Avances en Interacción Humano-Computadora, 2025, Volumen 10, No. 1, pp. 1-11
DOI: 10.47756/aihc.y10i1.205

RESEARCH PAPER

Towards Human-Centered Assisted Mobility in Intelligent Road Environments

Hacia una Movilidad Asistida Centrada en el Humano en Entornos Viales Inteligentes

Antonio Guerrero-Ibáñez [1], Juan Contreras-Castillo [1], Pedro C. Santana-Mancilla [1, *]

Published: 30 November 2025

Abstract
In this paper, we explore how Human-Centered Artificial Intelligence (HCAI), the Internet of Everything (IoE), and human-centric 6G ecosystems can converge to improve assisted road mobility and accessibility for vulnerable road users. Our study introduces a conceptual framework that integrates intelligent vehicles, road infrastructure, and pedestrians into a unified, inclusive, and interactive environment. By emphasizing human-centered design principles, the proposal highlights how emerging technologies can enhance user experience, safety, and autonomy for people with disabilities and other road users. Through the analysis of representative use cases, we discuss how HCAI and real-time communication technologies can enable adaptive interaction, personalized navigation, and inclusive participation in future mobility systems. The results outline a research agenda for developing intelligent road environments where technology actively supports human needs and values.

Keywords:
Human-Computer Interaction, Human-Centered Artificial Intelligence, Assisted Mobility, Accessibility, Inclusive Design, 6G, Internet of Everything.

Resumen
En este artículo se explora cómo la Inteligencia Artificial Centrada en el Humano (HCAI), el Internet de Todo (IoE) y los ecosistemas 6G centrados en el humano pueden converger para mejorar la movilidad asistida y la accesibilidad de los usuarios vulnerables del camino. El estudio introduce un marco conceptual que integra vehículos inteligentes, infraestructura vial y peatones en un entorno unificado, inclusivo e interactivo. A partir de principios de diseño centrado en el humano, la propuesta destaca cómo las tecnologías emergentes pueden potenciar la experiencia de usuario, la seguridad y la autonomía de las personas con discapacidad y otros usuarios de la vía. Mediante el análisis de casos de uso representativos, se discute cómo la HCAI y las tecnologías de comunicación en tiempo real pueden permitir interacciones adaptativas, navegación personalizada y participación inclusiva en los sistemas de movilidad del futuro. Los resultados proponen una agenda de investigación orientada al desarrollo de entornos viales inteligentes donde la tecnología responda activamente a las necesidades y valores humanos.

Palabras clave:
Interacción Humano-Computadora, Inteligencia Artificial Centrada en el Humano, Movilidad Asistida, Accesibilidad, Diseño Inclusivo, 6G, Internet de Todo.

1 Introduction
Mobility is an essential part of people's daily lives. However, in recent decades, this task has become a major challenge. Urban areas are becoming more chaotic daily. Modern society faces serious mobility problems due to uncontrolled urban sprawl, increasing distances from one point to another, and the growing number of cars in cities [17]. Automotive market research firm Head & Company estimates that over 1.475 billion cars are on the road in cities worldwide [15]. All this uncontrolled growth has left modern society with severe mobility problems, many of which have fatal consequences. These mobility challenges are not merely technological but deeply human, as they shape how individuals perceive, trust, and interact with the systems designed to assist them.

The World Health Organization (WHO) presented a series of road traffic data showing that road crashes are a leading cause of death and disability worldwide. Road traffic crashes are the cause of more than 1.3 million deaths, and another 50 million people are seriously injured. The WHO also states that road traffic injuries are the leading cause of death among children and young people aged

Guerrero-Ibáñez, A [1], Contreras-Castillo, J.[1], Santana-Mancilla, P. C.[1, *]
School of Telematics
Universidad de Colima
Colima, Mexico.
Email: {antonio_guerrero, juancont, psantana@ucol.mx

* Corresponding author

5 to 29. Worldwide, data show that one in four people who die on the road is a pedestrian [38]. While this data may paint an overwhelming picture for most people, for people with disability, tasks as simple as crossing a street or getting around urban areas can be a significant challenge. The World Bank reports that approximately 15% of the global population has a disability, with a higher prevalence in developing nations [27].

People with disabilities often face challenges when navigating urban areas. Here are some of the most common issues:

- **Inadequate Infrastructure**. The narrow design or poor condition of sidewalks and the lack of ramps at crosswalks can make it impossible for people with disabilities to move around.
- **Inadequate timing of traffic signals and lights**. The time to cross a sidewalk is often inadequate for elderly pedestrians, causing anxiety and stress. In addition, many countries, especially in the Third World, lack tactile or audible signals at traffic lights, which can cause disorientation and make it dangerous for people with disabilities to cross the street.
- **Public Awareness Lack**. Vulnerable road users like children face sidewalk blockages caused by a lack of awareness and empathy from other pedestrians and drivers, making it difficult for them to pass. In addition, in many countries, pedestrians do not respect marked crosswalk boundaries and cross into zebra crossings, increasing the difficulties people face when crossing.

Addressing these barriers requires not only technological innovation but also the adoption of Human-Centered Design principles to ensure accessibility, empathy, and inclusion. Furthermore, reflect the urgent need to create solutions that integrate all our society into the new traffic ecosystem, specifically by including new elements like connected and self-driving vehicles.

The road mobility environment of the future should be characterized by the following human-centered features (see Figure 1).

- Inclusive, where the environment is adapted to the needs of all people, regardless of their age, physical or sensory abilities.
- Networked, allowing transparent communication between devices for real-time transmission of relevant information (such as traffic alerts, changes in public transport and road conditions).
- Safe and accessible, meaning that all elements involved in mobility are designed to provide safety and comfort for all people, including those with disabilities, children, elderly, etc.
- Autonomous, meaning that it can enable all road users to move from one point to another independently.

The features mentioned above have motivated researchers, car manufacturers, and other government and non-government bodies to analyze how state-of-the-art technologies could be integrated to create a safer and more comfortable road environment [9, 42, 46, 51]. Building upon this foundation, our work contributes to Human–Computer Interaction by proposing a human-centered framework that integrates emerging technologies (6G, IoE, and AI) to enhance the interaction between humans and intelligent road infrastructures.

A study conducted in [42] found that people with disabilities are at a significantly higher risk of being involved in pedestrian collisions, injuries, and fatalities. The study identified walking speed and crossing decisions as risk factors for people with disabilities. The study concluded that further research is needed to determine how inaccessible or obstructive environments contribute to the increased risk of pedestrian injury among the disabled population.

The integration of technology to assist pedestrians with disabilities is essential to the improvement of their quality of life and level of independence. Technology can provide solutions to improve the accessibility of the urban environment and facilitate the mobility of pedestrians with disabilities, thus providing safer mobility in an unfamiliar environment for people with a visual impairment. Developing customized solutions that adapt to the specific needs of people with disabilities and provide real-time information on accessible routes, crosswalk locations, obstacle detection, and traffic signs can empower people with disabilities and promote social inclusion.

