

# CARRIE UGV: A Human-Centered Terminal UGV for Carry-on Transport and Wayfinding Support

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**Abstract**—Airports are facing increasing demand for accessible passenger support, particularly for older adults and passengers with disabilities navigating post-security terminal environments. This paper presents CARRIE UGV, an Uncrewed Ground Vehicle (UGV) concept designed to augment existing assistance services by transporting carry-on luggage and supporting indoor wayfinding after Transportation Security Administration (TSA) screening. Guided by a design thinking approach, the concept development was informed by accessibility needs, prior airport assistance studies, and practitioner input from wheelchair-assistance personnel at Daytona Beach International Airport, Hartsfield-Jackson Atlanta International Airport, and Incheon International Airport. These inputs highlighted persistent service gaps in carry-on handling and terminal navigation, particularly in complex and high-demand operating environments. In response, CARRIE UGV was designed as a human-centered system that integrates real-time environmental sensing with visual and auditory guidance to enable safer, less burdensome passenger movement. The paper further discusses preliminary feasibility through system-level risk, cost-benefit, and sustainability considerations. As a conceptual design, CARRIE UGV demonstrates the potential for UGV-enabled airport services to enhance accessibility and improve the post-security passenger experience without replacing existing human assistance.

**Keywords**—Uncrewed ground vehicle (UGV), Service robotics, Wayfinding, Accessibility technology

## I. INTRODUCTION

Air travel remains an essential mode of regional, national, and international mobility, including for older adults and passengers with disabilities. As the aging population grows and demand for accessible air travel increases, airports and airlines face rising pressure to provide services that support safe, efficient, and dignified passenger movement throughout the travel journey [1]–[4]. Existing assistance services, while important, do not always fully address post-security needs, such as handling carry-on luggage and navigating complex terminal environments. These gaps can create additional physical burden and stress, particularly for older adults and passengers with mobility or other accessibility challenges [5].

To help address these limitations, this paper presents CARRIE UGV, a human-centered terminal Uncrewed Ground Vehicle (UGV) concept designed to augment existing assistance services after the TSA checkpoint. The proposed system is intended to transport carry-on luggage and provide wayfinding

support through onboard sensing and passenger-facing guidance features. By focusing on post-security passenger movement, the concept aims to improve accessibility and reduce physical burden without replacing existing human assistance services.

## II. BACKGROUND

### A. Current Regulatory Context for Passenger Assistance

The primary U.S. regulatory framework governing disability-related air travel services is the Air Carrier Access Act (ACAA), codified at 49 U.S.C. § 41705 and implemented by the U.S. Department of Transportation (DOT) through 14 CFR Part 382 [1], [6], [7]. Under this framework, air carriers may not discriminate against passengers on the basis of disability, and they must provide specified assistance to support accessible air travel. DOT guidance further clarifies that these protections apply to flights to, from, and within the United States.

Under 14 CFR Part 382, carriers must provide, or ensure the provision of, assistance to passengers with disabilities in moving through the terminal environment. This includes access to key functional areas such as ticketing, gates, and baggage claim. The regulation also requires assistance with transporting gate-checked or carry-on luggage for passengers with disabilities who cannot carry their own luggage. In addition, mobility aids and other assistive devices receive specific protection under Part 382, including priority handling and accommodation subject to applicable safety and security requirements.

Beyond airline-specific obligations under the ACAA, airports operated by public entities are also subject to Title II of the Americans with Disabilities Act (ADA), which prohibits disability-based discrimination in public services and facilities [8]. Together, these regulatory frameworks establish the expectation that airport travel environments and related services be accessible, safe, and usable for passengers with disabilities.

### B. Passenger Assistance Requirements and Remaining Accessibility Gaps

Passenger assistance in airport environments is shaped by both legal requirements and operational service expectations. In the United States, the Air Carrier Access Act (ACAA), implemented through 14 CFR Part 382, requires carriers to provide or ensure assistance for passengers with disabilities in moving through the terminal, boarding, deplaning, and related travel activities. For passengers unable to carry baggage because

of a disability, these requirements also include assistance with transporting carry-on or gate-checked luggage. In Europe, Regulation (EC) No. 1107/2006 similarly establishes the rights of disabled persons and persons with reduced mobility and requires assistance throughout the air travel process [9]. Together, these frameworks reflect a common expectation that accessible air travel must include not only nondiscrimination but also practical support for passenger movement and use of airport facilities.

Despite these requirements, important accessibility challenges remain in practice, particularly in post-security terminal environments. Older adults and passengers with disabilities may still face difficulty navigating complex terminal layouts, interpreting mixed physical and digital wayfinding systems, and managing carry-on baggage over long walking distances or in crowded conditions. Prior studies and ACRP reports have identified persistent concerns about fatigue, wayfinding difficulties, and service limitations, suggesting that existing measures such as signage, maps, and staff assistance do not consistently meet passenger needs [10]–[12]. These

remaining gaps motivate the need for a human-centered support concept that can augment current assistance services, particularly for carry-on transport and wayfinding after the TSA checkpoint.

