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Evacuation of Vulnerable Populations: The Lima BRT Case

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Abstract*– his study proposes improvements to evacuation processes for vulnerable populations—including older adults, persons with physical, visual, or sensory disabilities, wheelchair users, pregnant women, and individuals with temporary mobility limitations—during ordinary accident and disruption scenarios in Lima's Bus Rapid Transit (BRT) system, known as the Metropolitano. The research addresses the increased exposure of these users in high-demand corridors, where congestion, limited accessibility infrastructure, and insufficient operational protocols can delay evacuation and increase safety risks. Methodologically, the study adopts an exploratory qualitative case-study approach based on a structured documentary review of scientific literature, technical reports, and institutional sources related to evacuation planning, humanitarian logistics, accessibility, and emergency management in public transportation systems. The review was used to build an analytical matrix linking real cases, operational problems, key insights, and proposed logistics improvements. In addition, the proposal was validated through a structured survey administered to six experts in transportation systems, emergency management, operations, and accessibility, using a five-point Likert scale. The findings identify three priority areas for improvement: real-time data governance and passenger-flow management, resilient and redundant accessibility infrastructure, and inclusive multisensory communication and assistance mechanisms. Expert validation showed high agreement, with most indicators scoring above 4.0 and 100% of experts classifying the framework as validated with minor adjustments, supporting its practical relevance for safer and more inclusive BRT evacuation planning.

Keywords*– evacuation, vulnerable populations, public transportation, BRT, Lima Metropolitan Buses.

I. Introduction

People in situations of vulnerability are those whose physical, sensory, cognitive, social, or economic condition limits the full exercise of their rights and exposes them disproportionately to situations of risk, exclusion, or discrimination. According [1], "persons are vulnerable in research either because they have difficulty providing voluntary, informed consent arising from limitations in decision-making capacity … or situational circumstances …, or because they are especially at risk for exploitation. This condition does not depend solely on individual characteristics, but on the interaction with environmental barriers that restrict their autonomy and participation in society. The United Nations has incorporated the vulnerability approach into the Sustainable Development Goals, highlighting the need to ensure inclusive, safe, and resilient cities, where equitable access to basic services such as public transportation is an effective right for all, especially for people with disabilities, older adults, and other vulnerable groups [2].

At a global level, the magnitude of the population in situations of vulnerability highlights the relevance of this approach in urban planning and emergency management; more than one billion people live with some type of disability, which represents approximately 16% of the world population [3]. This group faces greater constraints in achieving safe and autonomous mobility within public transportation systems due to the additional assistance they require during evacuation processes. These constraints intensify in emergency contexts, where evacuation efficiency depends on the reduction of reaction times, effective accessibility to evacuation facilities, and the availability of adequate logistical support, factors that are critical for the preservation of life [4]. In this context, the evacuation of people in situations of vulnerability represents one of the greatest challenges within emergency management and humanitarian logistics, especially in high-demand transportation systems. According to [5], stations, platforms, and tracks can become spaces of critical risk during an emergency, where a rapid and organized evacuation is crucial to preserve the safety of passengers. These conditions affect people with disabilities or reduced mobility more severely, as they face greater difficulties in reacting to hazardous situations. Structural factors play an important role in evacuation processes. The availability of complementary transportation means, such as emergency buses, makes it possible to evacuate a larger number of passengers in a shorter time, reducing exposure to risk and preventing dangerous crowding, especially in high-demand contexts [4].

The Urban Transport Authority for Lima and Callao (ATU) reported that between January and October 10, 2025, 79 traffic accidents were recorded on the exclusive Metropolitano lane, caused by unauthorized vehicles that entered improperly [6]. Emergency events are frequently differentiated in risk management literature according to their frequency and impact. In particular, operational disruptions can be categorized as low-frequency, high-impact events and high-frequency, low-impact events, as these exhibit distinct statistical properties and require different management strategies [7]. Low-frequency, high-impact events typically involve large-scale emergencies such as earthquakes, major infrastructure failures, or extreme natural disasters, which demand coordinated large-scale response mechanisms. In contrast, high-frequency, low-impact events correspond to operational disruptions inherent to the daily functioning of systems, including traffic accidents, service interruptions, vehicle breakdowns, or unauthorized lane intrusions due to people or vehicles [7]. Although these events may generate comparatively lower individual impact, their cumulative effect in high-demand transport systems can produce significant risk conditions, particularly for people in situations of vulnerability. This study focuses on high-frequency, low-impact operational events within the Metropolitano [7].

