty, air pressure, temperature), route selection, drive type switching, camera viewing, AC control, and depot fault communication.
- **Information Requirements:** The system provides continuous contextual feedback through alerts, diagnostic summaries, bilingual messages, and standardized color codes.

These specifications were empirically refined. Thirty-five interface attributes were identified from stakeholder and driver studies. These were filtered into eighteen essential dashboard elements. This refinement was carried out through expert validation workshops. This filtered set defined the operational boundaries for design and ensured the research prototype captured the most frequently mentioned usability needs: *visibility, alerts, diagnostics, and comfort control.*

6.3.3 Structure Plane

The *Structure Plane* organizes these features into a logical and ergonomic hierarchy, determining how drivers interact with and navigate between information. Each function was mapped to a corresponding driving context (*pre-trip, in-trip, post-trip*) to reflect real operational workflows.

The information architecture was categorized into three interaction zones:

- **Status Zone:** Constantly visible metrics such as speed, SoC, DTE, time, and AC temperature.
- **Control Zone:** Touch-based interactions for Drive Type, Route, Camera, and AC modules.
- **Alert Zone:** Disruptive feedback elements such as diagnostic warnings, telltales, and emergency alerts.

This structure aligns with interaction-design principles and Norman's perception–action–feedback cycle. The zonal organization (*Status = awareness*, *Control = action*, *Alerts = response*) directly corresponds to driver behaviors observed in contextual inquiries. Participants preferred right-hand placement for control inputs and left-hand positioning for informational modules, producing a horizontally symmetric and task-oriented layout.

6.3.4 Skeleton Plane

The *Skeleton Plane* defines the tangible arrangement of interface elements, translating abstract structure into physical layouts. This stage involved low-fidelity paper prototyping through participatory workshops with two stakeholder groups: (1) 12 professional electric-bus drivers (Group A), and (2) 24 design practitioners and students (Group B) from a national design conference.

A bilingual (English & Gujarati) card-sorting activity used the thirty-five dashboard attributes as movable components on a scaled cockpit layout. Participants collaboratively determined intuitive placements for each element through discussion and iteration. Co-creation sessions (including India HCI workshop exercises) produced paper prototypes that validated information hierarchy, alert prominence, and navigation flow. Quick tests surfaced content gaps and placement inconsistencies (see Appendix H). Insights from these sessions informed the low-fidelity digital mock-ups.

6.3.5 Surface Plane

The *Surface Plane* represents the most concrete level of Jesse James Garrett's framework. It defines the sensory qualities of the interface. These include color, typography, contrast, iconography, and spatial grouping. These qualities shape the user's perceptual experience. Decisions were not made only for aesthetics. They were made to reinforce clarity, readability, and emotional balance during operation.

At this stage, the e-bus dashboard design evolved into a perceptually coherent interface. Visual and tactile cues were refined through iterative testing to maintain usability under varying conditions, including sunlight glare, vibration, and variable ambient light.

Color Scheme. A high-contrast palette ensures legibility across driving conditions. Dark backgrounds minimize glare and visual fatigue, while vivid hues emphasize critical feedback. Consistent color semantics convey hierarchy and urgency:

- **Primary Information (Cool Colors):** Blue and green denote continuous vehicle states such as speed, SoC, and DTE.
- **Secondary Information (Neutral Tones):** Grey and white tones support non-critical data such as trip details and AC temperature.
- **Alerts and Warnings (Warm Colors):** Amber and red highlight caution and critical states, following AIS-071 standards (Automotive Research Association of India (ARAI), 2010).

Typography and Iconography. Sans-serif typefaces ensure legibility at distance and under motion. Icons follow ISO 7000 conventions and are paired with bilingual subtexts (English & Gujarati) for linguistic accessibility.

Information Hierarchy. Information is structured using proportional scaling and spatial grouping. Critical data appear centrally in large type; secondary elements occupy peripheral zones. Subtle contrasts delineate areas without visual clutter.

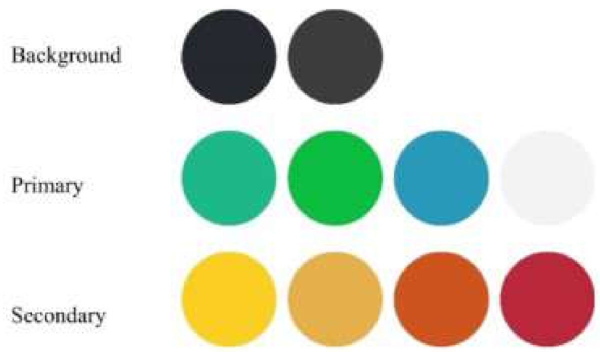


Figure 6.2: Color-coding scheme applied in the research prototype interface design (Source: Author, 2024).

Sensory Coherence. Visual and auditory (alert chimes) feedback combine to form a coherent sensory system. Each cue serves a functional role. This role may be confirmation, alerting, or guidance. These cues ensure that the sensory layer fully supports the cognitive and behavioral layers beneath.

6.3.6 Prototype Implementation

Following the completion of the Surface Plane design, the dashboard concept was translated into interactive digital formats for evaluation. Figma wireframes were first created to test information flow and layout consistency, focusing on (i) route versus alert contention, (ii) error-reporting flow to the depot, and (iii) technician-oriented bus-status visibility (see Appendix I).

The refined Figma interface was subsequently implemented as a high-fidelity, web-based research prototype using the TALL stack: Tailwind CSS, Alpine.js, Laravel 12, and Livewire. This architecture enabled a responsive, data-driven dashboard accessible on both tablets and monitors. Laravel 12 managed backend routing and state handling, Blade templates ensured component reuse, Livewire provided real-time interactivity without page reloads, and Alpine.js supported lightweight behaviors. Tailwind CSS maintained visual consistency with established design principles. Real-time alerts and notifications were implemented using Laravel Echo, supporting operational safety through timely driver feedback.

The resulting research prototype was fully functional, scalable, and aligned with the user-centered visual standards established during the Surface Plane phase. It served as the final version for heuristic and user-level usability testing described in the following sections.

6.4 Prototype Testing and Iterative Refinement

This stage represents the evaluation and refinement phase of the user-centered design process (see Methodology Section 3). The research prototype was first assessed through expert heuristic evaluation, then refined through iterative design updates, and finally validated through field usability testing with bus drivers. The same set of representative driving tasks was used across both evaluation stages to ensure comparability and traceability of improvements. These tasks were derived from actual operational workflows identified during earlier contextual inquiry, interviews, and field observations, ensuring alignment with real-world driving conditions (see Appendix F).

6.4.1 Heuristic Evaluation

A heuristic evaluation based on the ten usability heuristics proposed by Nielsen (1994) was conducted. These heuristics represent widely accepted principles for identifying usability issues in interactive systems.

6.4.1.1 Participant Selection

A total of sixteen participants were selected for the study (Male=12; Female=4; mean age = 37.2 years). The sample comprised HCI/UX researchers, usability specialists, and e-bus stakeholders such as technicians, depot managers, and city managers (see Table 6.2).

Table 6.2: Participant demographics and domain characteristics for heuristic evaluation ($N = 16$) (Source: Author, 2025).

SN	Participant ID	Gender	Profession / Role	Experience (yrs)	Age Group
1	P01	Female	PhD Scholar (HCI/UX)	<5	31–40
2	P02	Male	PhD Scholar (HCI/UX)	<5	20–30
3	P03	Female	PhD Scholar (HCI/UX)	<5	20–30
4	P04	Female	PhD Scholar (HCI/UX)	<5	20–30
5	P05	Male	PhD Scholar (HCI/UX)	<5	20–30
6	P06	Male	PhD Scholar (HCI/UX)	<5	20–30
7	P07	Male	PhD Scholar (HCI/UX)	<5	20–30
8	P08	Male	HCI Faculty	5	31–40
9	P09	Male	HCI Faculty	10	40–50
10	P10	Male	Usability Expert	20+	51–60
11	P11	Male	HCI Intern	1	20–25
12	P12	Male	HCI Faculty	2	31–40
13	P13	Male	E-bus Technician	10+	31–40
14	P14	Male	E-bus City Manager	10+	41–50
15	P15	Male	E-bus Depot Manager	15+	41–50
16	P16	Male	E-bus Maintenance Staff	10+	31–40

6.4.1.2 Method

The evaluation employed heuristic inspection to systematically identify usability issues related to interface consistency, feedback, and interaction flow.

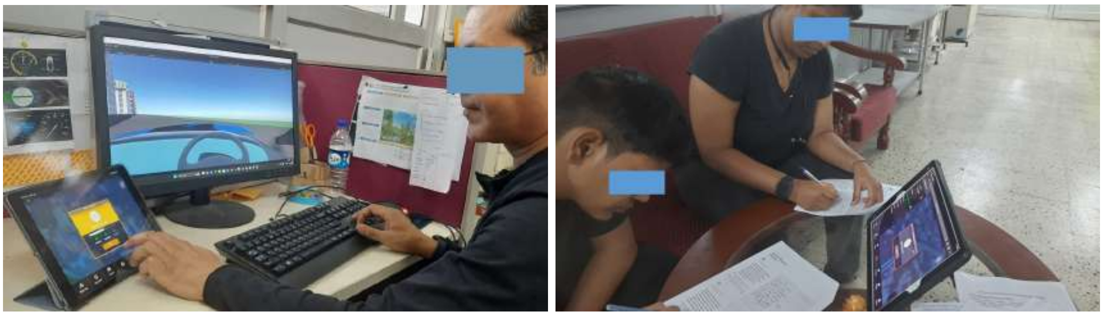


Figure 6.3: Photographs captured during the pilot study conducted with participants to evaluate the research prototype (Source: Author's fieldwork, 2025).

6.4.1.3 Procedure

Participants were first introduced to the research prototype and its primary functions. Each participant then interacted with the interface by performing a series of representative driver tasks (see Appendix L). During interaction, usability issues were identified based on heuristic violations, while the evaluator observed the sessions and documented usability issues along with participant feedback.

6.4.1.4 Data Collection

Usability issues were recorded during the evaluation sessions using a structured worksheet based on Nielsen's heuristics, adapted from commonly used heuristic evaluation templates. The template guided evaluators to assess the interface against each of the ten usability heuristics individually. For each heuristic, issues were documented along with their interface location, a description of the problem, and suggested recommendations. This heuristic-wise structured format ensured systematic coverage of all usability principles and consistency in data recording across participants.

6.4.1.5 Data Analysis

The collected usability data were analyzed through a multi-stage consolidation process. Initially, raw observations recorded by individual participants using the structured heuristic evaluation worksheet were compiled into a unified dataset. Similar and overlapping issues across participants were merged to remove redundancy and ensure clarity. Subsequently, the consolidated issues were grouped based on interface components (e.g., Alert system, AC Control, Bus Status) to support design-level interpretation. Each issue was then mapped to the corresponding Nielsen heuristic based on the nature of the usability violation. Following mapping, issues were assigned a priority level (High, Medium, Low) based on their frequency of occurrence, severity of impact on user interaction, and relevance to safety-critical driving tasks. Finally, each issue was translated into a specific UI change, forming a structured action list for iterative prototype refinement. This systematic process ensured traceability from raw user observations to final design interventions and enabled the identification of recurring usability patterns across the interface. Issues reported by multiple participants were treated as higher priority indicators of recurring usability breakdowns.

6.4.1.6 Findings

A total of 37 usability issues were identified during the heuristic evaluation, all classified and reported using Nielsen's ten usability heuristics. Figure 6.4 illustrates how these issues were distributed across the heuristic categories, revealing patterns of breakdown in visibility, consistency, and real-world match. Appendix J summarizes each issue along with its priority and the corresponding design update implemented. These findings guided the refinement of the research prototype before the driver usability testing phase.

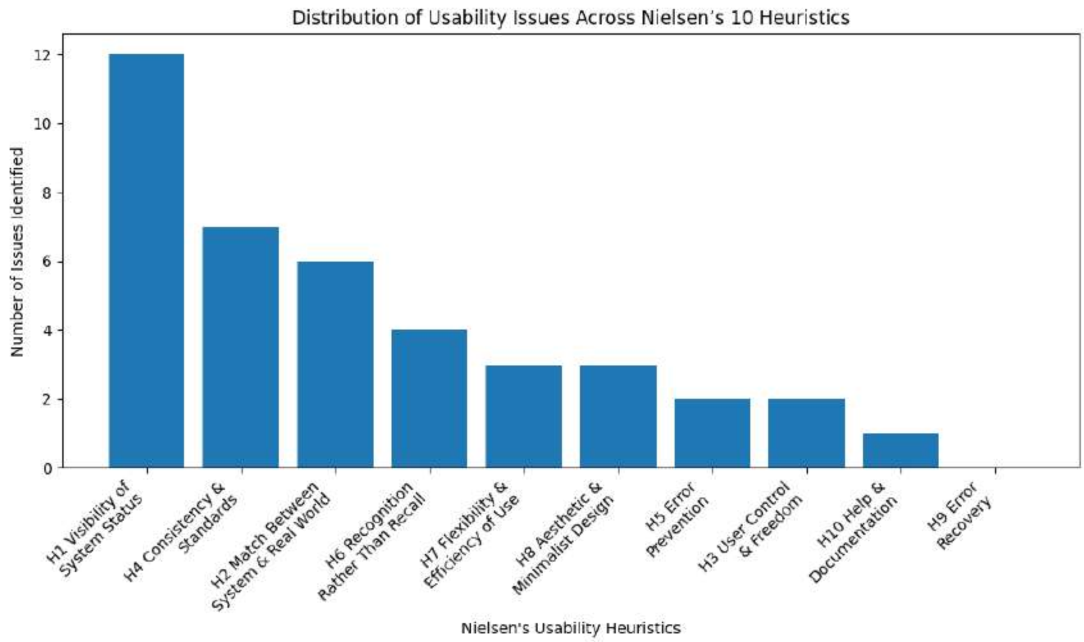


Figure 6.4: Heuristic evaluation of the research prototype based on Nielsen's usability heuristics (Source: Author, 2025).

6.4.2 Prototype Refinement

Findings from the pilot usability study directly informed several iterative refinements of the research prototype. The revision process focused on resolving interaction breakdowns, improving intuitiveness, and strengthening both the visual and functional hierarchy of the interface. All design updates were grounded in participant feedback and mapped to Nielsen's usability heuristics to ensure systematic improvements and clear traceability.

Pilot participants highlighted issues such as the absence of real-time feedback, inconsistent iconography, unclear affordances, and limited flexibility in performing critical tasks. In response, the research prototype was updated to provide clearer system feedback, establish consistent interaction logic, and better align interface behavior with drivers' mental models and operational workflows.

Key improvements included adding a "Vehicle Ready" indicator and enhancing trip and performance summaries to strengthen visibility into system status. Iconography and labels were standardized according to ISO conventions, improving recognition and reducing interpretation errors. Alert and reporting workflows were streamlined. Multi-step reporting was automated, pop-ups could be dismissed with a single tap, and information alerts were designed to auto-clear, reducing cognitive effort during busy operational conditions.

Further refinements ensured that high-priority elements, such as alerts, trip summaries, and AC controls, were visually emphasized, while secondary functions were compactly organized to minimize distraction. Collectively, these updates improved perceived usability, reduced visual clutter, and created a more coherent, safety-oriented driver interface ready for formal usability testing. Table 6.3 summarizes the implemented design refinements categorized according to Nielsen's heuristics.

Table 6.3: Pilot-study usability issues and corresponding design fixes mapped to Nielsen's usability heuristics (Source: Author, 2025).

SN	Heuristic (Nielsen)	Fixes Implemented
1	**Visibility of System Status**	Added Vehicle Ready indicator; coolant meters; trip summary with feedback; enlarged top-bar text; centered battery/DTE.
2	**Match Between System and the Real World**	Updated alert signs to ISO standards; aligned AC icons with real-world expectations; renamed unclear "Report" button; redesigned AC icon.
3	**User Control and Freedom**	Enabled single-tap alert dismissal; auto-dismiss information pop-ups; tap-anywhere to close pop-ups; added SOS/Help button.
4	**Consistency and Standards**	Added "Home" label; included Bus Ready icon; improved top-bar symmetry; drive type update planned.
5	**Error Prevention**	Automated multi-step alert reporting; clarified diagnostic alerts; added maintenance alerts with report submission.
6	**Recognition Rather Than Recall**	Simplified error codes; added local language and rating to performance summary; persistent diagnostic screens.
7	**Flexibility and Efficiency of Use**	Added feedback for AC temperature changes; clarified camera icons; minimized steps for alert reporting.

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Table 6.3 – continued from previous page

SN	Heuristic (Nielsen)	Fixes Implemented
8	**Aesthetic and Minimalist Design**	Removed irrelevant AC icons; resized the AC screen; consolidated layout to reduce visual clutter.
9	**Help Users Recognize, Diagnose, Recover from Errors**	Clarified error messages; enabled trip and maintenance summaries to be shared with depot; synchronized diagnostic alerts.
10	**Help and Documentation**	Integrated SOS/Help button; suggested driver training aids for future implementation.

Following the heuristic evaluation and pilot feedback, the research prototype was refined through multiple iterative cycles. These refinements focused on improving clarity, workflow consistency, real-time feedback, and alignment with drivers' operational practices. Issues identified during the pilot study—such as inconsistent iconography, unclear affordances, limited feedback for actions, and missing system status indicators—were addressed through targeted interface improvements mapped to Nielsen's usability heuristics.

Key refinements included:

- addition of a "Vehicle Ready" indicator and coolant meters to strengthen visibility of system status;
- use of standardized ISO-aligned icons and labels to support real-world interpretability;
- restructuring of alert workflows with single-tap dismissals and automated reporting to reduce driver workload;
- improved feedback mechanisms for AC control, camera access, route selection, and Post-Trip Reporting functions;
- simplification of layouts and removal of non-essential elements to reduce visual load during driving.

A complete description of the refined research prototype—including the Home Screen, Route Navigation, Drive Type, Camera, AC Control, Bus Status, Settings, and Diagnostics and Alerts modules are provided in Appendix K, along with high-resolution interface screenshots. This appendix documents the version of the dashboard that was used in formal usability testing with drivers.

6.4.3 Field Testing with End Users

In this stage, the research prototype was evaluated with professional e-bus drivers. The goal was to assess how well the redesigned dashboard supported real operational workflows when used in an actual depot environment. The evaluation focused on usability, cognitive effort, and user acceptance, comparing the existing bus dashboard with the research prototype. Drivers completed the same structured scenario-based tasks for both interfaces to ensure comparability (see Appendix L).

6.4.3.1 Participant Selection

Participants were selected through purposive sampling from an urban e-bus depot to ensure operational experience with e-bus systems. The study required participants to hold a valid commercial bus driver's license and to have at least 6 months of active e-bus driving experience. Participation was voluntary, and the study did not provide compensation. The participant's details are presented in Table 6.4.

Table 6.4: Participant demographics and domain characteristics for field usability study ($N = 32$) (Source: Author, 2025).

Variable	**Min**	**Max**	**Mean**	**SD**
Age (years)	21	52	33.5	7.2
Driving Experience (years)	1	32	9.1	–
EV Bus Experience (years)	1	6	3.0	–
Gender				
Male	32			
Education Level				
Primary (Below 10th)	3			
Secondary (10th–12th)	21			
Graduate and above	8			
Preferred Interface Language				
Gujarati	20			
Hindi	8			
English	4			
Technology Comfort (Self-reported, 1–5 scale)				
Low (1–2)	4			
Moderate (3)	9			
High (4–5)	19			

6.4.3.2 Method

The study adopted a within-subjects experimental design to compare the research prototype with the existing e-bus dashboard used in service operations. Each participant interacted with all three interface conditions—(1) the existing *Control* dashboard, (2) *Prototype–English*, and (3) *Prototype–Gujarati*. To control for order effects, all possible condition sequences were generated (six permutations: *Control, Prototype–English, Prototype–Gujarati*; *Control, Prototype–Gujarati, Prototype–English*; *Prototype–English, Control, Prototype–Gujarati*; *Prototype–English, Prototype–Gujarati, Control*; *Prototype–Gujarati, Control, Prototype–English*; *Prototype–Gujarati, Prototype–English, Control*), and participants were randomly assigned to one of these sequences by drawing from a predefined set. This approach ensured complete counterbalancing of condition order, thereby distributing potential learning and fatigue effects evenly across conditions.

Within the prototype conditions, participants experienced two language variants: *Prototype–English* and *Prototype–Gujarati*. Both variants shared an identical interface layout and functionality; only the displayed language differed. This structure enabled two levels of comparison: (1) *Control vs. Prototype–English* to evaluate functional redesign impact, and (2) *Prototype–English vs. Prototype–Gujarati* to assess the influence of language on usability and acceptance.

The intent of the evaluation was not to test operational competence but to observe how naturally the redesigned interface supported the expected driving workflow. To preserve ecological validity, all testing sessions were conducted in the afternoon after participants had completed their driving shifts, ensuring interaction under realistic cognitive load and familiarity conditions.

6.4.3.3 Procedure

The evaluation followed a structured protocol consistent with human–machine interface testing in transport environments. After obtaining informed verbal consent, participants were briefed about the study and completed a short familiarization session to ensure comfort with the touch-based interaction before formal testing. Each participant experienced all three conditions: (1) Control dashboard, (2) Research Prototype–English, and (3) Research Prototype–Gujarati in randomized order to counterbalance learning and fatigue effects. Each condition lasted approximately 10–15 minutes and was separated by a mandatory 5-minute break. The total session duration ranged between 40–50 minutes.

For each condition, participants followed a consistent task and evaluation sequence:

1. Complete the assigned tasks (7 tasks for the Control condition; 13 tasks for the Research Prototype), as listed in Table 6.5.

2. After each task, provide a Single Ease Question (SEQ) rating to assess perceived task difficulty.

3. Upon completing all tasks, complete three standardized post-condition questionnaires: System Usability Scale (SUS), Rating Scale for Mental Effort (RSME), and the Van der

Laan Acceptance Scale.

The difference in the number of tasks reflects the functional limitations of the existing dashboard and aligns with established transport-interface research practices, where legacy systems may not provide full feature parity with redesigned prototypes. Only Tasks 1–7 (pre-trip tasks) were comparable across all conditions, whereas Tasks 8–13 were exclusive to the Research Prototype and represent newly introduced functionalities. The complete set of tasks used in the evaluation is presented in Table 6.5.

Table 6.5: Instructions and expected responses for the 13 tasks used in the usability evaluation (Source: Author, 2025).

ID	Task Instruction (Question Form)	Expected Answer / Action
	Pre-trip Scenario	
Task1	What is the current air pressure?	Verbal answer: e.g., reading value.
Task2	What is the current date and time?	Verbal answer: e.g., “14:45.”
Task3	What is the current state of charge (SoC)?	Verbal answer: e.g., “78%.”
Task4	Can you set the AC temperature to 16°C?	Action: Adjust the AC controls.
Task5	Can you check the doors ?	Verbal answer: e.g., “closed.”
Task6	What is the current status of the bus?	Verbal answer: e.g., "vehicle ready".
Task7	Can you set the route sign to “12B”?	Action: Input the correct route signage.
	In-trip Scenario	
Task8	What does the alert indicate?	Verbal answer: e.g., “Overspeeding alert.”
Task9	Can you send alert notification to depot?	Action: Send alert report and wait for acknowledgment.
Task10	Can you set the drive mode to Depot?	Action: Activate the Depot mode.
	Post-trip Scenario	
Task11	Can you view the trip summary?	Action: Navigate and report the summary.
Task12	Can you view the performance report?	Action: Access the report.
Task13	How would you notify the depot for maintenance?	Action: Send a maintenance report.

The physical testing setup for both evaluation conditions is shown in Figure 6.5, illustrating how participants interacted with the Control dashboard and the research prototype interface inside the stationary bus.

(a) Control setup

(b) Research prototype setup

Figure 6.5: Physical test environment illustrating the two evaluation conditions: (a) existing control dashboard and (b) research prototype interface installed in the stationary bus (Source: Author's fieldwork, 2025).

The procedural overview is shown in Figure 6.6.

Figure 6.6: Step-by-step procedure of the field usability study, showing participant flow across experimental conditions, task execution, and data collection stages (Source: Author, 2025).

6.4.3.4 Data Collection

Data were captured using standardized subjective and task-level instruments to assess usability, cognitive workload, and system acceptance. Four validated tools were used:

- **Single Ease Question (SEQ)** administered after each task to assess perceived task difficulty (Sauro and Dumas, 2009).
- **Rating Scale for Mental Effort (RSME)** administered post-condition to measure perceived mental workload on a 0–150 continuous scale (Zijlstra and Van Doorn, 1985).
- **System Usability Scale (SUS)** used post-condition to assess dashboard interface usability and perceived satisfaction (Brooke et al., 1996).
- **Van der Laan Acceptance Scale** used post-condition to assess perceived usefulness and satisfaction as indicators of adoption likelihood (J. et al., 1997). The scale was selected for its established use in transport-related human–machine interface studies, making it suitable for evaluating driver acceptance of e-bus dashboards.

- **Post-task questionnaire** used to capture participants' reflections on usability, comfort, and language comprehension.

This multi-measure structure aligns with documented approaches in transport-HMI usability studies, where system acceptance and cognitive demand are evaluated alongside usability.

6.4.3.5 Data Analysis

The collected data were analyzed using a combination of descriptive and inferential statistical methods. Normality of the data was first assessed using the Shapiro–Wilk test. As the data did not follow a normal distribution, non-parametric statistical tests were employed. For pair-wise comparisons between conditions, the Wilcoxon signed-rank test was used. Descriptive statistics, including mean, median, and standard deviation, were computed for all dependent measures (SEQ, SUS, RSME, and acceptance scores). Effect sizes were also calculated to assess the magnitude of differences.

Quantitative results were complemented with qualitative analysis of participant feedback. Open-ended responses were reviewed and grouped into recurring themes to provide contextual interpretation of the statistical findings.

6.4.3.6 Ethical Considerations

Participants received a verbal briefing in their preferred language before the session began. They were provided with a written participant information sheet to review (see Appendix M), and a consent form in their local language, which they signed prior to participation (see Appendix N). Participation was voluntary, and participants were informed that they could withdraw at any point without consequence. Personally identifying information was not collected. All data were anonymized prior to analysis and handled in accordance with institutional ethical guidelines. A standardized briefing script (provided in English and Gujarati) ensured consistency across all sessions.

6.4.3.7 Methodological Limitations

Task parity across the two conditions was not possible due to functional constraints of the existing dashboard, which supports only basic pre-trip operations. While this introduces asymmetry in task volume, similar approaches are reported in HMI evaluation studies where legacy interfaces lack full functional equivalence with redesigned systems. This limitation is acknowledged and considered during analysis and interpretation.

6.4.3.8 Results

A total of 38 drivers initially volunteered, of which 32 completed the study. All participants were male, aged between 21 and 52 years ($M_{\text{age}} = 33.5$, $SD = 7.2$). Driving experience ranged from 1 to 32 years ($M = 9.1$), with 1–6 years of experience operating e-buses ($M = 3$). Educational backgrounds varied from primary schooling to postgraduate qualifications, with the majority having completed secondary education. Participants reported Gujarati ($n = 20$), Hindi ($n = 8$), or English ($n = 4$) as their preferred working language.

The analysis focuses on four dependent measures: *perceived task ease* (SEQ), *perceived usability* (SUS), *mental workload* (RSME), and *acceptance* (Van der Laan Scale). Reflecting the study design, two comparison levels were examined:

1. **Control vs. Research prototype (English):** to determine whether the redesigned interface improves usability outcomes relative to the existing dashboard.
2. **Research Prototype (English) vs. Research prototype (Gujarati):** to examine whether interface language influences reported experience when the underlying design remains unchanged.

The research prototype condition included two language variants (English and Gujarati), both identical in layout and functionality. Therefore, the statistical analysis treats the research prototype as one design evaluated in two language formats. Improvements consistently observed in both research prototype variants relative to the control are interpreted as evidence of a *redesign effect*, while differences between the English and Gujarati variants indicate a potential *language effect*.

6.4.3.9 Perceived Ease of Task

Participants rated each task using the Single Ease Question (SEQ) on a 7-point Likert scale, where higher scores indicate greater perceived ease of task completion (see Figure 6.7). For analysis, SEQ scores were examined in two parts based on task type. The first part compares performance on shared pre-trip tasks (Tasks 1–7), which were completed under both the existing Control dashboard and the research Prototype. This allows a direct comparison of how each interface supported routine operational activities.

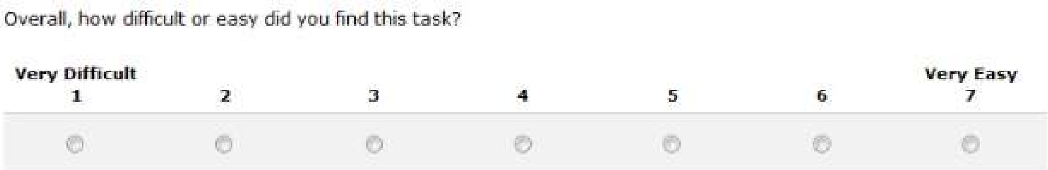

Figure 6.7: Single Ease Question (SEQ) scale used for post-task usability assessment (Source:Sauro and Lewis (2016)).

(1) Perceived Ease of Task In the first set, we have compared the results between the control and the research prototype for the common tasks, that is, pretrip (Task1-07).

Normality Test

Normality was assessed using the Shapiro–Wilk test. SEQ scores for all interface versions showed significant deviation from normal distribution (Table 6.6), mainly due to ceiling effects observed in the research prototype ratings. Based on this, non-parametric statistical methods were used for analysis.

Table 6.6: Results of the Shapiro–Wilk normality test for Single Ease Question (SEQ) scores for shared tasks (Tasks 1–7) across dashboard conditions ($N = 32$) (Source: Author, 2025).

Condition	Version	Shapiro–Wilk (p)
Control	–	$<.001$
Research Prototype	English	$<.001$
Research Prototype	Gujarati	$<.001$

Table 6.7 presents the SEQ descriptive results. The data are organised under the two study

conditions: the existing Control dashboard and the Research Prototype. The research prototype includes two language versions with identical layout and functionality.

Table 6.7: Descriptive statistics of Single Ease Question (SEQ) scores across dashboard conditions for shared tasks (Tasks 1–7) ($N = 32$) (Source: Author, 2025).

Condition	Version	Mean	Median	SD
Control	–	5.94	6.14	1.06
Research Prototype	English	6.46	6.64	0.84
Research Prototype	Gujarati	6.42	6.43	0.85

The descriptive results show a consistent improvement in perceived task ease when using the research prototype. Both the research prototype versions received higher SEQ scores compared to the control dashboard, indicating that drivers found the research prototype easier to operate. Lower standard deviation values in the research prototype scores also suggest a more consistent experience across participants.

