

Equitable Public Transit Evacuation Planning: A Systematic Review

Working Paper (January 2024)

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ABSTRACT

Climate change, extreme weather events, and human-initiated disasters necessitate resilient approaches to emergency preparedness and evacuation planning. Previous disasters, including in North America, have revealed the inadequacy of evacuation planning that is multi-modal and inclusive of vulnerable populations who primarily rely on public transit for mobility. Consequently, research and practical tools are needed to help develop more equitable evacuation strategies using public transit.

To address this fundamental gap in evacuation planning, we conducted a systematic literature review to address and provide an understanding of the role of public transit in the evacuation of underserved groups. In this review, underserved populations include but are not limited to carless residents, individuals with disabilities, older adults, low-income households, and people with Limited English Proficiency (LEP). First, our review found that while substantial research has been conducted on optimizing public transit logistics, most of this literature lacks a robust integration of equity metrics to ensure that transit services adequately serve underserved populations during evacuations. Second, we found that most evacuation literature broadly categorizes underserved groups as “special needs” populations, thereby overlooking specific transportation needs and challenges faced by these groups. Finally, we found that some jurisdictions in North America still lack public-facing evacuation plans and transit considerations for those without reliable personal transportation. We provide a discussion of these findings and offer policy recommendations to strengthen equitable, multi-modal evacuation planning.

Keywords: Evacuation Planning, Public Transit, Transportation Equity, Underserved Populations, Disasters

1. INTRODUCTION

As climate-induced and human-initiated disasters continue to increase in both frequency and intensity, it is necessary for cities globally to consider more resilient approaches to disaster planning and preparedness. Ensuring effective evacuation operations (i.e., identification of evacuation routes, preparation of transportation resources, and communication of evacuation information) is an essential component of disaster planning. In 2005, Hurricane Katrina revealed the inadequacy of evacuation planning for underserved and transit-reliant populations (Litman, 2006). In particular, older adults, people with disabilities, and carless residents faced considerable challenges evacuating and were most negatively impacted by the storm (Litman, 2006; Milligan and Company, 2007; Gibson and Institute, 2006). Following Hurricane Katrina, transportation planners and researchers called for a more multi-modal approach to evacuation planning to meet the needs of underserved populations. However, nearly two decades later, many North American cities still do not have adequate or reliable public transit evacuation plans (Renne and Mayorga, 2022). Moreover, while there is growing research on optimizing public transit logistics in an evacuation (e.g., routes, pick-up points, number of drivers), equity considerations and the specific needs of underserved populations are not always clearly defined, beyond a few select examples (e.g., Bian and Wilmot (2018), Aalami and Kattan (2017)).

Consequently, this review seeks to systematically examine existing literature on public transit evacuation planning for underserved populations. In this review, underserved populations include but are not limited to carless residents, individuals with disabilities, older adults, low-income households, and people with limited English proficiency¹. Our objective in this paper is to evaluate current practices, identify key gaps and challenges, and provide an understanding of the role of public transit in evacuation planning. To guide our research, we asked the following questions:

1. What strategies and policies have been developed and implemented for utilizing public transit during evacuations?
2. What are the unique needs and challenges of underserved and transit-reliant populations in the context of an evacuation?
3. What research gaps still exist in the literature related to public transit evacuations?

To effectively answer these questions, a systematic search of academic and research databases was conducted. By synthesizing findings from previous studies and identifying key gaps, this review provides the necessary foundation for future research and practice in the field of public transit evacuations. To achieve this, we organize this paper as follows. First, we present the methodology employed in conducting the literature review. Next, we present the findings sectioned according to themes and sub-topics. Finally, we discuss the findings, offer recommendations, and end with a conclusion.

2. METHODOLOGY

A systematic search of the literature was conducted across three peer-reviewed databases: Scopus, Web of Science, and TRID (Transport Research International Documentation). The same sets of keywords were used as search terms in each database and were combined by Boolean operators as follows:

(Evacuation OR evacuee*) AND ((Public transport*) OR (public transit) OR bus* OR multimodal OR train* OR mode* OR sharing* OR shared*) AND (Vulnerable OR carless OR car-less OR underserved OR disadvantaged OR special needs OR disabilit* OR Equity OR Justice) AND (Disaster* OR emergenc* OR wildfire* OR hurricane* OR tsunami* OR hazard*).*

¹ Given the North American focus of this literature review, limited English proficiency is often considered an evacuation barrier in most (but not all) jurisdictions. Even for communities where English is not commonly spoken, sufficient communication in commonly used local languages is required for evacuations. Most

These specific keywords were used to capture a variety of literature on equity and multi-modality in evacuations. Moreover, our review included different types of hazards rather than solely focusing on one type. This approach was chosen to ensure that our review would be comprehensive and applicable across different emergency scenarios, especially within a North American context. For the purposes of this review, we limited our query to research published between January 1999 and February 2023.

The search generated 839 results across all the databases. Initial screening involved removing 152 duplicates, leaving 702 documents for review. Further screening involved both abstract and full-text review in order to determine relevancy to our research. Studies were excluded if they primarily discussed building evacuations, automobile evacuations, or pedestrian-only evacuations. Studies were also eliminated if they were written in languages other than English. To supplement this review, we conducted a similar keyword search on Google Scholar and further included relevant news articles, reports, and websites (white and gray literature) relevant to our study. This resulted in a total of 100 studies for the review.

3. LITERATURE REVIEW

This section provides an examination of the existing literature on public transit evacuations. The review is organized into sub-sections, each providing insight into specific contexts in public transit evacuation planning.