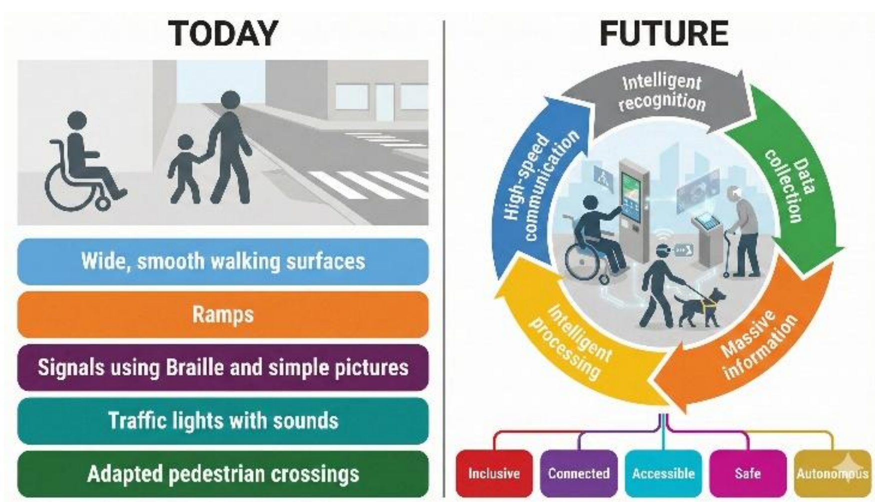

Figure 1. a) Current trends in the mobility of vulnerable road pedestrians in urban road areas, b) impact of technologies on road mobility environment.

Creating an environment that is in line with today's demands for inclusiveness has yet to be the subject of in-depth research.

1.1 Research Contributions of this Work

This work advances the field of Human–Computer Interaction by introducing a human-centered framework that integrates Human-Centered Artificial Intelligence (HCAI), the Internet of Everything (IoE), and human-centric 6G ecosystems to enhance assisted mobility and accessibility for vulnerable users.

Unlike previous studies that primarily address technical optimization, our proposal emphasizes the interaction between humans and intelligent road infrastructures as the focal point of innovation.

The core contribution lies in defining how emerging technologies can support adaptive, safe, and inclusive interaction in complex urban mobility environments. Specifically, the framework introduces:

- A conceptual integration model combining 6G ultra-low-latency communication, IoE-based sensing, and HCAI reasoning to enable real-time, user-adaptive decision making.
- An interaction perspective that situates technological components within the broader human experience, considering perception, trust, and accessibility as key determinants of usability.
- An inclusive design approach that promotes equity and participation of people with disabilities, aligning technical solutions with ethical and social dimensions of interaction design.

1.2 Scope and Limitations

It is important to define the boundaries of this proposal. This framework is a conceptual model focusing on the interaction layer between humans and technology; it does not provide specific hardware architectures or signal processing algorithms. Our primary assumption is the future availability of mature 6G networks and IoE infrastructure capable of ultra-low latency. Furthermore, unlike traditional ITS frameworks that prioritize traffic flow efficiency, our model is limited to prioritizing human inclusion and safety, potentially at the cost of vehicle speed optimization. We acknowledge that implementation in real-world scenarios will face challenges regarding legacy infrastructure compatibility, a limitation that future engineering studies must address.

By reframing assisted mobility as a human-centered ecosystem rather than a purely technological one, this work contributes to ongoing efforts in HCI to design intelligent environments that are transparent, trustworthy, and aligned with human needs. The conceptual foundation presented here provides a pathway for future empirical validation, participatory design studies, and prototyping of interactive mobility systems.

2 Assisted Road Mobility as a Human–Computer Interaction Domain

The concept of Assisted Road Mobility (ARM) for people with disabilities focuses on the development of technology-based solutions to facilitate mobility in the road environment for people with physical or cognitive disabilities. The goal of these solutions is to overcome the barriers that people with disabilities face daily in the road environment. This perspective extends beyond technical enablement; it positions assisted mobility as a domain of continuous interaction between humans and intelligent environments, where sensing, communication, and reasoning systems must adapt to human intentions and contextual needs.

Mobility assistance for people with disabilities aims to improve the independence and quality of life of people with disabilities by making their mobility easier and safer on the road. Solutions can vary according to each person's specific needs and type of disability. Designing such solutions requires understanding diverse user abilities, cognitive loads, and environmental constraints. In this sense, Assisted Road Mobility aligns with the Human-Centered Design paradigm, emphasizing co-creation with users and iterative evaluation of usability, safety, and trust.

To ground this interaction theoretically, we draw upon Donald Norman’s Theory of Action [37]. In our proposed framework, the integration of 6G and IoE aims to bridge the Gulf of Evaluation by providing users with real-time, perceptible feedback about the state of the road environment (e.g., a haptic vibration indicating it is safe to cross). Simultaneously, HCAI agents bridge the Gulf of Execution by anticipating user intentions and automating complex signaling tasks. Furthermore, the interface design for these systems adheres to Jakob Nielsen’s usability heuristics [35], particularly emphasizing 'Visibility of system status', ensuring users always know what the intelligent infrastructure implies, and 'User control and freedom', ensuring that human agency can always override automated suggestions.

2.1 Use Cases, Technical Requirements, and Interaction Challenges

To provide a clearer understanding of the ARM concept from a Human–Computer Interaction perspective, Table 1 summarizes representative use cases, outlining their technical requirements together with the interaction and design challenges that emerge when humans engage with these systems.

These use cases illustrate that assisted mobility must be conceived not only as a technological integration problem but as a continuous human–system interaction process. Each scenario involves perception, feedback, and decision-making loops where HCAI and inclusive interface design are essential to ensure trust, safety, and usability.

2.2 Assisted Road Mobility Ecosystem: Toward Human-Centered Integration

The application of modern technologies to the road environment will contribute to the creation of an inclusive and accessible road mobility ecosystem where people with disabilities would be able to move independently and safely from place to place. From an HCI standpoint, this ecosystem represents a socio-technical space where humans, intelligent vehicles, and digital infrastructure interact through adaptive feedback mechanisms and multimodal communication. This environment involves the close integration of technology and design, aiming to improve the quality of life and to promote equality in society. Achieving this goal involves addressing three key areas: i) communicating, ii) gathering and processing information, and iii) integrating intelligence into the environment.

Table 1. Representative use cases, technical requirements, and interaction challenges in Human-Centered Assisted Mobility.

Use case	Description	Technical requirements	Interaction and Design Challenges
Accessible Navigation Systems for the Visually Impaired	Adapted navigation technologies are used to assist visually impaired people in moving around urban areas.	Multimodal voice and haptic navigation; obstacle alerts and adapted routes integrated with sensing technologies.	Clear multimodal feedback for situational awareness; intuitive and low-cognitive-load interaction.
Pedestrian Assistance for the Visually Impaired	Technological aids for safe pedestrian mobility	Mobile and wearable applications providing real-time, context-aware navigation; integration with traffic lights and crossing signals.	Accurate perception of environmental conditions; consistent interaction between digital guidance and physical signage.
Real-Time Obstacle Detection Technologies	Use of technologies to detect obstacles in real time.	Multisensor fusion using ultrasound, cameras, and computer vision; real-time visual, auditory, and haptic alerts.	Maintaining reliability and interpretability in dynamic contexts; ensuring usability and interoperability with existing navigation interfaces.