Inferential Results (Tasks 1–7)

To determine whether the observed differences were statistically meaningful, Wilcoxon Signed-Rank tests were conducted for pairwise comparison (Table 6.8). In Step 1, the Control and the research prototype-English were compared. Step 2 compares the improved result with research Prototype-Gujarati.

Step 1 Control vs. Research Prototype–English A Wilcoxon Signed-Rank test showed that SEQ scores were significantly higher for the Research Prototype–English interface compared to the existing Control dashboard. This indicates that the redesigned layout and grouped information structure made routine pre-trip checks easier and more intuitive for drivers.

Step 2 Research Prototype–English vs. Research Prototype–Gujarati To further evaluate whether Research Prototype-English is better than the Research Prototype-Gujarati dashboard, we performed a second Wilcoxon comparison. We found the research prototypes were marginally different. Based on this, we interpret that the improvement in ease of use is driven by the research prototype itself, rather than the language presented on screen.

Table 6.8: Results of Wilcoxon signed-rank tests comparing Single Ease Question (SEQ) scores for shared tasks (Tasks 1–7) across dashboard conditions ($N = 32$) (Source: Author, 2025).

Comparison	**Wilcoxon** Z	p	**Effect size** (r)
Control vs. Research Prototype–English	-2.586	.010*	.46
Research Prototype–English vs. Research Prototype–Gujarati	-0.355	.722	.06

*$p < .05$ after Bonferroni adjustment.

Figure 6.8 visually reflects this trend: scores for the control condition are lower and more variable, whereas both the research prototype versions cluster near the upper end of the scale, indicating consistently easier user experience.

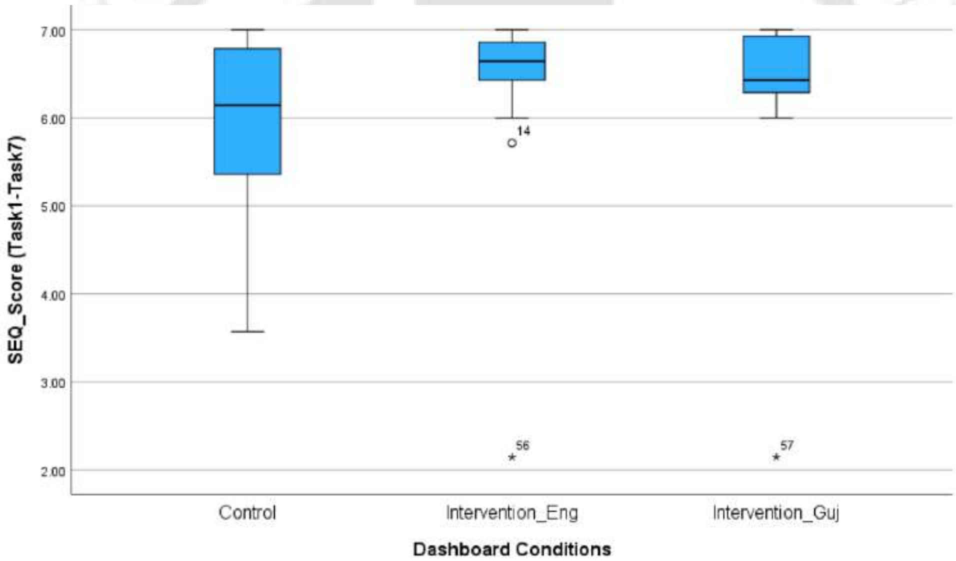

Figure 6.8: Distribution of Single Ease Question (SEQ) scores for shared pre-trip tasks across evaluation conditions (Source: Author, 2025).

(2) Research Prototype-Only Tasks (Tasks 8–13) Tasks 8–13 represent newly introduced functions that are not currently available in the Control dashboard. These tasks included responding to alerts, sending error reports to the depot, switching drive modes, and reviewing trip and performance summaries. As these features exist only in the redesigned system, the analysis focused on the two versions of the research prototype.

Normality Test

As with the shared tasks, SEQ scores for the research prototype-only tasks were not normally distributed (Table 6.9). This was expected, as many ratings reached the upper end of the scale, indicating a potential ceiling effect. Accordingly, non-parametric tests were used.

Table 6.9: Results of the Shapiro–Wilk normality test for Single Ease Question (SEQ) scores for research prototype-only tasks (Tasks 8–13) ($N = 32$) (Source: Author, 2025).

Version	Shapiro–Wilk (p)
Research Prototype–English	$<.001$
Research Prototype–Gujarati	$<.001$

Table 6.10 summarizes the SEQ ratings for these research prototype-only tasks. Scores in both the research prototype versions were clustered near the maximum value, indicating that drivers perceived these functions as very easy to complete.

Table 6.10: Descriptive statistics of Single Ease Question (SEQ) ratings for research prototype-only tasks (Tasks 8–13) ($N = 32$) (Source: Author, 2025).

Version	Mean	Median	SD
Research Prototype–English	6.49	6.67	0.74
Research Prototype–Gujarati	6.47	6.67	0.77

Inferential Results

A Wilcoxon signed-rank comparison confirmed that there was a marginal difference between Research Prototype–English and Research Prototype–Gujarati scores. This indicates that language did not influence task ease for these newly introduced functions.

The consistently high ratings suggest that drivers quickly understood and operated newly introduced functions such as error reporting, performance review, and in-trip alerts. The existence of a marginal difference between languages further indicates that these improvements stem from the redesigned interaction structure, not from language familiarity.

The boxplot in Figure 6.9 illustrates the pattern: both language versions produced tightly clustered scores near the ceiling, signaling strong usability and consistent performance across drivers.

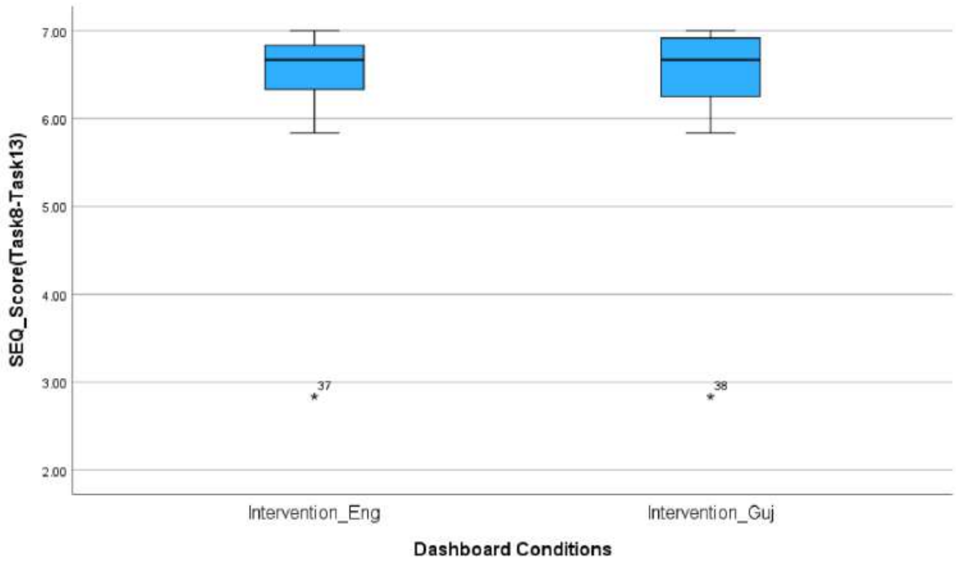

Figure 6.9: Distribution of Single Ease Question (SEQ) scores for research prototype-only tasks (Tasks 8–13) evaluated during the final user study (Source: Author, 2025).

6.4.3.10 System Usability

The System Usability Scale (SUS) was used to assess overall perceived usability of the dashboards (see details in Appendix P). Scores range from 0 to 100, with higher values indicating stronger perceptions of usability.

Normality Test: Shapiro–Wilk tests showed that SUS ratings were not normally distributed across any of the tested versions (Table 6.11). As a result, non-parametric tests were applied for all subsequent analyses.

Table 6.11: Results of the Shapiro–Wilk normality test for System Usability Scale (SUS) scores across dashboard conditions ($N = 32$) (Source: Author, 2025).

Condition	Version	Shapiro–Wilk (p)
Control		$<.001$
Research Prototype	English	$<.001$
Research Prototype	Gujarati	$<.001$

Descriptive Summary: Table 6.12 presents the SUS score distribution across the three tested versions. The research prototype (both English and Gujarati) received substantially higher usability scores than the existing Control dashboard.

Table 6.12: Descriptive statistics of System Usability Scale (SUS) scores across dashboard conditions ($N = 32$) (Source: Author, 2025).

Condition	Version	Mean	Median	SD
Control		58.13	57.50	17.63
Research Prototype	English	88.98	93.75	13.17
Research Prototype	Gujarati	89.53	92.50	11.94

The results indicate a clear improvement in perceived usability when drivers interacted with the research prototype interface. Compared to the control condition, usability scores increased by more than 30 points on average, representing a shift from a rating typically classified as "Marginal–OK" to the "Excellent" range on SUS interpretation benchmarks.

Inferential Results: To determine whether the observed differences were statistically meaningful, Wilcoxon Signed-Rank tests were conducted for pairwise comparison (Table 6.13). In Step 1, the Control and the research Prototype-English were compared. Step 2 compares the improved result with Research Prototype-Gujarati.

Step 1: Control vs Research Prototype–English A significant improvement was found. The research prototype was significantly much higher in usability than the Control, indicating that the redesigned layout and consolidated interaction flow substantially enhanced perceived usability.

Step 2: Research Prototype–English vs Research Prototype–Gujarati To further evaluate whether Research Prototype-English is better than the Research Prototype-Gujarati, we performed a second Wilcoxon comparison. We found research prototypes were marginally different. Based on this, we interpret that the usability improvements stem from the research prototype, independent of the language presented.

Table 6.13: Results of Wilcoxon signed-rank tests comparing System Usability Scale (SUS) scores across dashboard conditions ($N = 32$) (Source: Author, 2025).

Comparison	Wilcoxon Z	p	r
Control vs Research Prototype–English	-3.877	$<.001^{*}$	.69
Research Prototype–English vs Research Prototype–Gujarati	-0.313	.754	.06

$^{*}p < .001$ after Bonferroni adjustment.

Figure 6.10 shows the distribution pattern. Control scores appear more dispersed and lower, whereas both research prototype versions cluster tightly at the high end of the scale. This confirms that participants consistently perceived the research prototype as significantly more usable.

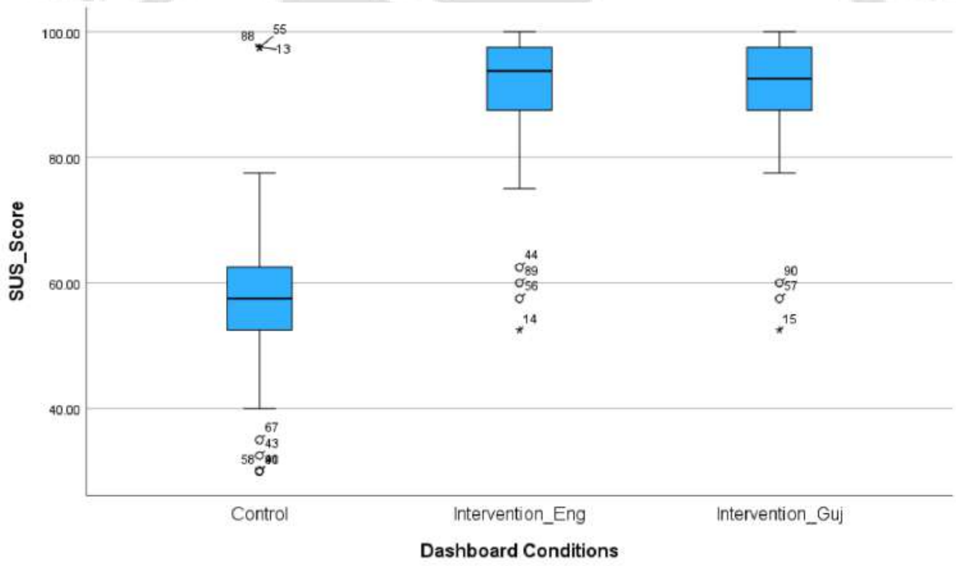

Figure 6.10: Distribution of System Usability Scale (SUS) scores across dashboard versions (Source: Author, 2025).

6.4.3.11 Mental Effort

Mental workload was assessed using the Rating Scale for Mental Effort (RSME), which ranges from 0 (no effort) to 150 (extreme effort). Lower scores indicate that the interface required less cognitive effort during task execution.

Normality Test: Shapiro–Wilk tests confirmed that RSME scores were not normally distributed for any version of the dashboard (Table 6.14). As with previous measures, non-parametric statistical tests were therefore used.

Table 6.14: Results of the Shapiro–Wilk normality test for Rating Scale Mental Effort (RSME) scores across dashboard conditions ($N = 32$) (Source: Author, 2025).

Condition	**Version**	**Shapiro–Wilk (p)**
Control		$<.001$
Research Prototype	English	$<.001$
Research Prototype	Gujarati	$<.001$

Descriptive Summary: Table 6.15 summarizes the RSME results. Both research prototype versions show noticeably lower mental effort scores than the existing control system.

Table 6.15: Descriptive statistics of Rating Scale Mental Effort (RSME) scores across dashboard conditions ($N = 32$) (Source: Author, 2025).

Condition	**Version**	**Mean**	**Median**	**SD**
Control		33.59	30.00	20.72
Research Prototype	English	20.84	20.00	15.04
Research Prototype	Gujarati	20.94	20.00	15.05

The reduction in workload suggests that drivers required less mental effort when interacting with the research prototype. This aligns with observations during testing, where participants interacted more fluidly with the research prototype interface.

Inferential Results: To determine whether the observed differences were statistically meaningful, Wilcoxon Signed-Rank tests were conducted for pairwise comparison (Table 6.16). In Step 1, the control and the research prototype-English were compared. Step 2 compares the improved result with Research Prototype-Gujarati.

Step 1: Control vs. Research Prototype–English A Wilcoxon Signed-Rank test showed a statistically significant reduction in mental effort when using the Research Prototype–English dashboard compared to the existing Control system. This indicates that the redesigned structure helped perceived reduction in cognitive load during interaction.

Step 2: Research Prototype–English vs. Research Prototype–Gujarati A second Wilcoxon comparison examined whether language affected mental effort. A marginally difference was found between the English and Gujarati versions. This suggests that the reduced workload is a result of the redesigned interface rather than language format.

Table 6.16: Results of Wilcoxon signed-rank tests comparing RSME workload scores across dashboard conditions ($N = 32$) (Source: Author, 2025).

Comparison	**Wilcoxon** Z	p	r
Control vs Research Prototype–English	-2.600	.009	.46
Research Prototype–English vs Research Prototype–Gujarati	-0.120	.907	.02

$p < .01$ after Bonferroni adjustment.

Figure 6.11 illustrates the pattern: scores for the Control system are higher and more variable, while both research prototype versions cluster at the lower end of the scale. This confirms that participants consistently required less effort when using the redesigned dashboard.

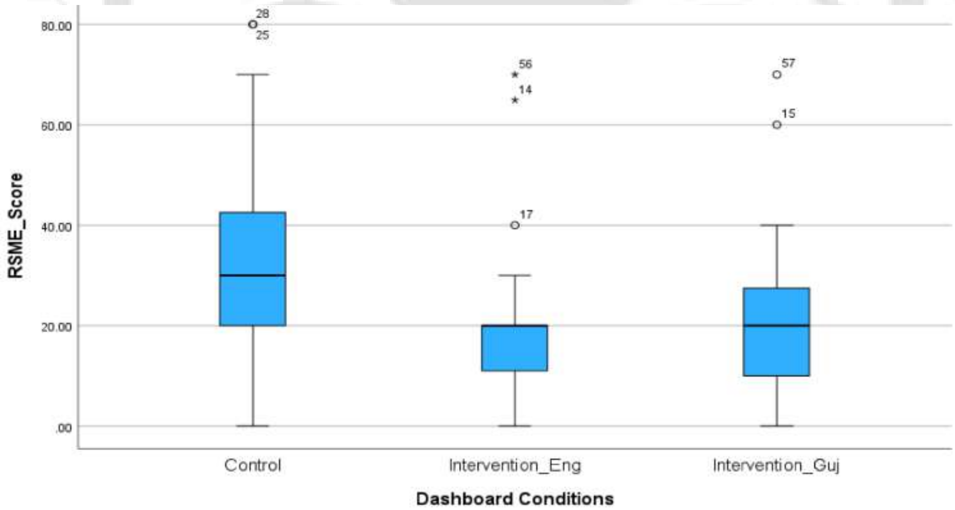

Figure 6.11: Distribution of Rating Scale Mental Effort (RSME) workload scores across dashboard versions (Source: Author, 2025).

6.4.3.12 Acceptance

Acceptance was measured using the Van der Laan Acceptance Scale, which captures perceived *usefulness* and *satisfaction*. Following established use of the scale, both sub-dimensions were averaged into a single composite acceptance score, where higher values indicate stronger acceptance of the dashboard.

Normality Test: Shapiro–Wilk tests confirmed that acceptance scores were not normally distributed for any condition (Table 6.17). Consistent with earlier measures, non-parametric analyses were therefore applied.

Table 6.17: Results of the Shapiro–Wilk normality test for acceptance scores across dashboard conditions ($N = 32$) (Source: Author, 2025).

Condition	**Version**	**Shapiro–Wilk (p)**
Control		<.001
Research Prototype	English	<.001
Research Prototype	Gujarati	<.001

Descriptive Summary: Table 6.18 summarizes acceptance ratings across the dashboard versions. Scores for the research prototype (both English and Gujarati) are substantially higher than those of the existing Control dashboard.

Table 6.18: Descriptive statistics of acceptance ratings across dashboard conditions ($N = 32$) (Source: Author, 2025).

Condition	**Version**	**Mean**	**Median**	**SD**
Control		0.43	0.78	1.08
Research Prototype	English	1.56	2.00	0.81
Research Prototype	Gujarati	1.65	2.00	0.79

The descriptive pattern shows that drivers expressed noticeably higher acceptance toward the research prototype. The shift reflects a move from mild to strong acceptance when compared to the existing system.

Inferential Results:

Step 1: Control vs. Research Prototype–English A Wilcoxon Signed-Rank test revealed a statistically significant increase in acceptance for the Research Prototype–English dashboard relative to the existing Control system. This indicates that the redesigned interface was not only easier to use but also perceived as more useful and satisfying.

Step 2: Research Prototype–English vs. Research Prototype–Gujarati A second Wilcoxon comparison tested whether language influenced acceptance. No statistically meaningful difference was found between the English and Gujarati versions. This suggests that stronger acceptance was driven by the research prototype itself rather than the interface language.

Table 6.19: Results of Wilcoxon signed-rank tests comparing acceptance ratings across dashboard conditions ($N = 32$) (Source: Author, 2025).

Comparison	**Wilcoxon** Z	p	r
Control vs Research Prototype–English	-3.630	$<.001^*$	.64
Research Prototype–English vs Research Prototype–Gujarati	-0.700	.482	.12

$^*p < .001$ after Bonferroni adjustment.

Figure 6.12 shows the distribution pattern. Acceptance scores for the control system vary widely and include negative responses, whereas both research prototype versions show consistently high ratings clustered near the top of the scale.

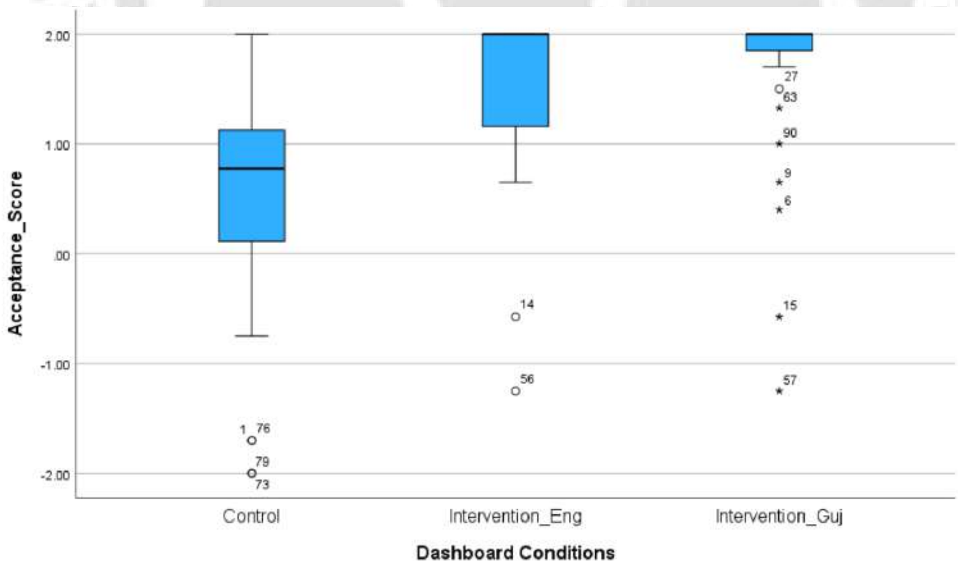

Figure 6.12: Distribution of acceptance ratings across dashboard versions (Source: Author, 2025).

6.4.3.13 Driver Preferences and Qualitative Insights

The qualitative data were analyzed and organized into six themes, offering additional context to the quantitative results. These themes help explain *why* drivers responded positively to the research prototype and provide insight into factors influencing usability, trust, and long-term adoption.

Dashboard Usability: A More Unified and Modern Experience Most drivers described the research prototype as significantly easier to operate compared to the existing system. They appreciated having key functions integrated into a single display, eliminating the need to shift attention between the instrument cluster, DDU, and physical switches.

> "The old system had buttons all over the place. This new one is like a mobile phone – everything is in one place and easier to find."

> "Earlier, I had to look at different screens for battery, alerts, and speed. Now it's all in one display. It feels modern and less tiring."

These comments reinforce the SEQ and SUS results showing improved ease of use and usability for the research prototype.

Language and Localization: Familiarity Builds Confidence While quantitative comparisons showed no statistical difference between English and Gujarati versions in task performance, qualitative responses revealed that language influenced comfort, confidence, and trust.

A clear majority of participants (29 out of 32) preferred the research prototype over the control dashboard. Among those who preferred the research prototype, language preferences were evenly distributed: 13 favored the English version, 12 favored the Gujarati version, and 4 expressed no strong preference, indicating equal acceptance of both versions (Figure 6.13).

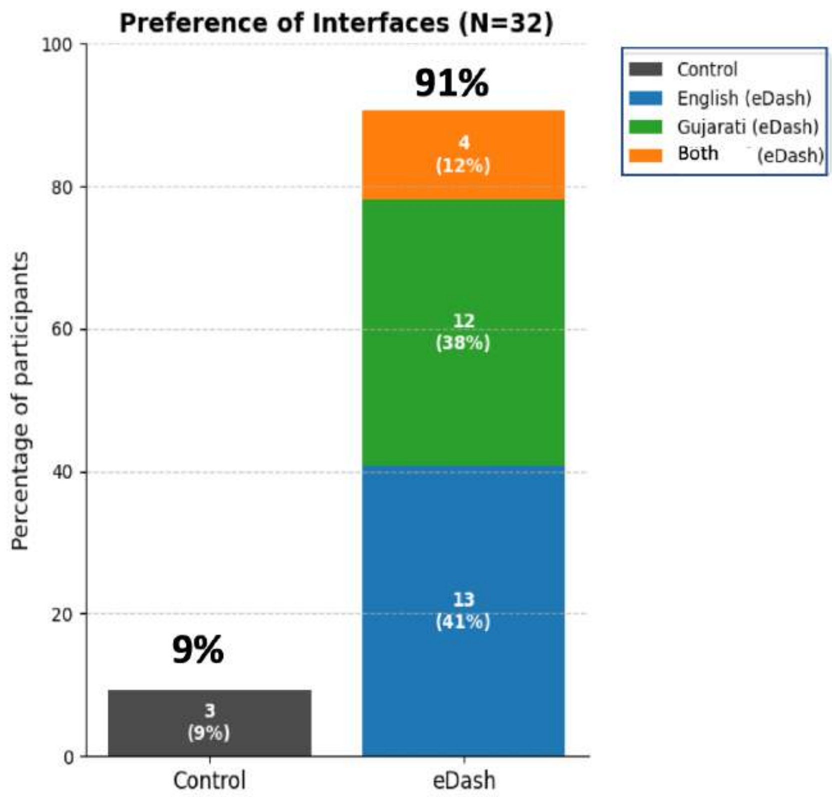

Figure 6.13: Participants' preferences for dashboard interface versions (Source: Author, 2025).

Drivers explained that localized messaging made alerts easier to interpret and reduced hesitation, especially during time-sensitive actions.

> "Reading in Gujarati felt more natural. When an alert appears, I understand it instantly. That makes me trust it more."

Localization, therefore, plays a role not in performance but in emotional engagement, confidence, and acceptance.

Design Refinements: Readability and Interaction Drivers also provided specific feedback on visual layout and interaction patterns, particularly regarding font size, touch area size, and responsiveness during motion.

> "The touch buttons should be bigger. While driving, especially on rough roads, it's hard to press accurately."

> "I would like to move important information like speed or battery to a more visible place. Alerts should flash or be brighter."

These comments indicate the need for adaptive UI elements and personalization features in future iterations.

Training and Familiarization Multiple drivers noted that although the research prototype was intuitive, structured training would support confidence, reduce errors, and standardize usage across the fleet.

> "Even if it is simple, proper training is needed. It removes doubt and helps understand what to do in different situations."

Training was seen not only as technical onboarding but as a mechanism for organizational trust building.

Future Opportunities: Connected and Assistive Features Finally, drivers expressed interest in additional smart features that could further reduce workload and improve operational efficiency.

> "If the dashboard could show navigation or traffic updates, it would be very useful. Then we don't need to check phones."

> "Voice commands in Gujarati would be great. It would be hands-free and safer while driving."

These suggestions indicate openness to advanced features, such as real-time data integration and multimodal interaction, provided they are designed to support workflows rather than disrupt them.

6.4.4 Cognitive Walkthrough Evaluation

Following the driver usability testing phase, a cognitive walkthrough (CW) was conducted to evaluate first-time learnability from an expert inspection perspective. Unlike the driver study, this method does not represent actual driver behavior but identifies potential learnability issues in the interaction flow. These findings are therefore complementary to, but distinct from, the results of the driver-based usability testing.

6.4.4.1 Participant Selection

Eight participants ($N = 8$, mean age = 39.5 years) were recruited for the cognitive walkthrough study, comprising four males and four females (see details in Table 6.20). The participant group represented a range of design and system-oriented expertise, including UI/UX design, interaction design, visual communication, design thinking, and transport-styling design. Professional experience ranged from 6 to 14 years ($M = 10.4$ years), indicating a cohort of experienced practitioners. None of the participants had prior exposure to the research prototype.

Table 6.20: Demographic profile of participants involved in the cognitive walkthrough study (Source: Author, 2025).

Participant ID	Gender	Education	Expertise / Professional Background	Experience (Years)
CW01	Male	MDes	Transport Styling (Tata Motors)	9
CW02	Female	MDes	UX / Interaction Design (Myntra)	10
CW03	Female	MDes	UI / UX Design (Myntra)	11
CW04	Male	MDes	Visual Design (Mixed Industry Exp)	14
CW05	Male	PhD	Communication Design (Industry + Teaching)	13
CW06	Male	MDes	UI / UX Design (Independent Practice)	6
CW07	Female	MDes	Design / HCI (Academic Teaching)	8
CW08	Female	MDes	Design Thinking (Infosys)	12

6.4.4.2 Method

The cognitive walkthrough was structured using a Hierarchical Task Analysis (HTA) derived from earlier user research and driver task workflows. Thirteen representative tasks were defined, corresponding to pre-trip, in-trip, and post-trip activities. Each task was decomposed into sequential sub-steps reflecting the intended interaction flow within the dashboard interface. Each sub-step was evaluated using the four standard cognitive walkthrough questions: (A) goal formation, (B) action visibility, (C) action–effect mapping, and (D) feedback and progress.

All evaluations were recorded using binary Yes/No judgments. A "No" response indicated a potential learnability breakdown and was used to identify usability issues at the interaction level.

6.4.4.3 Procedure

The cognitive walkthrough followed a structured expert inspection protocol. Each participant completed the evaluation individually using the high-fidelity research prototype in a controlled setting. At the beginning of each session, participants were briefed about the study and instructed to evaluate the interface from the perspective of a first-time user. A short familiarization was provided to ensure comfort with the interaction medium.

Participants were then given thirteen scenario-based tasks representing pre-trip, in-trip, and post-trip activities. Tasks were presented sequentially using predefined task cards. For each task, participants progressed through the interaction steps while the evaluator recorded their responses. No guidance or corrective feedback was provided during task execution to ensure that the evaluation reflected first-time interaction behavior. Each session lasted approximately 30–40 minutes, and all participants completed the walkthrough independently to avoid bias.

6.4.4.4 Data Collection

Data were collected using a structured cognitive walkthrough worksheet designed to capture responses at the task and sub-step levels. For each sub-step, participant evaluations (Yes/No) were recorded for all four cognitive walkthrough questions (A–D). Whenever a "No" response occurred, detailed observations were documented, including failure stories and identified usability problems. All data were recorded individually for each participant using a standardized template. This ensured consistent documentation of both quantitative responses and qualitative insights across all sessions.

6.4.4.5 Data Analysis

The cognitive walkthrough data were analyzed using a structured multi-level approach. At the first level, participant responses were recorded at the sub-step level for each task, where each interaction step was evaluated using the four cognitive walkthrough questions (A–D). Each question was assessed using a binary Yes/No judgment. A “No” response indicated a potential breakdown in learnability and was accompanied by a failure story and a usability observation. At the second level, sub-step evaluations were examined to identify breakdowns within each task. A task was considered to exhibit a learnability issue if one or more of its sub-steps received a “No” response for any of the four CW questions. At the third level, results were aggregated across participants. The frequency of breakdowns for each task was calculated (e.g., No = 3/8), allowing identification of recurring usability issues and their relative severity. Finally, qualitative failure stories recorded during the walkthrough were analyzed and synthesized to interpret the nature of interaction difficulties. These narratives were used to identify common usability problem types, such as issues related to discoverability, action–effect mapping, and feedback clarity. This multi-stage analysis ensured traceability from individual interaction breakdowns to consolidated task-level insights and design implications.

6.4.4.6 Findings

Table 6.21 presents the findings of the Cognitive Walkthrough (CW) conducted with eight expert participants to assess the learnability of the research prototype. Each task was evaluated using the four standard CW questions (A–D), corresponding to goal understanding, action discoverability, action–effect mapping, and feedback clarity. In the table, successful interactions are left implicit (–), while learnability breakdowns are explicitly reported as “No (x/8)”, where "x" denotes the number of participants who experienced difficulty during first-time interaction. Failure narratives are included only when a breakdown was observed.