In the Peruvian context, the National Institute of Statistics and Informatics states that there are 3.2 million people with disabilities, which is equivalent to 10.3% of the national population, with women (56.7%) and older adults (40.1%) being the most affected groups. Likewise, Metropolitan Lima concentrates 31.2% of this population [8], which increases the demands placed on the public transportation system. Despite this, current mobility conditions do not guarantee safe, accessible, and inclusive movement. In fact, according to Daniel Aparicio, technical coordinator of the programs offered by the Lima Center for the Rehabilitation of the Blind (Cercil), people with visual disabilities face physical obstacles that not only limit their daily mobility but also increase the time required to move around [9].

Likewise, the Ombudsman's Office indicates that, despite the current regulations, a significant portion of this population is forced to travel on foot or to frequently rely on taxi services due to the limitations of public transportation, which implies assuming considerably higher costs for each trip, generating a greater economic burden compared to other users [10].

These conditions reflect that the adaptation of transportation units, stations, and routes requires greater budgetary investments, which is essential to ensure the inclusion and autonomy of people with disabilities.

II. Methodology

This study adopts an exploratory qualitative case-study approach focused on Lima's Bus Rapid Transit (BRT), known as the Metropolitano. The research was developed through a structured documentary review of scientific articles, technical reports, and institutional documents related to evacuation planning, humanitarian logistics, accessibility, and emergency management in public transportation systems. This review made it possible to identify recurrent barriers affecting vulnerable populations and to organize the analytical matrix presented in this study, linking critical events, operational problems, key insights, and proposed improvement measures.

The study incorporates a validation phase based on expert evaluation through a structured survey instrument. The survey was administered to six experts in transportation systems, emergency management, and accessibility, ensuring a high level of technical reliability in the assessment process.

The instrument evaluated the relevance, coherence, feasibility, and expected impact of the proposed improvement measures using a five-point Likert scale. This approach enabled the collection of both quantitative and qualitative data to assess the applicability of the proposed evacuation framework in the context of Lima's BRT system. Similar approaches have been used in transportation research to incorporate stakeholder perspectives in the evaluation of system performance and implementation strategies [11], [12].

The validation process aims to contrast the documentary findings with expert judgment, identify potential implementation barriers, and assess the practical relevance of the proposed measures [13].

III. Transport System Gaps

Vulnerability in mass transportation is not an individual incapacity, but rather a systemic deficiency resulting from the lack of adaptation to the functional diversity of its users. In emergency situations, groups such as older adults, people with disabilities, and children face systemic vulnerability because standard protocols are designed for an average user. An example of the limitations in considering vulnerable populations, such as older adults, is presented in [14]. The authors identify the limited research aimed at making transportation systems more inclusive.

At the macro level, these gaps can also be explained by the fact that urban transportation systems have been primarily designed to optimize operational efficiency and passenger flow, rather than to respond to evacuation or emergency scenarios. As a result, when a critical event occurs, the limitations of the design become evident and disproportionately affect users with lower autonomous response capacity [15].

As identified in urban evacuation studies, populations with special needs include residents without private vehicles and individuals with physical limitations who require specific support infrastructure [4]. This lack of inclusive design generates critical barriers:

1) *Logistical time gap:* The reaction and evacuation times of people with reduced mobility are significantly longer, which requires a differentiated allocation of resources and support personnel to prevent them from being left behind [16].
2) *Infrastructure barriers:* Dependence on mechanical systems in buses implies that, in the event of structural failures, these users face disproportionate risks due to congestion and the lack of adequate assistance [16].
3) *Priority management:* It is essential to establish a hierarchy of attention in which logistical resources are directed first to populations with lower self-management capacity. Evacuation modeling studies indicate that prioritizing public transport resources for these groups can improve both the efficiency and equity of evacuation, while also reducing the risk of road network collapse [4],[16].

At the meso level, the evacuation capacity of the system depends on logistical factors such as the number of available exits, the width of corridors, the availability of evacuation routes, and the effective training of personnel to assist and guide users during an emergency. When these elements are limited, evacuation becomes slower and the risk to passengers increases.