### III. METHODOLOGY

#### A. Design Thinking Framework

This study used the Design Thinking framework to guide the development of a human-centered concept for airport assistance [13]. Design Thinking supports solution development through iterative stages of need identification, problem definition, ideation, prototyping, and refinement. In this study, the framework was used to translate accessibility-related passenger needs and stakeholder input into the concept development of CARRIE UGV. To strengthen the preliminary evaluation, the design process was complemented by risk, cost-benefit, and sustainability considerations. The resulting approach supported the development of a concept intended to augment airport assistance services for older adults and passengers with disabilities..

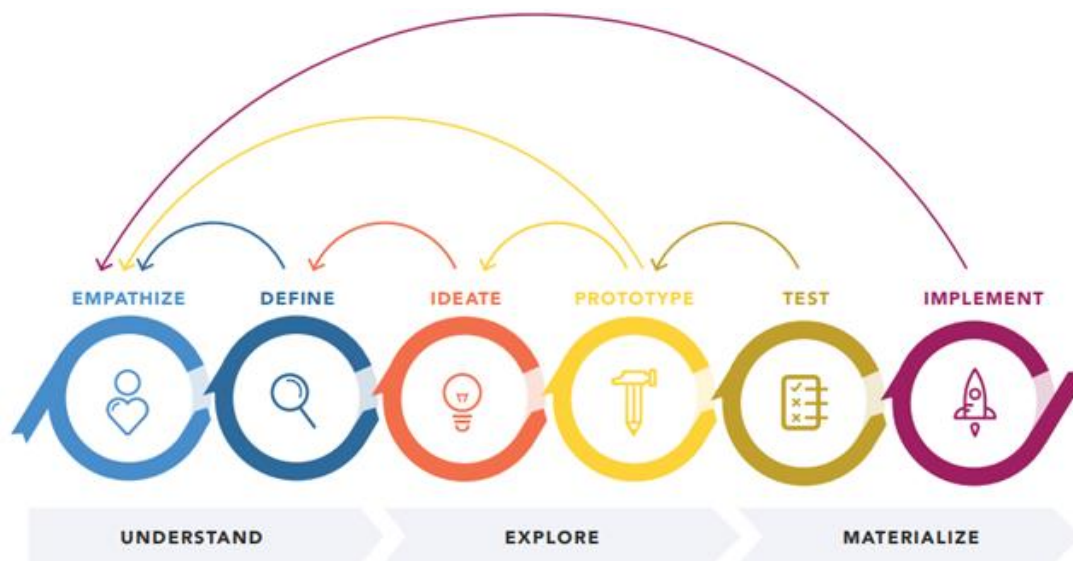


Fig. 1. Visual Representation of the Design Thinking Process

#### B. User Needs, Problem Definition, and Concept Development

The concept development process began by examining the needs of older adults and passengers with disabilities in airport terminal environments. A review of relevant literature, regulations, prior ACRP reports, and existing assistance practices was used to identify recurring challenges related to terminal navigation, physical burden, and carry-on baggage management [14], [15]. This review also highlighted growing service pressure associated with aging passenger populations and the continued need for accessible, practical support beyond existing assistance workflows.

Based on these findings, the problem was defined as a post-security service gap in which current assistance approaches do not always fully address both carry-on transport and wayfinding needs in complex terminal environments. This gap is particularly relevant for passengers with reduced mobility or other accessibility-related challenges, who may experience added fatigue, difficulty navigating, or increased reliance on staff support.

In response, the team developed CARRIE UGV, an Uncrewed Ground Vehicle (UGV) concept intended to augment existing airport assistance services. The concept evolved from an initial automated luggage-support idea into a more integrated system designed to transport carry-on luggage, support terminal

wayfinding, and operate safely in dynamic airport environments. To improve its relevance and distinctiveness, the concept was further refined by comparing it with prior ACRP design concepts and considering regulatory, operational, and user-centered design needs.

#### IV. DESIGN OF SYSTEM

Through the Design Thinking process, the team developed CARRIE UGV, a conceptual Uncrewed Ground Vehicle designed to augment post-security airport assistance services. The system is intended to transport carry-on luggage using a scissor-lift mechanism while providing wayfinding support through a leader-follower navigation approach (see Fig. 2). Operating alongside the passenger, CARRIE UGV is designed to assist movement through the terminal by reducing the physical burden of luggage handling and supporting navigation in complex indoor environments. The concept incorporates obstacle detection and avoidance, real-time navigation, and accessible user interaction features to improve safety, usability, and overall passenger support.