3.1. The Need for Public Transit Evacuations: Lessons from Previous Disasters

In the last two decades, Hurricane Katrina has stood out as an emergency response failure in the field of evacuation planning (Litman, 2006). While the evacuation plan for Katrina worked adequately for those with access to automobiles, many underserved populations struggled to evacuate. For example, a contraflow system was successfully implemented on all major highways in New Orleans, enabling motorists to flee the city (Renne et al., 2009). Those who were unable to drive or did not have access to personal transportation had to rely on the support of family and friends or they would otherwise be unable to evacuate. Many of these included low-income households, older adults, people with disabilities, and tourists (Eisenman et al., 2007). In addition, the 2017 California wildfires reinforced the importance of establishing appropriate transit resources for the evacuation of vulnerable and transit-reliant populations. During the 2017 Northern California Wildfires, local and regional transit services aided the evacuation of residents from assisted living facilities and hospitals in the Napa, Yountville, and Calistoga areas. Moreover, wheelchair-equipped vans were used to evacuate those with disabilities during the Thomas Fire (Wong et al., 2020b).

Previous disasters have further shown that public transit can play a significant role in mitigating congestion during mass evacuations. For example, as noted by Hess (2013), excessive reliance on automobiles during the evacuation of Hurricane Rita saw an estimated 3 million people evacuating the Texas Gulf Coast. This led to impassable traffic jams, fuel shortages, and restricted access to emergency vehicles (Hess, 2013; Abdelgawad and Abdulhai, 2012). The Terrorist Attacks of September 11 further showcased the role of multi-modality in mitigating evacuation congestion (Cavusoglu et al., 2013). Amidst the evacuation of lower Manhattan and extensive road congestion, both NYC Transit (NYCT) and the Port Authority Trans-Hudson (PATH) provided alternative routes and facilitated the movement of people away from Ground Zero (Zimmerman et al., 2014). Moreover, during Hurricane Sandy, while New York City experienced extensive gridlock, privately run commuter vans remained in operation and enabled the evacuation of residents in low-lying, flood-prone areas (Kaufman, 2012).

Experiences from previous disasters underscore the need for comprehensive approaches to multi-modal evacuation planning. Given this context, we next present literature on the logistics required for the effective implementation of public transit during evacuations.

3.2. Public Transit Evacuation Logistics

Within the framework of public transit evacuations, four logistical aspects have been considered in research: 1) establishing adequate public transit capacities, 2) determining appropriate pick-up locations, 3) identifying safe evacuation routes, and 4) ensuring effective communication of evacuation information.

3.2.1. Public Transit Capacity

A report by the Transportation Research Board (2008) recommends creating an inventory of available transit vehicles prior to an evacuation to determine whether sufficient capacity is available to meet anticipated demand. This may involve establishing Memoranda of Understanding (MOUs) with neighboring transit agencies in order to meet shortfalls in transit capacity (TRB, 2008). Literature also notes that, apart from buses and trains, other transit modes such as school buses, shuttles, van fleets, and vehicles provided by volunteer agencies can be considered (Wilmot et al., 2015; Abdelgawad and Abdulhai, 2012). A key consideration in establishing public transit capacities is to ensure adequate availability of transit drivers prior to an evacuation. Wang and Ozbay (2023) developed a chance-constrained optimization model to determine the optimal number of drivers required for transit-based evacuations. Using this model, planners and researchers can determine the number of drivers sufficient for each sub-network/evacuation zone and connect them to the pick-up locations and the subsequent shelters assigned. Schwartz and Litman (2008) further recommend that the inventory of drivers include clearly established instructions for emergencies and regular practice drills to enhance preparedness. Interestingly, Wilmot et al. (2015) found that out of 473 special needs and human services transit agencies, only 58 were willing to incorporate information about their resources into a collaborative inventory of transit assets. The research suggested creating an inventory of public transit resources, though this may prove challenging for jurisdictions and incentives/reimbursement rates may need to be considered for participating organizations (Wilmot et. al, 2015).

3.2.2. Pick-up Locations

Several researchers have studied and analyzed optimal pick-up points and transit allocations. Morrow and Srinivasan (2021) compared three mapping methods and proposed the Cadastral-Based Expert Dasymetric System (CEDS) to identify evacuee locations and subsequent pick-up points based on residential parcels. On the other hand, Bian and Wilmot (2018) used a modified dasymetric mapping method to estimate the spatial distribution of vulnerable populations (people with disabilities, older adults, and carless residents). Using this distribution, optimally located pick-up points (serving the greatest need) were then identified through integer linear programming. Wang and Ozbay (2023) considered three factors to determine bus pick-up locations: familiarity, accessibility, and coverage. A model was then developed as an integer linear programming problem to determine the minimum number of pick-up locations that ensure full demand coverage. Additionally, Kaisar et al. (2012) developed a linear programming optimization model and applied it to a microscopic traffic simulation model to identify and optimize pick-up locations. Aalami and Kattan (2017) further proposed a proportionally fair distributed algorithm that enabled the assignment of more equitable weights to pick-up locations based on the number of evacuees and severity of disasters. As noted by Bian and Wilmot (2018) and Cavusolgu et al. (2013), researchers seeking to optimize transit pick-up locations should consider the spatial distributions of underserved and transit-reliant populations to ensure that those with the greatest need for evacuation assistance are prioritized.

3.2.3. Evacuation Routes

Public transit evacuation routing has taken one of two approaches: 1) minimizing evacuation time or 2) maximizing the number of evacuated individuals. To minimize evacuation time, Bish (2011) developed the Bus Evacuation Problem (BEP), a variant of the Vehicle Routing Problem (VRP). With the BEP, the network structure within which the VRP operates is split into yards and shelters, representing pick-up

locations and destinations respectively. Literature has since built onto the BEP by considering more complex scenarios such as evacuating an unknown number of evacuees (Goerigk and Grün, 2014), evacuating from densely populated regions (Goerigk et al., 2013), and no-notice public transit evacuations (Goerigk et al., 2015). In a similar effort to minimize evacuation time, Naghawi and Wolshon (2010) found that routing buses to alternate arterial routes reduced the total evacuation time by up to 14% and the overall travel time by up to 52%. As such, route guidance during an evacuation may be necessary to determine alternative routes and better disperse traffic within the road network (Naghawi and Wolshon, 2010). In contrast, some researchers have investigated optimal evacuation routes by using the alternative approach: maximizing the number of evacuated individuals. For example, Shahparvari et al. (2016) proposed a multi-objective integer programming model for a short-notice evacuation problem. Applying this problem to the 2009 bushfire in Victoria, Australia, the researchers were able to identify optimal evacuation routes that maximized the number of evacuees while simultaneously minimizing the number of resources required (shelters and vehicles). Apte et al. (2015) additionally proposed the Overburdened Vehicle Routing Problem (OBVRP) to determine optimal evacuation routes by maximizing the number of evacuated individuals with mobility challenges. By mapping the evacuees' varying mobility levels, the OBVRP was also able to determine the capacities of each available transit vehicle during an evacuation.

