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Capacity Building and Workforce Development for Coastal Transportation Infrastructure Exposed to Multi-Hazards: Phase I

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16. Abstract

This report presents the Phase I activities of the multi-year research effort focused on capacity building and workforce development for coastal transportation systems exposed to multiple hazards. The objective of Phase I was to establish a baseline understanding of community perceptions regarding transportation accessibility, vulnerability, resilience, and Blue Economy activities in Puerto Rico while developing methodological frameworks to support future transportation vulnerability assessments, network analysis, visualization strategies, and workforce development initiatives.

A literature review was conducted to examine concepts related to coastal transportation resilience, accessibility, vulnerability, workforce development, and the Blue Economy. An online survey was administered to 366 adult residents throughout Puerto Rico to collect information on travel behavior, transportation accessibility, infrastructure quality and safety, vulnerability to natural hazards, and perceptions of coastal economic activities. Responses were analyzed according to municipality type, coastal community status, and geographical location. Phase I also included the development of a preliminary transportation vulnerability assessment framework based on the FHWA Vulnerability Assessment Scoring Tool [VAST], a transportation network analysis framework, virtual reality visualization scenarios for flood-risk education, and a research-to-practice framework to support workforce development.

Survey results indicate a strong dependence on private motor vehicles, with more than 90% of respondents identifying them as their primary transportation mode. More than half of respondents reported travel-time increases greater than 15 minutes when primary routes become inaccessible due to natural hazards, while approximately 13-15% reported having no alternative route available. Earthquakes, extreme heat, and hurricane-related winds generated the highest levels of concern among respondents, and roadway damage was consistently identified as the primary cause of mobility disruption. Environmental conservation and tourism emerged as the most highly valued Blue Economy activities, although roadway access to coastal destinations was frequently rated as fair or poor. Respondents also reported limited modal redundancy and concerns regarding the safety and quality of pedestrian, bicycle, and micromobility infrastructure.

The findings establish a baseline assessment of transportation resilience perceptions in Puerto Rico and provide methodological foundations for future CREATE activities. Results support the development of transportation vulnerability assessments, network simulations, educational resources, visualization tools, and workforce development programs aimed at strengthening resilient coastal transportation systems and supporting sustainable Blue Economy development.

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ABSTRACT

This report presents the Phase I activities of the multi-year research effort focused on capacity building and workforce development for coastal transportation systems exposed to multiple hazards. The objective of Phase I was to establish a baseline understanding of community perceptions regarding transportation accessibility, vulnerability, resilience, and Blue Economy activities in Puerto Rico while developing methodological frameworks to support future transportation vulnerability assessments, network analysis, visualization strategies, and workforce development initiatives.

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Keywords: Blue Economy, Coastal Communities, Transportation Resilience, Transportation Accessibility, Workforce Development.

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RESEARCH PROBLEM

Transportation systems must be resilient and adapt to the impacts of extreme natural events that threaten infrastructure, operations, and community accessibility. Coastal and island regions are particularly vulnerable, given their exposure to hurricanes, flooding, tsunamis, and coastal erosion. The impacts of past extreme natural events in the United States [U.S.] highlight the critical need for robust and adaptable infrastructure. The effects of hurricanes Harvey and Katrina serve as stark examples of this vulnerability. Hurricane Harvey, a Category 4 storm, caused widespread flooding in August 2017, submerging roads, highways, and damaging bridges, which severely disrupted mobility across Texas and neighboring states (US-DOT, 2017). Harvey brought a record-breaking rainfall of more than 50 inches on seven days, especially in the Houston area, causing an estimated $158.8 billion [adjusted for inflation] in damages, the second-costliest U.S. hurricane on record (NOAA, 2024). The storm claimed 89 lives and displaced more than 30,000 people and damaged or destroyed more than 200,000 homes or businesses.

Before Harvey, Hurricane Katrina, a Category 3 storm, inflicted extensive infrastructure damage in New Orleans, Louisiana, and the surrounding regions on the Gulf Coast in August 2005, rendering key bridges and highways impassable due to flooding and structural failures. Katrina winds drove a storm surge of 25-28 feet above normal sea level along the Mississippi coast, and about 10-20 feet along the southern Louisiana coast, causing catastrophic flooding, especially due to levee failures (CIEL, 2024). The storm was responsible for 1,833 deaths and the destruction or damage of more than one million housing units, with economic costs of approximately $160 billion [adjusted for inflation], making it the costliest hurricane in U.S. history.

Besides hurricanes, intense rainfall from 203 severe storms and 45 flooding events between 1980 and 2024 in the U.S. have caused widespread disruptions in communities and transportation networks, resulting in an estimated 2,833 deaths and over $202 billion [CPI-adjusted] in damages [NOAA, 2025]. The Houston area experienced two extreme weather events in 2024 that led to widespread flooding and damage that compounded transportation issues, as prolonged water damage led to road closures and the destruction of public transit systems, hindering rescue and recovery efforts (The Guardian, 2024). The cumulative impact of both events led to 44 deaths and over $314 million in federal disaster recovery funding for Houston.