Developing an inclusive mobility ecosystem requires better use of existing infrastructure and seamless integration of Information and Communication Technologies (ICT). Efforts have indeed been made to create inclusive and universally accessible cities [4, 18, 29]. However, many of these initiatives focus on physical infrastructure rather than the experiential layer of interaction, how users perceive, interpret, and respond to intelligent systems embedded in the urban fabric.

Efforts are being made to bring together concepts such as Smart City, Urban Computing, Accessibility, and Universal Design [13, 14, 23, 50]. The goal is to create an ecosystem that promotes independence and autonomy, especially for people with disabilities. However, the truth is that most of the improvements have focused on infrastructure, such as adapting pavements, traffic lights, and signage. With traffic growth over the last decades, it has become imperative to move one step further by integrating information technology to provide safe, easy, and adapted road environments for disabled people.

The future of road mobility must involve the seamless integration of heterogeneous technologies with human-adaptive interaction frameworks, enabling sensing, reasoning, and feedback processes that respond to individual contexts and preferences. Such a vision situates assisted mobility directly within HCI research, bridging intelligent infrastructure with inclusive user experience design.

3 Methodology

Methodologically, this work follows a Conceptual Framework Synthesis approach [28]. This involves deconstructing the functional capabilities of 6G, IoE, and HCAI technologies and reconstructing them into a unified interaction model. We operationalize 'Human-Centered Mobility' not merely as movement, but as a communicative act where the Intelligent Road Environment is defined as a proactive socio-technical system capable of sensing human intent, reasoning about context via HCAI, and engaging in transparent dialogue with the user.

Rather than focusing solely on technological optimization, the proposed approach emphasizes how humans interact with, experience, and benefit from these technologies within complex urban environments. The methodology is therefore conceptual and design-oriented, outlining the interaction mechanisms, data flows, and communication models that can enable adaptive, inclusive, and trustworthy mobility systems.

We adopt a human-in-the-loop perspective, where the system continuously learns from user behavior, contextual signals, and environmental feedback. This iterative feedback structure aligns with HCI principles of usability, adaptivity, and transparency, ensuring that intelligent systems serve human needs and values. The following subsections describe how 6G, IoE, and HCAI converge to support assisted mobility and outline the proposed integration framework.

3.1 Integration of 6G into the Human-Centered Assisted Mobility Ecosystem

6G technology is envisioned as a key enabler of real-time, multimodal interaction within intelligent road environments. Building on its ultra-low latency and high bandwidth, 6G allows mobility systems to exchange continuous streams of environmental and user data. In our framework, 6G serves not only as a communication backbone but as an interaction facilitator, ensuring that humans receive timely, context-aware feedback [45]. The integration of 6G technologies is modeled through three functional layers: (i) a perception layer that collects environmental and user data from sensors embedded in vehicles, infrastructure, and wearables; (ii) a communication layer that ensures ultra-reliable, low-latency transmission; and (iii) an interaction layer that delivers adaptive feedback through multimodal channels (visual, auditory, and haptic) [48]. By supporting these layers, 6G networks enable cooperative perception between vehicles and pedestrians, allowing HCAI agents to interpret user intent and mediate safe crossings, route planning, and hazard alerts [30].

This integration redefines connectivity as a means to support human awareness and decision-making, will allow people to wear devices or even use mobile phones to access real-time applications, for example, to receive warnings about traffic conditions, changes in public transport services, and warnings about obstacles or hazards on the roads, among others. Furthermore, this technology could establish direct communication with both the road infrastructure and vehicles moving around road users, such as the self-driving vehicles [3, 31, 36]. Direct communication would facilitate location and identification of road users, so that appropriate action can be taken through the integration of other technologies such as IoE and artificial intelligence to interact with the self-driving vehicles [34, 41], and pedestrian can express their intentions (i.e., crossing the road) [22, 44, 47].

3.2 Integration of the IoE

Within the proposed ecosystem, the Internet of Everything extends beyond connectivity to form a distributed, sensor-driven interaction network. IoE devices collect data from physical and social contexts (road conditions, traffic dynamics, and user movement patterns) that are later analyzed by HCAI modules to provide adaptive responses. From an HCI standpoint, IoE functions as a contextual sensing interface that enables the system to perceive users' states and intentions, supporting adaptive interaction and inclusive participation.

IoE technologies contribute to human-centered mobility by enabling real-time awareness of the environment and user context. The conceptual data workflow proceeds through four stages: (1) sensing, IoE nodes collect multimodal data from users and the environment; (2) transmission, data are shared via 6G communication channels; (3) interpretation, HCAI modules analyze and contextualize information; and (4) feedback, personalized, multimodal guidance is provided. This continuous loop creates a dynamic dialogue between humans and the intelligent environment, reinforcing trust and situational awareness.

Sensors in road infrastructure will facilitate the collection of real-time data on local traffic conditions (pedestrian presence, traffic, weather, and accessible parking availability) [1, 2, 10]. Data collected by IoE sensors will be transmitted over the network, providing real-time information to the road users. This information could include alerts about traffic light changes [8, 21, 32], warnings about hazardous conditions (such as ice or potholes in the pavement) [5, 49] and the availability of accessible routes and modes of transport [20, 26, 33].

The integration of technologies like IoE will allow a vehicle management platform able to handle organized and unstructured data to gather information from sensors through vehicle-to-vehicle and vehicle-to-infrastructure networks and to implement cloud-based automated driving systems.

By integrating the IoE with 6G and artificial intelligence, applications can be created that offer personalized navigation routes, help to avoid obstacles such as buildings or deteriorating pavements, and suggest safer and more accessible routes.

The information collected by IoE sensors will manage road traffic more efficiently by optimizing the timing of traffic lights based on the presence of pedestrians.

IoE technology can be used to detect high-risk situations, such as vehicles that ignore traffic lights or the presence of obstacles or cars in dangerous locations, and automatically send alerts to the connected vehicles, self-driving vehicles, and road users in general [7, 39, 43].

IoE technology is expected to provide real-time information on the availability of accessible seats in the public transport, the location of adapted vehicles, free parking slots, updated schedules, etc. The information gathered can be used to plan more effective journeys.

Through constant monitoring and feedback, IoE establishes the foundation for adaptive urban intelligence that enhances accessibility, inclusion, and user trust. Rather than automating the environment, IoE connects people and infrastructure through interaction-centered sensing, enabling collaborative mobility experiences.

3.3 Integration of HCAI

In the proposed framework, Artificial Intelligence functions as a mediator of human–system interaction rather than as an autonomous controller. Following HCAI principles, AI components enhance human perception, decision-making, and trust by maintaining human oversight and interpretability. Instead of emphasizing algorithmic performance, our approach conceptualizes how AI modules can process multimodal data (images, sensor readings, behavioral signals) to support situational awareness and personalized assistance. The interaction process involves perception (interpreting user and environmental inputs), adaptation (adjusting responses to user needs), and explanation (communicating reasoning transparently). This human-in-the-loop structure promotes safety, accessibility, and user confidence in intelligent environments [24, 25, 40].