3.2.4. Communication of Evacuation Information

Research has identified four issues that need to be addressed in communicating evacuation information with transit-reliant populations (Renne et al., 2013). First, Turner et al. (2010) recommended identifying the population most likely to use transit in an emergency evacuation. This involved estimating the number of evacuees, understanding their transportation needs, and identifying their approximate locations/spatial distribution (Turner et al., 2010). Second, Renne et al. (2013) highlighted the need to consider the type of media used to disseminate evacuation information. Previous studies have shown that 1) local media was generally more persuasive than national media (especially among minority groups) and 2) local and well-known community leaders were more persuasive than distant officials (Phillips and Morrow, 2008; Fothergill et al., 1999). Moreover, Renne et al. (2013) recommended ensuring media accessibility, particularly for those who are deaf or visually impaired. Third, research has identified the importance of the forms of communication used in emergencies. Rogers (2019) observed that failure to recognize linguistic and cultural differences among residents negatively impacts risk communication. As such, the study recommended that evacuation messages be broadcasted and delivered in culturally appropriate ways, and in languages that different groups could understand (Turner et al., 2010). Finally, legitimacy of the information sources was highlighted as a key need. In their respective studies, Nick et. al (2009) and Engelman (2022) noted that community-based organizations (CBOs) traditionally have a role in locating and reaching underserved populations while accommodating language, cultural, and accessibility needs. Transit agencies and emergency management offices may therefore consider collaborating with CBOs to ensure trusted and effective communication during public transit evacuations (Matherly and Mobley, 2011).

3.3. Addressing the Equity Gap in Public Transit Evacuations

While there has been a growing body of literature on transit evacuation logistics, equity considerations have not always been clearly defined in research and planning processes (Renne and Mayorga, 2022). This gap highlights the need for a more rigorous exploration and integration of equity principles to ensure that public transit evacuation planning is not only effective but also accessible to groups that are most vulnerable during disasters. The Federal Emergency Management Agency (FEMA) defines equity as the “consistent and systematic fair, just and impartial treatment of all individuals” (FEMA, 2022). In their review of equity literature, Lewis et al. (2021) further established that equity discussions are inherently normative. That is, discussions around equity consider how the world “ought to be” rather than viewing the world simply “as it is.” In this framework then, transportation equity can be viewed as a normative

condition in which no one is disadvantaged by a lack of access to the opportunities they need to lead a meaningful life (Karner et al., 2021).

Within the context of transportation, research conducted by Shaheen et al. (2017) proposed the STEPS framework to evaluate equity. In this framework, five dimensions were put forward for identifying transportation barriers and subsequently, transportation-disadvantaged populations: 1) Spatial barriers such as those caused by auto-oriented development, 2) Temporal barriers such as traffic congestion and transit unreliability, 3) Economic barriers including direct and indirect costs associated with travel, 4) Physiological barriers especially those involving physical and/or cognitive limitations, and 5) Social barriers including one's culture, language, or race (Shaheen et al., 2017). Applying the STEPS framework, Wong et al. (2020a) identified 18 groups that are particularly vulnerable during emergency evacuations. For the purposes of this review, we focus on 5 groups that are transportation-disadvantaged and most likely to use public transit during evacuations: carless residents, low-income households, people with disabilities, older adults, and people with limited English proficiency (GAO, 2005; GAO, 2006b; Litman, 2006; Renne et al., 2009; Renne and Sanchez, 2011; Renne et al., 2013; Wong et al., 2020a). These groups were also the most commonly considered in recent literature. To enhance equity during evacuations, it is important to identify the specific barriers these populations face and seek to address their challenges. Future research can continue to explore the transit needs of other underserved groups for evacuations.

3.3.1. Diverse Access and Functional Needs in Evacuation Planning

Research has shown that much of evacuation and emergency management literature still uses the term “special needs” to broadly group together those who require communication, transportation, or medical accommodations (Schroeder, 2019). However, as noted by Kailes and Enders (2007), many of these groups may have little in common with regard to their specific challenges and needs during an emergency. As such, using the “special needs” category can lead to vague planning and subsequent emergency response failures. Kailes and Enders (2007) recommend moving beyond generalization, and accurately assessing the unique needs of different underserved populations. This would provide appropriate guidance for planners and ensure effective public transit resources during evacuations (Renne and Sanchez, 2011). For example, while carless residents and low-income households would require regular transit services, people with disabilities and older adults may require paratransit services, accessibility features, or medical equipment to evacuate safely (Feng et al., 2015; Renne and Sanchez 2011). Communication needs may also differ among different underserved groups. Tourists and residents with limited English proficiency may benefit from a translation of evacuation information whereas those who are deaf, or blind may require accommodations such as sign language interpreters, and oral, written, or picture-based communication formats (Matherly and Mobley, 2011; Turner et al., 2010). Kailes and Enders (2007) addressed these differences through the C-MIST framework: Communication, Medical needs, functional Independence, Supervision, and Transportation. Moreover, FEMA has more recently adopted the term “access and functional needs” (AFN) to refer to any actions, services, or accommodations that must be provided to afford individuals equal opportunities during emergencies (FEMA 2011; FEMA 2021). Based on these needs, we present a summary of transportation challenges specific to different vulnerable/underserved groups and how transit agencies and emergency managers can address them in **Table 1**. Additional work related to shared mobility and associated strategies can be found in Wong et al. (2021), Borowski et al. (2021), and Wong et al. (2023). It should be noted that the focus of **Table 1** is on populations that would be more likely to take public transit in an evacuation, not on all underserved and vulnerable populations.