In the case of Puerto Rico, a U.S. territory in the Caribbean Sea, eight tropical cyclones have severely impacted the region between 1980 and 2024, causing an estimated 3,256 deaths and $235 billion in damages [NOAA, 2025]. Hurricanes Irma and María, which struck Puerto Rico only two weeks apart as Category 5 and Category 4 storms, respectively, impacted the territory in September 2017, causing severe infrastructure disruptions and significantly impairing transportation operations throughout the island. Hurricane María, the most devastating of the two, destroyed the communication system, including cellphone towers, and left residents and emergency responders unable to coordinate efforts. The destruction of the power grid also crippled gas station operations, with fuel lines extending up to eight hours. Hurricane María triggered more than 40,000 landslides in Puerto Rico and affected at least three-fourths of the island's 78 municipalities (Bessette-Kirton et al., 2019). Officials reported over 6,000 cases of transportation infrastructure damage, including 388 incidents involving bridges and 400 related to landslides caused by heavy rainfall. Nearly 20 percent of the island's bridges were damaged, with 26 collapsing entirely. Ecola et al. (2020) estimated approximately $1.8 billion in repair costs for transportation infrastructure, plus approximately $1.1 billion in recommended resilience upgrades. That same study concluded that the transportation sector lacked resilience even before the two hurricanes and recommended measures such as improved design standards, infrastructure hardening, asset management improvements, and resilience-oriented planning. According to the assessment of the Puerto Rico Recovery Plan in Ecola et al. (2020), many transportation assets had deferred maintenance, limited resilience, and operational challenges prior to the hurricanes, highlighting the need for both infrastructure improvements and enhanced institutional capacity to address future hazards.

Beyond the damage caused by individual storm events, studies have documented persistent challenges affecting transportation infrastructure and operations in Puerto Rico's coastal regions. Coastal highways, bridges, ports, and other critical transportation assets are increasingly exposed to flooding, storm surge, wave action, and shoreline erosion, creating long-term risks to mobility, accessibility, and economic activity. The Puerto Rico Coastal Study by the U.S. Corps of Engineers (USACE, 2024) identified erosion, flooding, and wave attack as continuing threats to critical infrastructure located along the island's coastline. Coastal hazard assessments by the USACE (2022) highlight the growing need to evaluate future storm and sea-level rise scenarios when planning and maintaining infrastructure. Similarly, research conducted by the U.S. Geological Survey (2022) has documented substantial shoreline change and coastal erosion in multiple regions

of Puerto Rico, underscoring the vulnerability of transportation facilities located near the coast. Together, these studies underline that transportation resilience in Puerto Rico requires not only recovery from extreme events, but also proactive planning, risk-informed decision making, and long-term adaptation strategies to address evolving coastal hazards and sustain access to communities and economic activities that depend on coastal transportation corridors.

Transportation routes in coastal regions are pivotal to sustainable development, facilitating the movement of essential items such as food, supplies, and consumer goods. Accessibility, defined as a community's ability to participate in daily and emergency activities, is a key component of transportation resilience. It refers to how easily people can reach essential destinations such as workplaces, schools, healthcare facilities, and recreational areas, using the available modes of transportation (Geurs & van Wee, 2004). This is especially critical for developing countries and coastal areas that often lack the financial resources to build robust transport systems. These regions are more susceptible to adverse weather and natural hazards compared to more affluent counterparts (Wei et al., 2022). As such, enhancing the adaptability of transportation infrastructure is not just a technical challenge but a developmental imperative.

Coastal resilience issues align with the principles of the Blue Economy, which advocates sustainable use and management of ocean resources for economic growth, improved livelihoods, and marine ecosystem preservation. It encompasses sectors such as fisheries, aquaculture, tourism, shipping, and renewable energy, many of which rely heavily on resilient coastal infrastructure (World Bank, 2017). The Blue Economy is projected to grow to $2.5-3.0 trillion by 2030 (OECD, 2016). Consequently, developing robust transportation systems in coastal areas is essential to unlocking its full potential. The Blue Economy shares common goals with the Green Economy, which emphasizes well-being and accessibility while significantly reducing environmental risks and ecological scarcities (Loiseau et al., 2016). While the Blue Economy focuses specifically on marine resources, both approaches stress the importance of balancing economic growth with environmental protection by fostering long-term sustainability through responsible resource use. In essence, these two frameworks offer complementary strategies for building prosperity while safeguarding the natural environment for future generations.

In this context, planning for resilient coastal corridors becomes essential. Webb et al. (2019) identify common vulnerabilities of U.S. coastal highways, including storm surges, sedimentation,

flooding, erosion, and wave action. Future-proofing these corridors means building infrastructure that not only withstands natural forces but also preserves surrounding ecosystems. This will require comprehensive and efficient transportation systems, coupled with a physically robust infrastructure. One approach involves nature-based solutions, which use natural materials and processes to mitigate risks. These include marsh restoration, beach nourishment, pocket beaches, and dune reinforcement (Webb et al., 2019). While effective in many scenarios, such solutions must be tailored to specific site conditions, making detailed analysis and planning essential before implementation.

Beyond the physical vulnerability of transportation infrastructure, the increasing frequency and intensity of natural hazards present significant challenges for the agencies, professionals, and communities responsible for planning, operating, and maintaining transportation systems in coastal regions. FHWA defines resilience as "*the ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from disruptions*" (FHWA Office of Natural Environment, 2024). Building resilient transportation systems requires transportation engineers, planners, and decision makers to develop the technical capacity to identify infrastructure vulnerabilities, assess the consequences of natural hazards, and prioritize resilience actions that reduce risk and improve system performance. Moreover, a resilient transportation network requires not only engineering solutions but also a workforce with technical knowledge, interdisciplinary skills, and decision-making capabilities needed to address complex interactions among transportation, climate adaptation, emergency management, and coastal development. As transportation agencies face evolving risks associated with climate impacts, there is a growing need to identify the competencies, training needs, and capacity gaps that may limit their ability to prepare for, respond to, and recover from disruptive events.

Transportation agencies throughout the U.S. are facing workforce-related challenges from employee retirements, evolving technological demands, resilience planning requirements, and the need for increasing interdisciplinary skill sets that integrate engineering, environmental sciences, risk management, and community engagement (Cronin et al., 2022). These trends emphasize the importance of developing educational pathways and professional training programs that prepare transportation professionals to address emerging coastal resilience challenges. These challenges are particularly important in regions whose economies depend on coastal and marine resources.