Vulnerability in public transport evacuation processes is not distributed uniformly among users; rather, it follows a hierarchy determined by physical, sensory, age-related, and contextual factors. From this perspective, vulnerability can be understood as a pyramidal structure, in which groups with lower autonomous response capacity are located at the upper levels and therefore require priority attention during emergency situations. At the lower levels are users with greater mobility and faster reaction capacity, who face a lower level of immediate risk [17]. This hierarchical approach is essential for planning safe and efficient evacuations, as it helps guide the allocation of resources, the design of accessible infrastructure, and the development of differentiated emergency protocols [4],[16]. Recognizing the vulnerability pyramid in public transportation does not imply excluding other users; on the contrary, it ensures that emergency measures consider existing functional inequalities, reducing the impact of hazardous events and promoting an inclusive and equitable safety framework [16]. In Bus Rapid Transit (BRT) systems, structural and operational deficiencies are mainly manifested through the high concentration of passengers in enclosed stations and articulated vehicles [4]. In the event of earthquakes, fires, or operational failures, these conditions significantly reduce the system's response capacity and hinder safe evacuation, disproportionately affecting people with disabilities due to the limited availability of alternative routes and the absence of differentiated evacuation procedures [17].

At the micro level, BRT systems often generate bottlenecks during evacuation, particularly at entrances, turnstiles, stairways, and narrow corridors within stations. These congestion points reduce passenger movement speed and can lead to dangerous crowd accumulations during emergencies. In this context, Lima's BRT system, known as the Metropolitano de Lima, presents vulnerability in emergency situations as a result of deficiencies in its infrastructure and insufficient operational response [18]. Various technical reports have identified problems such as inoperative access points, structural deterioration, lack of emergency lighting, inadequate signage, and restrictions in evacuation routes, all of which compromise user safety.

During emergencies, these limitations prolong evacuation times for vulnerable groups, who depend on the continuous operation of elevators, ramps, and staff assistance, resources that are often insufficient. The limited training and availability of specialized personnel further intensify the risk, reinforcing the urgent need to implement improvements in infrastructure, accessibility, and evacuation protocols to ensure a more inclusive and safer transportation system [10].

IV. Lima BRT

The Metropolitano is a mass public transportation system of the Bus Rapid Transit (BRT) type that operates along the north–south axis of Metropolitan Lima, using segregated corridors, enclosed stations, and high-capacity terminals. Due to its structural role in urban mobility, it accommodates a high daily demand and experiences recurrent saturation during peak hours, making it a critical corridor in emergency scenarios [18]. From an urban mobility perspective, these metropolitan corridors are conceived as structuring axes that concentrate significant movement flows and functionally connect different areas of the city, playing a key role within the metropolitan transportation system.

The Metropolitano constitutes one of the main mass transit systems in Metropolitan Lima, operating through a segregated trunk corridor approximately 26 km in length that connects 12 districts of the city through 35 intermediate stations, one central station, and two main terminals, integrated with a network of feeder routes that expand its territorial coverage [19]. The system operates with an approximate fleet of 300 articulated buses, each with a capacity of up to 160 passengers, allowing it to transport large volumes of users along the north–south axis of the city [20]. Due to this operational capacity, the Metropolitano has reached demand levels exceeding 630,000 daily trips, progressively approaching its operational capacity limit, highlighting its critical role within the urban mobility structure [19]. Furthermore, technical analyses from the Ministry of Transport and Communications indicate that the system experiences high demand levels at critical stations, where passenger flow can exceed 27,000 users per hour at certain boarding points, reflecting a high concentration of passengers and conditions of operational saturation [21]. This high concentration of passengers in stations and transport units creates high-density conditions that, from a humanitarian logistics perspective, represent a significant challenge in emergency scenarios, as they increase the complexity of evacuation processes, particularly for vulnerable populations who require more time and assistance to move safely.

In the context of Metropolitan Lima, the high concentration of transport flows, combined with the deficit of intermediate road infrastructure and the high urban density in central areas, generates recurring scenarios of congestion and saturation of public space. These structural conditions limit the capacity of the transport system to respond effectively to emergencies, increasing evacuation times and hindering the safe movement of users, particularly in high-demand corridors such as the Metropolitano. In such cases, the operational continuity of the service and the system's dependence on road infrastructure can amplify the risk for vulnerable populations [22].