Table 1. Group-Specific Evacuation Challenges and Strategies

Vulnerable/ Underserved Groups	Challenges and Needs During an Evacuation	Strategies for Transit Agencies and Emergency Managers
Carless Residents	<p>-Carless residents primarily rely on public transit for daily mobility. However, evacuation plans seldom include transit options for this segment of the population (Renne and Sanchez, 2011; Pulcinella et al., 2019).</p> <p>-In some cases, evacuees are required to pay for transit evacuation services. This presents a barrier for low-income carless residents (Litman, 2006; Nejad et al., 2021).</p> <p>-A shortage of drivers in emergencies affects public transit availability and use during evacuations (Renne et al., 2009).</p> <p>-State and local officials face challenges identifying and estimating the number of carless residents which may lead to a deflation of transit resources available for evacuations (GAO, 2006a).</p>	<p>- Utilize census data and Geographic Information System (GIS) mapping to approximate the number and locations of carless residents (Turner et al., 2010; Pulcinella et al., 2019, Nejad et al., 2021).</p> <p>-Use a spatial distribution of carless residents to strategically place pick-up points close to transit-reliant populations (Bian and Wilmot, 2018).</p> <p>-Improve access to pick-up locations by ensuring adequate pedestrian and cycling infrastructure (Renne and Mayorga, 2022).</p> <p>-Create an inventory of transit drivers to ensure driver availability during evacuations (GAO, 2006b; TRB, 2008).</p> <p>-Establish memoranda of understanding with neighboring municipalities/ jurisdictions to ensure sufficient transit capacity during emergencies (GAO, 2006a).</p>
Low-Income Households	<p>-Transit use is typically higher among low-income individuals who are consequently more likely to use transit during evacuations (TRB, 2008).</p> <p>-Multiple studies have found a positive correlation between income level and accessibility to safe evacuations (Serulle and Cirillo,</p>	<p>-Offer reduced transit fares and consider fare-free policies for low-income individuals during evacuations (Saphores et al., 2020; Wong et al., 2020a).</p> <p>-Partner with faith or culture-based organizations that are active in low-income communities to disseminate evacuation information (Cooper, 2019).</p>

	<p>2014; Yabe and Ukkusuri, 2020).</p> <p>-Low-income households are more likely to live in low-lying areas more vulnerable to hazards such as flooding (Serulle and Cirillo, 2014; Cooper, 2019). However, public services, including emergency response planning, are often scarce in low-income neighborhoods (Renne et al., 2009; Cooper, 2019).</p> <p>-Finances are more likely to be a barrier to evacuation for women. This is due to a higher number of female-led households in impoverished communities (Jenkins et al., 2011).</p>	<p>-Establish multi-modal evacuation plans that include active transportation modes to complement public transit (Renne and Mayorga, 2022).</p>
People with Disabilities	<p>-A lack of accessible transportation options affects access to pick-up locations and evacuation shelters among people with disabilities. This may in turn impact evacuation compliance within this group (Karaye et al., 2020).</p> <p>-Apart from facing mobility challenges, people with disabilities are likely to experience health-related complications during evacuations (Gibson and Institute, 2006). Moreover, less noticeable disabilities or impairments (e.g., diabetes, seizures) are often overlooked in evacuation planning (Renne and Sanchez, 2011).</p> <p>-Low-income people with disabilities may lack infrastructure such as telephone/internet services for evacuation communication and are most likely to lack personal transportation options (Renne and Sanchez, 2011).</p>	<p>-Identify transit vehicles with accessibility features (e.g., lift equipment, adequate spaces for wheelchairs) to be used in an evacuation (Feng et al., 2015).</p> <p>-Coordinate with paratransit services, ride-hailing networks, and ambulance fleets to increase transportation capacity for people with disabilities during an evacuation (Feng et al., 2015; Baou et al., 2018; Wong et al., 2020a; Alam et al., 2022).</p> <p>-Train drivers to assist people with disabilities in evacuation scenarios (Wong et al., 2020a).</p> <p>-Involve people with disabilities in regular evacuation drills and evacuation planning to improve emergency preparedness (Gershon et al., 2021).</p> <p>-Consider alternative forms of communication to increase the accessibility of evacuation information (e.g., braille, audiotope) (Gibson</p>

	<p>-Inaccessible communication formats affect evacuation preparedness among people with disabilities (Gershon et al., 2021).</p>	<p>and Institute, 2006).</p> <p>-Plan strategies for a variety of disabilities (i.e., physical, motor, cognitive, sensory) to enhance transportation equity (Gibson and Institute, 2006).</p>
Older Adults/ Medically Fragile	<p>-Older adults are likely to have health challenges (e.g., high blood pressure, arthritis, diabetes, memory/sensory impairments) that affect their ability to evacuate without significant assistance (Gibson and Institute, 2006; Rosenkoetter et al., 2007; Wong et al., 2020a).</p> <p>-Older adults are often isolated or homebound. This creates difficulties with both identification and outreach (Matherly and Mobley, 2011).</p> <p>-The absence of accommodations for pets or guide animals has been shown to affect the evacuation of some older adults (Heagele, 2021).</p> <p>-Caregivers at senior/nursing homes are generally underprepared for emergency response and evacuations (Wakui et al., 2017).</p> <p>-Research has shown that a lack of trust or confidence in officials and media sources affects evacuation willingness among older adults (Rosenkoetter et al., 2007).</p>	<p>-Provide accessible transit evacuation options for older adults with low mobility and low vision (Gibson and Institute, 2006).</p> <p>-Collaborate with local paratransit service providers as they are often familiar with the needs of groups with low mobility (Feng et al., 2015).</p> <p>-Ensure the presence of transit options that are accessible for older adults with guide animals and pets (Gibson and Institute, 2006).</p> <p>-Establish a database of senior/nursing homes in each jurisdiction to assess their needs and establish adequate capacity (Gibson and Institute, 2006; Abdul Sukor and Mohamad Ismail, 2016).</p> <p>-Communicate evacuation information through regular caregivers, community-based organizations, and senior-oriented newspapers (Rosenkoetter et al., 2007; Matherly and Mobley, 2011).</p> <p>-Prepare ‘go bags’ with necessary medicines/medical information for older adults/the medically fragile, particularly those who are hospital-bound (Wong et al., 2020a).</p> <p>-Conduct regular evacuation drills with seniors as well as their caregivers to improve preparedness (Wakui et al., 2017; Heagele,</p>