The long-term sustainability of the Blue Economy relies not only on resilient infrastructure, but also on the availability of professionals and institutions capable of integrating hazard mitigation, transportation planning, environmental stewardship, and community engagement into decision-making processes. Understanding stakeholder perspectives, community experiences, and perceptions of transportation-related risks is an essential first step toward developing educational programs, workforce development initiatives, and capacity-building strategies that support resilient coastal transportation systems.

Conceptual Framework

Despite growing awareness of natural hazards, climate risks, and the economic importance of coastal corridors, there remains a limited understanding of how communities, transportation professionals, and other stakeholders perceive the impacts of natural hazards on transportation systems and what knowledge, resources, and training may be needed to improve resilience.

Figure 1 presents the conceptual framework that provides the motivation of the multi-year research effort of the CREATE team at UPRM.

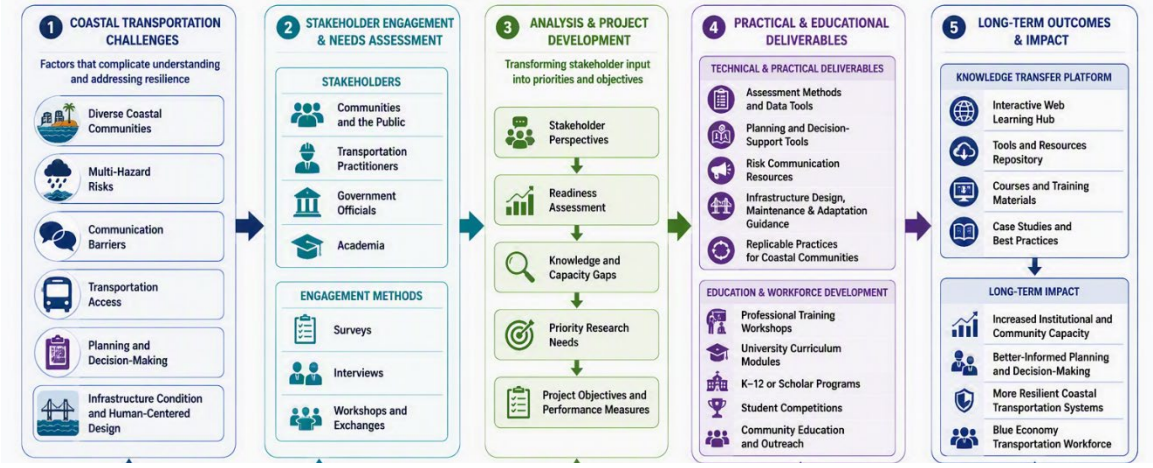


Figure 1. Conceptual Framework for Capacity Building and Workforce Development to Support Resilient Coastal Transportation Systems and the Blue Economy

The resilience of coastal transportation systems is influenced by a complex set of interconnected challenges that extend beyond the physical performance of infrastructure. Coastal communities face diverse social, economic, environmental, and geographic conditions that affect their vulnerability and ability to recover from disruptive events. At the same time, transportation systems are increasingly exposed to multiple hazards, including hurricanes, flooding, storm surge,

coastal erosion, landslides, and extreme precipitation. These risks are further compounded by communication barriers that limit the effective translation of technical information into actionable knowledge for practitioners, decision makers, and community members.

Other challenges include ensuring safe and efficient transportation accessibility, developing effective planning and decision-making processes that account for hazard exposure and long-term uncertainty, and improving methods for evaluating infrastructure conditions and implementing human-centered transportation solutions. Collectively, these factors create a complex environment in which transportation resilience must be understood not only as an engineering problem, but also as a social, institutional, educational, and workforce development challenge.

Addressing these challenges requires recognizing that resilience needs and priorities vary among stakeholder groups. Community members, transportation practitioners, academic researchers, and government officials often experience transportation disruptions differently and may possess distinct perspectives regarding risks, vulnerabilities, and potential solutions. Consequently, developing effective resilience strategies requires a systematic process for gathering and integrating knowledge from multiple stakeholders. Interviews, surveys, workshops, exchanges, and other participatory approaches provide mechanisms for capturing these perspectives and identifying critical needs, knowledge gaps, and opportunities for improvement.

The information obtained through stakeholder engagement serves as the foundation for defining research priorities and guiding the development of project-specific objectives and outcomes. Rather than focusing exclusively on theoretical advances, the project seeks to generate practical and measurable products that can be implemented, adapted, and replicated across coastal communities facing similar challenges. These outcomes may include assessment tools, planning methodologies, risk communication resources, educational materials, and decision-support frameworks that enhance transportation resilience in coastal environments.

The central objective of the project is to translate research findings into educational and capacity-building activities that support multiple audiences. Educational initiatives may include professional training programs, university-level curriculum enhancements, student competitions, workforce development workshops, K-12 outreach activities, and community engagement programs. By integrating research, education, and outreach, the project seeks to strengthen the

knowledge base and technical competencies required to address emerging transportation challenges in coastal regions.

To facilitate long-term accessibility and knowledge transfer, project products and educational resources will be incorporated into interactive web-based learning platforms and digital repositories. These tools are intended to support continuous learning, promote knowledge sharing among stakeholders, and expand the reach of project outcomes beyond individual communities or organizations.

Ultimately, the framework is designed to support the development of a transportation workforce capable of addressing the unique challenges faced by coastal regions exposed to multiple hazards. By combining research, stakeholder engagement, education, and technology transfer, the project seeks to strengthen institutional and workforce capacity while supporting transportation systems that contribute to the long-term sustainability and growth of the Blue Economy.