Figure 6.14: Photograph of a participant engaged in the cognitive walkthrough study (Source: Author's fieldwork, 2025).

Table 6.21: Cognitive walkthrough analysis results summarizing task-level breakdowns and failure stories (N = 8) (Source: Author, 2025).

Task ID	A	B	C	D	Failure Story (reported only for No)
T1	–	–	–	–	–
T2	–	–	–	No (1/8)	Time information was visible, but the text size was too small for quick confirmation, requiring additional visual effort.
T3	–	No (1/8)	–	–	Battery status lacked visual dominance and was not immediately noticeable at first glance.
T4	–	No (2/8)	No (3/8)	No (2/8)	Participants struggled to locate AC controls, interpret icons (snowflake/circular control), and confirm temperature settings. ON/OFF and adjustment mapping were unclear.
T5	–	–	–	No (1/8)	Camera feedback did not clearly confirm door closure; clearer visual confirmation of door status was expected.

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Task ID	A	B	C	D	Failure Story (reported only for No)
T6	–	No (1/8)	No (1/8)	–	The bus status icon was misinterpreted as a navigation or map alert due to symbol similarity, delaying the discovery of system errors.
T7	–	–	–	No (1/8)	After destination selection, the system did not clearly indicate the start of navigation; stronger visual confirmation was expected.
T8	–	–	–	No (1/8)	Overspeed alert lacked strong urgency cues and explicit action guidance during driving.
T9	–	–	–	No (1/8)	Alert reporting involved multiple steps and weak confirmation feedback, increasing cognitive load during driving.
T10	–	–	–	–	–
T11	–	No (3/8)	–	No (3/8)	The trip summary was not discoverable on the first attempt and required prior exposure; the text size also reduced readability.
T12	–	No (1/8)	–	–	The performance report entry point was not obvious initially and required exploration.
T13	–	No (3/8)	No (3/8)	–	Maintenance reporting was incorrectly associated with performance or bus status views, indicating a mental model mismatch.

Across all thirteen tasks, no learnability breakdowns were recorded for CW–A, indicating that participants consistently understood the intended task goals. This suggests that the dashboard communicates task intent effectively and that, when present, learnability issues are not related to goal comprehension but arise at the level of interface interaction.

Several tasks demonstrated strong first-time learnability, with no breakdowns across any CW dimensions. In particular, checking air pressure (T1) and setting the drive mode to depot (T10) were completed without difficulty by all participants, reflecting clear visibility of controls, intuitive action–effect relationships, and unambiguous feedback.

Isolated learnability breakdowns were observed in a number of tasks and were typically reported by a single participant. These include checking date and time (T2), checking state of charge (T3), verifying door status via the camera (T5), setting the route (T7), interpreting overspeed alerts (T8), reporting alerts to the depot (T9), and accessing the performance report (T12). In these cases, difficulties were primarily related to reduced visual salience, small text size, or weak confirmation feedback, rather than misunderstanding of the task itself.

A small set of tasks involving control interactions and post-trip workflows revealed opportunities to improve clarity in first-time interactions. In particular, setting the AC temperature (T4) showed learnability gaps related to discoverability (CW–B), action–effect mapping (CW–C), and feedback clarity (CW–D), suggesting that clearer control cues, more explicit icon semantics, and stronger confirmation feedback could further support intuitive use. Viewing the trip summary (T11) also highlighted areas for refinement: several participants required additional exploration to discover the feature and recognize successful access, and text readability influenced initial comprehension. Similarly, notifying the depot for maintenance (T13) indicated scope for improving alignment between the system's information organization and users' mental models of post-trip reporting. Overall, these findings point to targeted interface refinements that can further enhance learnability without altering core functionality.

6.4.5 Design–Evaluation Mapping and Synthesis

To consolidate the findings of this chapter, a structured mapping was developed linking the key usability problems identified in earlier stages (Chapter 5 and heuristic/CW evaluations), the corresponding design interventions implemented in the research prototype, and the observed evaluation outcomes from the field study.

Unlike earlier traceability tables that focus on design rationale, this synthesis integrates results across all evaluation stages to demonstrate the effectiveness of the user-centered design process and to establish a clear design–evaluation feedback loop.

Table 6.22: Consolidated mapping of usability problems, design interventions, and evaluation outcomes (Source: Author, 2025)

Usability Problem	**Design Intervention**	**Evaluation Outcome**
Difficulty interpreting faults and system status	Simplified diagnostics, color-coded alerts, and system status indicators	Significant improvement in perceived usability (SUS: 58.13 $\rightarrow$ 88.98) and clearer system understanding reported by drivers
Poor visibility and readability	High-contrast interface, large typography, centralized layout	Reduced mental workload (RSME: 33.59 $\rightarrow$ 20.84) and more consistent task performance
Missed or ignored alerts	Multimodal alerts, prioritization, and auto-clear logic	Improved task response and higher acceptance ratings across participants
High cognitive load during interaction	Workflow simplification, automation, and reduced interaction steps	Lower perceived effort and smoother task completion across conditions
Inconsistent iconography and unclear affordances	Standardized icons and improved labeling	Reduced confusion and improved recognition, reflected in higher usability scores
Low discoverability of features (CW findings)	Improved navigation structure and clearer entry points	Reduced learnability breakdowns and improved first-time interaction performance

The mapping demonstrates that the major usability challenges identified through empirical research and expert evaluation were systematically addressed through targeted design interventions. These improvements are consistently reflected across multiple evaluation measures, including perceived usability (SUS), task ease (SEQ), mental workload (RSME), and system acceptance.

Importantly, the results indicate that the observed improvements are primarily driven by the redesigned interaction structure and interface organization, rather than surface-level changes such as language variation. The cognitive walkthrough further supports these findings by confirming that task goals were consistently well understood, with remaining challenges limited to specific interaction-level refinements.

Overall, this synthesis establishes a clear and traceable link between problem identification, design response, and empirical validation, thereby demonstrating the effectiveness of the iterative user-centered design process adopted in this research.

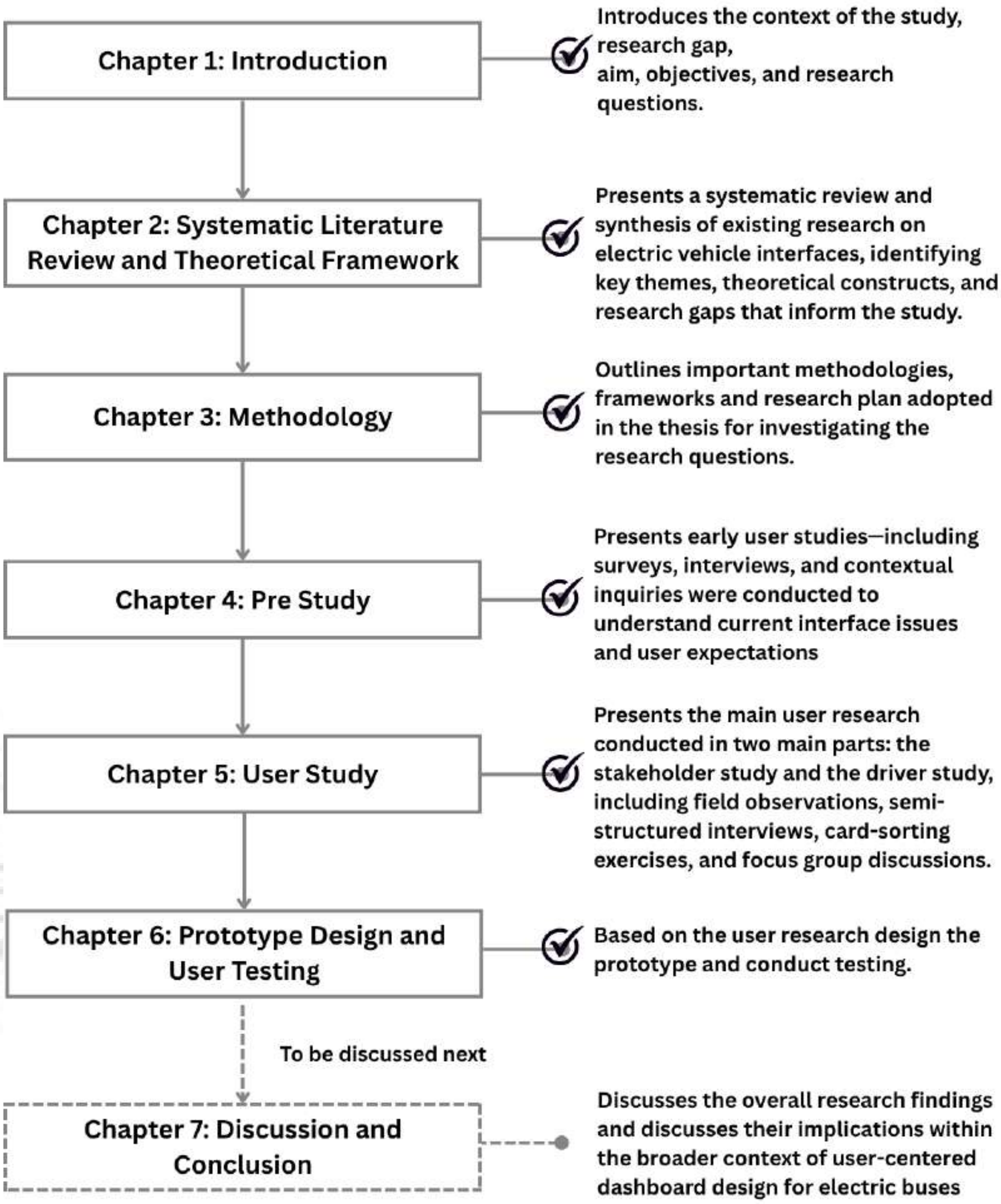
6.5 Chapter Summary

This chapter described the refinement and evaluation of the research prototype through a staged, user-centered process. The research prototype evolved iteratively based on insights from expert review, heuristic evaluation, pilot testing, and a cognitive walkthrough study, ensuring both usability and learnability were systematically addressed. Across the early evaluation stages, 27 usability issues were identified and resolved, leading to improvements in information hierarchy, interaction flow, visual clarity, and alert communication. The refined research prototype incorporated consolidated modules such as Home, Route, Drive Mode, AC Control, Bus Status, Camera, Diagnostics, and Reporting, designed to support operational workflows while reducing visual scanning and cognitive effort.

Following the refinement phase, a field-based user study was conducted with professional e-bus drivers to assess the redesigned dashboard in comparison to the existing system. Two research prototype language versions (English and Gujarati) were included to examine whether interface language influenced usability outcomes. Participants completed a controlled scenario covering routine pre-trip tasks as well as newly introduced in-trip and post-trip functions. Results from four standardized measures: the Single Ease Question (SEQ), System Usability Scale (SUS), Rating Scale Mental Effort (RSME), and Van der Laan Acceptance Scale. The research prototype achieved higher perceived usability, reduced mental workload, and greater acceptance. No statistically meaningful differences were observed between the English and Gujarati versions, indicating that the gains were primarily driven by interface redesign rather than language alone. Qualitative feedback, however, highlighted language familiarity as an important factor influencing confidence, comfort, and long-term adoption.

In addition to driver-based evaluation, a cognitive walkthrough was conducted with expert participants to examine the learnability of the final research prototype from a first-time use perspective. This analysis focused on key pre-trip, in-trip, and post-trip tasks and systematically assessed goal understanding, action discoverability, action–effect mapping, and feedback clarity. The cognitive walkthrough results indicated that task goals were consistently well understood across all evaluated scenarios, confirming the conceptual clarity of the interface. Learnability challenges, where identified, were primarily associated with control-heavy interactions and post-trip reporting workflows, highlighting opportunities for further refinement in visual hierarchy, icon semantics, and feedback cues. Importantly, these findings complemented the driver usability results by validating that the redesigned dashboard not only performed well in use but also supported intuitive first-time interaction.

A visual summary of the chapters covered so far is presented as follows:



Chapter 1: Introduction
Introduces the context of the study, research gap, aim, objectives, and research questions.
Chapter 2: Systematic Literature Review and Theoretical Framework
Presents a systematic review and synthesis of existing research on electric vehicle interfaces, identifying key themes, theoretical constructs, and research gaps that inform the study.
Chapter 3: Methodology
Outlines important methodologies, frameworks and research plan adopted in the thesis for investigating the research questions.
Chapter 4: Pre Study
Presents early user studies—including surveys, interviews, and contextual inquiries were conducted to understand current interface issues and user expectations
Chapter 5: User Study
Presents the main user research conducted in two main parts: the stakeholder study and the driver study, including field observations, semi-structured interviews, card-sorting exercises, and focus group discussions.
Chapter 6: Prototype Design and User Testing
Based on the user research design the prototype and conduct testing.
To be discussed next
Chapter 7: Discussion and Conclusion
Discusses the overall research findings and discusses their implications within the broader context of user-centered dashboard design for electric buses

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Chapter 7

Discussion and Conclusion

This chapter presents an integrated discussion of the research findings and reflects on their implications for the design of digital dashboards in e-buses within the Indian public transport context. The chapter interprets results from the evaluation study in relation to existing literature, connecting empirical outcomes to broader themes in HCI, transport ergonomics, and multilingual interface design. It further consolidates the key contributions emerging from this work and highlights how the redesigned dashboard advances current understanding of usability, workload reduction, and contextual adaptation in operational driving environments.

In addition to interpreting the findings, this chapter highlights the theoretical and practical contributions. These include the development of a user-centered prototype and a set of strategies specifically designed for real-world e-bus operations. The study acknowledges its limitations in defining applicability and areas needing further inquiry. In conclusion, the chapter suggests future research and development directions, focusing on longitudinal evaluation, multimodal interfaces, and real-time system integration to facilitate large-scale deployment in public e-bus systems.

7.1 Discussion

The findings of this study are discussed in relation to the research questions established at the beginning of the thesis. Each question framed a stage of inquiry, progressing from understanding the present landscape to evaluating the redesigned prototype.

RQ1: What are the prevailing practices and limitations in driver-facing dashboard interfaces of electric city buses? Analysis of existing dashboard systems indicates that e-bus cockpits in India predominantly follow an incremental adaptation approach rather than purpose-built electric-vehicle interface configurations. Current layouts are derived from conventional diesel bus dashboards and comprise multiple independent subsystems, including an analog-dominant instrument cluster, a government-mandated Driver Display Unit (DDU), isolated switch panels, and additional auxiliary controls. Similar subsystem-based cockpit structures have been documented in public transport and heavy-vehicle interface studies, where legacy layouts persist during technology transitions (Chang and Gunasekara, 2013; Mandujano-Granillo et al., 2024).

At the system level, these prevailing practices exhibit structural limitations in information organization and integration. Electric-specific parameters such as battery state, distance-to-empty, and thermal diagnostics are inconsistently distributed across displays, with limited coordination or prioritization. Prior research has shown that legacy fuel-gauge metaphors and add-on digital displays are inadequate for supporting electric-vehicle energy reasoning and system awareness (Gödker et al., 2018; Lundström and Bogdan, 2017). Stakeholder interviews conducted as part of this study further indicated the absence of adaptive alert hierarchy and context-aware visibility, reinforcing findings from bus and heavy-vehicle HMI research that emphasize the need for prioritized, readable, and safety-linked display logic in high-load operational environments (Schwambach Costa, 2020; Jiang et al., 2021).

Taken together, these findings indicate that existing dashboard practices in electric city buses represent a transitional phase. While technically functional and compliant with regulatory requirements, current configurations remain fragmented, non-standardised, and insufficiently integrated to support the informational structure demanded by e-bus operation. These observations characterise prevailing design practices and architectural choices at the system level, rather than driver-experienced usability challenges, which are examined in subsequent sections.

While RQ1 characterizes the structural configuration of existing dashboards, RQ2 shifts focus to how these configurations are experienced by drivers during real-world operation.

RQ2: What usability and workflow-related challenges do professional e-bus drivers experience when interacting with existing dashboard interfaces during operation? To address this research question, we conducted two user studies named the stakeholder study and the driver field study. We analyzed the studies in the KJ severity analysis (see Section 5.5). Together, these data sources helped us move from individual anecdotes to a structured picture of the main usability problems in current electric-bus dashboards and workflows.

We first observed that drivers operate in a highly demanding visual environment. During contextual inquiry, we saw drivers constantly shifting attention between three separate visual zones: the analog instrument cluster, the LCD diagnostic screen, and the Driver Display Unit (DDU). Many participants leaned forward or changed posture to read small text or interpret needles, especially under glare or bright daylight. Interview responses and severity ratings confirmed that *Layout and Visibility* is a critical problem: information is technically available but not always legible in real driving posture. This matches our KJ cluster results, where Layout and Visibility and Safety and Oversight were rated with the highest severity scores (4/4), and it echoes earlier findings that poor display ergonomics and multi-display layouts increase visual demand and cognitive load in public transport interfaces (Chang and Gunasekara, 2013; Nilsson and Olsson, 2014; Mayas et al., 2014; Harvey and Stanton, 2013).

We also found that drivers face a continuous tension between monitoring energy, thermal safety, and mechanical status. Every driver reported State of Charge (SOC) as their primary reference, followed closely by battery and coolant temperature, air pressure, and critical telltales. Card-sorting and importance ratings showed that sixteen parameters (e.g., SOC, DTE, temperatures, air pressure, route, alerts) were unanimously rated as "absolutely essential" for day-to-day operation. However, these parameters are spread across multiple displays and screens. In practice, drivers cope by scanning sequentially at signals or stops, or by relying on sound and vehicle "feel" when cognitive load is high. This aligns with earlier EV research, where drivers depend on a small set of range and safety related indicators but struggle when information is fragmented or difficult to interpret (Lundström and Bogdan, 2012; Lundström, 2014; Gödker et al., 2018;

Stahl et al., 2020).

Diagnostic communication emerged as another major usability challenge. We saw that drivers usually detect faults through a combination of color-coded symbols, chime sounds, and diagnostic messages, but only about one-third described the diagnostic system as "highly effective." Many reported that fault messages appear late, are vague, or are written in technical English. As a result, drivers often take photographs of the dashboard and send them via WhatsApp to supervisors or technicians for interpretation. Our KJ analysis captured this under the clusters *Diagnostic Clarity* and *Contextual Feedback*, both of which received high severity scores. Stakeholders in the depot focus groups confirmed that this informal workflow leads to delays, confusion about which bus reported which issue, and additional stress during breakdowns. These patterns are consistent with prior work showing that unclear fault feedback and weak integration between vehicle and depot systems create extra workload and safety risks in public transport operations (Astrain et al., 2021; Jönsson and Nilsson, 2019; Gödker et al., 2018).

Language and comprehension formed a further layer of difficulty. While all drivers were comfortable in Gujarati and Hindi, a majority reported limited comfort with English diagnostic text. They could often read the letters but not interpret the meaning, especially for technical terms such as "HV battery fault" or "motor error." In these situations, drivers depended again on color, position, and sound rather than message content, or they escalated the issue to supervisors. Our findings are consistent with stakeholder concerns about localization and with cross-cultural HCI work showing that language primarily influences trust, comfort, and emotional response rather than raw performance, but that this becomes critical in safety-related contexts (Hassenzahl, 2010; Oyugi et al., 2008; Boadi-Kusi et al., 2023; Le et al., 2023). In our severity evaluation, localization and language received a "major problem" rating (3/4), reinforcing that English-only messaging is a recurring barrier.

Stakeholder interviews added a system-level perspective to these driver-centered challenges. OEM and depot stakeholders repeatedly argued for larger TFT-based displays, integrated consoles, and centralized ADAS feedback, while at the same time insisting that safety-critical controls (e.g., emergency, isolators, fire system) must remain physical and independent of the touchscreen. They described the current cockpit as fragmented: route, ITS, HVAC, and diagnostic functions are distributed across different units, forcing drivers to "look in many places" and increasing the risk of missed alerts. These concerns directly tie to the KJ clusters of Safety and Oversight and Interaction and Touch Usability, and they align with earlier heavy-vehicle research that recommends integration of information with a clear alert hierarchy while retaining redundant physical access for safety functions (François et al., 2019; TCR, 2016; Board, 1997; Jiang et al., 2021).

Quantitatively, these qualitative findings were supported by baseline usability scores. The existing dashboard received a median SUS score in the "poor to marginal" range and was associated with higher perceived mental effort in our RSME ratings, confirming that drivers experience the current interface as effortful and fragmented. When triangulated with observation and interview data, this suggests that the core usability challenges do not come from a complete absence of information, but from the way information is distributed, timed, and communicated across the ecosystem of displays, controls, and depot workflows. Similar patterns have been reported in other automotive HMI studies, where ecosystem-level fragmentation leads to increased workload despite nominal information availability (Harvey and Stanton, 2013; François et al., 2021).

In summary, we state that drivers face four interrelated usability challenges in the current system: (1) high visual and cognitive workload due to multi-display monitoring and suboptimal visibility; (2) limited diagnostic clarity and delayed or vague fault feedback; (3) language and comprehension barriers for English-only messages; and (4) fragmented reporting and communication workflows that rely on external tools such as mobile phones. These challenges are rooted not only in dashboard layout but in the wider ecosystem of interfaces and organizational practices that surround the driver.

Building on the identified challenges, the next step was to determine what information and interaction support drivers are required to address these gaps in real-world operations.

RQ3: What information requirements and interaction needs are necessary to support drivers across key operational phases of an e-bus trip? To answer this research question, we synthesized findings from contextual inquiry, stakeholder interviews, driver focus groups, and affinity clustering. These methods helped uncover what information drivers actively rely on during operation and which gaps in existing dashboards create uncertainty, delays, or safety concerns. The resulting requirements reflect both functional and cognitive needs of professional drivers operating in a public transport environment. These requirements span key operational phases of e-bus operation, including pre-trip preparation, in-trip driving and monitoring, and post-trip reporting and fault handling.

Based on the analysis, five essential information categories emerged:

1. Real-time vehicle state: Drivers consistently prioritised information that supports situational awareness while driving—speed, State of Charge (SoC), distance-to-empty, thermal conditions, and brake/air pressure. This aligns with findings by Neumann and Krems (2016) and Gödker et al. (2024), who emphasized that energy-related feedback and clear powertrain indicators are central to decision-making in EVs.

2. Trip and operational context: Route identification, stop progress, expected arrival/departure timing, and operational status were critical for schedule adherence and passenger management. Similar requirements have been documented in public-transport HMI studies by Chang and Gunasekara (2013), where temporal and route context reduced cognitive workload and uncertainty.

3. Alert hierarchy and diagnostic clarity: Drivers stressed the need for clear, interpretable alerts with distinct urgency levels. This reflects findings from François et al. (2019) and industry standards (TCRP 185, 2016), which recommend progressively layered alerts to minimise confusion and promote rapid response in safety-critical contexts. Our findings that drivers prioritized State of Charge, range estimation, and energy-related feedback align with Lundström and Bogdan (2017), who argue that EV dashboards must empower drivers by making range-influencing factors transparent and trustworthy, rather than relying on ambiguous or fluctuating indicators.

4. Vehicle control and operational systems: Drivers indicated the need for clear access to operational controls related to HVAC, doors, interior lighting, drive mode, and auxiliary systems. Prior work by Strömberg and Karlsson (2011) and Row and Kim (2016) suggests that centralising frequently used operational controls improves task flow and reduces interaction cost.

5. Communication, documentation, and reporting: Drivers identified structured fault reporting, maintenance logs, and depot communication as essential for operational continuity. Similar insights were reported by Harvey and Stanton (2013) and Boadi-Kusi et al. (2023), who highlight that communication workflows in professional transport systems must be embedded directly in the interface rather than external or paper-based.

Across all information categories, participants also emphasized the importance of localized language support, not necessarily for task execution but for confidence and error handling—echoing cross-cultural HCI findings by Oyugi et al. (2008) and Le et al. (2023).

Having identified the key challenges (RQ2) and corresponding requirements (RQ3), RQ4 evaluates whether the redesigned dashboard effectively addresses these issues with respect to usability, workload, and acceptance.

RQ4: How do empirically examined alternative dashboard interaction and information organization configurations influence usability, mental workload, and acceptance among professional e-bus drivers? To address this research question, we adopted the usability and acceptance evaluation framework proposed by François et al. (2021). We selected this framework because it is well suited to capturing the perceptions, expectations, and experiential judgments of professional drivers.

Our statistical results show a clear performance shift in favor of the redesigned dashboard prototype. The System Usability Scale (SUS) scores reached the "Excellent" range for both versions of the prototype, indicating that drivers perceived the interface as easier to use and better aligned with their operational needs. The Single Ease Question (SEQ) scores also confirmed that drivers found both routine pre-trip tasks and the newly introduced workflows easier to complete. This suggests that the redesigned structure supported familiar actions while also enabling intuitive learning of new functions. The reduction in mental effort measured through the RSME scale reinforces this finding, showing that the consolidated layout lowered visual scanning effort, reduced uncertainty in decision-making, and decreased overall cognitive load. The redesigned dashboard also eliminated the need for drivers to lean forward or adjust posture to read critical information, as key parameters were made clearly visible within the primary line of sight. This improved glanceability and reduced physical strain during operation. The acceptance ratings further indicated strong perceived usefulness and a clear willingness among drivers to adopt the redesigned system in operational contexts. Similar findings in usability after dashboard redesigns have been reported in earlier electric-vehicle HMI studies. Strömberg and Karlsson (2011) and Nilsson and Olsson (2014) observed that unified layouts and EV-specific feedback improved comprehension and task performance in simulated driving environments. Similarly, Chang and Gunasekara (2013) found that reorganizing information flows in public transport driver systems improved interaction efficiency and increased driver confidence. The reduced cognitive workload in our findings aligns with François et al. (2019), who demonstrated that simplified information density and consistent visual structure helped reduce mental effort in heavy-vehicle displays. The strong acceptance scores in this study also reflect patterns reported by Lundström and Bogdan (2014) and Gödker et al. (2018), who noted that professional drivers are more willing to transition to digital systems when the interface enhances situational clarity and minimizes uncertainty rather than adding complexity.

In our results, acceptance scores showed a similar positive shift, reflecting not only improved task performance but also a meaningful increase in perceived usefulness and willingness to adopt the redesigned interface. What stood out to us was that the newly introduced features such as integrated fault reporting, trip summaries, and structured diagnostic alerts received some of the highest ratings. These elements were completely absent in the existing system, yet drivers were able to use them with almost no confusion or additional effort. This suggests that our design aligned well with their existing mental models and workflow patterns rather than forcing behavior change or adding unnecessary complexity. This aligns with earlier research in heavy-vehicle HMI design, where successful technological transition has been associated with systems that enhance established practices rather than replacing them abruptly (Andréasson and Boman, 2022; Jönsson and Nilsson, 2019; Harvey and Stanton, 2013).

One notable insight that emerged during our analysis was the effect of language on interaction experience. Statistically, we did not find significant differences between the English and Gujarati versions across any quantitative measure, including usability, workload, or ease of task completion. However, in the qualitative comments, drivers consistently shared that the localized Gujarati interface made them feel more confident, especially when handling alerts or unfamiliar system messages. This pattern resonates with findings from Boadi-Kusi et al. (2023) and Le et al. (2023), who reported that language localization contributes more to emotional trust and system acceptance than to performance metrics. Based on this, we interpret that no statistically significant differences were observed between language versions across quantitative measures.

The qualitative insights further reinforce the quantitative findings. Drivers consistently reported relief from fragmented workflows that previously required switching between the instrument cluster, physical switches, and the depot display. Their descriptions reflected reduced effort, increased clarity, and greater confidence when interacting with the redesigned dashboard. Similar patterns have been documented in previous bus cockpit usability studies, where interface consolidation and workflow-based structuring were shown to reduce perceived strain and improve task fluidity (TCR, 2016).

The findings from the cognitive walkthrough further strengthen this interpretation by addressing learnability from the perspective of first-time use. While the quantitative measures captured perceived usability, effort, and acceptance among experienced drivers, the CW analysis examined whether the redesigned dashboard could be understood and operated intuitively without prior training. The results indicated that task goals were consistently well understood across all evaluated scenarios, confirming the conceptual clarity of the interface. Learnability challenges, where observed, were limited to specific control interactions and post-trip reporting workflows, suggesting that the overall structure of the redesigned dashboard supports intuitive onboarding while leaving scope for targeted refinements in visual hierarchy, icon semantics, and feedback cues.

Taken together, our findings demonstrate that the redesigned dashboard prototype effectively addresses the usability and workflow limitations identified earlier in the study. The improvements observed across all four evaluation measures indicate that the prototype supports more efficient interaction, reduces mental effort, and is more acceptable to drivers compared to the existing system. In addition, the cognitive walkthrough results confirm that the redesigned interface supports strong learnability from a first-time use perspective, with task goals consistently understood and interaction breakdowns limited to a small number of control-heavy and post-trip scenarios. These results reinforce our conclusion that a user-centered redesign can yield measurable benefits in a professional driving context. Interaction level changes such as consolidating dispersed information, simplifying alert structures, aligning interface logic with real operational behavior, and supporting intuitive first-time interaction proved effective, even without major technological changes.

7.1.1 Derived Interaction and Information Organization Strategies for User-Centered E-Bus Dashboards

This research moves beyond interface evaluation to derive transferable design strategies for driver-facing e-bus dashboards. These strategies are grounded in field observations, usability evaluation, and qualitative analysis, and represent abstractions of recurring interaction principles addressing operational demands, cognitive constraints, and safety-critical requirements. Each strategy is linked to observed usability breakdowns or performance improvements and is intended to support applicability across similar public transport contexts. The term "strategies" is used here in an applied design sense; however, these should be understood as empirically derived and contextually grounded design directions rather than independently validated prescriptive solutions.

Strategy 1: Workflow-Aligned Information Structuring Dashboard information should be structured according to operational driving phases (pre-trip, in-trip, and post-trip) rather than being organized by underlying vehicle subsystems. Field observations and interviews revealed that drivers conceptualize their tasks sequentially based on operational workflow, not technical system boundaries. Usability testing demonstrated higher task ease and usability scores when information relevant to a specific driving phase was consolidated and presented within a coherent interaction flow. Cognitive walkthrough findings further indicated consistent goal understanding across tasks, suggesting alignment with drivers' mental models. This strategy emphasizes designing dashboards that reflect professional driving workflows to reduce cognitive switching and support efficient task execution.

Strategy 2: Persistent Visibility of Safety-Critical Parameters Safety-critical state variables such as vehicle speed, state of charge (SoC), driving range, air pressure, and system readiness should maintain persistent visibility without requiring navigational interaction. Driver prioritization exercises and task observations confirmed these parameters as continuously monitored during operation. The redesigned interface reduced mental workload by minimizing visual search and display switching, as reflected in lower RSME scores. Cognitive walkthrough failures related to visibility occurred only when parameters lacked sufficient visual prominence.