		2021).
People with Limited English Proficiency (LEP)	<p>-A survey of LEP residents in New Jersey found that over 50% relied on public transit for mobility (Liu and Schachter, 2013).</p> <p>-LEP groups may struggle to understand transit station announcements and ticket machine instructions which can impede evacuation ability (GAO, 2005; Liu and Schachter, 2013).</p> <p>-Research found that multilingual websites with emergency information generally received a less positive response from residents. This is because some LEP groups lack computer experience or internet access rendering them unable to receive evacuation information (Liu and Schachter, 2013).</p> <p>-Some LEP communities are unaware of the emergency preparedness resources that already exist in their languages (GAO, 2005).</p>	<p>-Estimate the number of LEP residents in each jurisdiction to ascertain evacuation demand (Liu and Schachter, 2013).</p> <p>-Ensure sufficient public transit services (drivers, pick-up points, evacuation routes) in areas with heavy concentrations of LEP populations (Liu and Schachter, 2013).</p> <p>-Consider recruiting bus drivers or other personnel capable of communicating in other languages to increase transit access among LEP groups (GAO, 2005).</p> <p>-Work with members of the LEP community to determine the most helpful/preferred forms of communication; while some groups may be more accustomed to computer technologies, others may prefer translated written materials or pictographs with transit and evacuation information (Renne and Sanchez, 2011; Burke et al., 2012; Liu and Schachter, 2013).</p> <p>-Collaborate with local broadcast/news agencies, community-based organizations, post offices, and libraries to disseminate multi-lingual evacuation information (TRB, 2008).</p> <p>-Publicize language access services and multilingual evacuation information to ensure awareness and preparedness among LEP groups (TRB, 2008; Burke et al., 2012; Wong et al., 2020a).</p>

3.3.3. Evacuation Assistance Registries

Because of the diversity of access and functional needs, multiple studies have recommended establishing and maintaining evacuation assistance registries to pre-identify transportation needs and prepare adequate evacuation resources (Renne et al., 2009; Whytlaw et al., 2021). Research by Matherly and Mobley (2011) noted, however, that registries can be labor-intensive as they require robust management and ongoing updates to ensure information accuracy. Moreover, a recent review of registries in Texas, New Jersey, and Florida found that exclusively relying on online registration methods may hinder participation from individuals with access and functional needs (Oneth, 2020). Confidentiality concerns have also been found to lower participation rates in some registries (Renne et al., 2009). Renne et al. (2013) noted that LEP populations may be particularly hesitant to disclose location data if their immigration status lacks formal documentation. Agencies may thus be required to assure immigrants that the information recorded will be used for evacuation assistance rather than deportation purposes (Renne et al., 2009). Despite these challenges, Gibson and Institute (2006) suggest that disaster registries can be an effective tool in supporting evacuation efforts, especially among those requiring medical attention or equipment. Ensuring accessible registration methods, performing ongoing data maintenance, and transparently communicating the intended use of a registry's information have been recommended as necessary strategies to bolster trust and the overall effectiveness of disaster registries (Oneth, 2020).

3.4. Inter-Agency Collaborations and Community Engagements

Several researchers have examined the benefits of inter-agency collaborations in the context of public transit evacuations. In their focus group study, Renne et al. (2013) noted that the effectiveness of cross-jurisdictional collaboration efforts is evident in three main scenarios: 1) collaborations within community-level emergency offices, 2) collaborative work between municipalities, and 3) collaboration that looks to higher authorities (state/provincial/federal agencies) to overcome financial and logistical evacuation obstacles. Research has also shown the importance of ongoing collaborations between emergency management offices and transit agencies. In a review of evacuations in Canada, Scanlon (2003) found that when transit agencies were aptly engaged in evacuation planning, the response was often quick and effective, even in short-notice disasters. This is because transit agencies regularly face schedule disruptions (caused by weather changes, traffic accidents, or chemical spills). Moreover, Scanlon (2003) noted that transit companies often have experience with transporting large numbers of people during special events (e.g., major sports events and concerts). As such, with sufficient preparation, engagement, and support, transit agencies can perform well in emergency scenarios and aid in the evacuation of underserved groups.

In addition to transit agencies, Renne et al. (2013) recommended sustained partnerships between emergency management offices and both private sector and non-profit organizations. These may include private bus companies, community transportation providers (e.g., school buses, church vans), CBOs, and community emergency response teams (CERTs) (Matherly and Mobley, 2011; Renne et al., 2013). Not only can these organizations help increase transit capacity, but they can also assist in the dissemination of evacuation information to communities that may otherwise be difficult to reach (Engelman, 2022; Nick et al., 2009).

Finally, the engagement and involvement of underserved populations in emergency planning have been widely considered by researchers. In his review of FEMA's Mitigation Handbook, Cooper (2019) noted that there was sparse guidance on community-inclusive planning processes. Moreover, Gershon et al. (2021) found a general pattern of disengagement of the disability community in evacuation plan development and community drills. Berke et al. (2014) further found that emergency planners were generally skeptical about the benefits of public engagement. Some planners expressed doubts that residents would have the expertise to engage meaningfully in emergency planning. Cooper (2019) however, observed that when planners are skilled in designing and facilitating public engagement meetings/workshops, underserved groups can participate more effectively and assist in the collection of

data from their communities. Moreover, employing a participatory approach in emergency planning has been found to create a shared responsibility, which is essential for building community resilience (Ingham and Redshaw, 2017).