Research Objectives

The CREATE research program at UPRM is planned as a multi-year effort focused on strengthening the resilience of coastal transportation systems through stakeholder engagement, workforce development, capacity building, education, and technology transfer activities. As illustrated in the conceptual framework presented in Figure 1, information collected from communities, transportation practitioners, government agencies, and academic stakeholders is intended to guide the development of practical resources, educational initiatives, and workforce development strategies that support resilient coastal transportation systems and the Blue Economy.

The objectives of Phase I, which are the focus of this report, are to:

- Assess stakeholders and community perceptions regarding transportation vulnerability, accessibility, and resilience in coastal regions.
- Identify transportation challenges, infrastructure vulnerabilities, and perceived risks associated with natural hazards and coastal threats.
- Evaluate stakeholder awareness, preparedness, and training needs related to transportation resilience and coastal risk management.

- Establish a baseline understanding of community and stakeholder perspectives to support future educational, workforce development, and capacity-building initiatives.
- Provide information that will guide subsequent phases of the CREATE research program.

The findings presented in this report represent the first phase of the CREATE research program and provide baseline information needed to guide future capacity-building, workforce development, educational, and technology transfer activities.

LITERATURE REVIEW

This chapter presents a review of the literature supporting the development of resilient coastal transportation systems and the long-term goals of the CREATE research program. Topics include the economic and societal importance of coastal regions, definitions of coastal zones, transportation vulnerability and accessibility, workforce development needs, and the use of innovative educational technologies to enhance resilience, preparedness, and community engagement.

The Importance of Coastal Regions and the Blue Economy

Coastal regions are vital to global development, sustaining nearly 40% of the world's population that lives within 100 kilometers of the shoreline (World Bank, 2016). These areas provide critical environmental services such as habitat protection and food supply, while also supporting economic activities ranging from port industries and fishing to tourism and raw material extraction (Creel, 2003). Their social importance is equally significant, as they host diverse populations that range from vulnerable communities to highly industrialized and developed hubs. However, coastal zones are increasingly vulnerable to natural disasters, climate impacts, and human pressures, making their protection and sustainable management a priority.

Appropriately, coastal regions play a critical role in the economic, social, and environmental well-being of the U.S. According to the National Oceanic and Atmospheric Administration (NOAA, 2026), coastal counties are home to more than 128 million people [40% of the U.S. population], support approximately 54.6 million jobs, and contribute about $10 trillion annually to the U.S. economy. These figures highlight the significance of coastal communities as centers of population, employment, commerce, tourism, recreation, maritime activities, and critical infrastructure. Given their economic importance and concentration of population and assets, understanding the characteristics, vulnerabilities, and transportation needs of coastal regions is essential for developing effective resilience and adaptation strategies.

The Blue Economy framework has emerged as a global response to these challenges, aiming to balance economic growth with environmental sustainability. If treated as a national economy, the ocean would rank as the world's seventh largest by GDP (Hoegh-Guldberg et al., 2015), and

projections estimate its value could grow up to $2.5–3.0 trillion by 2030 (OECD, 2016). This growth potential highlights the need for resilient infrastructure, sustainable resource use, and proactive adaptation strategies. By integrating goals such as marine conservation, emission reductions, and habitat restoration into international agendas, the Blue Economy offers a pathway to secure both biodiversity and livelihoods, ensuring that coastal and island communities like Puerto Rico can withstand future risks while continuing to thrive (Hoegh-Guldberg et al., 2015; OECD, 2016).

Defining Coastal Zones

The coastal zone is a diverse and dynamic landscape consisting of rivers, mangroves, coral reefs, and other ecological features, providing a wide array of social and environmental services. Remarkably, there is no universally accepted definition for what constitutes a coastal area, which complicates planning efforts (Creel, 2003). Voigt (1998) defines the coast as the strip of land extending from the seashore to the first major terrain change. As comparison, other studies suggest a broader buffer based on distance, ranging between 60 to 200 kilometers from the shoreline (Creel, 2003).

In the U.S., the Coastal Zone Management Act (1972) established a voluntary federal-state partnership to promote the effective management, protection, and sustainable use of coastal resources while balancing environmental, economic, and recreational interests. The 1972 Act defines the term "*coastal zone*" as the coastal waters (including the lands therein and thereunder) and the adjacent shorelands (including the waters therein and thereunder), strongly influenced by each other and in proximity to the shorelines of the several coastal states, and includes islands, transitional and intertidal areas, salt marshes, wetlands, and beaches. Broader definitions refer to coastal regions as areas where terrestrial, marine, and human systems interact and where communities, infrastructure, ecosystems, and economic activities are influenced by coastal processes and hazards (IPCC, 2019; NOAA, n.d.).

Applying a pertinent definition of "*coastal zones*" in island contexts like Puerto Rico, with a north-to-south distance of 56 kilometers [about 35 miles] and 799 miles of coastline (DRNA, 2017), takes relevance. Area-specific criteria are more appropriate for this context. This includes incorporating shoreline definitions, coastal flood maps, and Limit of Moderate Wave Action [LiMWA] data, which identify areas prone to waves 1.5–3 feet high during base flood events. The

LiMWA is an informational line that illustrates the risk of flood damage from waves and fast-moving water (FEMA, 2021). Figure 2 shows the flood zones and the LiMWA for the municipalities along the San Juan Bay in Puerto Rico.