These structural limitations also affect the operational capacity of the BRT system from a logistical perspective. The Metropolitano functions as a high-capacity transport system designed to continuously move large volumes of passengers; however, during an emergency, its function shifts from transportation to evacuation, requiring the rapid and safe management of passenger flows. Studies on evacuation in public transportation systems indicate that factors such as high passenger density and limited availability of exit routes can reduce evacuation efficiency and increase response times. When the system operates under saturated conditions, these limitations further increase the risk for users, particularly vulnerable populations who require additional assistance to evacuate safely [23],[24].

In response to these scenarios, the Urban Transportation Authority for Lima and Callao has established general emergency management guidelines, which include the controlled stopping of vehicles, the opening of station doors, and directing users toward safe areas. However, vulnerability is not limited to situations in which the transport system comes to a complete stop. Structural and operational deficiencies may also generate risk conditions during regular operations, both within stations and while buses are in transit. High passenger density, congestion at boarding points, and limited accessibility infrastructure can create hazardous environments even before a full-service interruption occurs [25].

Furthermore, the implementation of emergency protocols faces additional operational limitations when buses stop outside stations, where pedestrian access is restricted and evacuation becomes more complex. In these contexts, the absence of safe evacuation corridors and the dependence on external coordination significantly increase the vulnerability of users who require additional assistance, particularly those with reduced mobility or sensory limitations [25]. The evacuation of passengers while the bus is in transit represents a scenario of greater operational complexity, since the exclusive BRT lane is not designed as an evacuation environment, but rather as a controlled circulation corridor. Unlike stations, where defined access points and evacuation areas are available, buses stopped outside these locations lack safe pedestrian routes, limiting the rapid and orderly movement of passengers. Studies on evacuation in public transportation systems indicate that the absence of adequate infrastructure and the dependence on external assistance, such as operational staff or emergency response teams, can significantly increase evacuation times and the risk of congestion, particularly for passengers with reduced mobility. In these situations, evacuation depends on the system's ability to coordinate operational response and facilitate access to safe areas, which constitutes a critical challenge from a humanitarian logistics perspective [23],[24]. These limitations highlight the need to strengthen logistical planning and coordination within Lima's BRT system, particularly in scenarios where evacuation must be carried out outside stations and under adverse operational conditions. In this context, a relevant comparative reference in Latin America is TransMilenio in Bogotá, one of the highest-capacity BRT systems in the region, transporting more than two million passengers daily. Unlike the Metropolitano, this system has developed specific emergency response protocols, periodic evacuation drills, and differentiated procedures for vulnerable populations, incorporating trained personnel, clearly marked evacuation routes, and direct coordination with disaster response agencies. These practices reduce evacuation times and improve safety in crisis scenarios, emphasizing the importance of more robust, anticipatory, and inclusive logistical planning in mass transit systems such as Lima's BRT [26].

V. Solutions to Evacuation

The following presents the technical analysis of the Metropolitano and Bus Rapid Transit (BRT) Corridors. This matrix breaks down critical events based on real-world case studies and scientific literature, linking specific problems with logistics engineering solutions.

TABLE I
CRITICAL EVENT ANALYSIS AND LOGISTICS IMPROVEMENT PROPOSALS

Event / Real Case	Identified Problem	Learning (Insight)	Proposed Improvement (Solution)
E1. Special Needs Planning: Mass evacuation analysis in urban buses [4] *Miami, USA*	The system operates with "data blindness," ignoring the number of vulnerable users on each unit in route.	A1. Vulnerability Invisibility: Lack of dynamic data prevents the prioritization of relief resources for critical units.	P1. Dynamic Occupancy Census: Use of smart validators to alert the Management Center about passenger profiles.
E2. Infrastructure Equity: Disparity in evacuation times at BRT stations [16] *Dar es Salaam, Tanzania*	Elevators become mechanical traps during power failures or seismic events.	A2. Electrical Dependency Paralysis: Current infrastructure does not guarantee autonomous vertical mobility for vulnerable groups.	P2. Accessibility Redundancy: Implementation of deep-cycle UPS and immediate-deploy manual ramps.
E3. Logistics Coordination: Dynamic response modeling in dense metropolises [24] *Istanbul, Turkey*	Panic and noise nullify verbal communication, isolating people with sensory disabilities.	A3. Sensory Exclusion in Crisis: Protocols are mostly auditory, ignoring visual and tactile needs.	P3. Haptic and LED Signaling: Installation of floor vibration strips and high-contrast LEDs to guide exits.