3.5. Overview of Emergency Plans in Select North American Cities

In this section, we offer a brief overview of selected publicly available evacuation plans within major cities in the United States and Canada. We paid particular attention to whether the plans incorporated public transit use and whether they had accommodations for carless and transit-reliant populations. A more comprehensive analysis of evacuation plans can be found in Renne and Mayorga (2022) for the 50 largest cities in the United States.

3.5.1. United States

In the context of the United States, we found that cities such as New York and New Orleans are setting an example, both for predetermining public transit resources prior to emergency evacuations and making these plans publicly available (Renne and Mayorga, 2022; Schwartz and Litman, 2008). New York City's emergency plan, for example, includes pre-determined evacuation zones as well as preparedness guides available in 13 languages and in audio format (NYC Emergency Management, 2023). In addition, people with disabilities and those with medical needs can request either an accessible vehicle or ambulatory services during an evacuation (NYC Emergency Management, 2023). Similarly, the City of New Orleans offers a City-Assisted Evacuation Plan (including pick-up and drop-off locations and bus routes) for residents unable to self-evacuate (NOLA Ready, 2023). Moreover, an online registration platform is available for those with medical needs eligible for home-based pick-up (NOLA Ready, 2023). The emergency response plan created by the City of San Francisco further outlines the responsibilities of the Municipal Transportation Agency (MTA) including paratransit services for people with disabilities and those requiring life-sustaining medical treatment during an emergency (San Francisco, 2023). Research suggests that this trend in the United States may stem from previous experiences with large-scale disasters resulting in more comprehensive emergency plans (Lindsay, 2018). We found, however, that public-facing plans are not available in each city in the United States (see Appendix Table A1). A study by Renne (2018) found that some agencies in the United States may keep evacuation plans confidential due to an anticipated risk of terrorism. As such, some jurisdictions were concerned about the potential risks associated with publicly sharing information on pick-up locations, bus routes, and shelter locations (Renne, 2018).

3.5.2. Canada

In Canada, while major cities such as Toronto, Vancouver, and Montreal have emergency plans, public availability and incorporation of public transit considerations vary (see Appendix Table A1). Toronto's emergency plan, for example, outlines key roles and responsibilities of various agencies including the Toronto Transit Commission. However, the plan does not provide specific information for transit users such as pick-up/drop-off locations or transit information for people with disabilities (City of Toronto, 2017). On the other hand, while we could not find a public-facing transit evacuation plan for Montreal, we noted that the city has an Emergency Evacuation Assistance Program that enables people with reduced mobility to register and receive free evacuation assistance during an emergency (Ville de Montreal, 2023). Similarly, while the City of Vancouver does not detail information on transit use during emergencies, it utilizes the Evacuee Registration and Assistance (ERA) tool developed by the province of British Columbia to provide specialized support services during emergencies (ERA, 2023). In all, our review found that transit evacuation planning in Canada is predominantly *ad hoc* rather than pre-planned (Lindsay, 2018). While this approach has successfully worked in previous disasters (Scanlon, 2003), it may affect preparedness in the future and result in underserving transit resources to vulnerable populations.

4. DISCUSSION AND RECOMMENDATIONS

In this section, we discuss the findings from our review and provide recommendations for future research and evacuation planning and policy.

4.1. Integrating Public Transit into Evacuation Planning

Public transit is essential both for reducing traffic congestion during emergencies and for the evacuation of transportation-disadvantaged populations. Our review found that while some North American cities are establishing a multi-modal approach to evacuation planning, many still lack effective transit incorporations into their emergency plans. For example, in Canada, we found that evacuation planning in most Canadian cities is generally characterized by a reactive rather than a pre-planned approach (Lindsay, 2018). As a result, public-facing plans and consequently, specific information on transit evacuation resources, are largely missing in Canada's emergency management literature (see Appendix Table A1). We recommend that emergency management offices in Canada consider establishing Memoranda of Understanding (MOUs) with transit agencies to ensure sufficient transit resources prior to an evacuation. Moreover, we recommend that Canadian jurisdictions make evacuation plans available to the public. These should integrate public transit considerations (e.g., information on pick-up locations, evacuation routes, and evacuation support for people with disabilities) which will ultimately enhance public accountability and community preparedness (Renne, 2018). Our review found that in the context of the United States, cities and regions that have experienced large-scale natural disasters are generally more actively engaged in transit evacuation planning (Renne, 2018; Renne and Mayorga, 2022). However, we also found that some jurisdictions do not publicly provide evacuation information due to a heightened risk of terrorism. Similar to Renne et al. (2009), we recommend that jurisdictions consider creating an evacuation plan for natural disasters (open to the public) and another plan for man-made disasters such as terrorist attacks (kept confidential).

Finally, we found that our systematic literature search did not yield transit evacuation studies focused on rural areas. This may be due to the fact that public transit evacuation planning has been predominantly focused on large urban areas. Nonetheless, rural coastal communities are generally at high risk of disasters such as hurricanes and can be difficult to evacuate due to large geographic areas and limited resources (Ye et al., 2010; Perkins et al., 2011). Rural jurisdictions may also have fewer staffing and planning resources to develop evacuation plans for their communities (Chaudhari et al., 2015). Emergency management agencies should therefore ensure that rural communities have sufficient transit resources including transit vehicles (public buses, vans, school buses), drivers, and adequate finances to support evacuation efforts. Future research could further perform accessibility and transit route planning in rural and sub-urban areas to inform evidence-based evacuation strategies in these geographies.