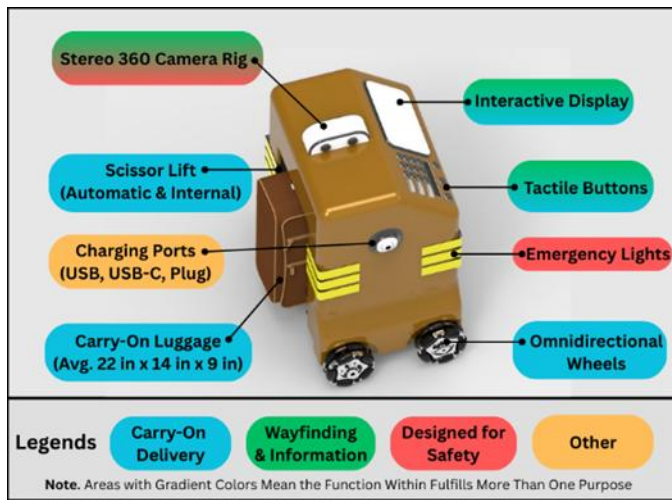


Fig. 2. Conceptual Design of Carrie UGV

##### A. System Purpose and Operating Role

CARRIE UGV is designed as a terminal assistance UGV that transports a passenger’s carry-on luggage and provides wayfinding support from the post-TSA checkpoint area to a designated destination, such as a departure gate. The system is intended to support both passengers using wheelchair services

and ambulatory passengers who may still require assistance with baggage handling or navigation. In wheelchair-assisted operations, the UGV is designed to complement service personnel by reducing the burden of luggage handling and supporting terminal routing. For ambulatory passengers, it functions as a personal wayfinding aid and carry-on transport platform. A central design principle is that CARRIE UGV augments rather than replaces existing assistance services. Human attendants remain responsible for services requiring direct physical support, regulatory oversight, or human judgment, while the UGV addresses practical gaps in luggage transport and navigation.

##### B. Core Operational Functions

The system is designed around two primary functions: carry-on transport and terminal wayfinding. First, CARRIE UGV provides a dedicated platform for transporting carry-on luggage, reducing the physical burden placed on passengers and airport personnel. The luggage-support mechanism uses a compact scissor-lift platform that enables secure placement of baggage while maintaining terminal maneuverability. Second, the UGV provides wayfinding support through a leader-follower operating mode, traveling alongside or slightly ahead of the passenger while guiding movement through the terminal environment. Together, these functions are intended to improve accessibility, reduce fatigue, and support more efficient passenger movement in complex post-security spaces.

##### C. Technological Architecture

The proposed system consists of four main elements: mobility hardware, onboard computing, perception sensors, and communication interfaces (see Fig. 3). The mobility subsystem includes the chassis, motor driver, battery system, control unit, and omnidirectional wheels to support maneuverability in indoor terminal environments. The perception subsystem includes camera-based sensing for environmental awareness and obstacle detection, as well as an inertial measurement unit (IMU) for motion context. Onboard computing supports real-time perception, navigation, and user-interaction functions. Communication interfaces such as Wi-Fi, Bluetooth, or other airport-compatible connectivity options may support integration with airport information systems, when available. For indoor navigation, the concept assumes a simultaneous localization and mapping (SLAM)-based approach to support routing and obstacle-aware movement in dynamic terminal environments.