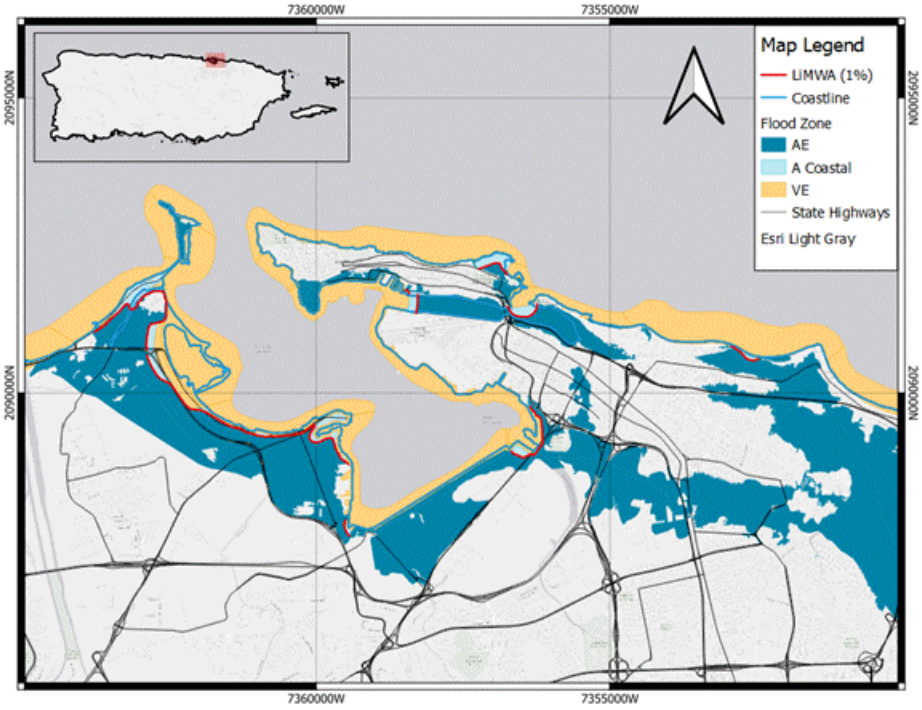


Figure 2. Map of the San Juan Area showing the LiMWA and Flood Zones
(Source: https://gis.pr.gov)

Public policy established by the Puerto Rico Department of Natural and Environmental Resources in the Puerto Rico Coastal Zone Management Program [PRCZMP] apply to the geographic, terrestrial, and marine area known as the coastal zone of the Puerto Rican archipelago, which is legally defined as: "*A strip of coastal land one thousand linear meters [1,000 m] inland measured from the shoreline, as well as additional distances necessary to include key natural coastal systems. It also includes Puerto Rico's territorial waters and the ocean or marine floor beneath them (three nautical leagues, 9 nautical miles, or 10.35 land miles), the islands of Vieques, Culebra, Mona, Monito, Desecheo, Caja de Muertos, and all cays and islets within them.*" (DRNA, 2009). Figure 3 shows the official delimitation of the coastal sectors and municipalities in Puerto Rico and the coastal zone inland boundary based on the definition established by the DRNA.

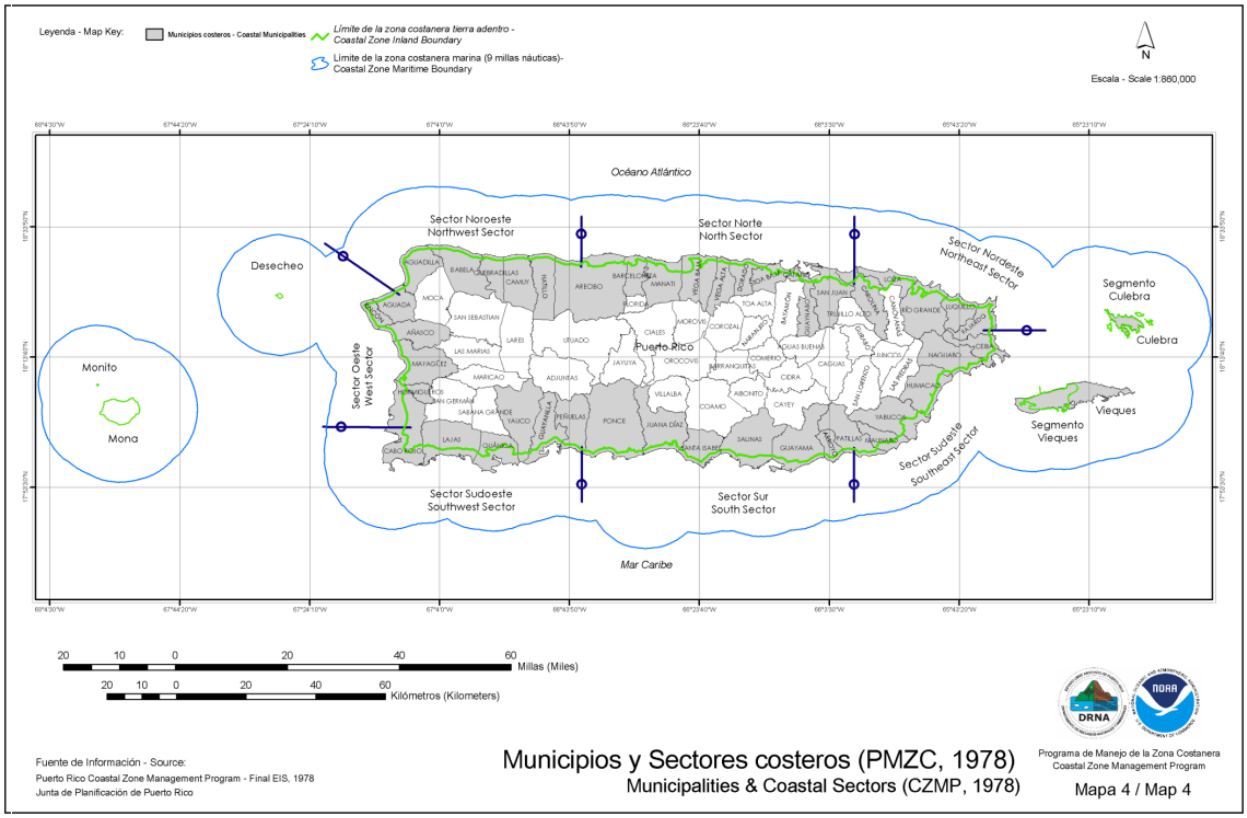


Figure 3. Municipalities and Coastal Sectors in Puerto Rico
(Source: DRNA, 2009)

While statutory definitions provide the legal framework for identifying coastal zones, planning for transportation resilience often requires understanding the interaction between coastal hazards, communities, infrastructure, and economic activities. Tools such as the NOAA's Coastal Flood Exposure Mapper support this broader perspective by allowing users to visualize the exposure of people, transportation assets, community facilities, and natural resources to various coastal flood hazards. The tool was developed to support community-based assessments of coastal risks and vulnerabilities and to facilitate discussions regarding resilience planning and adaptation strategies.