This strategy formalizes a visibility hierarchy tailored to public transport operations, extending existing EV dashboard research that is largely focused on private vehicle contexts.

Strategy 3: Progressive Diagnostic Disclosure with Action-Oriented Feedback Diagnostic and alert information should follow a progressive disclosure structure, moving from immediate status indication to explanation, recommended action, and reporting support. In existing systems, ambiguous alerts led drivers to seek clarification through external channels such as mobile messaging or depot communication, increasing cognitive load and operational delay. The integrated reporting and clearer feedback in the prototype interface resulted in higher acceptance ratings and reduced qualitative stress indicators. This strategy reframes diagnostics from interpretation-heavy displays to action-oriented interaction sequences that support timely decision-making in safety-critical environments.

Strategy 4: Localization as a Trust and Acceptance Symbol Interface localization should be treated as a symbol for building trust, confidence, and long-term acceptance rather than as a direct driver of performance improvement. Quantitative usability and workload measures showed no statistically significant differences between language versions of the prototype. However, qualitative feedback consistently highlighted greater comfort and confidence when alerts and messages were presented in the driver's preferred language, particularly during breakdown or time-critical scenarios. This strategy refines multilingual HCI perspectives by distinguishing between performance neutrality and emotional or experiential impact in professional transport systems.

Strategy 5: Retention of Operational Familiarity through Legacy-Aligned Interaction Logic Dashboard interfaces should retain recognisable analog–digital metaphors, control mappings, and interaction logic derived from legacy bus systems to support safe and confident transition to electric platforms. Field interviews and contextual inquiry revealed that professional bus drivers rely heavily on long-established conventions such as battery metaphors, left–right control associations, and procedural sequences formed through years of operational experience. Abrupt departures from these conventions increased hesitation, verification behavior, and reliance on trial-and-error during early use. Usability walkthroughs indicated fewer execution errors and faster task initiation when familiar representations and control logic were preserved, even when underlying systems were digitally restructured. This continuity reduced learning effort and mitigated transition-related risk without constraining innovation. The strategy formalizes a principle of progressive continuity, wherein novel EV-specific information is introduced within familiar interaction frameworks, ensuring that technological advancement does not undermine operational confidence or safety in public transport contexts.

Strategy 6: Minimisation of Interaction Complexity for High-Load Driving Environments Dashboard interaction should be deliberately simplified through the use of large touch targets, shallow navigation hierarchies, and predictable interaction patterns suited to safety-critical, high-workload driving conditions. Field observations and task analysis indicated that e-bus drivers interact with the interface under time pressure, vibration, traffic demands, and divided attention, making fine motor control and deep menu navigation error-prone. Usability walkthroughs revealed increased task completion time and higher hesitation rates when interactions required multiple navigation steps or precise touch input. Conversely, interfaces employing larger controls and flat structures supported faster access and reduced corrective actions. This strategy formalizes a principle of interaction economy, prioritising ease of execution and motor robustness over feature density, and reinforces established public-transport HMI practices that emphasise reliability and low cognitive demand during continuous vehicle operation.

Strategy 7: Learnability-Focused Design for Control-Intensive Interactions Control-intensive tasks, such as climate control adjustment, diagnostics access, and post-trip reporting, require enhanced learnability support through clearer affordances, explicit action–effect mapping, and strong feedback cues. While overall usability ratings for the prototype were high, cognitive walkthrough analysis identified isolated learnability breakdowns in these interaction-heavy tasks. These findings indicate that high usability does not necessarily guarantee intuitive first-time use. This strategy introduces learnability as a complementary design focus alongside usability, particularly for infrequently used but operationally critical functions in professional driving contexts.

To situate these strategies within established automotive HMI knowledge, Table 7.1 maps them to relevant principles and standards.

Table 7.1: Mapping of Derived Design Strategies to Automotive HMI Principles and Standards

Strategy	**Related HMI Principle**	**Supporting Standards / Guidelines**	**Alignment / Extension**
Strategy 1: Workflow-Aligned Information Structuring	Task-oriented information organization	ISO 15005 (Ergonomic principles for transport information and control systems)	Extends traditional system-based layouts toward workflow-driven structuring in public transport contexts
Strategy 2: Persistent Visibility of Safety-Critical Parameters	Continuous visibility of critical driving information	ISO 15007 (Visual behaviour and attention in driving)	Reinforces uninterrupted monitoring requirements specific to e-bus operational conditions
Strategy 3: Progressive Diagnostic Disclosure	Clear alert hierarchy and feedback design	TCRP 185; Automotive HMI alert guidelines	Extends alert systems toward action-oriented diagnostic workflows and integrated reporting
Strategy 4: Localization as a Trust and Acceptance Symbol	User comprehension and accessibility	General usability and HMI localization principles	Extends beyond usability to include emotional trust, confidence, and acceptance in multilingual contexts
Strategy 5: Retention of Operational Familiarity	Consistency and mental model alignment	ISO 15005	Adapts legacy interaction logic to support safe transition from diesel to electric bus systems

Strategy	Related HMI Principle	Supporting Standards / Guidelines	Alignment / Extension
Strategy 6: Minimisation of Interaction Complexity	Reduction of cognitive load and distraction	ISO 15007	Tailors interaction simplification for high-load, safety-critical public transport environments
Strategy 7: Learnability-Focused Design	Learnability and error prevention	General usability heuristics and HMI guidelines	Extends learnability considerations to control-intensive and infrequent operational tasks

Collectively, these strategies represent empirically derived and contextually grounded design directions that extend beyond the specific prototype developed in this study. They offer structured and transferable guidance for the design and evaluation of driver-centered dashboard interfaces in e-buses and comparable public transportation systems, contributing actionable insights at the intersection of HCI, transportation design, and electric vehicle interface research.

These strategies further serve as the foundation for the broader theoretical and practical contributions of this thesis, as detailed in the following section.

7.2 Contributions

The contributions of this thesis are positioned as extensions and contextual adaptations of established HCI and automotive interface knowledge. Rather than proposing entirely new theories, the study advances existing understanding by applying and validating these principles within a real-world public transport context that has been underrepresented in prior research.

7.2.1 Theoretical Contributions

This thesis advances theoretical understanding in the domains of HCI, transport ergonomics, and EV interface design through the following contributions:

1. **Extending information integration as a workload reduction mechanism in e-bus dashboards:** Existing research in automotive HMI demonstrates that improved information organization and display integration can reduce visual demand and cognitive workload (François et al., 2019; Harvey and Stanton, 2013). However, as identified in the literature review (Chapter 2), these findings are largely derived from private electric vehicle contexts and controlled environments, with limited attention to fragmented multi-device ecosystems in public transport settings.

   This study addresses this gap by empirically demonstrating how distributed subsystems (instrument cluster, DDU, and auxiliary displays) increase cognitive load in e-bus operations. The findings advance existing knowledge by reframing integration not merely as a display-level improvement, but as a system-level requirement that supports continuous monitoring, workflow coordination, and decision-making in professional driving environments.

   This contribution represents a **contextual extension** of existing workload and integration theories to multi-device public transport environments.

2. **Advancing usability evaluation for multilingual, professional driver populations:** Prior studies in automotive HMI predominantly rely on simulator-based experiments or controlled usability testing with homogeneous user groups (François et al., 2021). The literature review highlights a lack of evaluation frameworks that account for real-world operational constraints, multilingual users, and varying literacy levels in professional driving contexts.

   This study addresses this gap by proposing a field-grounded evaluation approach that combines usability (SUS, SEQ) and workload (RSME) measures within a stationary in-bus testing environment. The methodology demonstrates how structured subjective evaluation can yield reliable, ecologically valid insights under real-world constraints, thereby extending existing evaluation practices in automotive interface research.

This contribution represents a **methodological extension** of existing usability evaluation frameworks to real-world, multilingual driving contexts.

3. **Extending automotive HMI research to developing-country public transport contexts:** The literature review identifies a strong geographic bias in existing EV interface research, with most studies conducted in Europe and North America and limited representation of developing regions such as India. Furthermore, public transport systems, particularly e-buses, remain underexplored.

   This study addresses this gap by providing an empirically grounded investigation of dashboard interaction within the Indian e-bus ecosystem. The findings demonstrate how infrastructural variability, multilingual usage, and operational complexity influence driver–interface interaction. This contribution extends existing HMI knowledge toward more context-sensitive and globally relevant design frameworks.

   This contribution represents a **contextual adaptation and empirical expansion** of automotive HMI research to developing-country public transport systems.

4. **Reframing localization as a trust and acceptance construct in public transport HMI:** Existing HCI literature primarily treats localization as a usability factor that improves comprehension and accessibility (Oyugi et al., 2008; Le et al., 2023). However, its role in safety-critical, professional driving environments remains insufficiently examined.

   This study addresses this gap by demonstrating that localization does not significantly affect task performance but plays a critical role in shaping driver confidence, trust, and perceived system reliability. This finding extends multilingual HCI theory by distinguishing between functional usability and experiential acceptance in high-stakes operational contexts.

   This contribution represents a **novel insight** into the role of localization as an experiential factor rather than a purely functional usability component.

5. **Multi-stakeholder perspective in e-bus dashboard research:** This study incorporates insights from drivers, OEM stakeholders, and depot-level actors to examine dashboard interaction as a socio-technical system. While prior studies often focus on single user groups, this work demonstrates the value of integrating multiple operational perspectives

to better understand real-world constraints and interaction requirements in public transport environments.

7.2.2 Practical Contributions

The practical outcomes of this thesis include:

1. **Empirical identification and prioritization of driver-centric dashboard information:**

   While prior studies identify key EV parameters such as range and energy consumption (Lundström and Bogdan, 2017; Gödker et al., 2018), the literature lacks structured prioritization of information specific to professional e-bus drivers operating in public transport systems.

   This study addresses this gap by systematically identifying and prioritizing critical dashboard elements (e.g., SoC, DTE, alerts, air pressure, trip context) through field-based methods, including focus groups, participatory design, and card sorting. This contribution provides an empirically validated hierarchy of information tailored to real-world e-bus operations, extending beyond private EV contexts.

2. **Design and empirical validation of a unified e-bus dashboard prototype:**

   Existing research proposes alternative dashboard concepts but provides limited empirical validation using professional drivers in realistic operational settings, particularly for public transport systems.

   This study addresses this gap by developing and evaluating a unified digital dashboard prototype that integrates operational monitoring, trip management, and diagnostic workflows within a single interface. The prototype is validated through field-based usability testing with professional e-bus drivers, demonstrating measurable improvements in usability, reduced cognitive workload, and increased acceptance. This contribution advances the translation of conceptual HMI research into deployable, real-world interface solutions.

3. **Derivation of empirically grounded design strategies for e-bus dashboards:**

While existing automotive HMI guidelines provide general principles for interface design, the literature review highlights a lack of context-specific guidance for public transport systems, particularly in e-bus operations.

This study addresses this gap by deriving seven design strategies grounded in field observations, usability evaluation, and workflow analysis. Unlike prior guidelines, these strategies explicitly account for operational phases, fragmented system environments, and professional driver workflows. This contribution translates abstract HMI principles into actionable, context-specific design guidance for real-world e-bus applications.

4. **Improved glanceability and reduction of posture-dependent interaction:** Existing e-bus dashboards often require drivers to lean forward or adjust posture to read small or poorly positioned displays, increasing physical strain and visual distraction. The redesigned dashboard addresses this limitation by centralizing critical information within the driver's primary line of sight and improving visual clarity. This reduces the need for posture adjustment, enhances glanceability, and supports safer and more comfortable interaction during operation.

To further clarify the positioning and novelty of the contributions, Table 7.2 presents a comparative mapping of this thesis in relation to existing literature.

Table 7.2: Positioning of Thesis Contributions in Relation to Existing Literature, highlighting areas of extension, adaptation, and novel insight

Contribution Area	**Existing Literature**	**This Thesis**	**Type of Contribution**
Information Integration	Focus on display-level integration in private EVs and simulators	Demonstrates system-level integration across fragmented multi-device e-bus environments	Contextual Extension

Contribution Area	Existing Literature	This Thesis	Type of Contribution
Usability Evaluation	Simulator-based, controlled studies with homogeneous users	Field-based evaluation with professional drivers in real operational settings using SUS, SEQ, RSME	Methodological Extension
Geographic Context	Predominantly Europe and North America; private EV focus	Empirical study in Indian public transport e-bus ecosystem	Contextual Expansion
Localization	Treated as usability and comprehension factor	Reframed as trust and acceptance factor in safety-critical contexts	Novel Insight
Information Prioritization	Identifies key EV parameters (range, energy) but lacks structured prioritization	Provides empirically derived prioritization specific to e-bus drivers and workflows	Applied Contribution
Dashboard Design Solutions	Conceptual prototypes with limited real-world validation	Fully developed and empirically validated unified dashboard prototype	Applied + Empirical Advancement
Design Guidelines	General HMI principles not tailored to public transport	Seven context-specific, workflow-aligned design strategies for e-buses	Contextual Adaptation
Evaluation Methodology	Emphasis on simulator or lab-based testing	Stationary in-bus evaluation preserving ecological validity	Methodological Adaptation
Task Design in Evaluation	Assumes task equivalence across systems	Introduces differentiated task framework for non-equivalent systems	Methodological Innovation

Contribution Area	Existing Literature	This Thesis	Type of Contribution
Visual Ergonomics / Glanceability	Limited focus on posture and physical interaction in EV dashboards	Demonstrates improved glanceability and elimination of posture-dependent interaction through centralized and clearly visible interface design	Applied Contribution
Stakeholder Perspective	Primarily single-user focus (drivers or lab participants)	Multi-stakeholder field-based analysis incorporating drivers, OEMs, and depot actors to capture system-level interaction requirements	Methodological Extension

The contributions outlined in Table 7.2 are grounded in the empirical evidence generated across the research process. To ensure transparency and traceability, Table 7.3 maps each research objective to the corresponding methods, findings, and thesis sections. Together, these tables demonstrate not only how the contributions extend existing literature, but also how they are systematically derived from field-based investigation and evaluation.

Table 7.3: Contribution Matrix Mapping Research Objectives to Evidence and Thesis Sections

Research Objective	Empirical Method(s)	Key Findings / Evidence	Chapter / Section
Identify prevailing dashboard practices	Literature review, stakeholder interviews	Existing systems are fragmented, legacy-driven, and subsystem-oriented rather than integrated	Chapter 4

Research Objective	**Empirical Method(s)**	**Key Findings / Evidence**	**Chapter / Section**
Identify usability and workflow challenges	Contextual inquiry, driver interviews, KJ analysis	High cognitive workload, poor visibility, unclear diagnostics, fragmented workflows	Chapter 5
Identify driver information and interaction needs	Focus groups, card sorting, affinity clustering	Prioritization of SOC, DTE, alerts, trip information, and operational controls	Chapter 5
Evaluate redesigned dashboard prototype	Usability testing (SUS, SEQ, RSME), acceptance measures, cognitive walkthrough	Improved usability, reduced workload, high acceptance, and strong learnability	Chapter 6
Derive design strategies for e-bus dashboards	Synthesis of empirical findings across all methods	Seven empirically derived, contextually grounded design strategies addressing usability and workflow issues	Chapter 7

To improve transparency and traceability of contributions, Table 7.3 maps each research objective to its corresponding empirical evidence and thesis sections. Together, these contributions offer a framework for designing future electric-bus dashboards that balance usability, safety, and contextual relevance within India's multilingual and operationally demanding public-transport ecosystem.

7.3 Conclusion

The findings from this research demonstrate that current electric-bus dashboards present fragmented information across multiple subsystems, increasing visual effort and cognitive load for drivers. Our empirical studies showed that drivers require a single consolidated display integrating speed, state of charge, air pressure, distance-to-empty, diagnostic alerts, and trip-level information, with support for clear telltale symbols and accessible wording.

To address these needs, we designed and evaluated a unified digital dashboard prototype developed in two language versions: English and Gujarati. Both versions were grounded in field-derived requirements and replaced the multi-device workflow used in existing buses. Usability testing showed a consistent performance improvement across all key measures, including SUS, SEQ task ease, mental workload, and acceptance. These findings confirmed that the redesigned dashboard reduced cognitive burden and improved interaction experience when compared to the current system.

This work contributes: (1) an empirically evaluated dashboard user interface demonstrating the feasibility and benefits of integrated dashboards for public e-buses, (2) a set of empirically derived and contextually grounded design strategies for multilingual and resource-constrained mobility contexts, (3) a reusable field-based evaluation method using a stationary bus setup, suitable for driver–interface research and future EV development.

Overall, the novelty of this work lies in extending established HMI and usability principles to the complex, real-world context of public e-bus operations, supported by empirical validation with professional drivers. This provides context-specific insights and design knowledge for a domain that has remained underexplored in existing literature.

7.4 Limitations

This study focuses on the driver-facing dashboard interface and does not include engineering integration with backend vehicle communication systems such as Controller Area Network (CAN), telematics, or real-time sensor fusion. Consequently, system performance under live operational data conditions could not be evaluated.

The participant sample was drawn from a single operational electric-bus depot within the Ahmedabad Bus Rapid Transit System (BRTS), which may limit the generalizability of findings across different geographic regions, fleet configurations, and organizational practices. The BRTS operates under relatively structured conditions, including dedicated lanes, centralized control, and regulated service patterns, which differ from mixed-traffic public transport environments in many Indian cities. Furthermore, all usability evaluations were conducted in a controlled, stationary bus setting. While this approach enabled focused assessment of interface interaction, it restricted the ability to capture dynamic driving conditions such as traffic density, time pressure, road variability, and real-time cognitive load during vehicle operation. Consequently, certain findings related to driver workload, attention distribution, and interaction behavior may vary under real-world driving conditions. However, the core usability challenges identified—particularly those related to information visibility, diagnostic clarity, and interface comprehension—are intrinsic to the dashboard design itself and are therefore expected to remain relevant across different operational contexts.

The absence of female drivers reflects current workforce demographics rather than intentional exclusion; however, this limits insights into gender-specific accessibility and interaction considerations. Variations in literacy levels and English proficiency among participants may also have influenced preferences for interface language, particularly in relation to comprehension and confidence rather than task performance.

With respect to measurement, although the Van der Laan Acceptance Scale is widely used in transport-related studies, it has been criticized for inconsistencies in its factor structure across contexts. In this study, the scale is used as a general indicator of perceived usefulness and satisfaction rather than as a strict two-factor construct. Accordingly, the results are interpreted in conjunction with other usability measures, including SUS, RSME, and SEQ, to ensure a more robust and triangulated evaluation.

A further limitation arises from differences in the interaction medium between conditions. The control condition utilized the existing physical dashboard, whereas the research prototype was implemented as a tablet-based interface mounted within the bus. This introduces a potential confounding factor, as differences in interaction modality, visual presentation, and the novelty of touchscreen-based interaction may influence user responses independently of the interface design itself. While efforts were made to maintain functional equivalence in tasks across conditions, the observed improvements in usability, workload, and acceptance should be interpreted as reflecting both interface design and, to some extent, device-related affordances. Accordingly, the findings are interpreted with caution, acknowledging that the interaction medium may have contributed to the overall user experience.

Finally, the study did not examine structured training, onboarding processes, or long-term organizational adoption of the proposed dashboard interface.

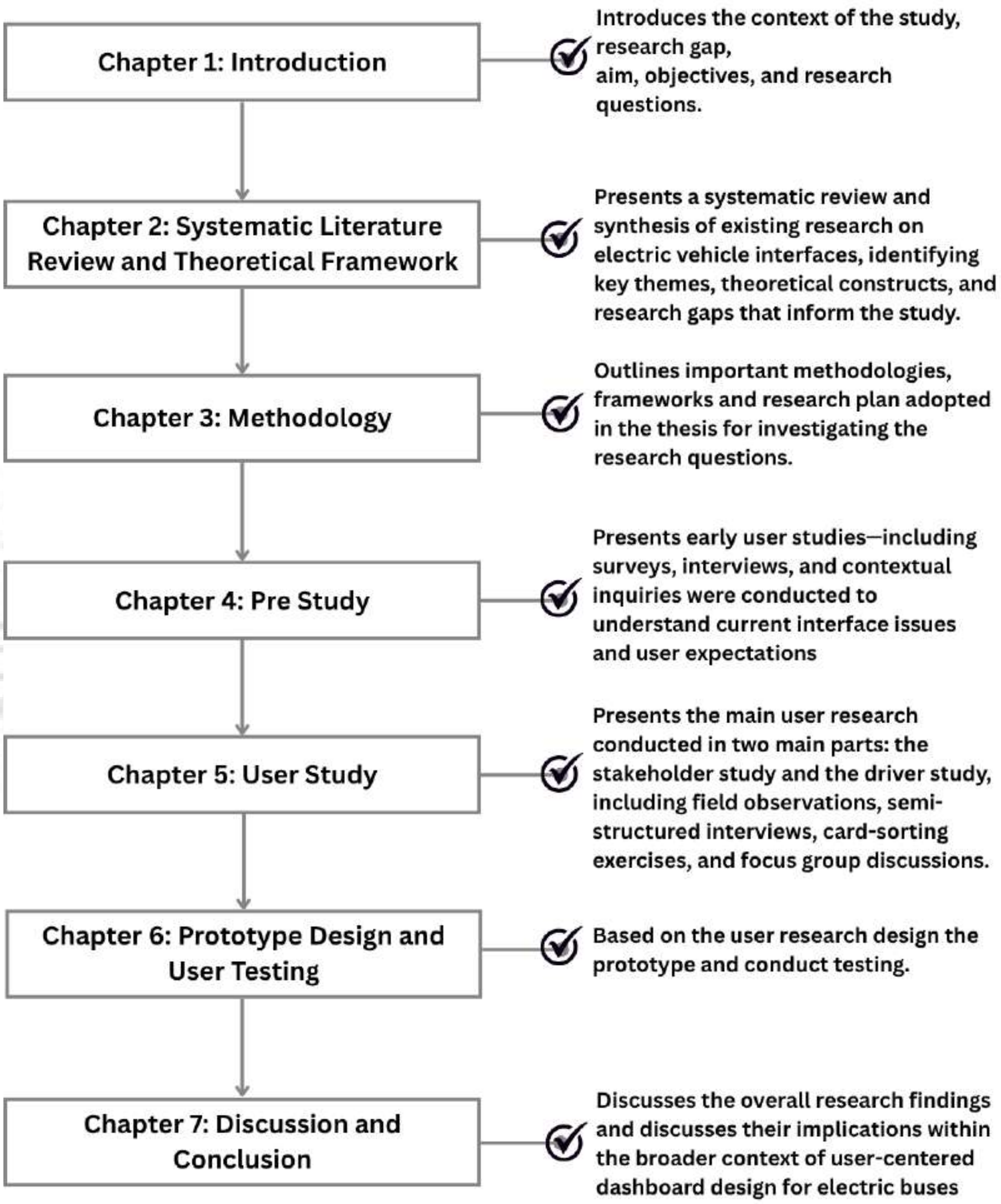
7.5 Future work

The future scope of this research will include the following:

- Integration of the proposed interface with live vehicle systems (e.g., CAN, telematics, and sensor networks) and deployment within embedded vehicle hardware would enable evaluation under real operational conditions. This would support assessment of real-time diagnostics, system responsiveness, and safety-critical feedback, while also isolating the effects of interface design from those of the interaction medium.
- Future studies should validate the proposed framework across multiple depots, cities, and fleet operators to examine adaptability across diverse operational contexts and organizational cultures, thereby strengthening generalizability.
- Future studies should incorporate controlled on-road trials or high-fidelity driving simulators to evaluate interface performance under dynamic traffic conditions, including attention management, alert effectiveness, and cognitive workload.
- Future studies should examine gender-specific, age-related, and literacy-sensitive interaction needs to support more inclusive and accessible dashboard designs, including adaptive multilingual interfaces.
- Longitudinal field deployments and structured training studies should be conducted to examine learning curves, trust development, and sustained use over time. Collaboration

with transport authorities and industry stakeholders may further support the translation of these findings into standardized design guidelines.

A visual summary of the chapters covered so far is presented as follows:



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Lipsa Routray

Appendix A

Driver Interview Questionnaire

A.1 Demographic Details

1. What is your name?
2. What is your gender? (a) Male (b) Female (c) Other
3. What age group do you belong to? (a) 18–25 (b) 26–35 (c) 36–45 (d) 46–55 (e) 55+
4. How many languages do you know? Please specify below:

Language	Speak	Read	Write

5. What is your educational qualification? (a) Below 10th (b) 10th (c) 12th (d) Graduation (e) Other
6. Do you use a smartphone? Yes / No If yes, for how many years? ____
7. How long have you been a bus driver (in years)? Please specify for each vehicle type: Diesel ___ CNG ___ EV ___ Other ___
8. On average, how many days per week do you drive? (a) 1 (b) 2 (c) 3 (d) 4 (e) 5 (f) 6 (g) 7

A.2 Interview Questions

1. Please walk me through your daily routine at work.

2. Have you taken any training for using the electric bus dashboard? Yes / No If yes, please describe the training content and duration.

3. How easy was it for you to learn about electric bus information on the dashboard? **Scale:** 1 (Very Difficult) – 7 (Very Easy)

4. How often do you look at the dashboard every 30 minutes during your typical driving routine? (a) Once (b) Twice (c) Three or more times **a.** For what kind of information do you depend on the dashboard while driving? (e.g., Speedometer, SOC meter, Battery temperature, Air pressure, Diagnostic errors, etc.)

5. How comfortable are you with the information displayed on the dashboard? **Scale:** 1 (Not Comfortable at All) – 7 (Very Comfortable)

   a. Please mention any information or symbols that you find difficult to understand. **b.** Describe any past situation where the dashboard design caused confusion or misunderstanding about the bus status or operation.

6. How do you typically find out about diagnostic problems or issues in the bus? (a) Dashboard (b) Shift Manager (c) Other sources (specify) ___

   a. How does the dashboard help you identify an issue? **b.** Apart from dashboard alerts and chime sounds, are there any other ways you get informed about problems? **c.** Rate how well the dashboard system provides diagnostic information. **Scale:** 1 (Very Poor) – 7 (Very Good) **d.** What improvements would help you detect issues more easily?

7. Once you detect a problem, what steps do you typically take to handle it? Step 1: ___ Step 2: ___ Step 3: ___ Step 4: ___ Step 5: ___

   a. Can you suggest any ways to improve your efficiency in handling such situations?

8. Which type of dashboard do you prefer in the bus? (a) Analog (b) Digital (c) Both (Mixed) Please explain your reasons.