Artificial intelligence is a viable technology to address many of the mobility challenges providing mechanisms that adapt to the individual road user's needs.

Figure 2 shows a proposed architecture where the integration of 6G, IoE and artificial intelligence can help to create a more inclusive and accessible transportation ecosystem.

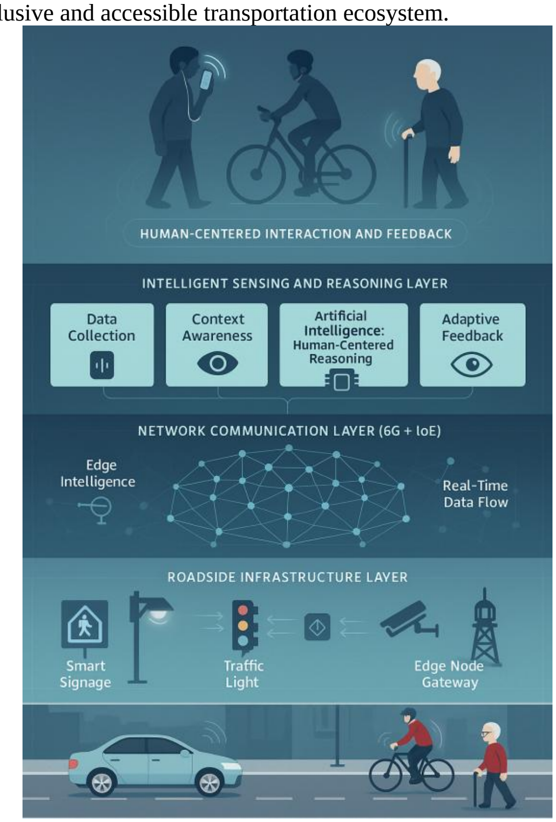

Figure 2. Human-centered integration of HCAI, IoE, and 6G technologies for assisted mobility.

The integration of these three technological domains forms a multi-layer human-centered architecture uniting sensing, communication, reasoning, and feedback. This architecture embodies user-adaptive interaction, transparency, and ethical data handling. Privacy and security mechanisms are integral from the design phase, ensuring compliance with international standards such as GDPR and promoting user agency. The architecture positions the human as an active participant within the ecosystem, reinforcing the notion of Human–Environment Interaction central to HCI.

4 Human–System Interaction Scenarios for Assisted Mobility

To illustrate how HCAI, IoE, and 6G technologies jointly support assisted mobility, this section presents three representative scenarios. A series of shared mechanisms underpin all three cases: environmental sensing through IoE devices, ultra-low-latency communication enabled by human-centric 6G networks, and adaptive reasoning carried out by HCAI modules. These components form a continuous cycle of perception, transmission, interpretation, and feedback, establishing the basis for human–environment interaction in intelligent road ecosystems. To avoid redundancy, these common principles are summarized here, allowing each scenario to focus more clearly on the distinctive interaction challenges it presents for users with disabilities.

To clarify the interaction dynamics described in the following use cases, Figure 3 illustrates the cyclical data flow between the user, the HCAI reasoning module, and the physical infrastructure.

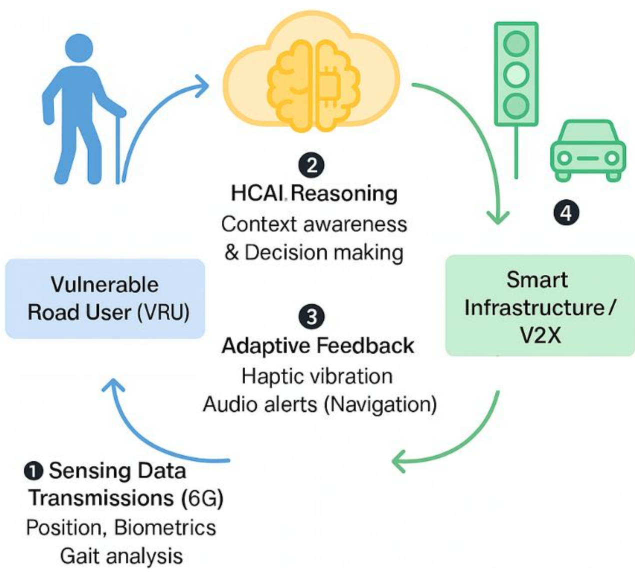

Figure 3. Interaction data flow diagram in the human-centered assisted mobility ecosystem.

4.1 Use case: Personalized Navigation for Visually Impaired People

In this scenario, visually impaired pedestrians navigate urban environments with the support of wearable devices, IoE-enabled infrastructure, and HCAI-based interpretation of context. Real-time information about obstacles, traffic density, and changes in the environment is transmitted through 6G networks and transformed into intuitive guidance delivered via haptic or auditory channels. The central interaction challenge lies in balancing informational accuracy with cognitive simplicity. Navigation support must not overwhelm the user, especially in dynamic contexts, and must be capable of adapting to personal preferences and sensory abilities. Ensuring that these adaptive mechanisms operate in a privacy-preserving fashion is equally important for maintaining user trust in the system.

4.2 Use case: Safe Crossing for People with Disabilities

The second scenario examines interactions in road crossings, where communication between pedestrians, vehicles, and infrastructure becomes critical. IoE sensors embedded in traffic lights, crosswalks, and vehicles continuously detect motion, environmental conditions, and potential hazards. Through 6G connectivity, detection data is transmitted to HCAI modules, which assess pedestrian intent and crossing safety. The system responds by adapting traffic light timing, communicating intent to connected vehicles, and providing multimodal cues to pedestrians. The distinctive interaction challenge in this case concerns the interpretability and predictability of system behavior. Because crossing decisions are safety-critical, pedestrians must understand and trust the cues they receive. Similarly, connected vehicles must interpret human intentions accurately, avoiding conflicting signals or ambiguous behavior that could compromise safety.

4.3 Use case: Access to Adapted Public Transport

The third scenario focuses on the challenges users with mobility impairments face when accessing public transportation systems. IoE sensors installed in stations and vehicles monitor accessibility features such as ramp availability, elevator status, and seat occupancy. These data are transmitted across the 6G network and synthesized by HCAI reasoning modules, which provide users with personalized, context-aware guidance. The primary interaction challenge arises from the complexity of transit spaces, where users must process large quantities of spatial and temporal information. The system must therefore prioritize clarity, streamline route suggestions, and present only the most relevant details without overloading the user. Coordinating information between the station infrastructure, the transport service, and the user's personal device poses an additional challenge, requiring seamless interoperability to maintain continuity in the user experience.

Together, these three scenarios reveal that the effectiveness of assisted mobility depends not only on the sophistication of sensing and communication technologies but also on how users perceive, interpret, and trust the feedback provided by an intelligent environment. Each case highlights a distinct facet of human–system interaction: cognitive load management in navigation, interpretability of safety-critical signals in road crossings, and situational awareness in complex transportation nodes. These distinctions strengthen the argument that assisted mobility must be designed fundamentally as an HCI problem, where technological integration is guided by human-centered principles.