E4. Crowd Behavior: Study of "stampede effect" and flow segregation in stations [24] *Istanbul, Turkey*	The general population involuntarily obstructs the escape routes of the elderly and families with infants.	A4. Massive Flow Obstruction: Mixing flows of different speeds increases the fatality rate at the top of the pyramid.	P4. Dynamic Safe Zones: Protected security areas within stations for waiting for professional assistance.
E5. Transport-Health Response: Integration of emergency services in buses [4] *Miami, USA*	First responders arrive at the scene without prior information, losing vital time in wound classification.	A5. Medical Response Gap: The absence of a pre-triage on the bus delays care during the patient's "golden hour."	P5. Digital Cabin Triage: Immediate driver-EMS reporting interface for real-time injury classification.

VI. Expert Validation Results

To validate the proposed improvements, a structured survey was administered to six experts with professional experience in transport management consulting and education.

The results show a high level of agreement across all evaluated dimensions, including relevance, coherence, feasibility, and expected impact of the proposed measures. Most indicators obtained average scores above 4.0 on a five-point Likert scale, reflecting strong technical consistency and applicability.

Notably, 100% of the experts classified the proposal as “validated with minor adjustments,” confirming the robustness and practical relevance of the proposed evacuation framework.

Qualitative feedback highlighted the importance of incorporating real-time data integration, reducing congestion during peak hours, and strengthening coordination with external emergency response institutions to ensure effective implementation. In addition, expert feedback provided valuable insights for refining the proposed model, particularly emphasizing the need to incorporate external operational conditions, such as surrounding traffic, which may affect evacuation performance.

Some respondents also suggested the implementation of pilot tests and phased deployment strategies to evaluate system performance under real operating conditions. These recommendations contribute to enhancing the feasibility and scalability of the proposed evacuation framework.

TABLE II
Summary of Expert Validation Comments

Expert	Area of Expertise	Years of Experience	Main Recommendation
E1	Road and pedestrian transit infrastructure	11–15 years	Include access to emergency care points in the evacuation analysis, not only the local evacuation process.
E2	Transportation systems research	11–15 years	Prioritize variables and strengthen simulation, pilot testing, and continuous data collection.
E3	Project management	11–15 years	Strengthen user participation and stakeholder coordination under a continuous-improvement approach.
E4	Operations management	6–10 years	Incorporate financing mechanisms, particularly external funding sources, to support implementation.
E5	Transport planning and operations	More than 15 years	Add a preventive measure and consider service frequency as a factor in evacuation manageability.
E6	Operations management	11–15 years	Prioritize drills, safe zones, and accessibility redundancy measures in the short term.

As shown in Table II, all six experts validated the proposed framework with minor adjustments. Their feedback consistently highlighted the need to strengthen implementation conditions, particularly by considering access to emergency care points, improving simulation and continuous data collection processes, reinforcing stakeholder coordination, evaluating financing mechanisms, and prioritizing feasible short-term actions such as safe zones, accessibility redundancy, evacuation drills, and service-frequency improvements.

VII. Conclusions and Recommendations

The following conclusions are the result of a multi-dimensional technical diagnosis that integrates the operational reality of the Metropolitano with international scientific frameworks. To facilitate their implementation, the information has been segmented into three strategic categories:

1) *Category A:* It emerges from the analysis of crisis management and humanitarian logistics based on the coordination models and data resilience approaches identified in the literature [24], [27].
2) *Category B:* It is founded on the analysis of physical infrastructure and transport equity, based on findings reported in the literature [16], [29].
3) *Category C:* It is derived from the study of the human factor and sensory accessibility, following service-oriented systems criteria reported in the literature [30].

The following section will further explain each category in detail, outlining their technical components, operational implications, and specific strategic recommendations for strengthening system resilience and emergency response capacity.