4.2. Incorporating Equity Metrics in Public Transit Evacuation Research

Our review identified a growing body of literature on public transit evacuation logistics. Several researchers have studied and analyzed the optimal number of pick-up locations, evacuation routes, and the number of drivers required to minimize evacuation time and/or maximize the number of transported evacuees (see for example Wang and Ozbay (2023), Goerigk and Grün, (2014), Kaisar et al. (2012), Bish (2011)). However, our review found that most of this research lacks a robust integration of justice and equity metrics to ensure that public transit can realistically serve vulnerable/underserved communities during disasters. Moreover, as noted by Kailes and Enders (2007), public transit evacuation studies largely utilize the broad term, "special needs" to refer to underserved populations. However, we observed a diversity of access and functional needs resulting in group-specific transportation challenges during an emergency (see **Table 1**).

Based on these findings, we recommend that research focused on transit evacuations for vulnerable populations specify the unique needs of the groups in question (i.e., the mobility needs of older adults

may be significantly different from those of low-income households). This will ensure that research findings can realistically address the transportation and equity challenges faced by specific groups. Similar to Bian and Wilmot (2018), we further recommend that in order to ensure spatial equity, optimization studies should be conducted based on the spatial distribution of carless and underserved groups rather than the general population. This approach will increase the potential for meeting the needs of populations that rely on transit the most. Finally, researchers should consider community-centered approaches to transit evacuation studies. These may involve conducting surveys, focus group discussions, or in-depth interviews with underserved groups to inform equitable research applications.

4.3. Engaging Underserved Populations in Evacuation Planning

Our review observed a general lack of participation and engagement of underserved populations in transit evacuation planning (Cooper, 2019; Gershon et al., 2021). As noted by Berke et al. (2014), this may at times result from skepticism of the benefits of public engagement in planning. Consequently, existing evacuation plans may have been created with a limited understanding of the challenges, needs, and experiences of transit-dependent populations. As Cooper (2019) observed, underserved populations can effectively participate in planning if they have both the platform and resources to advocate for their needs. Therefore, we recommend that evacuation planners consider designing participatory spaces where underserved populations can effectively share their needs, challenges, and preferences in relation to transit evacuations. While it is not feasible to involve an entire community in the planning process, adequate stakeholder identification and their degree of engagement should guide the participatory planning process (Cilliers and Timmermans, 2014). Moreover, transit agencies and emergency management offices should consider working with non-governmental organizations (NGOs) and CBOs representing underserved populations to effectively reach these groups and involve them in the planning process (Engelman, 2022).

Finally, we found that while emergency registries can be beneficial in pre-identifying the transportation needs of underserved populations, accessibility and confidentiality concerns may render them ineffective (Renne et al., 2009). We recommend that jurisdictions provide both online and paper-based registration formats to accommodate those with limited internet access. We further recommend that emergency management offices maintain transparency regarding the use of registration data to mitigate confidentiality concerns, especially among LEP residents (Renne et al., 2009).

Table 2. Summary of Key Takeaways and Recommendations

Key Takeaways	Key Recommendations
Integrating Public Transit into Evacuation Planning	<ul style="list-style-type: none"> • Emergency management offices should collaborate with transit agencies to ensure coordinated planning and sufficient transit resources before an evacuation. • Jurisdictions can consider creating an evacuation plan for natural disasters (open to the public) and another plan for man-made disasters such as terrorist attacks (kept confidential). • Emergency management offices should ensure comprehensive plans for rural jurisdictions including transit considerations for underserved populations in these areas.
Incorporating Equity Metrics into Transit Evacuation Research	<ul style="list-style-type: none"> • Research focused on transit evacuations for underserved populations can specify the unique access and functional needs of the groups in question to ensure effective and equitable research outcomes. • Optimization studies should be conducted based on the spatial distribution of underserved groups to increase the potential of serving those who rely on transit the most.

	<ul style="list-style-type: none"> • Researchers should consider community-centered approaches such as surveys, focus group discussions, and interviews with underserved groups to inform equitable transit evacuation systems.
Engaging Underserved Populations in Transit Evacuation Planning	<ul style="list-style-type: none"> • Evacuation planners can design participatory spaces for underserved populations to discuss their needs, challenges, and preferences regarding transit evacuations. • Emergency management offices could consider working with NGOs and CBOs in the evacuation planning process to effectively reach and communicate with underserved groups. • Emergency registries could be established to ensure a pre-identification of transit resources for those with access and functional needs.

5. CONCLUSIONS

Disasters such as Hurricanes Katrina and Rita and more recent wildfires across North America have demonstrated the necessity of adopting a multi-modal approach to evacuation planning. During emergency evacuations, public transit plays an important role in ensuring equitable transportation of underserved populations and traffic congestion relief. Our review uncovered three critical insights. First, we found that there is a general lack of rigorous and multi-disciplinary integration of equity into public transit evacuation planning, including missing justice and equity metrics in research on the topic. Second, our review found that, while some jurisdictions in North America are incorporating transit into their evacuation plans, many still lack public-facing evacuation plans and/or do not have transit information available for underserved populations. Third, our review highlights the need for multi-stakeholder collaboration in designing public transit evacuation plans.

In all, the insights from this paper provide the necessary groundwork for future research and practice in the field of public transit evacuations. In particular, the results demonstrate that a comprehensive and equitable integration of public transit into evacuation planning is essential for enhancing community resilience while meeting the transportation needs of underserved populations. Future multi-disciplinary research and effective knowledge exchange can help address gaps, strengthen strategies, and improve equitable outcomes.

6. AUTHOR CONTRIBUTIONS

The authors confirm their contribution to the paper as follows: **Veronica Wambura:** Conceptualization, Methodology, Investigation, Writing – Original Draft, Writing – Review & Editing. **Stephen D. Wong Ph.D.:** Conceptualization, Methodology, Investigation, Writing – Original Draft, Writing – Review & Editing, Supervision. All authors reviewed the results and approved the final version of the manuscript.

7. ACKNOWLEDGEMENTS

This study was made possible through funding received by the Alberta Ecotrust Foundation, Mitacs, and the City of Edmonton, Alberta via funding from the Cities IPCC Legacy Grant Program.