5 Human-Centered Challenges in Technology Integration

The integration of IoE, 6G, and HCAI technologies constitutes a distributed socio-technical ecosystem where humans, intelligent devices, and infrastructures continuously exchange information. From an HCI perspective, this integration must balance technical efficiency with human values such as transparency, privacy, and trust.

Within this ecosystem, 6G connectivity enables real-time fusion of multimodal data from sensors, vehicles, and pedestrians, while HCAI modules interpret this information to support context-aware, human-supervised decision-making. The combination of these layers transforms mobility into a collaborative human–machine process rather than a fully automated system.

However, there are several important challenges that need to be addressed for this integration to be successful. Some of these challenges are outlined below.

5.1 Privacy, Security, and Trustworthiness

Protecting privacy and ensuring data security are foundational to building user trust in assisted mobility ecosystems. The continuous collection and exchange of location, behavioral, and contextual data may expose sensitive personal information, making ethical governance essential. From a Human-Centered AI perspective, privacy is not only a technical safeguard but an element of perceived control that shapes how users engage with intelligent systems.

To address these concerns, data flow within the Intelligent Road Environment is designed according to privacy-by-design and data minimization principles, ensuring that only strictly necessary data are collected, processed, and retained. In addition, authentication mechanisms and role-based access control are enforced so that only authorized entities and personnel can access sensitive mobility data, thereby strengthening system security and trustworthiness.

To address these concerns, data flows should follow privacy-by-design and data-minimization principles. In addition, authentication and control mechanisms should be implemented to ensure that only authorized persons can access the data. Privacy policies should be established that define the appropriate mechanisms for data collection, storage, and use. Mechanisms should be implemented to conduct periodic security reviews to identify vulnerabilities and, if necessary, modify the implemented security measures to ensure their efficacy. All actors involved in the handling of information in the new road mobility environment must be compliant with local and international data protection laws and regulations, such as the General Data Protection Regulation (GDPR) in Europe [16] or the California Consumer Privacy Act (CCPA) in the United States [12], and Mexican regulations such as the Federal Law on the Protection of Personal Data Held by Private Parties (LFPDPPP) [11] and the Mexico's General Law on Personal Data Protection Held by Obligated Subjects (LGPDPPSO) [19]. Compliance with these diverse legal frameworks ensures that the deployment of intelligent mobility remains ethically robust across different jurisdictions [6].

Thus, this challenge requires close collaboration between all stakeholders in the road environment to ensure that data collection is in line with the protection of privacy and security, and to implement robust security measures to effectively address this challenge.

5.2 Interoperability and User-Centered Standardization

Interoperability remains a key challenge not only for technical compatibility but also for the consistency of user experience. In a human-centered mobility ecosystem, devices from different vendors must communicate seamlessly while preserving accessibility and interaction predictability. Lack of standardization can cause fragmented experiences that reduce user confidence.

To mitigate this, open and inclusive communication standards should integrate usability and accessibility criteria alongside technical specifications. Collaborative frameworks between manufacturers, policymakers, and HCI researchers are required to ensure that interoperability extends to interface consistency, multimodal feedback, and user trust in cross-platform environments.

5.3 Universal Accessibility and Inclusive Interaction

Ensuring universal accessibility is central to the vision of Human-Centered Assisted Mobility. Interaction design must accommodate a wide spectrum of abilities, preferences, and situational constraints. Rather than treating accessibility as an add-on, it should drive the design of interfaces, feedback mechanisms, and information presentation.

From an HCI standpoint, this entails creating adaptive systems that can tailor font size, contrast, modality (visual, auditory, tactile), and interaction pace to everyone.

Validation of these systems requires moving beyond standard usability testing towards Participatory Design (Co-design) methodologies. Involving people with disabilities from the earliest conceptual stages ensures that the Intelligent Environment addresses real-world friction points rather than theoretical ones. This approach guarantees that multimodal interaction (the redundancy of visual, auditory, and haptic cues) is not just a technical feature, but a functional requirement to support diverse sensory capabilities.

5.4 Resilience, Reliability, and Human Awareness

A resilient mobility ecosystem must maintain reliability and awareness even under network disruptions or hardware failures. In Human-Centered systems, resilience is measured not only by network uptime but by how transparently failures are communicated and how users remain informed and in control.

Redundant communication paths, adaptive routing, and self-healing protocols are technical enablers, but they must be complemented with user-facing feedback that clearly indicates system status. When interruptions occur, interfaces should provide actionable guidance rather than silent degradation. This emphasis on graceful degradation preserves safety, reduces anxiety, and strengthens user confidence in intelligent infrastructure.

5.5 Human-Centric Design and Ethical Alignment

At the core of these integration challenges lies the need to design intelligent systems that remain aligned with human intentions, ethics, and values. A Human-Centric Assisted Mobility system must support transparency, explainability, and accountability at every interaction point.

Services such as assistive navigation, adaptive traffic control, or context-aware alerts should provide not only functional output but understandable rationale, why a route was changed, why a light signal extended, or why an alert was issued. Embedding explainability into the interaction reinforces user agency and trust. Ultimately, 6G-enabled HCAI ecosystems should enhance, not replace, human decision-making, ensuring that automation operates as an extension of human capability and social responsibility.

Addressing these human-centered challenges is crucial for realizing inclusive and trustworthy intelligent mobility systems. The synergy among HCAI, IoE, and 6G technologies must therefore evolve under design principles that prioritize transparency, inclusion, and ethical alignment.

6 Discussion

This research introduces a human-centered conceptualization of assisted mobility, combining HCAI, IoE, and 6G technologies to advance accessibility and interaction in intelligent road environments. Beyond technological convergence, this framework situates mobility as a form of Human–Computer Interaction, an ongoing dialogue between people, intelligent infrastructure, and adaptive systems, as seen on Table 2.

Table 2. Comparison between Traditional Intelligent Transport Systems (ITS) and the Proposed Human-Centered Framework.

Dimension	Traditional ITS / Automated Mobility	Proposed Human-Centered Assisted Mobility
Primary Goal	Traffic efficiency, speed, and congestion reduction.	Accessibility, social inclusion, and user safety.
Role of AI	Autonomous control and optimization of vehicle dynamics.	Augmentation of human perception and decision-making support.
Human Role	Passive passenger or obstacle to be detected.	Active participant (Human-in-the-loop) with agency.
Interaction	Unidirectional (System informs User).	Bidirectional/Dialogic (System adapts to User intent).
Metrics	Throughput, latency, error rates.	Trust, transparency, cognitive load, user experience.

The proposal emphasizes that the potential of these technologies lies not only in automation but in their ability to mediate safe, efficient, and empathetic interactions between humans and their environment. The study identifies key challenges (trust, interpretability, and accessibility) and discusses design strategies that prioritize inclusion, user control, and the co-adaptation of systems and users.

Compared with previous approaches that focused primarily on technical optimization, our human-centered integration model emphasizes interaction quality as the key indicator of success. Improvements in responsiveness, navigational accuracy, and user adaptation arise from the synergy between 6G's real-time communication, IoE's contextual sensing, and HCAI's reasoning and personalization capabilities. This triad collectively enhances situational awareness and fosters mutual adaptation between humans and intelligent systems, aligning with HCI principles of transparency and feedback.