Appendix B

Activity Card

Battery Percentage / બેટરી પર્સેન્ટેજ

Date / ડેટ

Time /ટાઇમ

Route Information / રૂટ ઇન્ફોર્મેશન

Camera / કેમેરા

Symbols / સિમ્બોલ્સ

Message Alert / મેસેજ એલર્ટ

Drive type / ડ્રાઈવ ટાઇપ

Start / સ્ટાર્ટ

AC Control / એસી કંટ્રોલ

Door / ડોર

Passenger Lamp / પેસેંજર લેમ્પ

Hill hold / હિલ હોલ્ડ

Mobile Charger / મોબાઈલ ચાર્જર

Dipper / ડિપર

Driver lamp / ડ્રાઈવર લેમ્પ

Driver fan / ડ્રાઈવર ફેણ

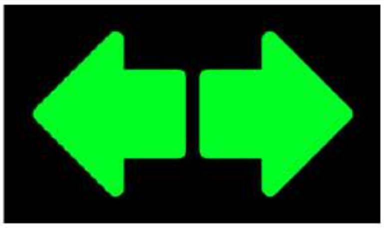
Emergency / એમરજન્સી

Speedometer / સ્પીડોમીટર

SOC Meter / એસ્ઓસી મીટર

Main coolant temperature / માઇન કોલન્ટ ટેમ્પરેચર

Battery Temperature / બેટરી ટેમ્પરેચર

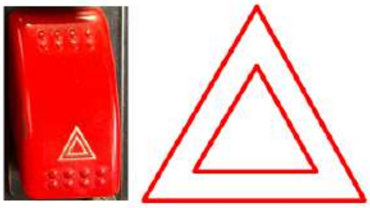

Direction Indicator / ડિરેક્શન ઇન્ડિકેટર

DTE / ડીટીઈ

Air Pressure / એર પ્રેશર

Odometer / ઓડોમીટર

Gear Mode / ગિયર મોડ


Hazzard symbol / હઝાર્ડ સિમ્બોલ

Destination Board / ડેસ્ટિનેશન બોર્ડ


ITS / એટીએસ


Inverter / ઇન્વર્ટર

Headlight / કેમેરા


Isolator / આઇસોલેટર

Diagnostics Information / ડાયગ્નોસ્ટિક ઇન્ફોર્મેશન

Fire Protection / ફાયર પ્રોટેક્શન

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Appendix C

Stakeholder Study and Driver Study Quotes

Table C.1: Collected Stakeholder and Driver Quotes (Study 1 & 2)

ID	Quote (Verbatim)	Participant
Q1	"Every bus is tracked in real time so we can see its route, charge level, and issues from the control room."	S3
Q2	"If anything goes wrong on the route, the control team identifies it immediately and contacts the driver."	S8
Q3	"Each bus goes for full charging at night in the depot, and we do fast charging after every trip."	S5
Q4	"Charging costs differ from less than Rs.5/kWh to nearly Rs. 11/kWh across states, which significantly changes running costs per kilometre."	S3
Q5	"An e-bus today costs nearly twice that of a diesel one because the battery alone makes up around 50% of the total price. Operators have to plan carefully before committing to large EV fleets."	S3
Q6	"For example, charging costs differ from less than Rs.5 per kWh in Delhi to almost Rs.11 in Tamil Nadu ... Since a bus consumes roughly 1 kWh per km ... almost equal to diesel costs."	S3
Q7	"During night shifts, all the inspections take place. The technicians check specific e-bus requirements like insulation, charging connectors, and battery temperature."	S3

Table C.1 continued

ID	Quote (Verbatim)	Participant
Q8	"When the buses return to the depot, drivers share any issues they noticed during the trip. Those reports are recorded and checked by the maintenance team."	S8
Q9	"For any alert, we have two features: a telltale with a buzzer and an LCD pop-up."	S5
Q10	"Drivers are trained to park the bus safely, clear passengers, and mark the vehicle's location before contacting the control room."	S3
Q11	"Due to the reduced number of mechanical parts . . . the vehicle can be perceived as a black box . . . service locations lack adequate skilled experts . . . unlike roadside breakdown services for other fuel vehicles."	S3
Q12	"Recruiting new drivers for the EV city bus system is challenging due to the need for specific skills and training. Additionally, the less developed service network . . . poses maintenance and servicing challenges."	S4
Q13	"When connectors are repeatedly engaged, they develop scoring marks that lead to oxidation and blackening . . . especially due to India's dusty environment."	S3
Q14	"The EV interface is highly sensitive. If it detects even a small current leak, it shuts down automatically to protect passengers . . . even a drop of water on a connector can trigger a short and stop the bus."	S3
Q15	"Driving an e-bus is an easy and stress-free experience. There is no sound or vibration . . . With just an accelerator and brake, driving becomes simpler and more enjoyable."	D0
Q16	"In diesel buses, there are no error codes, but with electric, I have to keep an eye on the dashboard every ten minutes, or else the buzzer will sound repeatedly."	D0
Q17	"Reading and understanding error messages is challenging, so I take a photo and send it to the engineer for guidance."	D1
Q18	"Initially, it might be new to the drivers. However, as time goes by, the driver's familiarity with digital clusters may improve."	S7

Table C.1 continued

ID	Quote (Verbatim)	Participant
Q19	"Some drivers struggle to comprehend the severity of situations conveyed through telltales ... Critical telltales ... are sometimes misunderstood or ignored."	S10
Q20	"I have difficulty reading detailed error messages and usually rely on the feel of the vehicle or telltale indicators."	D3
Q21	"The dashboard should prioritize battery charge and electric-related functions."	S3
Q22	"For example, if the driver is driving in a city, for him, for that particular moment, he just wants to see the route of the path — only the map could be displayed."	S7
Q23	"The instrument cluster should have a complete LCD display with gauges positioned on the edges and telltales placed on the top. This arrangement allows for easy visibility and access to essential information."	S2
Q24	"With bigger screens, you can get more information without needing physical switches. The screen can display the route, vehicle performance, speed, charge, etc."	D0
Q25	"Various essential systems, including the AC system, fire detection alarms, and emergency switches, are in place. We aim to streamline the interior design, minimizing distractions for optimal focus and functionality."	S5
Q26	"The biggest solution is that with the screens, you get more information but don't require more infrastructure."	S5
Q27	"Getting preventive maintenance notifications through the interface would help ensure proper maintenance during service ... It would be better if the operations and service teams took appropriate actions based on dashboard system alerts."	S3
Q28	"Implementing a digital instrument cluster might initially be costly. Once it becomes a practice, it will reduce. Eliminating switches and dashboards can reduce production and maintenance costs."	S6

Table C.1 continued

ID	Quote (Verbatim)	Participant
Q29	"It is important to place vital Advanced Driver Assistance System (ADAS) information in the center of the instrument panel so drivers can promptly access alerts and warnings for enhanced safety and decision-making."	S2
Q30	"A single and integrated digital console that can support various technologies, such as air conditioning controls and ITS."	S4
Q31	"Essential safety components such as isolators, fans, and emergency alarms should always be situated outside the digital dashboard and given priority over other information."	S5
Q32	"In critical situations, the dashboard should prioritize safety-related information, overriding non-essential details. This ensures drivers are promptly alerted to urgent issues like leaks or fires."	S6
Q33	"If a leak or fire is detected, all other dashboard information should be overridden to display only the warning."	S5
Q34	"It is in front of my eyes. So I often look into it. All the time you can say."	U–D03
Q35	"I look at the dashboard continuously. In each 5–7 minutes. Whenever there is a stoppage, I see the dashboard."	U–D06
Q36	"Twice or thrice in 30 minutes."	U–D12
Q37	"Whenever there is any stoppage, I find a chance to look at the dashboard to see if there is any problem."	U–D07
Q38	"Whenever there is an issue, alert sound would come. Then I see the dashboard."	U–D16
Q39	"When I start, I see the battery percentage first because issues in battery occur frequently."	U–D09
Q40	"Chiller temperature, coolant temperature, and SOC are the most important features of the bus. If these parameters go up, then the bus will catch fire. So I keep an eye on battery and chiller temperature."	U–D13
Q41	"Air pressure gives real power to the bus. If it goes below six, braking will not work."	U–D18

Table C.1 continued

ID	Quote (Verbatim)	Participant
Q42	"In every signal post, I press the button to know diagnostic info, SOC, and odometer. By seeing the LCD, I find motor, door, or chiller temperature issues myself."	U–D20
Q43	"My default screen shows SOC in percentage and DTE in km. These two I keep in front of my eyes."	U–D22
Q44	"While going down from the bridge, our bus catches speed. We have to monitor not to cross 40 kmph."	U–D15
Q45	"During going from depot and coming to depot, they ask to say the SOC and km."	U–D10
Q46	"When the bus slows down or the pickup changes, I can tell something is wrong even before the symbol appears."	U-D24
Q47	"First I check the symbols. The color of the symbol helps me identify the fault. Then I read the LCD diagnostic information."	U–D09
Q48	"When I start the bus, if 'Vehicle Ready' doesn't come, I know there is a problem. Sometimes 'Emergency Off' appears — then I stop and check."	U–D13
Q49	"Both text and symbol appear. There's also a chime sound for low battery."	U–D14
Q50	"Symbols, meter, and sound — like battery error or door sound — tell me what's wrong."	U–D18
Q51	"If SOC drops below 15%, I notify the manager and may skip stops to return to the depot."	U–D22
Q52	"When I see a symbol, first I check the screen, then restart the bus once or twice to see if it clears."	U–D15
Q53	"When the symbol is green everything is okay. When it turns red, it means some issue is there."	U–D15
Q54	"It's in front of my eyes, but I mostly understand issues from driving feel and sound."	U–D12
Q55	"As soon as we see a red sign, we check the screen, restart if needed, and call the supervisor. Most issues like motor error or chiller fault get managed this way."	U-D25

Table C.1 continued

ID	Quote (Verbatim)	Participant
Q56	"As a driver I get to know the issues first. The symbols show very late. I inform the supervisor, but at that time nothing is visible. Later the motor error symbol appears and the bus stops in traffic — that becomes a panic moment."	U–D16
Q57	"When I don't understand the message, I take a photo and send it to the supervisor. They tell me what to do next."	U–D16
Q58	"We depend on WhatsApp to report faults. Sometimes the supervisor replies late, so we have to decide ourselves whether to continue or stop."	U–D13
Q59	"Messages come from many drivers at once. It's difficult to track who reported first or which bus it belongs to."	U–M02
Q60	"When the bus stops in the middle of the road, passengers start shouting. I have to calm them and call the control room. At that time, there's no one to help."	U–D09
Q61	"The diagnosis system is not good. We need automatic messages to go to the technician or alerts when high speed or breakdown happens."	U-D25
Q62	"The analog meters don't help. If temperature and SOC were shown in numbers, we could explain the problem better."	U–D27
Q63	"One display, all data. Speedometer and SOC should be in digits so we can say the exact value."	U–D09
Q64	"If temperature and SOC were shown in numbers, we could explain the problem better."	U–D27
Q65	"Change the dashboard location to a bit up. Steering comes in between, and we can't see it clearly."	U–D11
Q66	"I feel difficulty seeing the dashboard. The bonnet should be a little lower so I can see both the dashboard and the road."	U–D13
Q67	"Make the LCD bigger with large text size and clear black-and-white colors."	U–D17
Q68	"Add sound at 30% and 20% SOC to alert early, but not continuously. There should be a stop button."	U–D10
Q69	"Announce diagnostic issues like battery or motor problems with chime or voice. Volume control should be given to the driver."	U–D13

Table C.1 continued

ID	Quote (Verbatim)	Participant
Q70	“The chime for low battery is fine, but it irritates when I return with 15%. A stop button is needed.”	U–D08
Q71	“Audio feedback is useful for low battery, but not for everything. There should be a stop button. Only important faults should make sound.”	U-D24
Q72	“If the issue could be detected by the control room and they notify us with the next steps, that would be faster.”	U–D06
Q73	“The management should be proactive. The person who receives the call should be connected directly to a technician. If the dashboard could send messages itself, it would save time.”	U–D15
Q74	“Automatic diagnostic messages to the technician will save time. Now it depends on when the mechanic replies.”	U–D16
Q75	“Feedback should be in local language with sound. I can read English but cannot explain it correctly to the technician.”	U–D18
Q76	“Make the LCD text in English, Hindi, or Gujarati — whichever is comfortable.”	U–D21
Q77	“Add tyre puncture and AC issue symbols. Notify the driver to do less braking and accelerating to save battery.”	U–D12
Q78	“Add speed limit mark on the speedometer dial to avoid fines.”	U–D20
Q79	“Use of camera for safety and to see door status clearly should be in the dashboard itself.”	U–D09
Q80	“They trained us about new symbols and how to start or stop the e-bus. We also learned to check the dashboard for battery percentage and air pressure before trips.”	U–D28
Q81	“When new drivers face a problem, they call me or show me the photo of their dashboard. I tell them which issue it is and what to do next. This is how we all learn over time.”	U–D27
Q82	“Feels difficult in recognising symbols due to small size.”	U–D19
Q83	“The size of the symbols are also very small. The symbol should remain on the screen so I can take the photo.”	U–D08

Table C.1 continued

ID	Quote (Verbatim)	Participant
Q84	"Sometimes the meter is incorrect. Different color sometimes confuses."	U–D10
Q85	"There are some symbols that I don't know. While running it shows up but I don't know what it is for."	U–D16
Q86	"The colors (green/yellow/red) are helpful to identify how serious the issue is."	U–D13
Q87	"The dashboard works fine, but some information is too small or hidden behind menus. I can't always find what I need quickly."	U-D26
Q88	"Some messages appear suddenly in English, and I have to stop and think what it means."	U–D04
Q89	"At a time, all information should be visible on one screen—battery, temperature, and door issues together."	U–D23
Q90	"I like the DDU the most. It feels like using a mobile. I can touch, select routes, and even adjust speaker volume."	U–D05
Q91	"For me, the DDU is simple because it works like a mobile. I log in, select my route, and even adjust the volume. But for new drivers, it takes some time to remember which button does what."	U–D24

Appendix D

Main-study-User-Requiremnt

D.1 Important Information

Table D.1: Importance Ratings (1–9 Scale) Across Six Driver Groups

Dashboard Parameter	Mean	SD	Rank
Speedometer	9.00	0.00	1
Soc meter	9.00	0.00	1
Main coolant temperature	9.00	0.00	1
Battery temperature	9.00	0.00	1
DTE (Distance to Empty)	9.00	0.00	1
Air pressure	9.00	0.00	1
Battery percentage	9.00	0.00	1
Time	9.00	0.00	1
Route information	9.00	0.00	1
Telltales	9.00	0.00	1
Message alerts (DDU)	9.00	0.00	1
Drive Type	9.00	0.00	1
Start	9.00	0.00	1
AC Control	9.00	0.00	1
Diagnostics Information	9.00	0.00	1
ITS/DDU	9.00	0.00	1
Headlight	8.83	0.37	2

Continued on next page

Table D.1 (continued): Mean and Standard Deviation of Importance Ratings (1–9 Scale)

Dashboard Parameter	Mean	SD	Rank
Destination Board	8.83	0.37	2
Door	8.67	0.47	3
Internal/External Isolator	7.67	1.63	4
Mobile Charger	7.67	0.52	4
Driver Lamp	7.33	0.82	5
Odometer	6.00	0.89	6
Gear modes	6.33	0.82	6
Passenger Lamp	6.33	0.52	6
Camera	5.67	0.52	7
Hill hold	5.00	0.63	8
Invertor	5.67	2.52	8
Dipper	5.00	2.00	8
Emergency	5.67	3.27	8
Driver fan	6.00	3.27	8
Hazzard Symbol	6.33	3.56	8
Date	7.67	0.82	9
Fire protection system	3.33	1.49	10
Direction indicators	5.00	1.41	10

D.2 Frequency of Information

Table D.2: Frequency of the Dashboard attribute usage

Information available on the existing design	Need it occasionally	Need it all the time	Never needed (Can be hidden)
Speedometer		yes	
Soc meter		yes	

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Table D.2 (continued): Frequency of the Dashboard attribute usage

Information available on the existing design	Need it occasionally	Need it all the time	Never needed (Can be hidden)
Main coolant temperature		yes	
Battery temperature		yes	
Direction indicators	yes		
DTE		yes	
Air pressure		yes	
Odometer	yes		
Gear modes		yes	
Battery percentage		yes	
Date	yes		
Time		yes	
Route information		yes	
Camera	yes		
Telltales		yes	
Message alerts	yes		
Drive Type		yes	
Start		yes	
AC Control	yes		
Door		yes	
Passenger Lamp	yes		
Hill hold	yes		
Mobile Charger	yes		
Dipper	yes		
Driver Lamp	yes		
Driver fan		yes	
Emergency		yes	
Hazzard Symbol	yes		

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Table D.2 (continued): Frequency of the Dashboard attribute usage

Information available on the existing design	Need it occasionally	Need it all the time	Never needed (Can be hidden)
Destination Board		yes	
ITS/DDU	yes		
Invertor		yes	
Headlight	yes		
External Isolator		yes	
Internal Isolator		yes	
Diagnostics Information	yes		
Fire protection system		yes	

D.3 Tripwise Need of Information

Table D.3: Before starting the trip

SN	Information on the existing design	Group 1	Group 2	Group 3	Group 4	Group 5	Total
1	AC Control	P	P	P	P	P	5
2	Air pressure	P	P	P	P	P	5
3	Battery percentage	P	P	P	P	P	5
4	Battery temperature	P	P	P	P	P	5
5	Camera		P			P	2
6	Date	P	P	P	P	P	5
7	Destination Board	P	P	P	P	P	5
8	Diagnostics Information	P	P	P	P	P	5
9	Dipper	P	P				2

Continued on next page

Table D.3 (continued): Before starting the trip

S. No	Information on the existing design	Group 1	Group 2	Group 3	Group 4	Group 5	Total
10	Direction indicators	P	P			P	3
11	Door	P	P		P	P	4
12	Drive Type	P	P			P	3
13	Driver fan	P	P		P	P	4
14	Driver Lamp	P	P				2
15	DTE	P		P	P	P	4
16	Emergency		P			P	2
17	Fire protection system		P	P		P	3
18	Gear modes	P	P	P	P	P	5
19	Hazzard Symbol	P	P				2
20	Headlight	P		P		P	3
21	Hill hold	P					1
22	Internal/External Isolator		P		P	P	3
23	Inverter			P		P	2
24	ITS/DDU	P	P	P	P	P	5
25	Main coolant temperature	P	P		P	P	4
26	Message alerts						0
27	Mobile Charger	P		P	P	P	4
28	Odometer	P	P	P	P	P	5
29	Passenger Lamp	P	P				2
30	Route information	P	P	P		P	4
31	Soc meter	P	P	P		P	4
32	Speedometer	P				P	2
33	Start	P	P	P	P	P	5
34	Symbols/Telltales	P	P	P	P	P	5

Continued on next page

Table D.3 (continued): Before starting the trip

S. No	Information on the existing design	Group 1	Group 2	Group 3	Group 4	Group 5	Total
35	Time	P	P	P	P	P	5

Table D.4: During the trip

SN	Information on the existing design	Group 1	Group 2	Group 3	Group 4	Group 5	Total
1	AC Control	P		P	P	P	4
2	Air pressure			P	P	P	3
3	Battery percentage	P	P	P		P	4
4	Battery temperature	P	P	P	P	P	5
5	Camera	P	P	P	P	P	5
6	Date		P				1
7	Destination Board	P	P	P		P	4
8	Diagnostics Information	P	P	P	P	P	5
9	Dipper	P	P	P	P	P	5
10	Direction indicators	P	P	P	P	P	5
11	Door	P	P	P	P		4
12	Drive Type			P	P		2
13	Driver fan	P	P	P	P	P	5
14	Driver Lamp	P	P	P	P	P	5
15	DTE	P			P	P	3
16	Emergency	P	P	P	P	P	5
17	Fire protection system	P		P	P	P	4
18	Gear modes	P		P		P	3
19	Hazzard Symbol		P	P	P		3
20	Headlight	P	P	P	P	P	5
21	Hill hold	P	P	P	P	P	5
22	Internal/External Isolator	P		P	P	P	4

Continued on next page

Table D.4 (continued): During the trip

S. No	Information on the existing design	Group 1	Group 2	Group 3	Group 4	Group 5	Total
23	Inverter	P		P			2
24	ITS/DDU		P	P			2
25	Main coolant temperature	P	P	P	P	P	5
26	Message alerts	P	P	P	P	P	5
27	Mobile Charger	P	P	P	P		4
28	Odometer						0
29	Passenger Lamp	P	P	P	P	P	5
30	Route information	P	P	P		P	4
31	Soc meter	P		P	P	P	4
32	Speedometer	P	P	P	P	P	5
33	Start			P			1
34	Symbols/Telltales	P	P	P	P	P	5
35	Time	P	P	P	P		4

Table D.5: While ending the trip

SN	Information on the existing design	Group 1	Group 2	Group 3	Group 4	Group 5	Total
1	AC Control			P			1
2	Air pressure			P	P		2
3	Battery percentage	P	P	P	P	P	5
4	Battery temperature	P		P		P	3
5	Camera			P	P	P	3
6	Date		P	P			2
7	Destination Board	P	P	P	P	P	5
8	Diagnostics Information		P			P	2
9	Dipper			P			1
10	Direction indicators	P		P		P	3

Continued on next page

Table D.5 (continued): **While ending the trip**

S. No	Information on the existing design	Group 1	Group 2	Group 3	Group 4	Group 5	Total
11	Door	P		P		P	3
12	Drive Type	P	P	P	P	P	5
13	Driver fan	P		P		P	3
14	Driver Lamp			P	P		2
15	DTE		P		P	P	3
16	Emergency			P			1
17	Fire protection system			P		P	2
18	Gear modes	P		P	P		3
19	Hazzard Symbol	P		P	P	P	4
20	Headlight			P			1
21	Hill hold	P					1
22	Internal/External Isolator			P			1
23	Inverter						0
24	ITS/DDU			P	P	P	3
25	Main coolant temperature	P		P		P	3
26	Message alerts						0
27	Mobile Charger		P	P			2
28	Odometer	P	P	P	P	P	5
29	Passenger Lamp			P			1
30	Route information			P		P	2
31	Soc meter	P	P	P		P	4
32	Speedometer					P	1
33	Start			P	P		2
34	Symbols/Telltales			P	P	P	3
35	Time	P	P	P		P	4

Appendix E

EV Tell-Tales on Electric Bus and Evaluation form

Identify the icons				
Sno	Symbols		S.no	Symbols
1			12	
2			13	
3			14	
4			15	
5			16	ABS
6			17	
7			18	
8	STOP		19	VEHICLE READY
9			20	
10	EM		21	
11			22	

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Appendix F

User Journey

User Journey

Based on daily routine (From Observations + Interviews)

Mapping the Driver Journey, through the day

01 Pre-trip checkup

Reached bus depot 20-30 minutes ahead of the shift timimgs → Checks the allotted bus for external damages and informs the supervisor if any → Checks the internal cleanliness of the bus → Starts the bus and checks the charge status, coolant temperatures and air pressure of the tires → Checks if the instrument cluster indicates any error symbol or diagnostic issues and resolves it with the help of the technicians → Checks AC and door working conditions

02 Starts the shift

Selects the destination on the DDU → Leaves the depot and reaches the starting point of the trip → Starts the route on the DDU to show on the destination board

03 Duration of the trip

Reaches a bus stop and opens the door for the passengers → Checks the rear mirror and right side mirror to monitor the passengers and closes the door → Occasionally checks the dashboard for error symbols, issues or to know the bus status - SOC, coolant temperatures → Uses the hazard symbol to stop at points which is off the allotted bus lanes

Repeats the same at each bus stop & traffic signal

04 Reaches end destination of the trip

Opens the doors at the last stop for the passengers → Shifts the bus to neutral gear and switches off the bus → Eats or rests for 30 mins during the break before the next trip

05 Return trip (Consider that the driver encounter an issue)

Starts the bus and changes the end destination → During the trip notices an diagnostic error on the instrument cluster and isn't sure on what to do → Stops the bus on the side of the road → Takes a picture of the instrument cluster and sends it in the WhatsApp group → After a few minutes → Receives a call from the point supervisor to take necessary steps

06 Goes back to the depot

After dropping off all the passengers at the last stop → Clicks drive mode and changes destination board to "Going to depot" on DDU → Reaches depot and informs odometer and battery percentage at the entrance office → Changes to reverse mode and docks the bus → Checks mirrors, opens the doors, switches off all lights and turns off the bus

Appendix G

Driver Persona

"I take people where they need to go, making sure they reach their place safely"

Raj Patel

Age: 34
Location: Ahmedabad, Gujarat
Occupation: Bus Driver
Education Qualification : 10th
Years of experience in driving : 8 years (Heavy vehicle) with 1.5 years (Electric bus)
Number of shifts : 2 (Morning & evening)

INTRODUCTION

Raj Patel is an experienced electric bus driver, working for the public transportation system in Ahmedabad. He has been a part of the city's evolving public transport network and has witnessed and experienced the transition from traditional buses to electric buses.

CHALLENGES

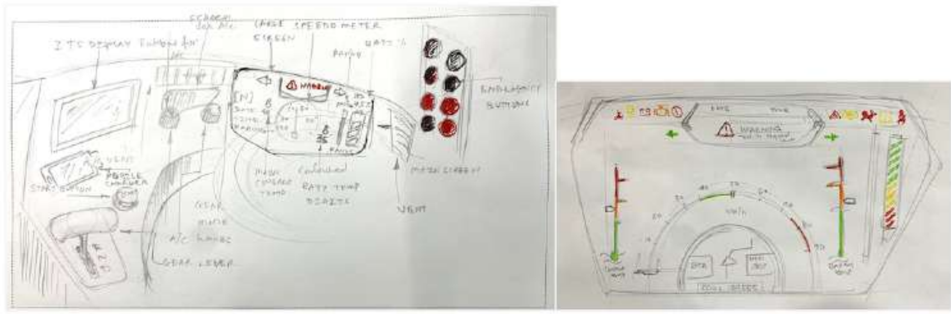
- I find it hard to recognize and read the small text and symbols on the instrument cluster, making it difficult for me to grasp the information effectively and quickly.
- The analog meters are faulty and not accurate, so I'm not sure if it's showing the right data sometimes.
- It's hard to comprehend the technical language of the diagnostics errors, so I've to contact the point supervisor each time to verify if it's fine to continue driving or if should I stop the bus.
- The sun glare during the daytime makes it hard for me to see what is there in the dashboard, so it forces me to bend down and check the LCD screen with the buttons to access the other screens.

NEEDS

- I need quick guidance in cases of emergencies or errors, as it's time-consuming to send images of the dashboard and wait for responses from the point supervisors with the passengers onboard.
- I need feedback from the dashboard to alert me in case of issues or diagnostic errors without distracting me or disturbing the passengers.
- I want real-time route information to be warned about the traffic conditions in different areas and a rear camera would be really helpful in heavy traffic zones as the bus doesn't have a conductor to help the driver.