Understanding coastal regions requires not only defining their geographic boundaries but also characterizing the hazards that affect their communities, infrastructure, and economic activities. One of the principal indicators incorporated into NOAA's visualization tool is the Coastal Flood Hazard Composite, which combines multiple sources of coastal flood risk information, including FEMA flood zones, storm surge scenarios, flood frequency zones, and sea-level rise projections. The composite index provides a screening-level representation of relative

exposure to coastal flooding and is intended to support community discussions, vulnerability assessments, and resilience planning efforts. The Composite does not represent flood depth or probability, but rather the overlap of multiple coastal hazard zones.

Figure 4 presents the Coastal Flood Hazard Composite indicator developed by NOAA for the 48 contiguous States. Higher composite values indicate locations where multiple coastal flood hazard zones overlap, suggesting greater potential exposure to coastal flooding and related hazards. The map reveals a clear concentration of high-exposure areas along the Atlantic Coast and the Gulf of America, where extensive low-lying coastal plains, estuaries, barrier islands, and densely developed coastal regions experience the combined influence of storm surge, coastal flooding, and sea-level rise. In contrast, much of the Pacific Coast exhibits a narrower band of exposed coastal areas, reflecting different coastal geomorphology and hazard characteristics.

Figure 5 presents the Coastal Flood Hazard Composite indicator for the four U.S. jurisdictions [Florida, Oregon, Texas, and Puerto Rico] with a CREATE consortium partner university. Although the extent and spatial distribution of coastal flood exposure vary considerably among Oregon, Texas, Florida, and Puerto Rico, all regions exhibit transportation corridors, communities, and economic assets located within areas potentially exposed to coastal flooding. Oregon is characterized by a relatively narrow coastal exposure zone constrained by coastal topography, whereas Texas and Florida display extensive low-lying coastal areas that experience broader spatial exposure to coastal flooding hazards. Puerto Rico presents a distinct island-wide condition in which much of the critical transportation infrastructure and population are concentrated near the coastline, including the San Juan Metropolitan Area. These differences illustrate the need for region-specific resilience strategies while highlighting a common need for improved planning, stakeholder engagement, education, and workforce development to support resilient coastal transportation systems.

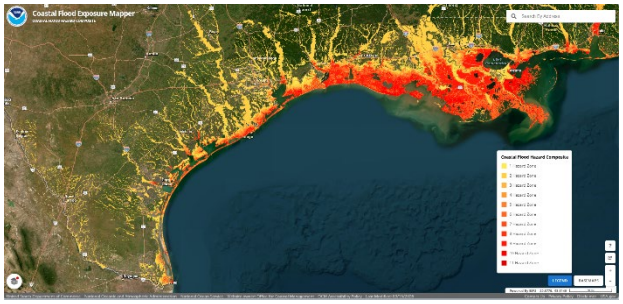
Prior to Hurricanes Irma and María, Puerto Rico's transportation system faced various issues, such as infrastructure with deferred maintenance or repair, limited public transit, and financial concerns (ASCE-PR, 2019; Ecola et al., 2020). The public transit system in most urban areas is deemed insufficient, marked by insufficient service frequency rates and low ridership numbers.



Figure 4. Coastal Flood Hazard Composite Indicator for the 48 Contiguous States
(Source: NOAA Office for Coastal Management, Coastal Flood Exposure Mapper, 2026)



(a) State of Oregon



(b) Coast of Texas



(c) State of Florida



(d) Territory of Puerto Rico

Figure 5. Coastal Flood Hazard Composite Indicator in CREATE Jurisdictions
(Source: NOAA Office for Coastal Management, Coastal Flood Exposure Mapper, 2026)

Figure 6 shows the location of ports and airports in Puerto Rico along with FEMA 1% Flood Zones. Ports play a fundamental role in supporting Puerto Rico's Blue Economy by facilitating the

movement of essential goods, energy resources, and visitors. Given the island's dependence on imported fuel and food products, maritime transportation serves as a critical lifeline for economic activity and community well-being. Ports also support the tourism industry, which received approximately 1.2 million cruise passengers in FY2018 and contributed an estimated $152 million to the economy (ASCE, 2019). The island heavily relied on the Port of San Juan for maritime transport, and Luis Muñoz Marín International Airport [SJU] in Carolina dominated air travel, accounting for 90 percent of passenger movements, even though flight numbers had been declining since 2000. There are two other major airports for passenger travel in Ponce [PCE] and Aguadilla [BQN].