The proposed framework enhances the independence, safety, and agency of individuals with disabilities, demonstrating how HCAI and user-centered design can converge to create inclusive urban experiences. Beyond accessibility, this work contributes to broader HCI discussions on technology-mediated autonomy, how intelligent systems can expand human capabilities without diminishing control or accountability.

While the proposed framework establishes a strong conceptual basis, empirical validation remains essential. Future work should include participatory design sessions, field studies, and usability evaluations involving diverse user populations to assess acceptance, trust, and long-term interaction patterns. Further research should also integrate ethical impact assessment and privacy audits to ensure compliance with human-centered AI principles and global data protection standards.

This framework offers a new perspective for city planners and policymakers. It suggests that modern urban design must go beyond physical accessibility (ramps, tactile paving) to include digital accessibility, ensuring that data infrastructure is available to all. In the context of developing countries or diverse urban environments where full 6G deployment may be gradual, this framework advocates for a phased adoption. Policymakers can prioritize mobile-based HCAI solutions that leverage existing networks to provide immediate assistance to vulnerable groups, bridging the gap while heavier infrastructure is developed.

Overall, this research highlights the transformative potential of combining HCAI, IoE, and 6G technologies within an interaction-centered framework. By treating mobility as a domain of continuous human–system collaboration, it bridges technical innovation with ethical, social, and experiential dimensions of HCI. This paradigm opens new avenues for designing transparent, inclusive, and adaptive systems that redefine accessibility as an essential aspect of digital interaction in smart cities.

7 Conclusions

Every day, people with disabilities face significant challenges in moving independently and safely through urban environments. Addressing these challenges requires not only technological innovation but also a human-centered approach that integrates HCAI, the IoE, and 6G communication within existing infrastructures.

This study has outlined how these emerging technologies can converge to create a human-centered assisted mobility ecosystem that promotes inclusion, accessibility, and trust. By reframing assisted mobility as a form of Human–Computer Interaction, the proposed framework emphasizes the interaction between humans, intelligent infrastructure, and adaptive systems. The use cases presented illustrate how sensing, reasoning, and communication layers can cooperate to enhance situational awareness, safety, and autonomy for vulnerable pedestrians, including people with disabilities, older adults, and children.

Ultimately, integrating HCAI, IoE, and 6G within intelligent road environments can foster safer, more responsive, and ethically aligned urban mobility systems. Beyond improving efficiency, this human-centered integration advances the broader goal of designing cities where intelligent technologies amplify human capability and inclusion rather than merely automating movement. Future systems must be built on a foundation of privacy, transparency, and social justice, ensuring that the benefits of the IoE and HCAI are distributed equitably to foster a truly inclusive society.

8 Acknowledgments

During the preparation of this manuscript, the authors used Grammarly to improve language clarity also ChatGPT-5 and Gemini 3 to assist in generating images. All scientific ideas, analyses, methodological designs, and conceptual contributions were solely developed by the authors.

9 References

[1] Mohamed Abdel Raheem and Moumen El-Melegy. 2020. Drive-By Road Condition Assessment Using Internet of Things Technology. In *2019 International Conference on Advances in the Emerging Computing Technologies (AECT)*, February 2020. IEEE, Al Madinah Al Munawwarah, Saudi Arabia, 1–6. https://doi.org/10.1109/AECT47998.2020.9194190

[2] Mohamed AbdelRaheem, Muhammad Hassan, Mahmoud A. Alyousify, Ali Hussein, and Amr A. Nassr. 2023. Design and Implementation of a Vibration-Based Real-Time Internet of Things Framework for Road Condition

Monitoring. *IEEE Open J. Veh. Technol.* 4, (2023), 867–876. https://doi.org/10.1109/OJVT.2023.3328493

[3] Abdullah M. Algarni and Vijey Thayananthan. 2023. Autonomous Vehicles With a 6G-Based Intelligent Cybersecurity Model. *IEEE Access* 11, (2023), 15284–15296. https://doi.org/10.1109/ACCESS.2023.3244883

[4] Sukaina Al-Nasrawi, Ali El-Zaart, and Carl Adams. 2017. The Anatomy of Smartness of Smart Sustainable Cities: An Inclusive Approach. In *2017 International Conference on Computer and Applications (ICCA)*, September 2017. IEEE, Doha, United Arab Emirates, 348–353. https://doi.org/10.1109/COMAPP.2017.8079774

[5] Sami Alshammari and Sejun Song. 2022. 3Pod: Federated Learning-based 3 Dimensional Pothole Detection for Smart Transportation. In *2022 IEEE International Smart Cities Conference (ISC2)*, September 26, 2022. IEEE, Pafos, Cyprus, 1–7. https://doi.org/10.1109/ISC255366.2022.9922195

[6] Beatriz A. Álvarez Magallán, Ricardo Acosta-Díaz, and Elba A. Morales-Vanegas. 2024. Privacy-Aware Artificial Intelligence: A Review of Design Principles and Applications. *Avances en IHC* 9, 1 (November 2024), 209–213. https://doi.org/10.47756/aihc.y9i1.169

[7] Shankar Y B, Kavya Baiju, and Bansilal Bairwa. 2023. IoT Enabled Innovative Accident Detection and Rescue System. In *2023 International Conference on Advances in Electronics, Communication, Computing and Intelligent Information Systems (ICAECIS)*, April 19, 2023. IEEE, Bangalore, India, 663–667. https://doi.org/10.1109/ICAECIS58353.2023.10170604

[8] Basavaraju R and Chetana Hegde. 2015. Traffic signal time analysis and voice - based app for visually impaired pedestrians. In *2015 International Conference on Emerging Research in Electronics, Computer Science and Technology (ICERECT)*, December 2015. IEEE, Mandya, India, 477–480. https://doi.org/10.1109/ERECT.2015.7499062

[9] Nicolas Blanc, Zhan Liu, Olivier Ertz, Diego Rojas, Romain Sandoz, Maria Sokhn, Jens Ingensand, and Jean-Christophe Loubier. 2019. Building a Crowdsourcing based Disabled Pedestrian Level of Service routing application using Computer Vision and Machine Learning. In *2019 16th IEEE Annual Consumer Communications & Networking Conference (CCNC)*, January 2019. IEEE, Las Vegas, NV, USA, 1–5. https://doi.org/10.1109/CCNC.2019.8651850

[10] Beepa Bose, Joy Dutta, Subhasish Ghosh, Pradip Pramanick, and Sarbani Roy. 2018. D&RSense: Detection of Driving Patterns and Road Anomalies. In *2018 3rd International Conference On Internet of Things: Smart Innovation and Usages (IoT-SIU)*, February 2018. IEEE, Bhimtal, 1–7. https://doi.org/10.1109/IoT-SIU.2018.8519861

[11] Cámara de Diputados. 2010. Ley Federal de Protección de Datos Personales en Posesión de los Particulares. Retrieved from https://www.diputados.gob.mx/LeyesBiblio/pdf/LFPDPPP.pdf