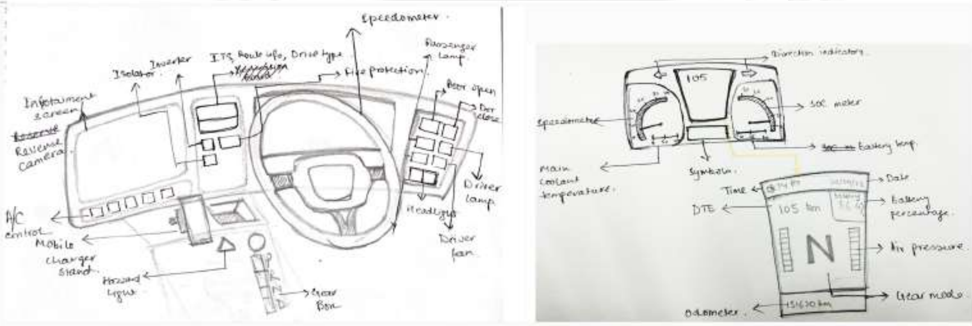
Appendix H

Paper Prototypes



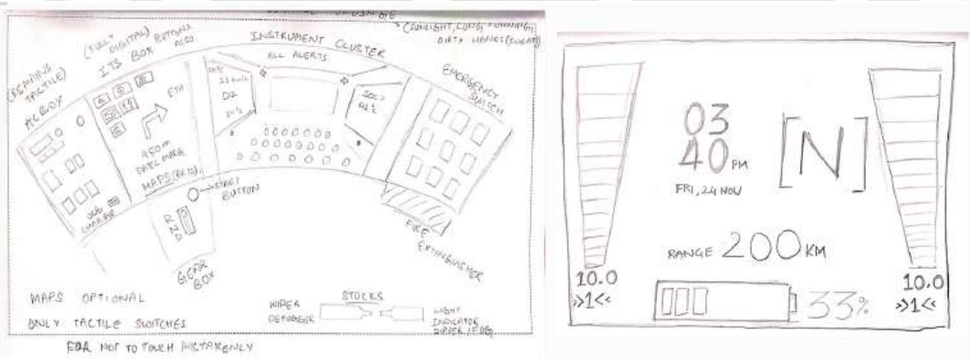
(a) Entire dashboard (b) LCD display

Figure H.1: Group 1 Paper Prototype



(a) Entire dashboard (b) LCD display

Figure H.2: Group 2 Paper Prototype



(a) Entire dashboard (b) LCD display

Figure H.3: Group 3 Paper Prototype

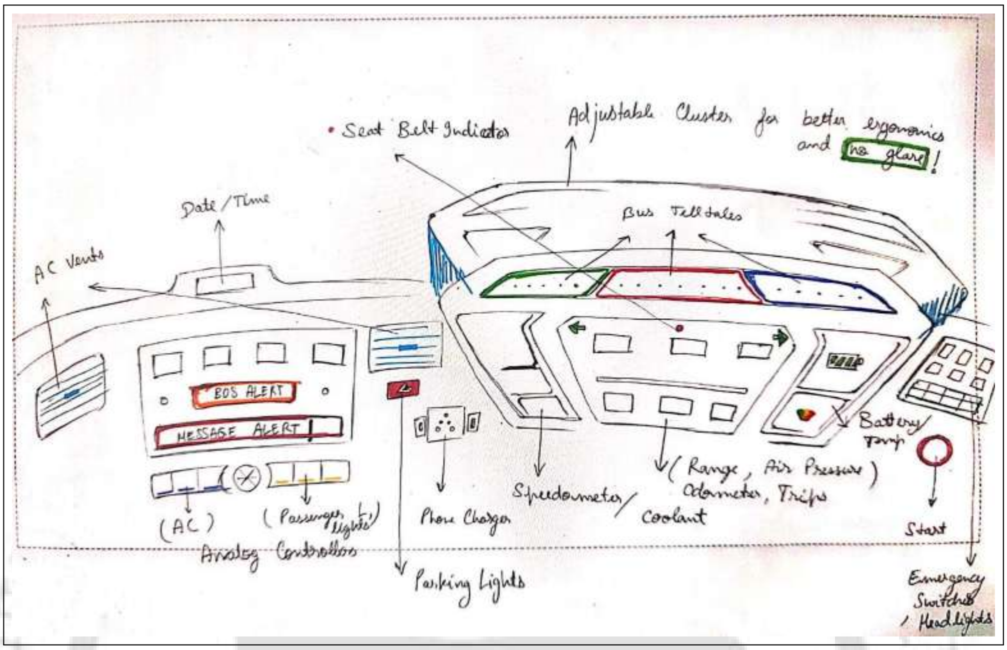


Figure H.4: Group 4 Paper Prototype

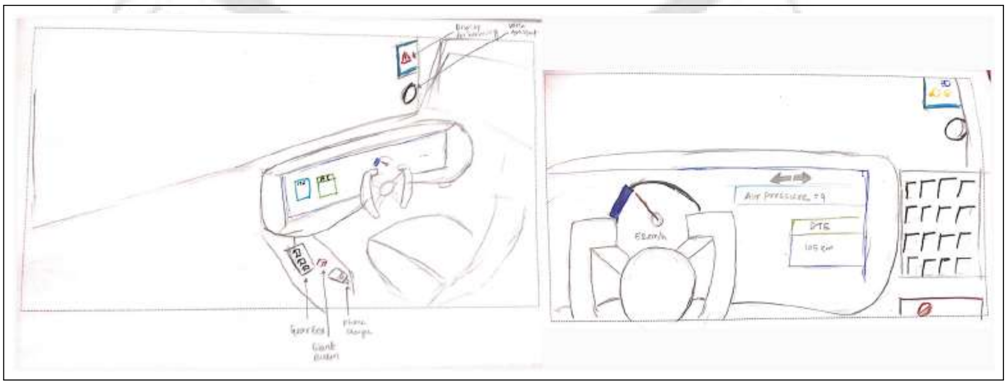


Figure H.5: Group 5 Paper Prototype

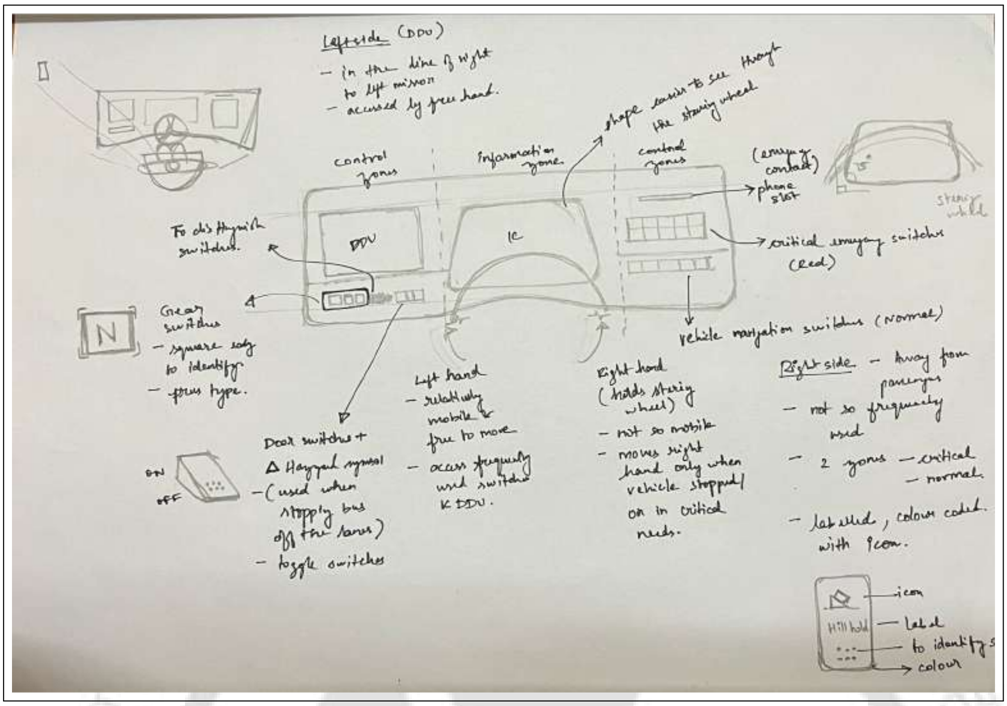


Figure H.6: Rough sketches

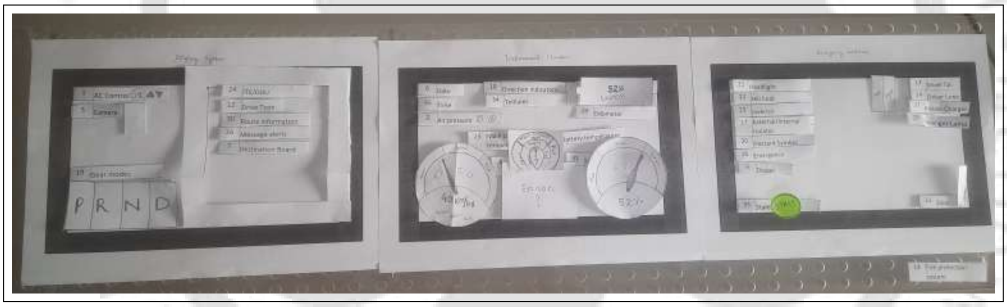


Figure H.7: Proposed Paper Prototype

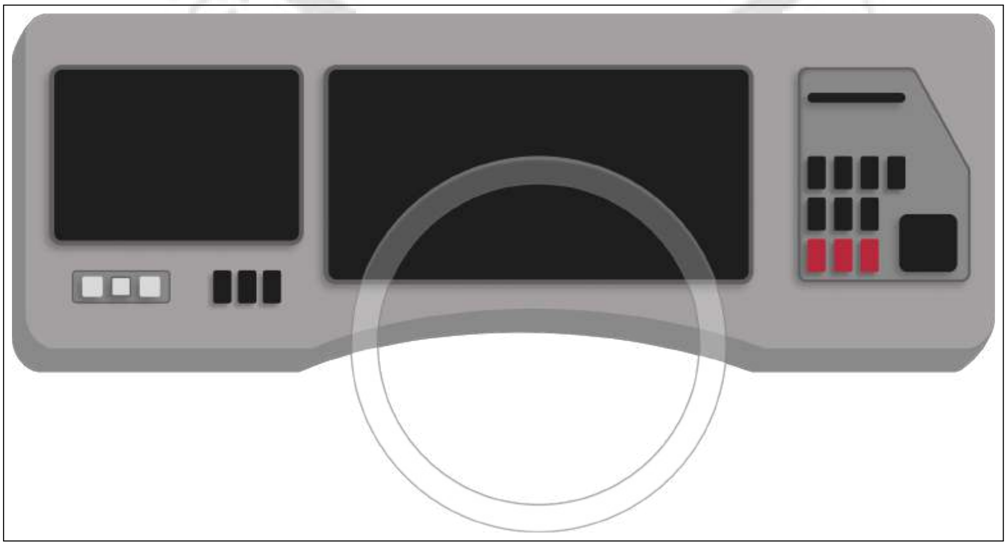


Figure H.8: Proposed Dashboard Layout

Appendix I

Figma Prototypes

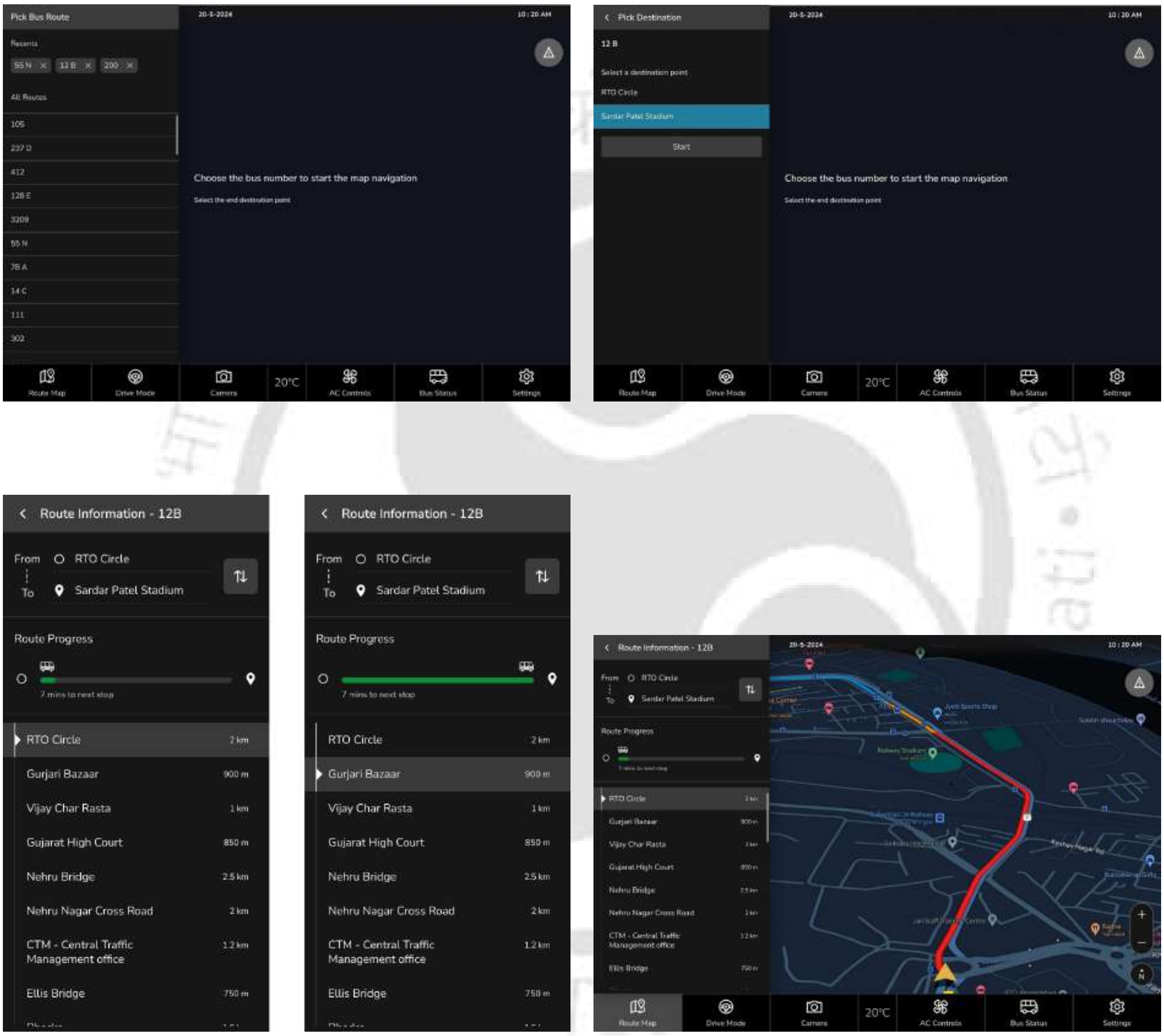


Figure I.1: Bus route configuration screens in the e-bus dashboard prototype

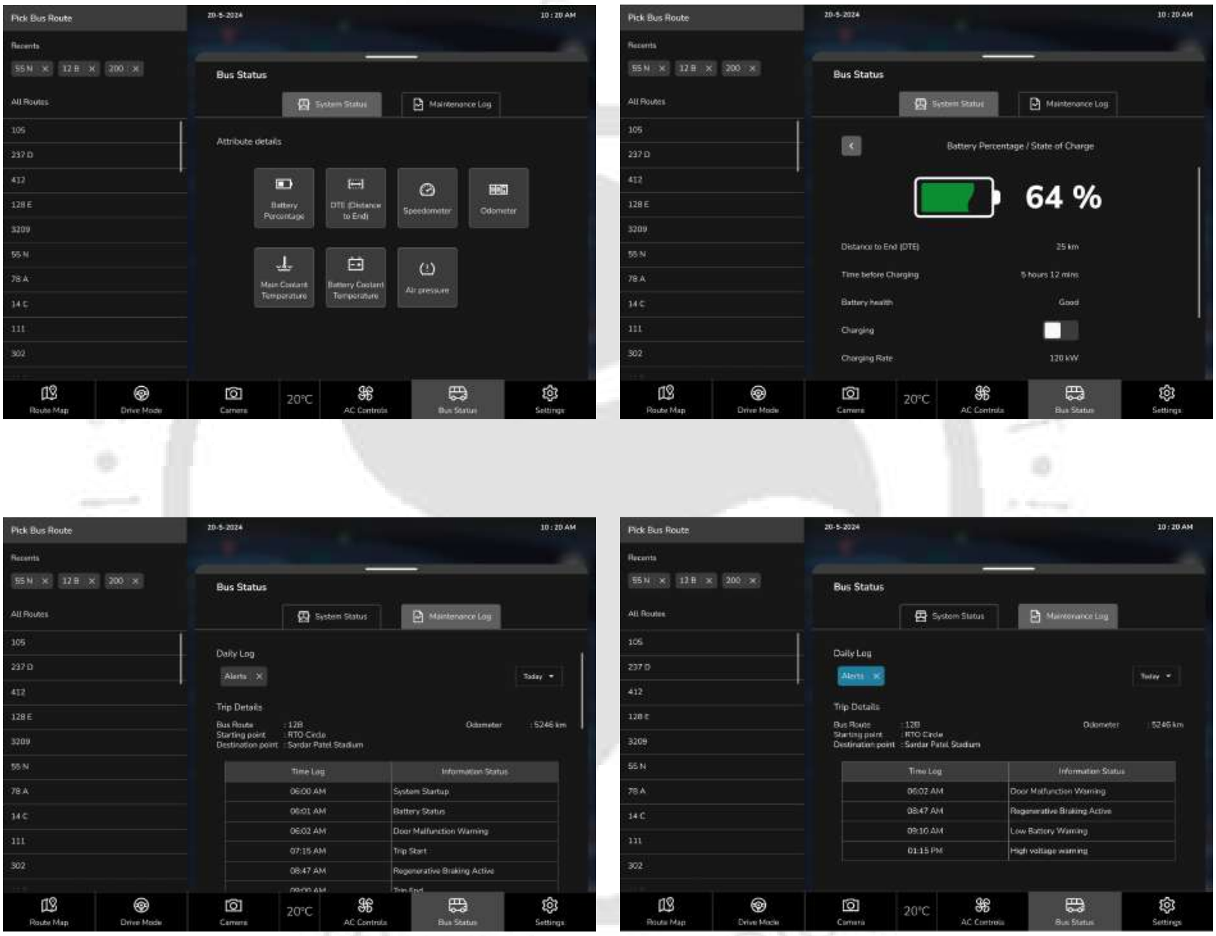


Figure I.2: Bus status and configuration screens in the e-bus dashboard prototype

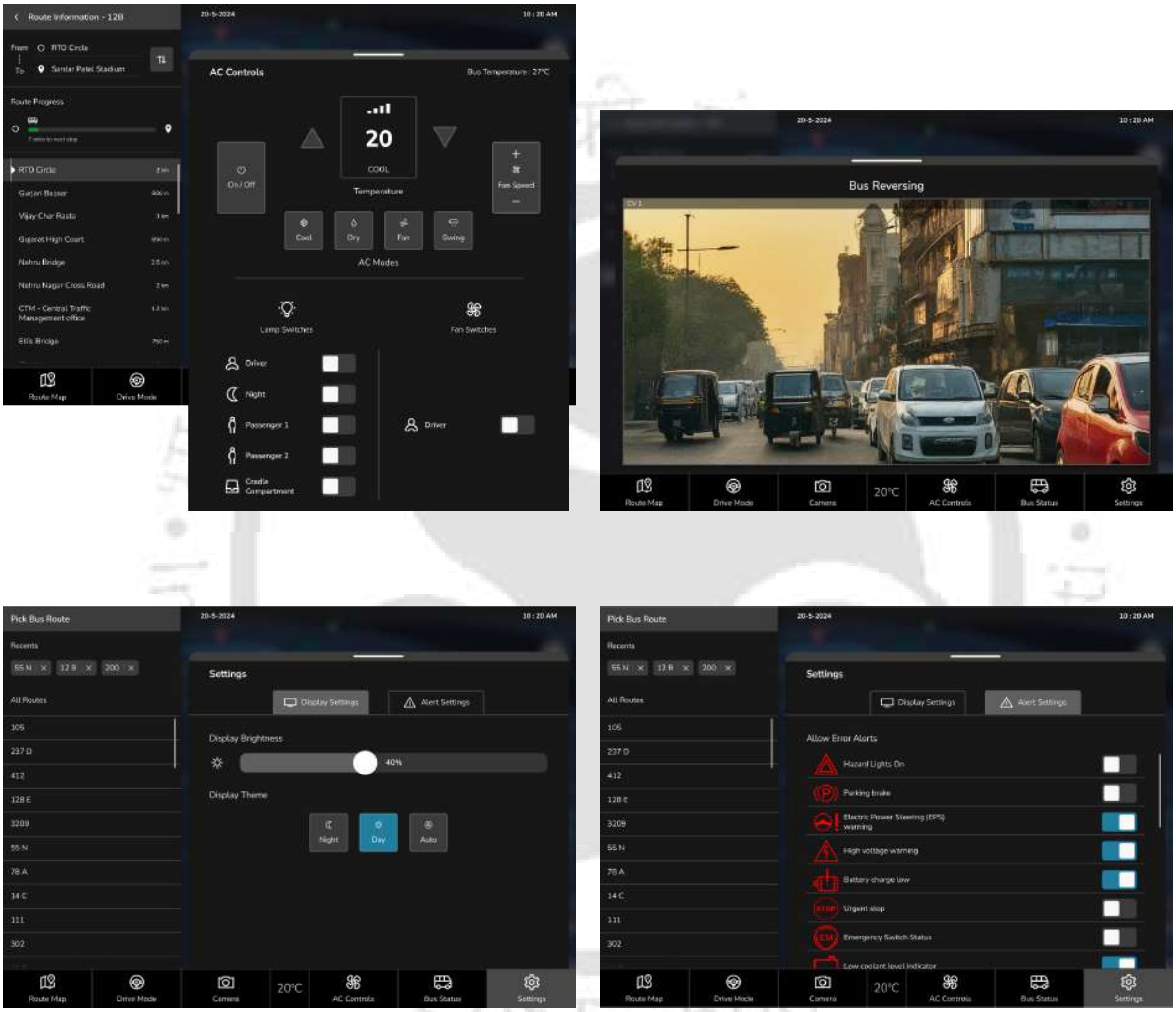
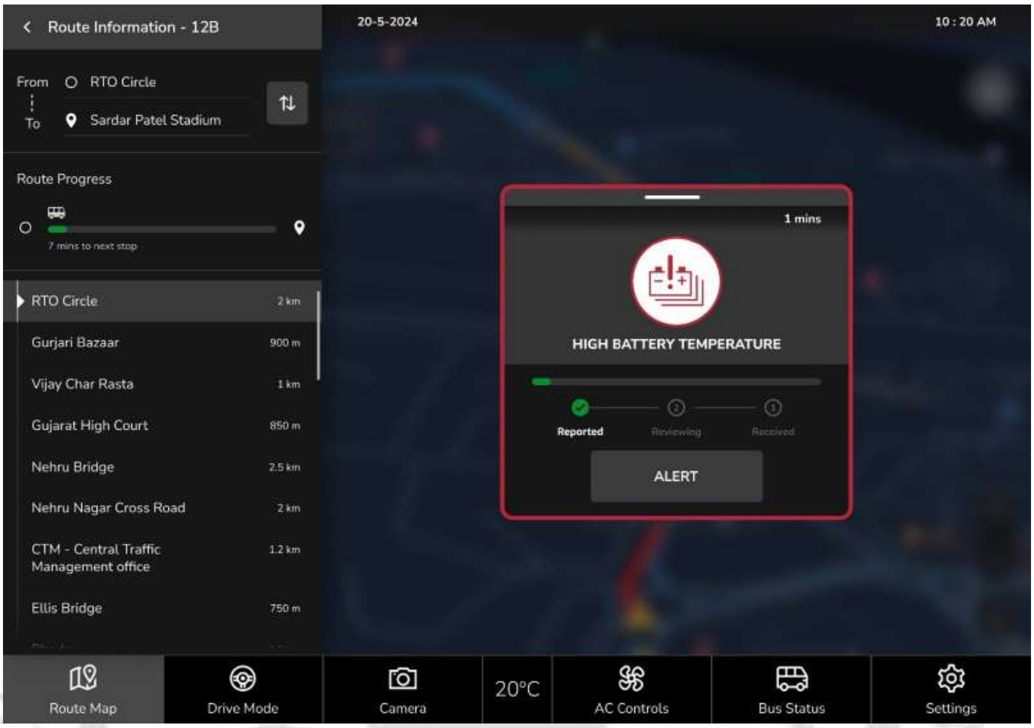


Figure I.3: Auxiliary controls and bus status configuration screens in the e-bus dashboard prototype


Route Information - 12B
20-5-2024
10 : 20 AM
From RTO Circle
To Sardar Patel Stadium
Route Progress
7 mins to next stop
RTO Circle 2 km
Gurjari Bazaar 900 m
Vijay Char Rasta 1 km
Gujarat High Court 850 m
Nehru Bridge 2.5 km
Nehru Nagar Cross Road 2 km
CTM - Central Traffic Management office 1.2 km
Ellis Bridge 750 m
1 mins
HIGH BATTERY TEMPERATURE
Reported
Reviewing
Received
ALERT
Route Map
Drive Mode
Camera
20°C
AC Controls
Bus Status
Settings


OVER SPEEDING - 70 km/hr
0 mins
HIGH BATTERY TEMPERATURE
Reported
Reviewing
Received
ALERT
TIME FOR NEXT TRIP


No Response
Drop Passengers & Return To Depot

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Appendix J

Heuristic Evaluation

Table J.1: Usability Issues found and resolved in Nielsen's Heuristics Analysis

SN	Section	Usability Issue	Mapped Heuristic	Priority	Status
1	Alert Pop-up	Alert signs not standard	Consistency and Standards	High	Done
2	Alert Pop-up	Reporting requires 4 clicks; auto-dismiss missing	Flexibility and Efficiency of Use	High	Done
3	Alert Pop-up	iPad alert sound and settings not working	Visibility of System Status	High	Done
4	Alert Pop-up	"Report" label unclear	Match Between System and Real World	High	Done
5	Alert Pop-up	No clear Bus Ready indication	Visibility of System Status	High	Done
6	Alert Icon	Issue icon unclear on homepage	Recognition Rather Than Recall	Medium	Done
7	Bus Status	Trip summary missing feedback indicator	Visibility of System Status	High	Done
8	Bus Status	Performance summary unclear; needs local language	Match Between System and Real World	Medium	Done
9	Bus Status	Main coolant missing	Visibility of System Status	Medium	Done
10	Bus Status	Battery coolant missing	Visibility of System Status	Medium	Done

SN	Section	Usability Issue	Mapped Heuristic	Priority	Status
11	Pop-ups	Pop-ups should close when tapping outside	User Control and Freedom	Medium	Done
12	Pop-ups	Alerts required double-tap	Flexibility and Efficiency of Use	High	Done
13	AC Control	No feedback when changing temperature	Visibility of System Status	High	Done
14	AC Control	Irrelevant lamp/fan icons	Aesthetic and Minimalist Design	Low	Done
15	AC Control	Layout too large; information split	Aesthetic and Minimalist Design	Medium	Done
16	AC Control	Temperature icons reversed	Consistency and Standards	High	Done
17	AC Control	Bus temperature not updating properly	Visibility of System Status	High	Done
18	AC Control	On/Off button not working	Error Prevention	Medium	Done
19	AC Control	AC icon not intuitive	Match Between System and Real World	Medium	Done
20	Camera	Camera icons unclear	Recognition Rather Than Recall	Medium	Done
21	Drive Mode	Drive mode unclear / incomplete	Match Between System and Real World	Medium	Done
22	Button Drawer	"Home" label missing under icon	Consistency and Standards	High	Done
23	Button Drawer	Missing Bus Ready icon	Visibility of System Status	High	Done
24	Top Drawer	Text size too small	Visibility of System Status	High	Done
25	Top Drawer	Asymmetric layout; inconsistent alignment	Consistency and Standards	High	Done
26	Top Drawer	Battery and DTE misaligned	Consistency and Standards	High	Done

SN	Section	Usability Issue	Mapped Heuristic	Priority	Status
27	SOS/Additions	Missing SOS button	Help and Documentation	High	Done
28	Additions	Trip summary not visible initially	Visibility of System Status	High	Done
29	Additions	Missing maintenance active alerts	Visibility of System Status	High	Done
30	Additions	Missing send button for maintenance report	User Control and Freedom	High	Done
31	Alerts	Confusing color hierarchy	Match Between System and Real World	Medium	Done
32	Alerts	No distinction between major/minor alerts	Error Prevention	High	Done
33	Alerts	Alert timing inconsistent	Visibility of System Status	Medium	Done
34	Navigation	Hard to locate route setting	Recognition Rather Than Recall	Medium	Done
35	Navigation	No confirmation after route set	Visibility of System Status	Medium	Done
36	Interface Layout	Too many pop-ups interrupting workflow	Aesthetic and Minimalist Design	Medium	Done
37	General UI	Inconsistent terminology across screens	Consistency and Standards	High	Done

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Appendix K

Research Prototype

K.1 Implementation of Research Prototype Refinements

Following the pilot study and subsequent heuristic-based refinements, the research prototype was implemented with a series of user-informed design improvements. These refinements focused on optimizing interaction flow, enhancing visibility of critical information, improving system feedback, and strengthening the visual hierarchy to support intuitive use under real driving conditions. The following subsections describe each module of the research prototype, illustrating how user feedback was translated into specific design and interface elements.

K.1.1 Home Screen

The Home Screen serves as the main interface for the driver, designed to be simple, clear, and easy to read while displaying all essential driving information without causing distraction (see Figure K.1).

The home layout presents important information in a well-organized manner. The top bar shows key vehicle parameters such as battery charge level, distance-to-empty, air pressure, cabin temperature, vehicle speed, and time/date. This ensures that critical data are always visible at a glance. The central map displays the real-time location of the bus with a blue marker, along with nearby roads and landmarks, helping drivers stay aware of their position during operation. On the right side, quick-access buttons allow the driver to check alerts, use the SOS feature

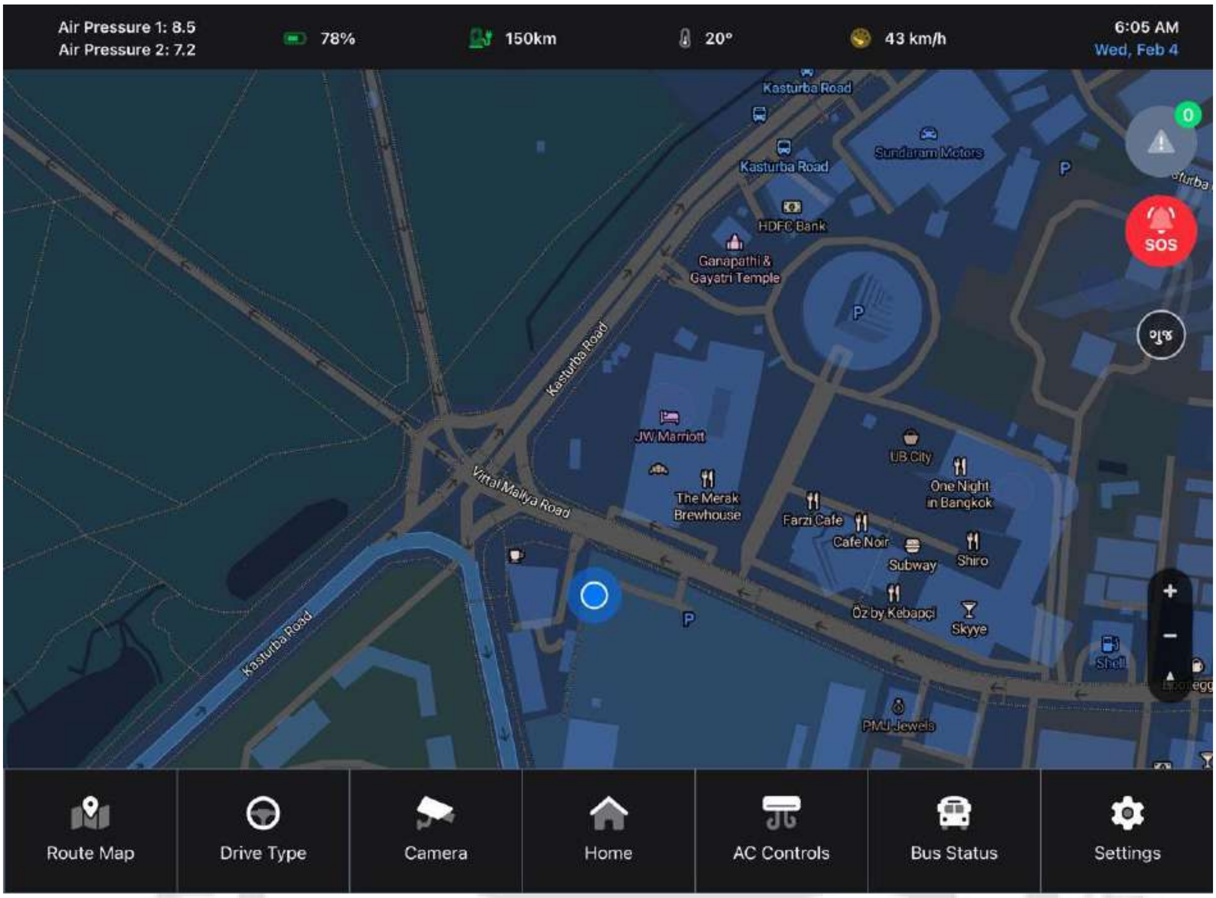

Figure K.1: Home Screen of the research prototype

for emergencies, and zoom in or out on the map. At the bottom, a navigation bar provides easy access to other modules—Route, Drive Type, Camera, Home, AC Controls, Bus Status, and Settings. This simple and consistent layout helps drivers find what they need quickly, maintaining focus on the road while still keeping essential information within view.

K.1.2 Route and Navigation

The Route and Navigation module helps the driver easily select, start, and follow the assigned bus route (see Figure K.2). It is designed to reduce effort and avoid confusion by presenting route information in a clear and structured way. The interface allows the driver to select a route from a simple list of available or recent options. Once a route is chosen, the system displays all stops from the starting point to the final destination. The driver can then press “Start Navigation” to begin the trip. During the journey, the active route is highlighted on the map in blue, while the current bus position is marked by a red arrow. A progress bar shows how far along the route the bus has traveled, and upcoming stops are listed with their distances. This clear, real-time display helps the driver stay informed and focused, without needing to switch screens or perform additional actions.

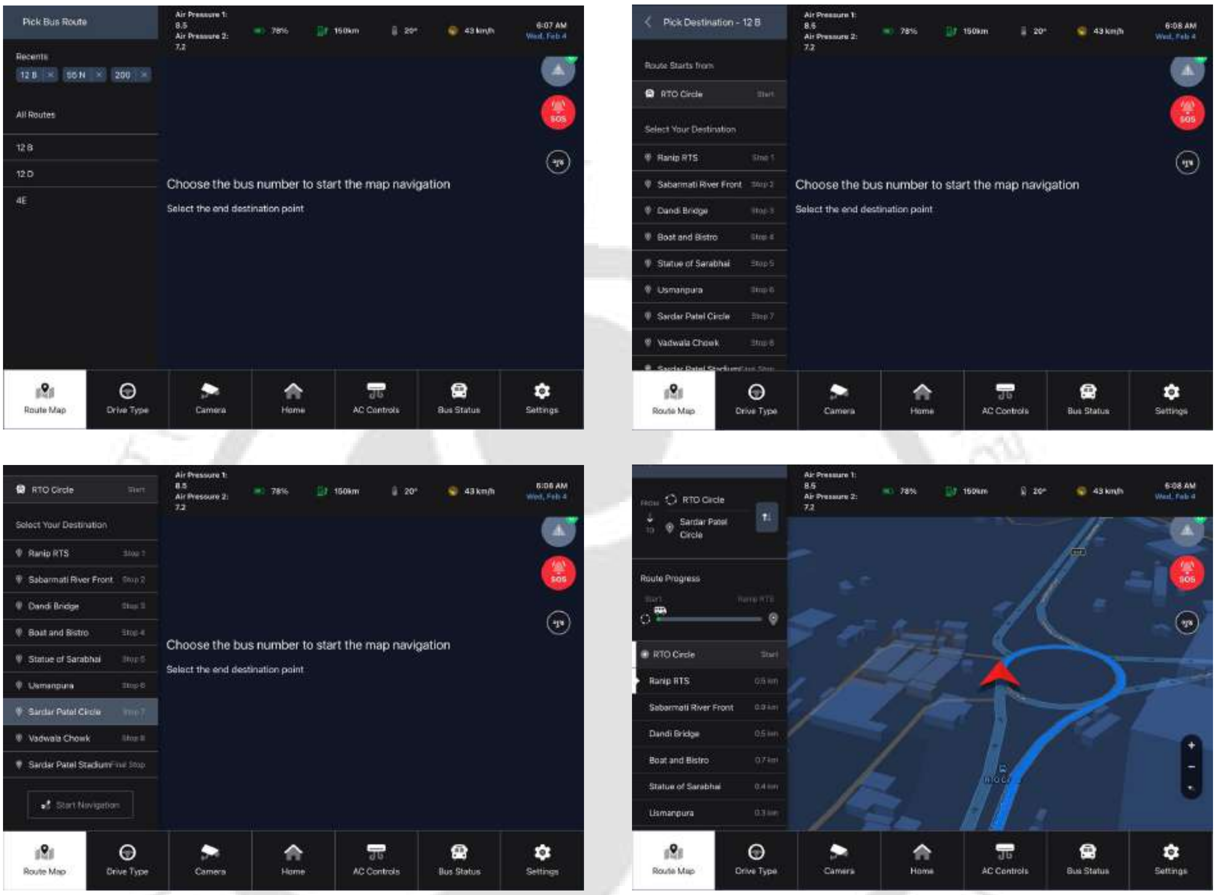

Figure K.2: Steps in route selection and initialization.

K.1.3 Drive Type

The Drive Type module allows the driver to select the current operating mode of the bus quickly and clearly (see Figure K.3). It is designed to minimize confusion and ensure the system accurately reflects the vehicle's status during non-passenger operations. When opened, the module displays a simple list of options such as Empty Run, Dead Run to Depot, Dead Run from Depot, and Breakdown. The driver can select the appropriate mode with a single tap. Once selected, the system immediately confirms the update on screen, ensuring the driver is aware of the active drive type. This feature helps differentiate between passenger and non-passenger operations and supports clear communication with the depot team. The interface is minimal and intuitive, allowing drivers to make quick decisions without distraction during vehicle operation.