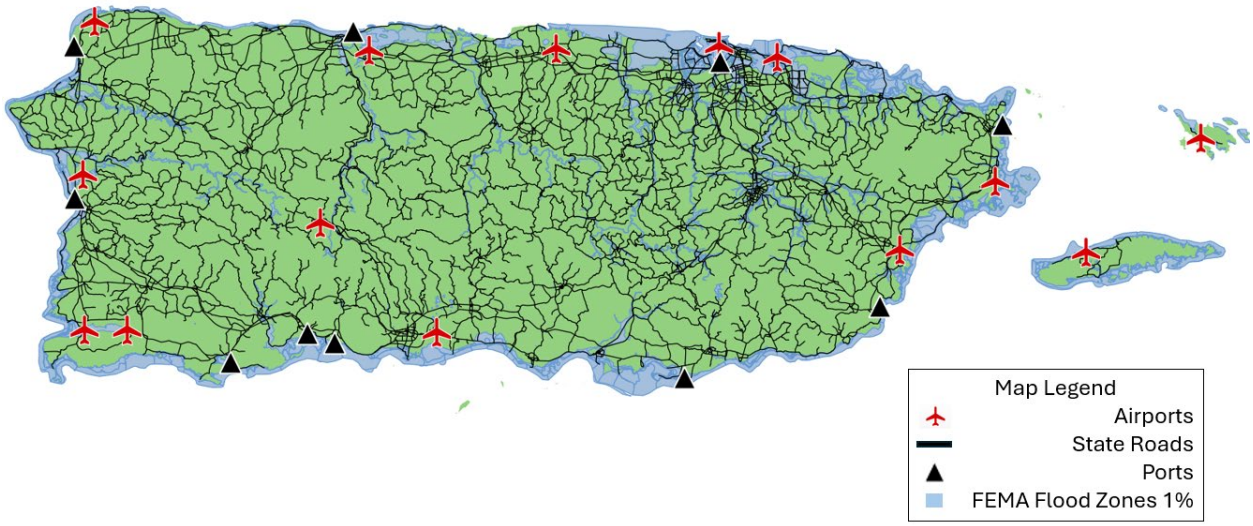


Figure 6. Critical Transportation Infrastructure and Flood Risk Zones in Puerto Rico

The hurricanes exacerbated these challenges, causing extensive damage with estimated repair costs of $1.8 billion and recommended resilience improvements of $1.1 billion. The recovery plan suggests 22 courses of action, covering repairs, enhancements, new capacity, and planning. Key findings underscored the need for greater resilience and coordination in the transportation sector, a reliance on maritime transport, and the necessity of designing infrastructure capable of withstanding future storms. Despite many facilities reopening in 2018, ongoing permanent work is required (Ecola et al., 2020).

Reevaluating the Marine Transportation System Recovery Plan can leverage lessons learned from hurricane responses, including pre-positioning resources, establishing an integrated

operations center, developing communication protocols for first responders during disasters, and implementing pre-hurricane protective measures cohesively to safeguard critical resources.

Recovery efforts involve repairing roads and bridges to reinstate pre-hurricane functionality, ensuring the smooth mobility of people, goods, and services. This initiative aims to replace missing road signs, non-functional traffic signals, and repair or replace weakened bridges within a four-year timeframe (Ecola et al., 2020).

These conditions illustrate the importance of understanding not only the physical vulnerability of transportation infrastructure but also the institutional, operational, and workforce factors that influence the resilience of transportation systems in coastal and island environments.

Transportation Resilience, Vulnerability and Network Analysis

For this report the following definitions are applied based on the United Nations' Office for Disaster Risk Reduction (2017):

- Disaster risk: The potential loss of life, injury, or destroyed or damaged assets which could occur to a system, society or a community in a specific period, determined probabilistically as a function of hazard, exposure, vulnerability and capacity.
- Capacity: The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce disaster risks and strengthen resilience.
- Exposure: The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas.
- Hazard: A process, phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.
- Vulnerability: The conditions determined by physical, social, economic, and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.

Vulnerability in the transportation context is a function of a transportation asset or system sensitivity to climate effects, exposure to extreme weather and climate effects, and adaptive

capacity (FHWA, 2017). Extreme natural events can cause a negative influence that results in substantial reductions in the serviceability of a transportation network, rendering parts inoperable under certain circumstances (Berdica, 2002). Alabbad et al. (2021) highlights that a natural event, such as a flood, can significantly disrupt road networks by interrupting key connections and extending access routes to essential services. These conditions limit mobility and complicate institutional emergency response (Chen et al., 2015). Through spatial analysis, the use of Geographic Information Systems [GIS] allows for precise representation of road network connectivity, relying on graph theory and topology to identify critical points in the infrastructure (Das et al., 2019). This approach is useful for assessing how the loss of road links affects the overall operation of the transportation system (El-adaway et al., 2016). Understanding and addressing vulnerability in transportation is crucial for ensuring the durability and reliability of the network, especially in the face of natural disasters and other extreme events.

Another definition for vulnerability is the likelihood of a system being damaged or altered by a predetermined disturbance. There are two types of vulnerability: actual vulnerability (V_a), which occurs when a system is exposed to a disturbance, and potential vulnerability (V_p), which exists when a system is not currently exposed to a disturbance but could face future exposure (e.g., climate anomalies). A high vulnerability can lead to a great impact once a disturbance occurs. (Scondras, 2020).

Transportation infrastructure, including ports, roads, airports, and others, is susceptible to a range of hazards caused by climate and weather. These hazards encompass various extreme weather events such as hurricanes, storms, heavy rainfall, and strong winds, which can lead to infrastructure damage, flooding, and disruptions in transportation services. Coastal infrastructure, such as ports and roads, faces additional risks from sea-level rise and storm surges, which can cause inundation and erosion. Temperature extremes, both hot and cold, can impact the durability and performance of roads, bridges, and airport runways. Changes in precipitation patterns can result in droughts or intense rainfall, affecting the condition and usability of transportation networks. Natural disasters like earthquakes, landslides, and tsunamis also pose significant threats by damaging infrastructure and disrupting services. Furthermore, the increasing frequency and intensity of extreme weather events exacerbate vulnerabilities in transportation systems. Addressing these hazards requires robust planning, risk assessment, and adaptation strategies to

enhance the durability and reliability of transportation networks against climate and weather-related challenges.