[12] CCPA. 2018. The California Consumer Privacy Act. Retrieved from https://theccpa.org/

[13] Xuanguang Chen. 2020. Application of GNN in Urban Computing. In *2020 International Conference on Communications, Information System and Computer Engineering (CISCE)*, July 2020. IEEE, Kuala Lumpur, Malaysia, 14–17. https://doi.org/10.1109/CISCE50729.2020.00010

[14] Sin-Ho Chin. 2017. Examining the bicycle bottle cage based on universal design principle. In *2017 International Conference on Applied System Innovation (ICASI)*, May 2017. IEEE, Sapporo, Japan, 1714–1717. https://doi.org/10.1109/ICASI.2017.7988269

[15] Hedges Company. 2021. How Many Cars Are There In The World? Statistics by Country. Retrieved from https://hedgescompany.com/blog/2021/06/how-many-cars-are-there-in-the-world/

[16] Intersoft Consulting. 2018. General Data Protection Regulation (GDPR). Retrieved from https://gdpr-info.eu/

[17] Rebecca Currano, So Yeon Park, Lawrence Domingo, Jesus Garcia-Mancilla, Pedro C. Santana-Mancilla, Victor M. Gonzalez, and Wendy Ju. 2018. ¡Vamos!: Observations of Pedestrian Interactions with Driverless Cars in Mexico. In *AutomotiveUI '18: Proceedings of the 10th International Conference on Automotive User Interfaces and Interactive Vehicular Applications*, 2018. ACM, 210–220. https://doi.org/10.1145/3239060.3241680

[18] João Soars De Oliveira Neto and Sergio Takeo Kofuji. 2016. Inclusive Smart City: Expanding design possibilities for persons with disabilities in the urban space. In *2016 IEEE International Symposium on Consumer Electronics (ISCE)*, September 2016. IEEE, Sao Paulo, Brazil, 59–60. https://doi.org/10.1109/ISCE.2016.7797370

[19] Diario Oficial de la Federación. 2017. Ley General de Protección de Datos Personales en Posesión de Sujetos Obligados. Retrieved from https://www.dof.gob.mx/nota_detalle.php?codigo=5478205&fecha=26/01/2017

[20] Ahmed Elbery, Hossam S. Hassanein, and Nizar Zorba. 2020. Vehicular Crowd Management: An IoT-Based Departure Control and Navigation System. In *ICC 2020 - 2020 IEEE International Conference on Communications (ICC)*, June 2020. IEEE, Dublin, Ireland, 1–6. https://doi.org/10.1109/ICC40277.2020.9148635

[21] Anam Firdous, Indu, and Vandana Niranjan. 2020. Smart Density Based Traffic Light System. In *2020 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions) (ICRITO)*, June 2020. IEEE, Noida, India, 497–500. https://doi.org/10.1109/ICRITO48877.2020.9197940

[22] Keke Geng and Guodong Yin. 2020. Using Deep Learning in Infrared Images to Enable Human Gesture Recognition for Autonomous Vehicles. *IEEE Access* 8, (2020), 88227–88240. https://doi.org/10.1109/ACCESS.2020.2990636

[23] Elizabeth Guffey. 2021. In the Wake of Universal Design: Mapping the Terrain. *Design Issues* 37, 1 (January 2021), 76–82. https://doi.org/10.1162/desi_a_00629

[24] Md. Zahidul Hasan, Shovon Sikder, and Muhammad Aminur Rahaman. 2022. Real-Time Computer Vision Based Autonomous Navigation System for Assisting Visually Impaired People using Machine Learning. In *2022 4th International Conference on Sustainable Technologies for Industry 4.0 (STI)*, December 17, 2022. IEEE, Dhaka, Bangladesh, 1–6. https://doi.org/10.1109/STI56238.2022.10103268

[25] Zahid Hasan, Samsoon Nahar Shampa, Tasmia Rahman Shahidi, and Shahnewaz Siddique. 2020. Pothole and Speed Breaker Detection Using Smartphone Cameras and Convolutional Neural Networks. In *2020 IEEE Region 10*

Symposium (TENSYMP), 2020. IEEE, Dhaka, Bangladesh, 279–282. https://doi.org/10.1109/TENSYMP50017.2020.9230587

[26] Amin S. Ibrahim, Khaled Y. Youssef, Ahmed H. Eldeeb, Mohamed Abouelatta, and Hesham Kamel. 2022. Adaptive aggregation based IoT traffic patterns for optimizing smart city network performance. *Alexandria Engineering Journal* 61, 12 (December 2022), 9553–9568. https://doi.org/10.1016/j.aej.2022.03.037

[27] Laura Ivers. 2023. Disability Inclusion Overview. Retrieved from https://www.worldbank.org/en/topic/disability

[28] Yosef Jabareen. 2009. Building a Conceptual Framework: Philosophy, Definitions, and Procedure. *International Journal of Qualitative Methods* 8, 4 (2009), 49–62. https://doi.org/10.1177/160940690900800406

[29] Payyazhi Jayashree, Feras Hamza, May El Barachi, and Ghazaleh Gholami. 2019. Inclusion as an Enabler to Sustainable Innovations in Smart Cities: A Multi-Level Framework. In *2019 4th International Conference on Smart and Sustainable Technologies (SpliTech)*, June 2019. IEEE, Split, Croatia, 1–9. https://doi.org/10.23919/SpliTech.2019.8783013

[30] Wei Jiang, Bin Han, Mohammad Asif Habibi, and Hans Dieter Schotten. 2021. The Road Towards 6G: A Comprehensive Survey. *IEEE Open J. Commun. Soc.* 2, (2021), 334–366. https://doi.org/10.1109/OJCOMS.2021.3057679

[31] Latif U. Khan, Yan Kyaw Tun, Madyan Alsenwi, Muhammad Imran, Zhu Han, and Choong Seon Hong. 2022. A Dispersed Federated Learning Framework for 6G-Enabled Autonomous Driving Cars. *IEEE Trans. Netw. Sci. Eng.* (2022), 1–12. https://doi.org/10.1109/TNSE.2022.3188571

[32] K.T.Y. Mahima, R.A.B. Abeygunawardana, and T.N.D.S. Ginige. 2020. Dynamic Traffic Light Controlling System Using Google Maps and IoT. In *2020 From Innovation to Impact (FITI)*, December 15, 2020. IEEE, Colombo, Sri Lanka, 1–5. https://doi.org/10.1109/FITI52050.2020.9424870

[33] Alessandro Massaro, Nicola Savino, Sergio Selicato, Antonio Panarese, Angelo Galiano, and Giovanni Dipierro. 2021. Thermal IR and GPR UAV and Vehicle Embedded Sensor Non-Invasive Systems for Road and Bridge Inspections. In *2021 IEEE International Workshop on Metrology for Industry 4.0 & IoT (MetroInd4.0&IoT)*, June 07, 2021. IEEE, Rome, Italy, 248–253. https://doi.org/10.1109/MetroInd4.0IoT51437.2021.9488483