8. DECLARATION OF COMPETING INTERESTS

The authors report there are no competing interests to declare.

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10. APPENDIX

Table A1: An Overview of Emergency Evacuation Plans in Select North American Cities

Country	City	Findings	Source
United States	New York City	<p>-The City's emergency plan includes evacuation zones and the likelihood of evacuation for each zone.</p> <p>-The evacuation zone map and personal preparedness guides are available in 13 languages and in audio format.</p> <p>-The city advises against car travel during an evacuation and encourages the use of mass transit to reduce roadway congestion.</p> <p>-People with disabilities and those with medical needs can request either an accessible vehicle or ambulance services</p>	(NYC Emergency Management, 2023)

		<p>during an evacuation.</p> <p>-Service animals/pets in carriers are also allowed in subways, trains, and buses during an evacuation.</p>	
	New Orleans	<p>-The City of New Orleans offers a City-Assisted Evacuation Plan for residents unable to self-evacuate.</p> <p>-The City-Assisted Evacuation Plan has information on pick-up locations, bus routes, and drop-offs for those using ridesharing services.</p> <p>-An online registration platform is available for those with medical needs eligible to be picked up from their homes.</p> <p>-While smaller pets/service animals are allowed on buses with their owners, larger animals are evacuated on separate buses.</p>	(NOLA Ready, 2023)
	San Francisco	<p>-The City of San Francisco has an emergency response plan detailing the role of the Municipal Transportation Agency (MTA) during an emergency.</p> <p>-The MTA is responsible for providing transportation for those unable to evacuate themselves including those who are sick and/or injured.</p> <p>-San Francisco Paratransit, operated by the MTA, provides transportation for people with disabilities and those needing life-sustaining medical treatment during an emergency.</p> <p>-As of 2022, the Mayor's Office was working to engage non-profit organizations that work with people with disabilities and older adults in a Statement of Understanding (SOU) project to enhance disaster preparedness.</p> <p>-The Animal Support Annex provides guidance on transporting and sheltering service animals and pets during an evacuation.</p>	(San Francisco, 2023)
	Chicago	<p>-There is no public-facing evacuation plan for the city of Chicago. However, the Central Business District (CBD) of Chicago has an evacuation plan that describes the responsibilities of appropriate departments and agencies during an emergency.</p> <p>-In an emergency, evacuees within the CBD gather at the Assembly and Transfer Centers (ATCs). The Chicago Transit Authority then provides public transit assets from the ATCs to designated shelter locations.</p>	(Daley, 2007; Office of Emergency Management and Communications, 2023)

		<p>-Transportation resources for those who need evacuation assistance (e.g., older adults, people with disabilities) are not specified in the evacuation plan. It is also not specified how people without personal transportation can get to the ATCs.</p> <p>-A voluntary registry form is available to identify individuals with disabilities and those with special needs.</p> <p>-Personal preparedness information is available in American Sign Language (ASL) videos to accommodate deaf residents.</p>	
	Los Angeles	<p>-City evacuation plan defines and has provisions for those with access and functional needs (AFN).</p> <p>-During evacuations, the Los Angeles Department of Transportation (LADOT) provides transportation through a variety of sources including Metro, Downtown Area Short Hop (DASH), Commuter Express, private-contracted transportation services, and City Ride.</p> <p>-The City establishes alternative and temporary public transportation routes and stops as needed in an evacuation.</p> <p>-All transportation equipment managed by the City meets ADA Title II accessibility.</p>	(City of Los Angeles, 2020)
Canada	Toronto	<p>-The Toronto Emergency Plan includes key roles and responsibilities of different agencies during an emergency.</p> <p>-While the Toronto Transit Commission is listed among the Emergency Management Working Groups, there is no clear incorporation of public transit considerations (e.g., information for carless evacuees, pick-up locations, or paratransit providers).</p> <p>-People with disabilities and other special needs are advised to arrange in advance for help from a friend/family/healthcare provider.</p>	(City of Toronto, 2017)
	Vancouver	<p>-The City of Vancouver primarily follows the emergency evacuation guides set by the province of British Columbia.</p> <p>-Public-facing information provided by the province includes a list of potential hazards, a personal preparedness/home emergency plan, and emergency contact information.</p>	(City of Vancouver, 2023; ERA, 2023)

		<p>-A public-facing evacuation plan that includes public transit use during emergencies is not available.</p> <p>-Developed by the province of British Columbia, the Evacuee Registration and Assistance (ERA) tool is an online platform that enables evacuees to self-register for support services during emergencies.</p>	
	Edmonton	<p>-The City of Edmonton provides an Emergency Guide in 8 different languages, with information on personal emergency preparedness.</p> <p>-The City utilizes a self-registration online platform created by the province of Alberta. This enables emergency officers and first responders to provide support as needed during an emergency.</p> <p>-A public-facing evacuation plan that includes public transit use during emergencies is not available.</p> <p>-People with disabilities and other special needs are advised to arrange in advance for help from a friend/family/healthcare provider. They are also advised to call 311 for further assistance.</p>	(City of Edmonton, 2023)
	Montreal	<p>-The City of Montreal provides information on Household Emergency Plans/Kits to enhance personal preparedness.</p> <p>-Montreal's Emergency Evacuation Assistance Program enables people with reduced mobility to register and receive free evacuation assistance during an emergency. The registration form can be completed and submitted online or through mail.</p> <p>-A public-facing evacuation plan that includes public transit use during emergencies is not available.</p>	(Ville de Montreal, 2023)
	Halifax	<p>-The City of Halifax provides information on Household Emergency Plans/Kits to enhance personal preparedness.</p> <p>-The Halifax Regional Municipality states that Metro Transit would provide transportation for carless populations and ambulances for those who are medically fragile.</p> <p>-There is no information on pick-up locations or specialized transportation based on need (e.g., for people with disabilities).</p>	(Halifax, 2023; Clarke and Habib, 2010)