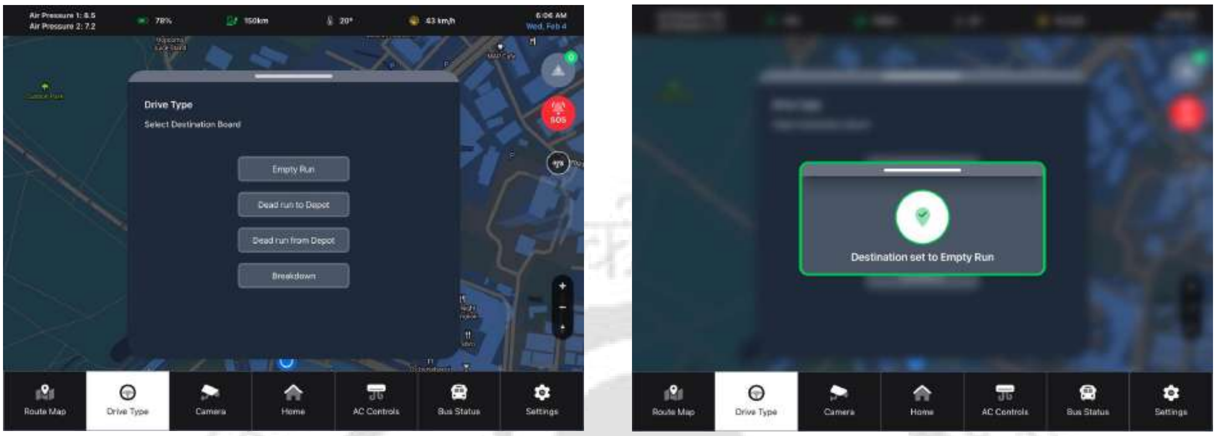

Figure K.3: Drive type steps.

K.1.4 Camera

The Camera module provides real-time visual monitoring of the bus interior and surroundings, helping the driver maintain safety and awareness during operation (see Figure K.4). The interface shows multiple camera views labeled CV1–CV6, each offering a different perspective such as the rear view, side doors, or passenger entry and exit areas. The driver can tap any camera view to enlarge it or switch between views quickly. This module is designed to support safe driving and passenger management, especially during parking, reversing, or door operations. The layout is clean and free of unnecessary details, allowing the driver to access visual information without distraction.

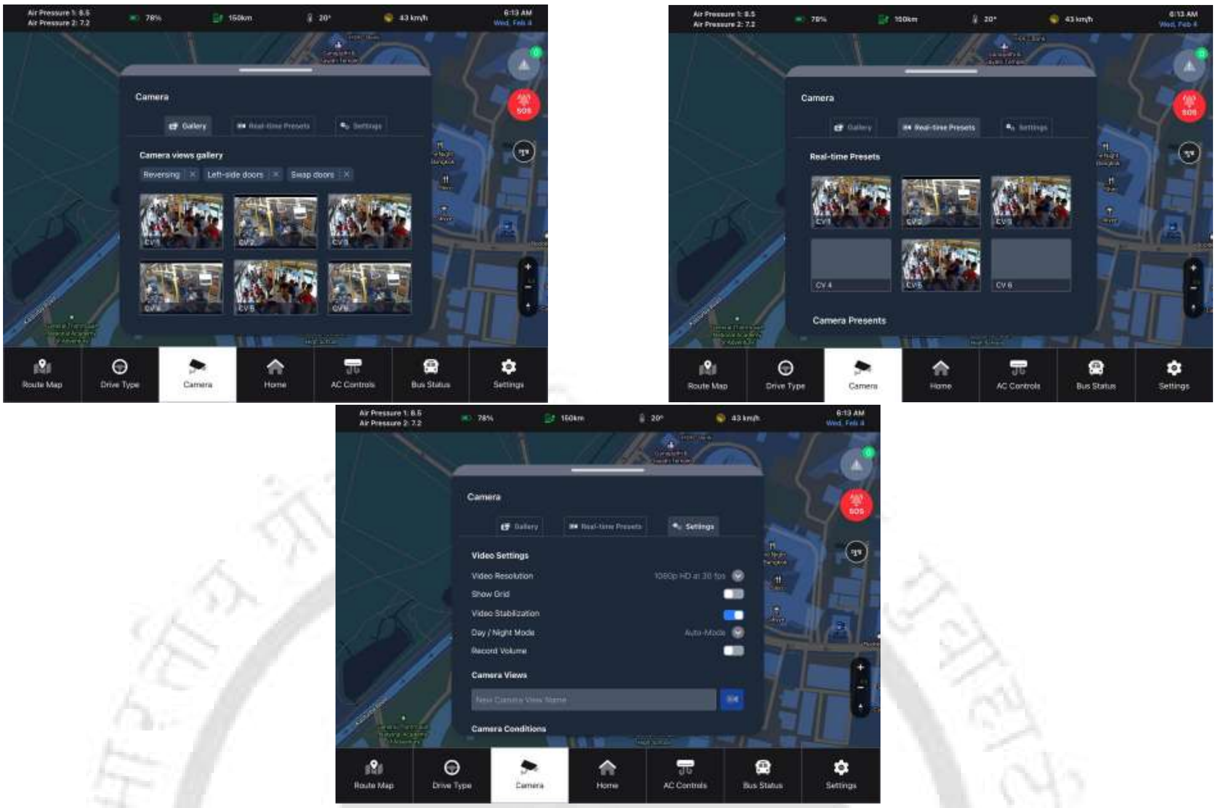

Figure K.4: Camera interface.

K.1.5 AC Control

The AC Control module allows the driver to adjust the bus cabin temperature easily and quickly through a simple, intuitive interface (see Figure K.5). The interface presents all controls within a single window, showing the current cabin temperature, fan speed, and AC mode. Drivers can switch the system On/Off, adjust temperature and fan levels, or select quick modes such as Cool, Dry, Fan, and Swing. Visual feedback is provided instantly for each action, confirming that the adjustment has been registered. The layout avoids clutter and keeps all essential functions within thumb reach, allowing the driver to make quick changes without losing focus on the road.

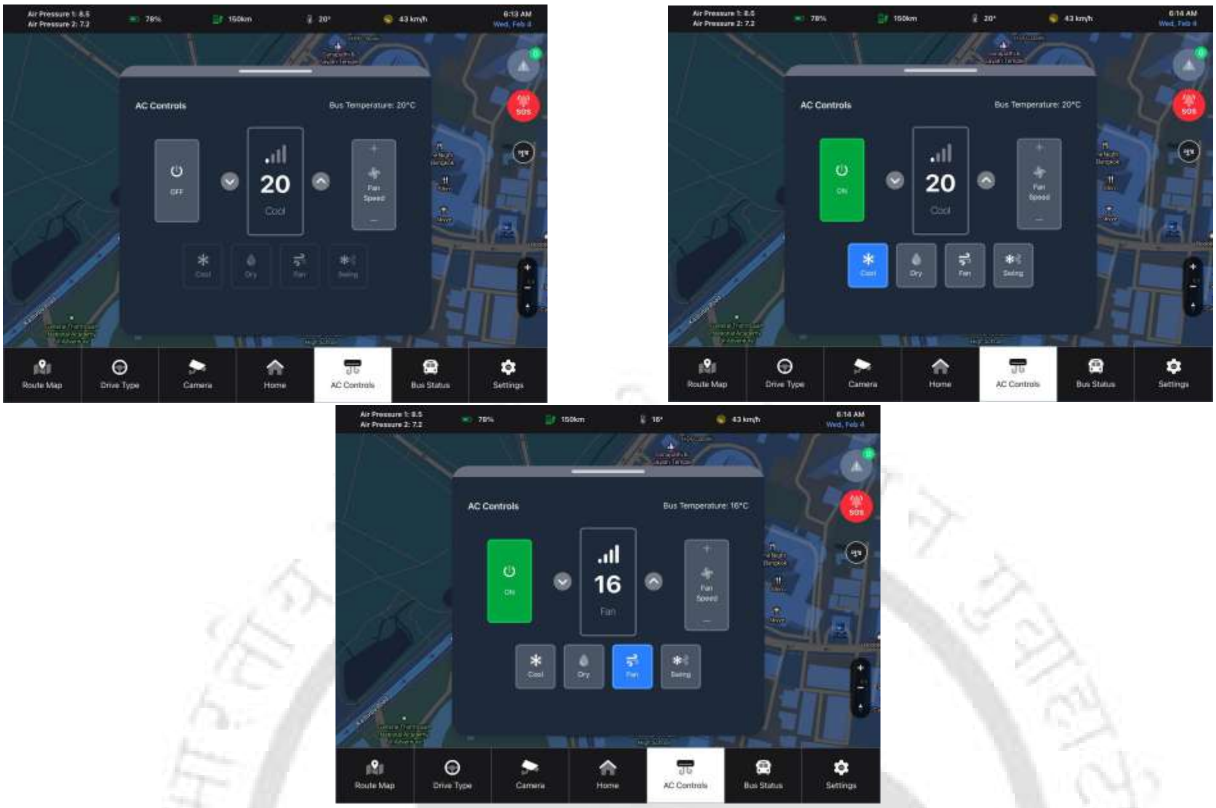

Figure K.5: AC control interface.

K.1.6 Bus Status

The Bus Status module gives the driver a quick and organized overview of the vehicle's health and performance (see Figure K.6). It is divided into three main tabs — System Status, Trip Summary, and Performance Summary — each focusing on a specific aspect of the bus operation. The System Status tab shows live information such as battery percentage, coolant temperature, air pressure, and other vital indicators, helping drivers complete pre-trip checks with confidence. The Trip Summary tab logs route details and recent system events, supporting post-trip reviews and communication with the depot. The Performance Summary tab highlights efficiency-related data such as energy use, operating hours, and driving score, allowing drivers to monitor performance trends over time. All information is displayed in a clean layout with icons and simple text labels. The design ensures that drivers can quickly interpret data without unnecessary visual load or distraction.

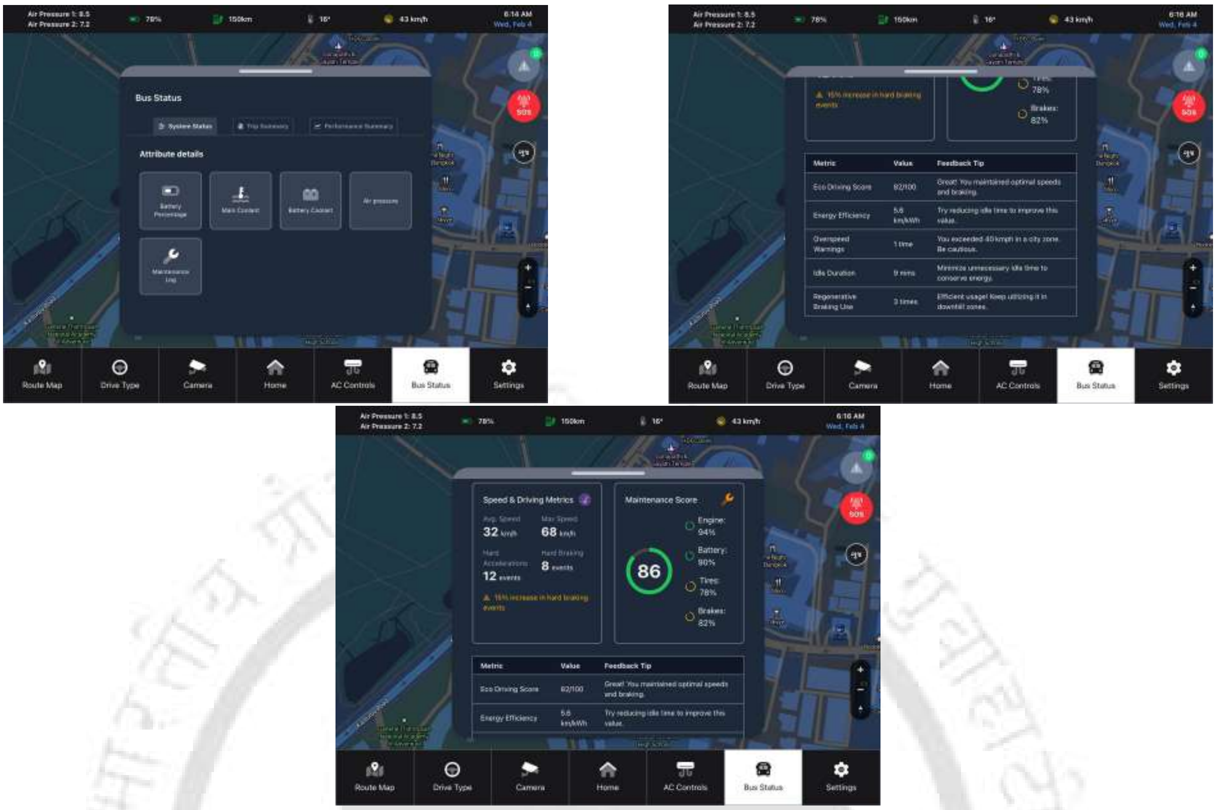

Figure K.6: Bus status module.

K.1.7 Settings

The Settings module allows drivers to customize the dashboard according to their comfort and preferences (see Figure K.7). The layout is simple and easy to navigate, ensuring that adjustments can be made quickly without confusion. The Display settings allow drivers to adjust screen brightness and choose between Light, Dark, or Auto themes for better visibility under different lighting conditions. The Voice settings provide control over voice type, volume, and speed, along with a “Test Voice” option for quick preview. The Alert Settings tab helps drivers manage notifications for system faults or warnings. Alerts can be turned on or off based on preference, ensuring that only critical messages appear during driving. These customizable options allow drivers to maintain focus while ensuring that essential alerts and information remain clear and accessible.

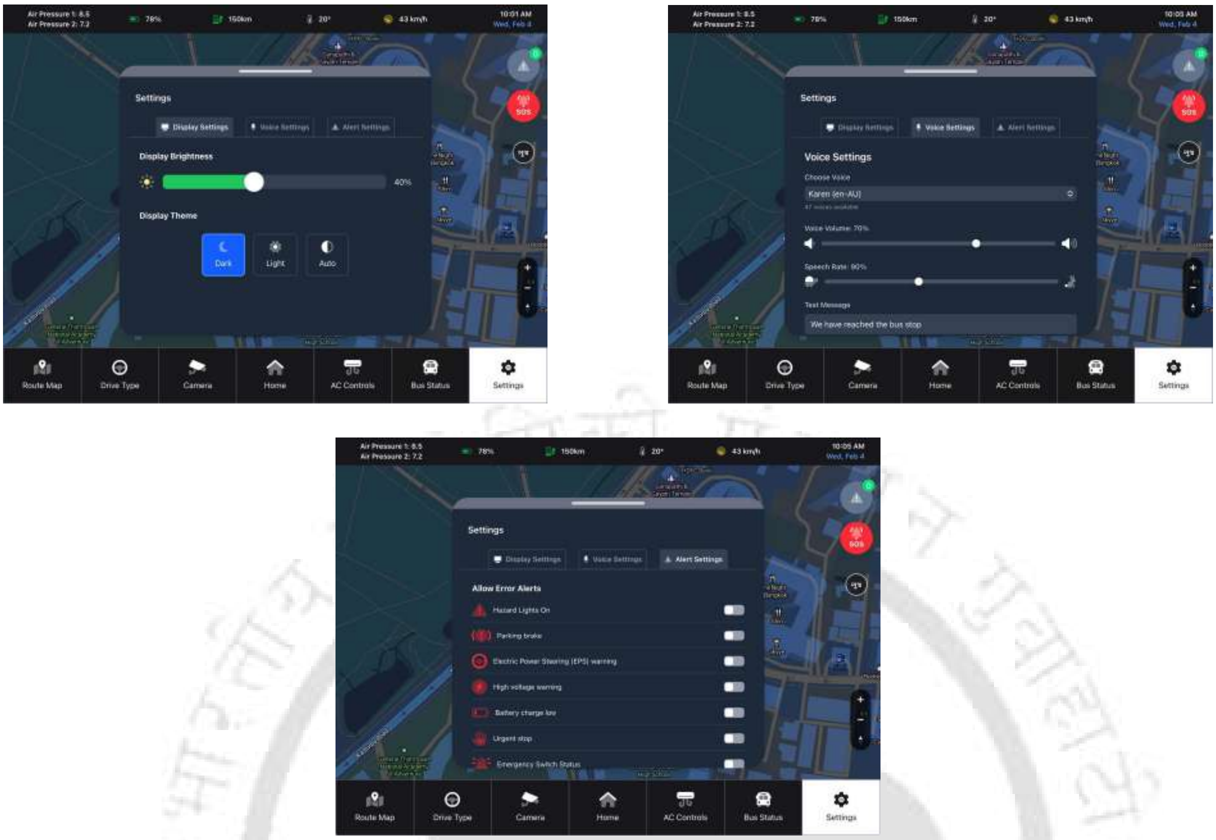

Figure K.7: Settings interface.

K.1.8 Diagnostics and Alerts

The Diagnostics and Alerts module provides clear, color-coded notifications that help drivers stay informed about the vehicle's condition without distraction.

Alerts are categorized into minor and major types based on their urgency (see Figures K.8 and K.9).

- Minor alerts, such as overspeeding or parking brake reminders, appear as small red-bordered pop-ups. These alerts are meant for quick driver action and disappear automatically after acknowledgment.
- Major alerts, such as low battery or high-voltage faults, require immediate attention. They include a "Report" button that sends the issue to the depot. Once reported, the alert

changes color from red (active) to yellow (under review) to green (resolved) providing continuous feedback on the issue's status.

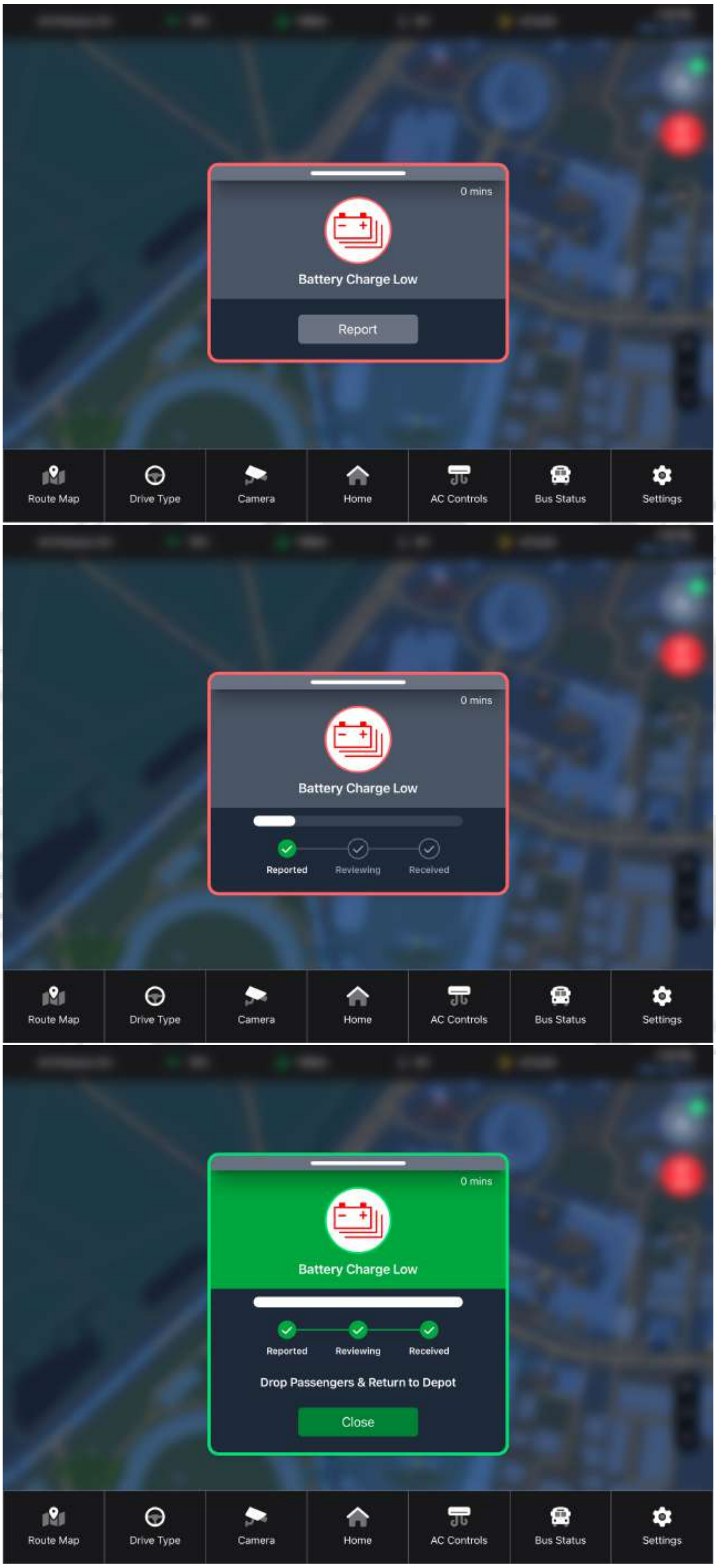

Figure K.8: Major alert workflow.

Alerts are triggered in real-time through a connected Live Alerts Panel operated by the depot or study facilitator (see Figure K.10). This web-based tool sends events directly to the driver's dashboard, categorized as major, minor, or eco-driving alerts (e.g., regenerative braking or energy usage).

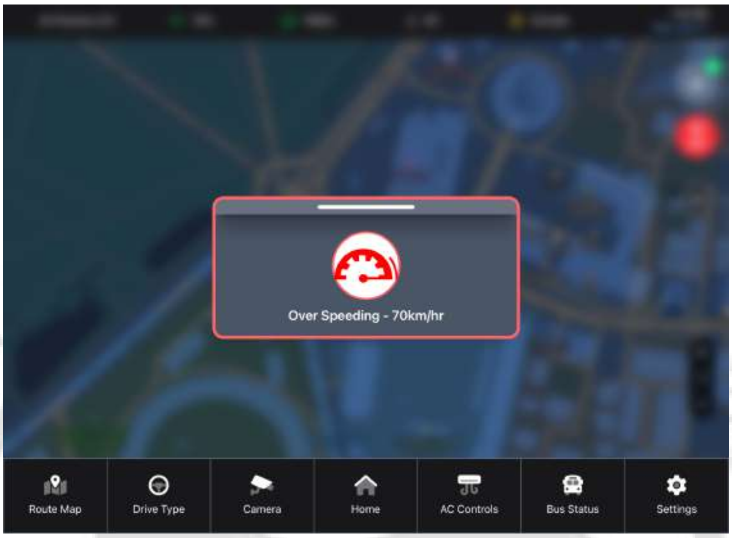

Figure K.9: Minor alert.

Figure K.10: Facilitator's Live Alerts Panel.

The color-coded feedback system and simplified interaction process ensure that drivers can recognize, report, and resolve alerts efficiently, improving both safety and communication between the bus and the depot.

Appendix L

Interview Guide for Usability Test

Hello,

We are research scholars from the Indian Institute of Technology Guwahati, Assam. This session is part of a doctoral research project focused on designing and evaluating a digital dashboard for electric buses. The purpose of this study is to understand how professional drivers interact with a newly developed prototype interface (*eDash*) compared to the existing dashboard system. We request your participation to help us evaluate if this system is good and useful. The interface has been developed based on interviews and field observations with e-bus drivers. Our aim is to create a dashboard that is easy to use, clear to understand, and makes your driving experience better.

You will first get an overview of how the new dashboard system is designed, and then you will get to interact with it. There will be three dashboards that you will use during the session: the current one and two new prototype versions called *eDash–English* and *eDash–Gujarati*. This is just a prototype, so some functions may not work exactly as they would in the final version of the system. The display will appear on a tablet mounted beside the steering wheel inside the electric bus. The bus will stay stationary during the test, but the setup will help you experience how the system would look and feel in a real driving situation.

You will complete a simulated trip divided into three parts: *pre-trip checks*, *in-trip driving and alert handling*, and *end-trip reporting*. Each part includes a few short tasks, and you will receive bilingual task cards (English and Gujarati) to guide you. Please perform the tasks as you normally would during your regular driving routine.

While you perform the tasks, please think aloud—share what you are noticing, expecting, or finding confusing. There are no right or wrong answers; we are evaluating the dashboard, not you. We will record audio and screen interactions to help us analyze your experience later. Please let us know if you have any questions before we begin.

We will begin with a few short questions to get to know you better:

1. What is your name and gender?
2. How old are you?
3. What is your highest level of education?
4. Which bus do you currently drive?
5. How many years of total driving experience do you have?
6. How many years of experience do you have driving electric buses?
7. How comfortable are you with using digital technology?
8. Which language do you prefer for the dashboard interface?
9. Have you taken part in any of our earlier studies?

Let's look at the new dashboard interface! There are two versions of the prototype: *eDash–English* and *eDash–Gujarati*. Both have the same layout and features, but the language of the text and alerts is different. In this design, several functions that were earlier scattered across different panels have been brought together in one place. You can now view and control features such as the AC temperature, camera view, bus status, Distance-to-Empty (DTE), and diagnostic alerts directly from a single screen. The goal is to make it easier for you to monitor and manage everything without switching between devices or menus.

What are your first impressions of this combined layout? Does it feel clear and convenient, or do you find any section confusing at first glance?

We will now try three different scenarios. Before we begin, let's take a short tour of the dashboard to understand its main functions and layout. You will get to explore how each section works and what kind of information it provides.

- **Dashboard Overview:** The dashboard combines several key functions:*route selection, AC control, camera view, bus status, and diagnostic alerts* in one interface. You can switch between these modules using the icons at the top and bottom of the screen.
  - What are your first thoughts about this layout?
  - Do you find it easy to identify where each function is located?
- **Route Setup and Drive Type Setting:** The route and drive type system works in the same way as on the DDU. Please explore the menu and try setting the route number and drive type to see how it functions.
  - How certain are you that you entered the route and drive type correctly?
  - Did any step feel unclear or confusing while navigating the menu?
- **AC Control:** The AC module allows you to view and adjust temperature directly from the screen. You can set the cabin temperature using the control buttons.
  - Was it easy to change the temperature?
  - Did you notice the feedback when the setting was applied?
- **Camera View:** You can switch to the camera view to check passenger doors or monitor safety.
  - Was it clear how to open and close the camera view?
  - Do you think this feature would be useful during daily operation?
- **Diagnostics and Alerts:** We have streamlined the diagnostics system so that drivers can view warnings, understand detected issues, and send reports directly to the depot from the dashboard. You can also receive messages from the depot within the same system, without needing a mobile phone. Alerts are color-coded and can be reported with a single tap.
  - Did the color and message make it clear how serious the issue was?
  - Was the reporting process simple and easy to understand?

- **Bus Status: Trip Summary and Reporting** This section includes new features that let you view your trip summary, check performance reports, and send maintenance feedback directly to the depot.
  - Was it easy to find and review your trip information?
  - Do you think this summary would be useful for your daily reporting and communication with the depot?
- **General Feedback:**
  - Are these the kinds of functions you expected in a driver's dashboard?
  - Is there anything important that you feel is missing?
  - Was there something included that you particularly appreciated?

Scenario and Task Execution

Now, let's start the main part of the session. We will go through three short trip situations just like in your daily driving: *Pre-Trip Checks*, *In-Trip Driving and Alerts*, and *End-Trip Reporting*. The bus will stay parked during the whole session, but please imagine that you are operating it normally. Whenever I mention an action, you can tap the screen as if you are pressing the real controls in the bus.

We will test three dashboard versions: the *Current Dashboard* (control version) and two new prototypes called *eDash–English* and *eDash–Gujarati*. Each participant will experience all three versions, and the order of testing will be randomly assigned to avoid sequence bias. A short five-minute break will be provided between each test condition to reduce fatigue and reset learning effects.

Note that the *Pre-Trip Checks* scenario will be conducted for all three dashboard conditions to maintain baseline comparability across systems. The subsequent two scenarios: *In-Trip Driving and Alerts* and *End-Trip Reporting* will be performed only on the prototype versions, as these features were not present in the current dashboard.

Scenario 1: Pre-trip Checks Let's start with your pre-trip routine. Please look at the dashboard and check the following one by one.

- What is the current air pressure shown on the screen? *(Wait for response.)* Please tell me how easy this task was for you on a 7-point scale, where 1 means very difficult and 7 means very easy.
- Can you tell me the date and time displayed? Please rate how easy that was.
- Please check and tell me the current State of Charge (SoC). How easy or difficult did that feel?
- Now, try setting the AC temperature to 16°C. Did you notice any feedback when it changed? Please rate how easy it was to adjust the temperature.
- Check the door and light status. Are they open or closed? How easy was it to find that information?
- What does the bus status panel show right now—any faults or errors? Please rate how easy that was to identify.
- Finally, please set the route sign to "12B." Was it simple to do? Please rate how easy that task felt.

Scenario 2: In-Trip Driving and Alerts Now, imagine that you have started driving. The dashboard will display alerts while you are "in motion."

- An alert has appeared—what does it indicate? *(Wait for response.)* Please tell me how easy it was to recognize and understand this alert.
- Now you've received a low-battery warning. Please send a message to the depot about it. Was it simple to locate and send the report? Please rate the ease of this task.
- Finally, switch the drive type to *Depot mode.* Did you find that option easily? Please rate how easy it was to complete this step.

How did this screen feel overall during driving—was the information visible and easy to read without distraction?

Scenario 3: End-Trip Reporting Now you have completed your route and parked at the depot. We will check how the system helps with end-trip reporting and maintenance.

- Please open and view your trip summary. What do you notice there? Please rate how easy it was to find and review that information.
- Next, check the performance summary. Was it easy to interpret? Please rate the ease of this step.
- Finally, send a maintenance message to the depot. Was it clear how to do that? Please rate how easy it was to complete this action.

That completes the three scenarios. Please take a five-minute break before moving on to the next dashboard version.

Post-Test Debrief

Now that you've completed this dashboard version, we'll take a short pause. I'll ask you to fill out three short rating sheets about your experience with this dashboard:

- the System Usability Scale (SUS),
- the Rating Scale for Mental Effort (RSME), and
- the Van der Laan Acceptance Scale.

These will help us understand how usable, mentally demanding, and acceptable this version felt to you. Please answer based on your experience just now, before we move to the next dashboard. After this, we'll take a short five-minute break before starting the next one. Once all three dashboards are done, we'll sit together for a short discussion about your overall experience.

Post-Session Interview

Now that you've finished trying all three dashboards, I'd like to ask you a few quick questions. There are no right or wrong answers; you just tell me what you honestly felt.