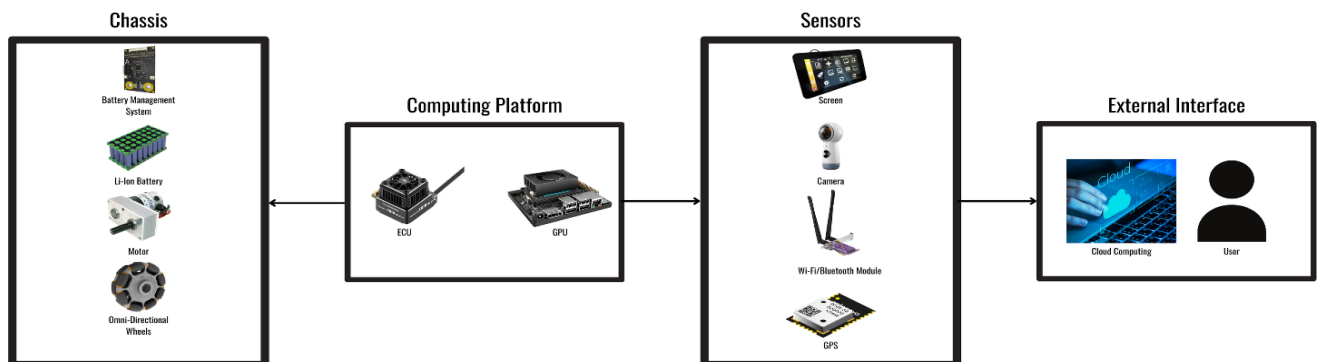


Fig. 3. Operational Architecture

D. Dynamic Environment and Obstacle Handling

Airport terminals are dynamic, pedestrian-dense environments that require cautious and adaptive robot operation. Accordingly, CARRIE UGV is designed for safe movement in shared indoor spaces rather than dedicated robotic lanes. The operating concept assumes continuous obstacle detection, conservative local path planning, and speed adjustment based on surrounding traffic conditions. When encountering pedestrians, wheelchairs, carts, or temporary obstructions, the UGV is expected to slow, stop at a safe distance, wait when necessary, and reroute when a clear path becomes available. Additional caution is assumed in crowded areas, near floor transitions or slopes, and around passengers with reduced mobility. These behaviors are intended to support safe, predictable, and user-acceptable operation in accessibility-sensitive terminal environments.

V. DISCUSSION

CARRIE UGV addresses a practical accessibility gap in post-security terminal environments by supporting carry-on transport and wayfinding for older adults and passengers with disabilities. As a human-centered assistance concept, the system is intended to augment existing airport services by reducing luggage-handling burden and improving passenger movement through complex indoor spaces. The concept also raises broader implementation considerations, including phased deployment, compatibility with existing airport operations, and adaptability across airports of varying sizes, layouts, and passenger demand profiles. While additional operational and economic validation is still needed, the proposed system provides a preliminary framework for examining how terminal UGVs could support accessibility-focused airport service innovation.

A. Safety Risk Assessment

Safety is a critical consideration for any airport assistance concept operating in shared terminal environments. Because CARRIE UGV is intended to interact with passengers, service personnel, wheelchairs, and other moving objects in pedestrian-dense areas, a preliminary safety risk assessment was conducted to identify potential operational hazards. This assessment drew on the risk assessment matrix in FAA Order 5200.11A and an Operational Risk Assessment framework to evaluate hazards associated with system use (see Table 1) [16]. The purpose of this assessment was not to certify the concept, but to identify major safety concerns and inform early design considerations for safer deployment.

TABLE I. RISK ASSESSMENT MATRIX UNDER FAA ORDER 5200.11A

Severity \ Likelihood	Minimal (1)	Minor (2)	Major (3)	Hazardous (4)	Catastrophic (5)
Frequently (5)	5	10	15	20	25
Probably (4)	4	8	12	16	20
Remotely (3)	3	6	9	12	15
Extremely Remote (2)	2	4	6	8	10
Extremely Improbable (1)	1	2	3	4	5

The preliminary risk assessment identified three primary categories: operational risk, technical risk, and human factors risk. Operational risk captured hazards associated with the terminal environment and system operation, technical risk addressed hardware, software, and firmware issues, and human factors risk focused on user-system interaction. The highest pre-mitigation risk was associated with overweight or oversized luggage, which received a score of 12 and was classified as high risk, whereas human factors-related hazards were generally assessed as medium risk. Following the application of proposed mitigations, many risks were reduced to acceptable levels. In total, the aggregate risk score decreased from 86 to 41, indicating that the concept may be operationally manageable at this preliminary design stage.

B. Cost-Benefit and Sustainability Considerations

A preliminary cost-benefit analysis was conducted to examine the potential economic implications of developing and deploying CARRIE UGV. Based on a phased concept-development model, estimated costs include design and planning, prototype development and testing, system integration, and annual operation and maintenance. Although the initial investment is substantial, the analysis suggests that long-term savings may be achievable through reduced service burden and improved operational efficiency after deployment. Because these estimates are based on conceptual assumptions and an airport-specific implementation scenario, they should be interpreted as preliminary rather than predictive.

From a sustainability perspective, the concept was also examined using the EONS framework [17]. The assessment suggested potential positive effects in economic vitality and service innovation, while also identifying limitations related to operational dependence, battery-related environmental considerations, and constraints associated with wheelchair-service workflows. Overall, the sustainability review indicates that CARRIE UGV has promising yet mixed implications that

require further validation through prototype testing and analysis of real-world implementation.

## VI. CONCLUSION

As airports serve growing populations of older adults and passengers with disabilities, the need for accessible support services that extend beyond conventional wheelchair assistance is increasing. This paper presented CARRIE UGV, a human-centered terminal UGV concept intended to augment post-security airport assistance through carry-on transport and indoor wayfinding support. Guided by accessibility considerations, prior ACRP-related design insights, and a design thinking-based development process, the study translated identified operational gaps into a preliminary system concept and architecture. The results suggest that CARRIE UGV could reduce passenger burden and complement existing assistance workflows in complex terminal environments. Although deployment would require upfront investment and further validation, the concept demonstrated manageable preliminary risks and promising operational potential. Future work should focus on prototype development, stakeholder testing, and implementation assessment in real airport settings.

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