Category A. It addresses operational resilience and humanitarian logistics, focusing on crisis management and real-time data governance. Applying operational resilience diagnostic criteria from the literature, it is concluded that humanitarian logistics efficiency within the Metropolitano is constrained by "operational blindness," where decision-making lacks granular and real-time information [27]. The findings demonstrate that survival during evacuation scenarios depends not solely on speed, but fundamentally on data precision and anticipatory flow management. In alignment with the intelligent boarding identification model reported in the literature [4], early recognition of vulnerable users transforms the transport corridor from a passive mobility channel into an adaptive life-saving network. Furthermore, the logistics coordination framework reported in the literature establishes that without dynamic flow optimization models, emergency responders physically compete with evacuees for limited spatial capacity, thereby reducing the effectiveness of medical intervention during the critical "golden hour" [4], [24], [27]. Consequently, it is recommended to implement a Digital Twin platform structured under a five-layer architecture (Terminal–Data–Model–Scenario–User), as reported in the literature [27], capable of processing large-scale operational data to predict congestion nodes, dynamically reallocate evacuation flows, and optimize bimodal exit strategies, potentially achieving up to a 22% reduction in evacuation time. Complementarily, based on systemic preparedness criteria reported in the literature [28], formal cooperation agreements with emergency institutions such as SAMU and Fire Departments must be institutionalized and digitally integrated into the Metropolitano's management center to ensure coordinated and proactive large-scale emergency response [27], [28]. In line with these findings, expert validation further emphasized the importance of real-time data integration and coordinated institutional response as critical factors for improving evacuation efficiency.

Category B. It examines infrastructure equity and pedestrian flow, focusing on physical resilience and systemic road safety as structural determinants of safe evacuation. The road safety diagnosis reported in the literature identifies critical "single points of failure," particularly the absence of electrical redundancy for elevators and emergency signaling systems [29]. Transport equity frameworks indicate that infrastructure design is not neutral but disproportionately penalizes individuals who depend on mechanical accessibility systems [16]. The technical evaluation concludes that physical resilience measures—including ramps, uninterrupted power supply (UPS) systems, and backup generators—constitute a fundamental requirement of spatial justice, preventing technical failures from transforming stations into containment zones for reduced-mobility users. [16], [29]. In response, the deployment of Intelligent Transport Systems (ITS) and integrated speed control sensors is recommended. Empirical evidence reported in the literature confirms that overspeeding regulation represents one of the most effective interventions to reduce road mortality, achieving reductions of up to 54% [29]. Additionally, based on organizational preparedness principles, inclusive evacuation drills must be institutionalized, training regular users to function as "flow facilitators," capable of clearing refuge corridors, assisting vulnerable individuals, and mitigating stampede effects during panic-driven events [28]. Consistent with these findings, expert feedback reinforced the need to address infrastructure limitations and highlighted the importance of incorporating external operational conditions, such as congestion and traffic interactions, into evacuation planning.

Category C. It concentrates on inclusion and the human factor, emphasizing universal accessibility and sensory safety as essential components of systemic resilience. Applying service-oriented systems frameworks reported in the literature, the station design assessment reveals a structural underestimation of user heterogeneity, where operational logic prioritizes transit velocity over sensory protection [30]. The analysis determines that transitioning toward a segregated and multi-sensorial environment is not merely an enhancement but a structural necessity. The absence of haptic and LED signaling systems, combined with the lack of protected "Sanctuary Zones," increases the exposure of vulnerable users to unintended crowd-related threats, compromising their physical integrity during high-density evacuation scenarios [30]. Consistent with these findings, expert validation results further stressed the importance of inclusive design, multi-sensory communication systems, and enhanced user-centered safety mechanisms.

Therefore, it is recommended to mandate the redesign of passenger information interfaces to deliver simultaneous visual, audible, and tactile communication channels. Additionally, structurally reinforced refuge areas incorporating appropriate lighting, climate control, and spatial buffering should be integrated into station layouts. To operationalize inclusive response at the fleet level, bus driver consoles must be upgraded with digital triage systems capable of automatically identifying assistance requirements through smart card validation data. Such intelligent identification mechanisms ensure prioritized and coordinated assistance for vulnerable users during emergency conditions [4], [16], [30].

In this context, the expert validation process confirms the technical feasibility and practical relevance of the proposed framework, supporting its potential implementation in Lima's BRT system with minor adjustments. The integration of data-driven decision-making, resilient infrastructure design, and inclusive operational strategies provides a comprehensive approach to improving evacuation performance and enhancing safety for vulnerable populations. Additionally, future research may incorporate direct input from vulnerable users, as qualitative evidence shows that first-hand accounts can reveal accessibility barriers and service limitations not always captured through technical analysis alone [13].

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