[34] Abhishek Mishra, Jahanvi Purohit, Maruf Nizam, and Suresh Kumar Gawre. 2023. Recent Advancement in Autonomous Vehicle and Driver Assistance Systems. In *2023 IEEE International Students' Conference on Electrical, Electronics and Computer Science (SCEECS)*, February 18, 2023. IEEE, Bhopal, India, 1–5. https://doi.org/10.1109/SCEECS57921.2023.10063089

[35] Jakob Nielsen. 1995. *How to Conduct a Heuristic Evaluation*. Retrieved from http://www.nngroup.com/articles/how-to-conduct-a-heuristic-evaluation/

[36] Md. Noor-A-Rahim, Zilong Liu, Haeyoung Lee, Mohammad Omar Khyam, Jianhua He, Dirk Pesch, Klaus Moessner, Walid Saad, and H. Vincent Poor. 2022. 6G for Vehicle-to-Everything (V2X) Communications: Enabling Technologies, Challenges, and Opportunities. *Proc. IEEE* 110, 6 (June 2022), 712–734. https://doi.org/10.1109/JPROC.2022.3173031

[37] Donald A. Norman. 1979. *Slips of the Mind and an Outline for a Theory of Action:* Defense Technical Information Center, Fort Belvoir, VA. https://doi.org/10.21236/ADA081932

[38] PAHO. 2023. 7th UN Global Road Safety Week 2023. Retrieved from https://www.paho.org/en/campaigns/7th-global-road-safety-week-2023

[39] K K Pradeep, P Tamilvani, P N Palanisamy, M Mohammadha Hussaini, S Ragul, and N Selvam. 2023. An Intelligent IoT based Advanced Accident Detection and Sensor Fusion Categorization System. In *2023 2nd International Conference on Automation, Computing and Renewable Systems (ICACRS)*, December 11, 2023. IEEE, Pudukkottai, India, 1647–1655. https://doi.org/10.1109/ICACRS58579.2023.10405257

[40] M Sandhya, S Gowrishankar, and A Veena. 2022. Applications of Deep Learning Models for Detecting the Road Damages and Obstacles Using Multiple Images. In *2022 6th International Conference on Electronics, Communication and Aerospace Technology*, December 01, 2022. IEEE, Coimbatore, India, 868–871. https://doi.org/10.1109/ICECA55336.2022.10009439

[41] Paul Schmitt, Nicholas Britten, JiHyun Jeong, Amelia Coffey, Kevin Clark, Shweta Sunil Kothawade, Elena Corina Grigore, Adam Khaw, Christopher Konopka, Linh Pham, Kim Ryan, Christopher Schmitt, and Emilio Frazzoli. 2022. Can Cars Gesture? A Case for Expressive Behavior Within Autonomous Vehicle and Pedestrian Interactions. *IEEE Robot. Autom. Lett.* 7, 2 (April 2022), 1416–1423. https://doi.org/10.1109/LRA.2021.3138161

[42] Naomi Schwartz, Ron Buliung, Arslan Daniel, and Linda Rothman. 2022. Disability and pedestrian road traffic injury: A scoping review. *Health & Place* 77, (September 2022), 102896. https://doi.org/10.1016/j.healthplace.2022.102896

[43] Kr Senthil Murugan, L R Sonal, S Sureshkumar, K Shrimeenatchi, M Srinithi, and R Swatheka. 2023. IOT Based Road Accident Detection and Prevention System. In *2023 International Conference on Quantum Technologies, Communications, Computing, Hardware and Embedded Systems Security (iQ-CCHESS)*, September 15, 2023. IEEE, KOTTAYAM, India, 1–5. https://doi.org/10.1109/iQ-CCHESS56596.2023.10391565

[44] Ethan Shaotran, Jonathan J. Cruz, and Vijay Janapa Reddi. 2021. Gesture Learning For Self-Driving Cars. In *2021 IEEE International Conference on Autonomous Systems (ICAS)*, August 11, 2021. IEEE, Montreal, QC, Canada, 1–5. https://doi.org/10.1109/ICAS49788.2021.9551186

[45] Mustafa A. Shihab, Salma Abdullah Aswad, Rawshan Nuree Othman, and Saadaldeen Rashid Ahmed. 2023. Advancements and Challenges in Networking Technologies: A Comprehensive Survey. In *2023 7th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, October 26, 2023. IEEE, Ankara, Turkiye, 1–5. https://doi.org/10.1109/ISMSIT58785.2023.10304990

[46] Salem Mokhtar Tarhuni. 2022. Accessibility for Disabled People at Peshmerga Park, Erbil, Iraq. In *2022 8th International Engineering Conference on Sustainable Technology and Development (IEC)*, February 23, 2022.

IEEE, Erbil, Iraq, 199–204. https://doi.org/10.1109/IEC54822.2022.9807483

[47] Pavani Tripathi, Rohit Keshari, Soumyadeep Ghosh, Mayank Vatsa, and Richa Singh. 2019. AUTO-G: Gesture Recognition in the Crowd for Autonomous Vehicl. In *2019 IEEE International Conference on Image Processing (ICIP)*, September 2019. IEEE, Taipei, Taiwan, 3482–3486. https://doi.org/10.1109/ICIP.2019.8803692

[48] Cheng-Xiang Wang, Xiaohu You, Xiqi Gao, Xiuming Zhu, Zixin Li, Chuan Zhang, Haiming Wang, Yongming Huang, Yunfei Chen, Harald Haas, John S. Thompson, Erik G. Larsson, Marco Di Renzo, Wen Tong, Peiying Zhu, Xuemin Shen, H. Vincent Poor, and Lajos Hanzo. 2023. On the Road to 6G: Visions, Requirements, Key Technologies, and Testbeds. *IEEE Commun. Surv. Tutorials* 25, 2 (2023), 905–974. https://doi.org/10.1109/COMST.2023.3249835

[49] Jacquline Morlav S. Waworundeng, Micha Adeleid Tisyana Kalalo, and Daniel Putra Yudha Lokollo. 2020. A Prototype of Indoor Hazard Detection System using Sensors and IoT. In *2020 2nd International Conference on Cybernetics and Intelligent System (ICORIS)*, October 27, 2020. IEEE, Manado, Indonesia, 1–6. https://doi.org/10.1109/ICORIS50180.2020.9320809

[50] Lin Wu, Guogui Yang, Jintao Yan, Shuguang Ran, Baokang Zhao, and Huan Zhou. 2023. Simulation for urban computing scenarios: An overview and research challenges. In *2023 IEEE 10th International Conference on Cyber Security and Cloud Computing (CSCloud)/2023 IEEE 9th International Conference on Edge Computing and Scalable Cloud (EdgeCom)*, July 2023. IEEE, Xiangtan, Hunan, China, 12–17. https://doi.org/10.1109/CSCloud-EdgeCom58631.2023.00012

[51] B. A. O. S. Yasaswin and T. M. K. K. Jinasena. 2019. Automated, low-cost pedestrian crossing carriage for efficient traffic control and pedestrian safety. In *2019 International Research Conference on Smart Computing and Systems Engineering (SCSE)*, March 2019. IEEE, Colombo, Sri Lanka, 234–239. https://doi.org/10.23919/SCSE.2019.8842755