- Which dashboard did you like the most overall?
- Why did you prefer that one?
- What could be improved to make it better for your daily use?

You can also tell me anything else you noticed, what you liked, what felt confusing, or what might make it easier to use in your regular driving.

Closing Script

That brings us to the end of today's session. Thank you very much for your time and for sharing your thoughts so openly. Your feedback will really help us make this digital dashboard more useful and comfortable for drivers like you in everyday work. Before we finish, is there anything else you'd like to add—any suggestions, or something that you feel could be improved further? We truly appreciate every comment. Thank you once again for participating in this study. Your input will directly contribute to improving the safety, usability, and overall driving experience of electric buses.

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Appendix M

Participant Briefing Script for EV Bus Usability Study

Hello, and thank you for participating in this study. We are working to improve dashboard interfaces used in electric buses so that they become easier to use, safer, and better aligned with real operational conditions. During this session, you will interact with two dashboard systems and complete a short sequence of tasks similar to your daily driving activities. One system represents the existing dashboard, and the other is a redesigned digital interface displayed on a tablet.

Purpose of the Study The aim of this study is to understand how the dashboard designs support your routine driving workflow. While completing the tasks, we are interested in observing how naturally you can:

- Notice and interpret information displayed on the dashboard
- Understand alerts or system warnings
- Perform actions such as checking bus readiness or reporting an issue
- Navigate routine pre-trip, in-trip, and post-trip steps

There are no right or wrong answers. This evaluation is focused on the system design—not on your performance.

Scenario Context Please imagine yourself in a normal workday situation inside your bus. The dashboard may show information such as State of Charge (SoC), battery status, alerts (e.g., overspeeding, low pressure), or maintenance reminders. You may interact with the dashboard just as you would during your usual shift.

During the Session For each task, we will describe a short situation and ask you to respond using the dashboard. You may think aloud if it feels comfortable—sharing what you are noticing or expecting. At the end of each dashboard session, we will ask a few questions, and you will fill out short rating forms about your experience.

Ethics and Comfort Participation is voluntary. You may stop at any time or choose not to answer a question. Your identity will remain confidential, and your responses will be used only for research and design improvement.

Before We Begin If you have any questions, please feel free to ask. If not, we will begin with the first system.

Appendix N

Participant Consent Form for E-Bus Usability Study

Purpose: This study evaluates a driver interface for electric buses.

Procedure: You will perform simple tasks using two interfaces: the current system and a proposed tablet-based prototype.

Voluntary Participation: You may withdraw at any time without any consequence.

Confidentiality: No personal identifiers will be stored. Your responses will remain anonymous.

Risks & Benefits: No known risks. Your input will help improve future EV dashboard designs.

Consent Statement: I have understood the information above and voluntarily agree to participate in the study.

Signature:

Date:

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Appendix O

Rating Scale Mental Effort (RSME)

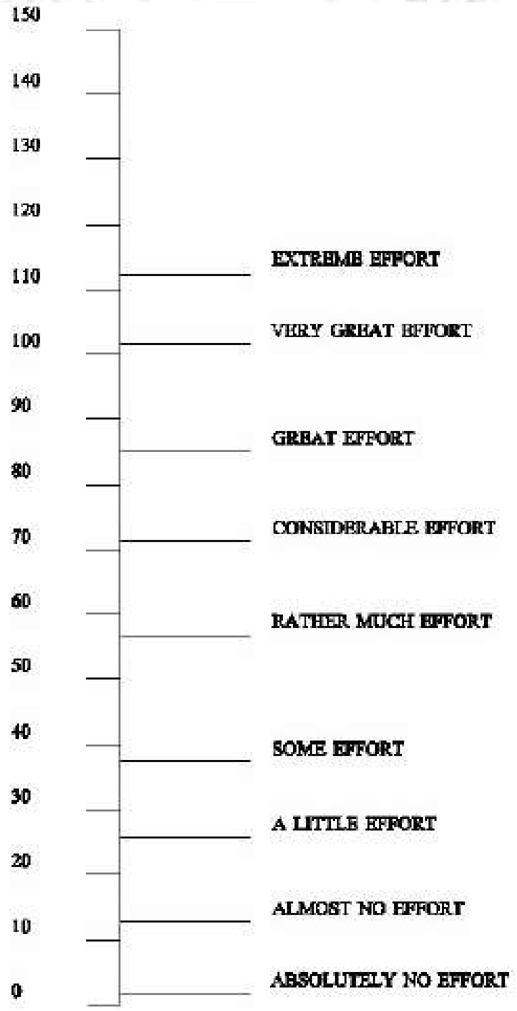

Figure O.1: Rating Scale Mental Effort (RSME) used for measuring subjective mental workload

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Appendix P

System Usability Scale (SUS)

Instructions: Please rate the following statements on a scale from 1 to 5, where 1 represents "Strongly Disagree" and 5 represents "Strongly Agree."

A. I think that I would like to use this electric vehicle bus interface frequently.

B. I found the electric vehicle bus interface unnecessarily complex.

C. I thought the electric vehicle bus interface was easy to use.

D. I think that I would need the support of a technical person to be able to use this interface.

E. I found the various functions in the interface were well integrated.

F. I thought there was too much inconsistency in the interface.

G. I would imagine that most people would learn to use this interface very quickly.

H. I found the interface very cumbersome to use.

I. I felt confident using the interface.

J. I needed to learn a lot of things before I could get going with this interface.

Scale					
Rating	1	2	3	4	5
Label	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree

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Appendix Q

Acceptance Scale

Please tick a box on every line. I found such a system…

Useful	— — — — —	Useless
Pleasant	— — — — —	Unpleasant
Bad	— — — — —	Good
Nice	— — — — —	Annoying
Effective	— — — — —	Superfluous
Irritating	— — — — —	Likeable
Assisting	— — — — —	Worthless
Undesirable	— — — — —	Desirable
Raising Alertness	— — — — —	Sleep-inducing

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Appendix R

Hierarchical Task Analysis (HTA)

A Hierarchical Task Analysis (HTA) was conducted to identify and structure the main user actions involved in operating the proposed electric bus dashboard interface. The analysis decomposes each operational phase into primary tasks and subtasks, representing the step-by-step actions a driver would perform when interacting with the interface. The HTA served as the foundation for the subsequent Cognitive Walkthrough (CW), where each subtask was evaluated for learnability and usability.

Thirteen representative tasks were grouped into three phases: *Pre-trip*, *In-trip*, and *Post-trip*. Each task was broken down into its constituent subtasks, as shown below.

R.1 Pre-trip Tasks

Task 1: Check Air Pressure

1. Locate the air pressure gauge on the dashboard.
2. Identify Gauge 1 and Gauge 2.
3. Read the displayed pressure values.
4. Interpret whether both gauges indicate safe pressure levels.

Task 2: Check Date and Time

1. Locate the date and time indicator on the screen.
2. Read the current date and time.
3. Verify that the displayed information is correct.

Task 3: Check State of Charge (SoC)

1. Locate the SoC indicator on the dashboard.
2. Read the percentage of charge.
3. Interpret whether the charge level is sufficient for the trip.

Task 4: Set AC Temperature to 16°C

1. Locate the AC control interface.
2. Open the temperature setting.
3. Adjust temperature to 16°C using the control.
4. Confirm that the display reflects the new temperature.

Task 5: Verify Door and Indoor Light Status

1. Locate the door and light indicators.
2. Identify the state (open/closed, on/off) of each element.
3. Confirm that all are safe for operation.

Task 6: Check Bus Status

1. Open the system status display.

2. Review readiness and fault indicators.
3. Note any errors or alerts displayed.

Task 7: Set Route Sign to "12B"

1. Locate the route sign input area.
2. Enter the route number "12B".
3. Confirm that the route sign updates correctly.

R.2 In-trip Tasks

Task 8: Interpret Overspeeding Alert

1. Notice the alert icon or sound.
2. Interpret the meaning of the alert.
3. Reduce speed accordingly.
4. Verify that the alert disappears.

Task 9: Send Low-Battery Alert Notification to Depot

1. Notice the low battery icon.
2. Open the communication or alert menu.
3. Select "Send Alert to Depot".
4. Wait for acknowledgment or confirmation message.

Task 10: Set Drive Mode to Depot

1. Locate the drive mode selector.
2. Select “Depot” mode.
3. Confirm that the mode change is displayed.

R.3 Post-trip Tasks

Task 11: View Trip Summary

1. Locate the “Trip Summary” option.
2. Open the summary page.
3. Review the trip duration, distance, and energy data.

Task 12: View Performance Report

1. Locate the “Performance Report” button.
2. Open the performance screen.
3. Review and interpret efficiency metrics.

Task 13: Notify Depot for Maintenance

1. Locate the “Maintenance Report” option.
2. Select or type the maintenance issue.
3. Send the report and confirm acknowledgment.

Output of HTA

The completed HTA provides a structured decomposition of each driver task, identifying decision points and interface interactions to be further examined in the Cognitive Walkthrough. Each subtask will subsequently be evaluated against the four CW questions: (1) Right Goal, (2) Notice Action, (3) Associate Action, and (4) Understand Feedback.

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Appendix S

Cognitive Walkthrough Analysis

The following tables summarize the results of the Cognitive Walkthrough (CW) conducted on the dashboard prototype. Each subtask was evaluated using the four cognitive walkthrough questions:

1. Will the user try to achieve the right effect?
2. Will the user notice that the correct action is available?
3. Will the user associate the correct action with the effect that the user is trying to achieve?
4. If the correct action is performed, will the user see that progress is being made toward the solution of the task?

If a question was answered with "No", the reason was recorded in the "Fail Story", and the related usability problem was stated. This section documents the walkthrough results for all thirteen dashboard tasks.

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References

, 2016. Tcrp report 185: Bus operator workstation design for improving occupational health and safety. Tech. rep., Transportation Research Board, National Academies of Sciences, Engineering, and Medicine, Washington, DC.

, 2017. Iso 15008:2017 road vehicles — ergonomic aspects of transport information and control systems. Available from ISO Online Browsing Platform.

Andersson, P., Ericsson, J., 2011. Redesign of an instrument panel cluster in the electric vehicle saab zero emission.

Andréasson, F., Boman, C., 2022. A comfortable transition to the electric–terminal tractor investigating the design process of developing a dashboard interface for an electric terminal tractor.

Astrain, J. J., Falcone, F., Lopez-Martin, A. J., Sanchis, P., Villadangos, J., Matias, I. R., 2021. Monitoring of electric buses within an urban smart city environment. IEEE Sensors Journal 22 (12), 11364–11372.

Automotive Research Association of India (ARAI), 2010. Ais-071 (automotive industry standard): Code of practice for road vehicles — installation of lighting and light-signalling devices. https://hmr.araiindia.com/api/AISFiles/AIS_071_Rev_1_and_Amd_f470ee21-99c9-4d34-8725-bf6674db96d6.pdf, indian Automotive Industry Standard for tell-tale symbols and alerts.

Ba, T., Li, S., Gao, Y., Wang, S., 2022. Design of a human–computer interaction method for intelligent electric vehicles. World Electric Vehicle Journal 13 (10), 179.

Barbosa, F. C., 2024. Battery electric transit bus fleet implementation challenges-infrastructure and operational topics review. Tech. rep., SAE Technical Paper.

Boadi-Kusi, S. B., Amoako-Sakyi, R. O., Abraham, C. H., 2023. Access to public transport to persons with visual disability: A scoping review. British Journal of Visual Impairment.

Board, T. R., 1997. Tcrp report 25: Bus operator workstation evaluation and design guidelines. Tech. rep., Transit Cooperative Research Program.
URL `https://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_25.pdf`

Braun, V., Clarke, V., 2013. Successful qualitative research: A practical guide for beginners.

Brooke, J., et al., 1996. Sus-a quick and dirty usability scale. Usability evaluation in industry 189 (194), 4–7.

Bryson, J. M., 2004. What to do when stakeholders matter: stakeholder identification and analysis techniques. Public management review 6 (1), 21–53.

Burns, P., Harbluk, J., Foley, J. P., Angell, L., 2010. The importance of task duration and related measures in assessing the distraction potential of in-vehicle tasks. In: Proceedings of the 2nd international conference on automotive user interfaces and interactive vehicular applications. pp. 12–19.

Chang, F., Gunasekara, Y., 2013. A study on the improvement of the bus driver's user interface.

De Meyer, D., Kottner, J., Beele, H., Schmitt, J., Lange, T., Van Hecke, A., Verhaeghe, S., Beeckman, D., 2019. Delphi procedure in core outcome set development: rating scale and consensus criteria determined outcome selection. Journal of Clinical Epidemiology 111, 23–31.

Farahpoor, M., Esparza, O., Soriano, M., 2023. Comprehensive iot-driven fleet management system for industrial vehicles. IEEE access.

Feng, F., Liu, Y., Chen, Y., 2018. Effects of quantity and size of buttons of in-vehicle touch screen on drivers' eye glance behavior. International Journal of Human–Computer Interaction 34 (12), 1105–1118.

Fleiss, J. L., Cohen, J., 1973. The equivalence of weighted kappa and the intraclass correlation coefficient as measures of reliability. Educational and psychological measurement 33 (3), 613–619.

François, M., Fort, A., Crave, P., Osiurak, F., Navarro, J., 2019. Gauges design for a digital instrument cluster: efficiency, visual capture, and satisfaction assessment for truck driving. International Journal of Industrial Ergonomics 72, 290–297.

Francois, M., Osiurak, F., Fort, A., Crave, P., Navarro, J., 2016. Analogue versus digital speedometer: effects on distraction and usability for truck driving. In: European Conference on human Centred Design for Intelligent Transport Systems. pp. 8–p.

François, M., Osiurak, F., Fort, A., Crave, P., Navarro, J., 2017a. Automotive HMI design and participatory user involvement: review and perspectives. Ergonomics 60 (4), 541–552. URL http://dx.doi.org/10.1080/00140139.2016.1188218

François, M., Osiurak, F., Fort, A., Crave, P., Navarro, J., 2017b. Automotive hmi design and participatory user involvement: review and perspectives. Ergonomics 60 (4), 541–552.

François, M., Osiurak, F., Fort, A., Crave, P., Navarro, J., 2021. Usability and acceptance of truck dashboards designed by drivers: Two participatory design approaches compared to a user-centered design. International journal of industrial ergonomics 81, 103073.

Franke, T., Görges, D., Arend, M. G., 2019. The energy interface challenge. towards designing effective energy efficiency interfaces for electric vehicles. In: Proceedings of the 11th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. pp. 35–48.

Franke, T., Krems, J. F., 2013. Interacting with limited mobility resources: Psychological range levels in electric vehicle use. Transportation Research Part A: Policy and Practice 48, 109–122.
URL http://dx.doi.org/10.1016/j.tra.2012.10.010

Franke, T., Trantow, M., Günther, M., Krems, J. F., Zott, V., Keinath, A., 2015. Advancing electric vehicle range displays for enhanced user experience: the relevance of trust and adaptability. In: Proceedings of the 7th international conference on automotive user interfaces and interactive vehicular applications. pp. 249–256.

Gibson, J. J., 1966. The senses considered as perceptual systems.

Gibson, Z., Butterfield, J., Marzano, A., 2016. User-centered Design Criteria in Next Generation Vehicle Consoles. Procedia CIRP 55, 260–265.

Gödker, M., Herrmann, D., Franke, T., 2018. User perspective on eco-driving hmis for electric buses in local transport. In: Mensch und Computer 2018-Tagungsband. Gesellschaft für Informatik eV, pp. 10–18420.

Gödker, M., Moll, V. E., Franke, T., 2024. Energy consumption displays in electric vehicles: Differential effects on estimating consumption and experienced energy dynamics awareness. Human Factors, 00187208231222154.

Gödker, M., Schmees, S., Bernhardt, L., Görges, D., Franke, T., 2025. Two types of eco-driving support–the effects of an instantaneous consumption and an optimal speed display on energy-efficient driving and energy dynamics awareness. International Journal of Human–Computer Interaction, 1–20.

Gödker, M., Schrills, T., Franke, T., 2024. Improved Ecodriving Using Instantaneous Consumption Displays in an Electric Vehicle Driving Simulator: The Role of Energy Dynamics Awareness. Human Factors.

Harvey, C., Stanton, N. A., 2013. Usability evaluation for in-vehicle systems. Crc Press.

Hassenzahl, M., 2010. Experience design: Technology for all the right reasons. Vol. 8. Morgan & Claypool Publishers.

Holtzblatt, K., Beyer, H., 1998. Getting started on a contextual project. In: CHI 98 Conference Summary on Human Factors in Computing Systems. pp. 137–138.

India, W., 2024. Open e-bus blueprint: Scaling electric buses in india. Tech. rep., World Resources Institute.
URL https://wri-india.org/sites/default/files/Open%20E-bus%20blueprint_working%20paper_web.pdf

International Organization for Standardization, 2019a. Iso 9241-210:2019 ergonomics of human-system interaction — part 210: Human-centred design for interactive systems. https://www.iso.org/standard/77520.html, accessed: 2025-09-12.

International Organization for Standardization, 2019b. Iso 9241-210:2019 ergonomics of human-system interaction — part 210: Human-centred design for interactive systems.

J. D. v. d. L., Heino, A., de Waard, D., 1997. A simple procedure for the assessment of acceptance of advanced transport telematics. Transportation Research Part C: Emerging Technologies 5 (1), 1–10.

Ji, Y., He, L., Zhang, H. M., 2014. Bus drivers' responses to real-time schedule adherence and the effects on transit reliability. Transportation Research Record 2417 (1), 1–9.

Jiang, K., Shao, C., Feng, Z., Yue, Q., Yu, Z., Zhu, S., Huang, Z., 2021. The impact of e-bus satisfaction on driving behaviour: A questionnaire-based study on e-bus drivers. Transportation research part F: traffic psychology and behaviour 83, 238–251.

Jönsson, R., Nilsson, M., 2019. Developing an interface for bus drivers: Simplifying complexity through usability and user experience.

Jung, J., Lee, S., Hong, J., Youn, E., Lee, G., 2020. Voice+ tactile: Augmenting in-vehicle voice user interface with tactile touchpad interaction. In: Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems. pp. 1–12.

Jung, M. F., Sirkin, D., Gür, T. M., Steinert, M., 2015. Displayed uncertainty improves driving experience and behavior: The case of range anxiety in an electric car. In: Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems. pp. 2201–2210.

Jung, S., Park, J., Park, J., Choe, M., Kim, T., Choi, M., Lee, S., 2021. Effect of touch button interface on in-vehicle information systems usability. International Journal of Human–Computer Interaction 37 (15), 1404–1422.

Jung, Y., Others, 2020. Voice+: Multimodal Voice Interface for In-Vehicle Systems. ACM Transactions on Computer-Human Interaction.

Khan, T., Williams, M., Wellings, T., Robertson, D., Binersley, J., 2012. Designing the human machine interface to address range anxiety. World Electric Vehicle Journal 5 (1), 72–82.

Kujala, T., Sarkar, A., 2025. Evaluating in-car tasks' distraction effects with drive-in lab. In: Proceedings of the 2025 CHI Conference on Human Factors in Computing Systems. pp. 1–24.

Landau, M., Loehmann, S., 2014. The Energy Flow: A Multimodal Dashboard Prototype for Electric Vehicles. In: Proceedings of the International Conference on Automotive User Interfaces.

Landis, J. R., Koch, G. G., 1977. The measurement of observer agreement for categorical data. biometrics, 159–174.

Le, D. H., Ihme, K., Köster, F., 2023. Involving users in automotive hmi design: A participatory approach. AHFE International.

Li, R., Chen, Y. V., Sha, C., Lu, Z., 2017. Effects of interface layout on the usability of in-vehicle information systems and driving safety. Displays 49, 124–132.

Lin, S.-C., Hsu, C.-H., Talamonti, W., Zhang, Y., Oney, S., Mars, J., Tang, L., 2018. Adasa: A conversational in-vehicle digital assistant for advanced driver assistance features. In: Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology. pp. 531–542.

Lipman, T. E., 2025. Recent developments and challenges with electric bus implementation for transit fleets. Current Sustainable/Renewable Energy Reports 12 (1), 19.

Loehmann, S., Landau, M., Koerber, M., Butz, A., 2014. Heartbeat: Experience the pulse of an electric vehicle. In: Proceedings of the 6th international conference on automotive user interfaces and interactive vehicular applications. pp. 1–10.

Lundström, A., 2014. Differentiated driving range: Exploring a solution to the problems with the" guess-o-meter" in electric cars. In: Proceedings of the 6th international conference on automotive user interfaces and interactive vehicular applications. pp. 1–8.

Lundström, A., Bogdan, C., 2012. Cope1–taking control over ev range. adjunct proc. Automitive-UI 2012, 17–18.

Lundström, A., Bogdan, C., 2014. Having a lead foot? exploring how to visualize energy consumption and driving in electric cars. In: Adjunct Proceedings of the 6th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. pp. 1–4.

Lundström, A., Bogdan, C., 2017. Design to support energy management for electric car drivers. In: Automotive User Interfaces: Creating Interactive Experiences in the Car. Springer, pp. 121–141.

Lundström, A., Bogdan, C., Kis, F., Olsson, I., Fahlén, L., 2012. Enough power to move: dimensions for representing energy availability. In: Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services. pp. 201–210.

Lundström, A., Hellström, F., 2015. Getting to know electric cars through an app. In: Proceedings of the 7th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. pp. 289–296.

Mandujano-Granillo, J. A., Candela-Leal, M. O., Ortiz-Vazquez, J. J., Ramirez-Moreno, M. A., Tudon-Martinez, J. C., Felix-Herran, L. C., Galvan-Galvan, A., Lozoya-Santos, J. D. J., 2024. Human-machine interfaces: a review for autonomous electric vehicles. IEEE Access.

Mayas, C., Hörold, S., Rosenmöller, C., Krömker, H., 2014. Evaluating methods and equipment for usability field tests in public transport. In: International Conference on Human-Computer Interaction. Springer, pp. 545–553.

Ministry of Heavy Industries, Government of India, 2019. Fame india scheme phase ii. Https://fame2.heavyindustry.gov.in.

Ministry of Housing and Urban Affairs, Government of India, 2026. Pm e-bus sewa scheme dashboard.

Mohammed, A., Yazid, M. R. M., Zaidan, B., Zaidan, A., Garfan, S., Zaidan, R. A., Ameen, H. A., Kareem, Z. H., Malik, R. Q., 2021. A landscape of research on bus driver behavior: taxonomy, open challenges, motivations, recommendations, limitations, and pathways solution in future. IEEE Access 9, 139896–139927.

Musabini, A., Nguyen, K., Rouyer, R., Lilis, Y., 2020. Influence of adaptive human–machine interface on electric-vehicle range-anxiety mitigation. Multimodal Technologies and Interaction 4 (1), 4.

Nehiba, C., 2024. Electric vehicle usage, pollution damages, and the electricity price elasticity of driving. Journal of environmental economics and management 124, 102915.

Neumann, I., Krems, J. F., 2016. Battery electric vehicles – implications for the driver interface. Ergonomics 59 (3), 331–343.
URL http://dx.doi.org/10.1080/00140139.2015.1078914

Nielsen, J., 1994. Enhancing the explanatory power of usability heuristics. In: Proceedings of the SIGCHI conference on Human Factors in Computing Systems. pp. 152–158.

Nilsson, M., Olsson, A., 2014. Redesign of instrument cluster-user-centred product development at volvo bus corporation.

Norman, D. A., 1988. The psychology of everyday things. Basic books.

Normark, C. J., 2015. Design and evaluation of a touch-based personalizable in-vehicle user interface. International Journal of Human-Computer Interaction 31 (11), 731–745.

Ordóñez-Hurtado, R. H., Crisostomi, E., Shorten, R. N., 2018. An assessment on the use of stationary vehicles to support cooperative positioning systems. International Journal of Control 91 (3), 608–621.

Ouwehand, K., Kroef, A. v. d., Wong, J., Paas, F., 2021. Measuring cognitive load: Are there more valid alternatives to likert rating scales? In: Frontiers in Education. Vol. 6. Frontiers Media SA, p. 702616.

Oyugi, C., Meixner, G., Hock, C., 2008. Cultural influences on mobile phone interface usability in kenya. In: Proceedings of NordiCHI. pp. 299–306.

Patton, M. Q., 2014. Qualitative research & evaluation methods: Integrating theory and practice. Sage publications.

Piechulla, W., Mayser, C., Gehrke, H., König, W., 2003. Reducing drivers' mental workload by means of an adaptive man–machine interface. Transportation Research Part F: Traffic Psychology and Behaviour 6 (4), 233–248.

Preece, J., Rogers, Y., Sharp, H., 2015. Interaction Design: Beyond Human-Computer Interaction. John Wiley & Sons.

Rauh, N., Franke, T., Krems, J. F., 2015. Understanding the impact of electric vehicle driving experience on range anxiety. Human factors 57 (1), 177–187.

Row, Y.-K., Kim, C.-M., 2016. Dooboo: A Pet-Morphic Interface for Emotional EV Driving Experience. In: Proceedings of the Conference on Designing Interactive Systems.

Salmanzadeh, H., Pishnamazzadeh, M., Mirmajlesi, S., Samimi, Y., Landau, K., 2018. Investigating the usability of a user interface for display of an electro vehicle in a driving simulation. J. Ergon. Res 1 (2).

SAREP, 2024. Scaling up e-bus deployment in india: White paper. Tech. rep., South Asia Regional Energy Partnership.
URL https://shorturl.at/eSvmK

Sauro, J., Dumas, J. S., 2009. Comparison of three one-question, post-task usability questionnaires. In: Proceedings of the SIGCHI conference on human factors in computing systems. pp. 1599–1608.

Sauro, J., Lewis, J. R., 2016. Quantifying the user experience: Practical statistics for user research. Morgan Kaufmann.

Schwambach Costa, B., 2020. Evaluating drivers' understanding of automotive symbols related to powertrain and advanced driver assistant systems.

Scupin, R., 1997. The kj method: A technique for analyzing data derived from japanese ethnology. Human organization 56 (2), 233–237.

Shao, Y., Zhang, Y., Li, J., 2020. Impact of environmental conditions on electric vehicle performance: A review. Renewable and Sustainable Energy Reviews 124, 109788.

Stahl, J., Gödker, M., Franke, T., 2020. Range insight: Visualizing range-related information in battery electric buses. In: International Conference on Human-Computer Interaction. Springer, pp. 393–403.

Strömberg, H., Andersson, P., Almgren, S., Ericsson, J., Karlsson, M., Nåbo, A., 2011. Driver interfaces for electric vehicles. In: Proceedings of the 3rd International Conference on Automotive User Interfaces and Interactive Vehicular Applications. pp. 177–184.

Strömberg, H., Karlsson, I., 2011. Driver interfaces for electric vehicles. Behaviour & Information Technology 30 (5), 629–642.

Sustainable Bus, 2025. Electric bus, main fleets and projects around the world. Accessed: 2025-09-20.
URL https://www.sustainable-bus.com/electric-bus/electric-bus-public-transport/

Sweller, J., 1988. Cognitive load during problem solving: Effects on learning. Cognitive science 12 (2), 257–285.

Szalma, J. L., 2014. On the application of motivation theory to human factors/ergonomics: Motivational design principles for human–technology interaction. Human factors 56 (8), 1453–1471.

Taylor, T., Naimoli, S., Latham, S., Shok, K., Fertik, T., Rayef, R., Pinchot, A., Johnson, R., Policy, A. P., 2025. Tracking the state of us ev manufacturing. Atlas Public Policy, January.

Wang, Y., Limmer, S., Van Nguyen, D., Olhofer, M., Bäck, T., Emmerich, M., 2022. Optimizing the maintenance schedule for a vehicle fleet: a simulation-based case study. Engineering optimization 54 (7), 1258–1271.

Wei, H., Zhang, B., Kumar, A., 2020. Design considerations for electric bus dashboards in developing countries. Journal of Transport and Health 17, 100856.

World Resources Institute, 2024. How to enable electric bus adoption in cities worldwide. Accessed: 2025-09-20.
URL https://shorturl.at/dD2a2

World Resources Institute, 2025. These countries are electrifying their bus fleets the fastest. Accessed: 2025-09-20.
URL https://www.wri.org/insights/countries-electrifying-bus-fleets-fastest

Yoon, S. H., Lim, J. H., Ji, Y. G., 2015. Perceived visual complexity and visual search performance of automotive instrument cluster: A quantitative measurement study. International Journal of Human-Computer Interaction 31 (12), 890–900.

Young, K. L., Regan, M. A., Stanton, N. A., 2018. Designing in-vehicle technologies for older drivers: Evidence from driving simulators and on-road studies. Applied Ergonomics 68, 514–525.

Zhang, W., Liu, Y., Kaber, D. B., 2024. Effect of interface design on cognitive workload in unmanned aerial vehicle control. International Journal of Human-Computer Studies 189, 103287.

Zhao, J., Song, X., Yin, Y., 2020. Electric bus operations: A review of technological status, energy management, eco-driving, and economic challenges. Energy Reports 6, 3646–3659.

Zijlstra, F. R. H., Van Doorn, L., 1985. The construction of a scale to measure subjective effort. Delft, Netherlands 43 (1985), 124–139.

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List of Publications

International Conferences

1. Routray, L., Shrivastava, A., Sarmah, P. (2024). Enhancing E-Rickshaw Driving Experiences: Insights from User-Centric EV Dashboards in India. In *Intelligent Human Computer Interaction* (pp. 355-366). Switzerland: Springer Nature Switzerland.

2. Routray, L., Shrivastava, A., Sarmah, P. (2024). Assessing the Usability of Electric Car Interfaces: A Focus Group Study. In *International Conference on Intelligent Human Computer Interaction* (pp. 159-170). Switzerland: Springer Nature Switzerland.

3. L. Routray, A. Shrivastava and P. Sarmah (2023). A survey on Indian user's purchasing intention of electric vehicle and the factors influencing their decision. In *2023 IEEE 3rd International Conference on Sustainable Energy and Future Electric Transportation* (pp. 1-6). Bhubaneswar, India.

4. Chinmoy Deka, Shiva Sah, Abhishek Shrivastava, Mridumoni Phukon, Lipsa Routray (2021). Assessing a Voice-Based Conversational AI prototype for Banking Application. In *2021 8th NAFOSTED Conference on Information and Computer Science (NICS)* (pp. 211-216).

Manuscripts Under Review

1. *Driving the Change: Stakeholder Insights into the Challenges of India's Electric Bus System*, manuscript submitted to *Transportation Research Interdisciplinary Perspectives*, November 2025 (major revision submitted).

2. *Beyond the Dials: Rethinking Dashboard Design for Electric Bus Drivers*, manuscript

submitted to *Transportation Research Interdisciplinary Perspectives*, November 2025.