Cantillo et al. (2018) developed a method for assessing vulnerability of transportation networks for disaster response operations. The methodology consists of identifying critical links in a transportation network by analyzing logistical costs of the distribution operations and the external effects derived from the delays in the provision of basic supplies. The method allows us to put a level of importance to networks links for access of humanitarian operations to areas hit by disasters.

Lin et al. (2022) measures vulnerability by system travel time-based vulnerability [STTV] and system emissions-based vulnerability [SEV]. STTV is measured by the ratio of the added total travel time after an extreme event and the original travel time. SEV is quantified by the ratio of CO emissions after an extreme event and the emissions before.

Yang et al. (2013) evaluates vulnerability through three key components: physical exposure, disaster loss sensitivity, and resistance ability. Physical exposure considers geographic location, climate patterns, and historical weather data to measure infrastructure exposure to hazards. Disaster loss sensitivity assesses potential impacts on the transport system, including infrastructure damage and operational disruptions. Resistance ability evaluates the system's capacity to withstand and recover from disasters, considering infrastructure quality, maintenance practices, and emergency response effectiveness. Thirteen specific evaluation indices are quantified and prioritized using the Analytic Hierarchy Process [AHP], which breaks down the assessment into a hierarchical structure of objectives and criteria. The Fuzzy Comprehensive Evaluation [FCE] theory integrates these indices into a single vulnerability index, addressing uncertainty and subjectivity.

The US-DOT developed a spreadsheet-based tool called Vulnerability Assessment Scoring Tool [VAST] that measures vulnerability as a function of three categories: exposure, sensitivity, and adaptive capacity of a transportation asset. By collecting data on indicators for each category for vulnerability, each category has a relative score giving a total vulnerability score.

While vulnerability assessments help identify transportation assets exposed to hazards, accessibility measures evaluate how those disruptions affect the ability of people and communities

to reach critical opportunities and services. Together, vulnerability and accessibility provide complementary perspectives for understanding transportation resilience.

Transportation Accessibility and Social Mobility

The concept of social mobility, widely explored in sociology, has been adapted in this study as a conceptual framework for analyzing phenomena related to accessibility in the field of transportation. In sociological terms, the concept of social mobility refers to the movement of individuals or groups between different social categories. Tadeusz and Kazimierz (1986) address this phenomenon through three fundamental dimensions: material, cognitive, and normative. The relationship among these dimensions is illustrated in the diagram shown in Figure 7.

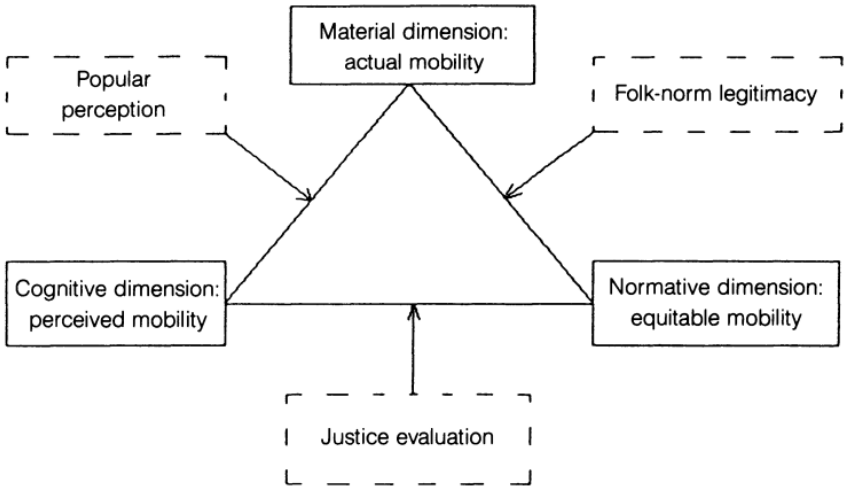


Figure 7. Material, Cognitive, and Normative Dimensions of Social Relations

(Source: Tadeusz K. & Kazimierz M., 1986)

The material dimension, also known as actual mobility, is defined as an objective and verifiable social process. In this approach, mobility is analyzed through the actual transitions of individuals between their origin and destination categories. Empirical analysis begins with the measurement of the frequency of these transitions, which allows the observation of actual patterns of mobility within a given society.

The cognitive dimension, also referred to as perceived mobility, refers to the beliefs, perceptions, and subjective representations that individuals hold regarding the frequency and

nature of social mobility. This dimension focuses on "*what is believed to be*" the social reality. Such perception is shaped by individuals' ideas about how members of different social groups are distributed according to their origin. The comparison between the subjective view and objective data allows for the evaluation of the popular perception of the social structure. When there is a significant discrepancy between the two, it is considered that a degree of "*false consciousness*" exists, meaning a distorted interpretation of the actual dynamics of mobility.

The normative dimension, also called equitable mobility, refers to the ideal or desired mobility, as understood in accordance with standards of fairness and justice established by a social group. This dimension concerns the frequencies of mobility that "*should be*" if the social system operated under principles considered fair. It involves a comparison between what people believe is happening and what they think ought to happen. The gap between these two perceptions generates varying degrees of perceived injustice. Likewise, by comparing actual mobility with what is considered equitable mobility, it becomes possible to evaluate the perceived illegitimacy of existing social structures.

Although social mobility traditionally refers to movement between social categories, its conceptual framework offers useful parallels for understanding accessibility by distinguishing between actual, perceived, and desired conditions.

Paez et al. (2012) defines accessibility as the ability to reach spatially distributed opportunities, such as employment, recreation, or social interaction. It is considered a key outcome of spatial development and results from the interaction between the transportation network and the geographical distribution of activities. Martellato and Nijkamp (1999) emphasize that accessibility has historically been an essential concept in both transportation and regional development research, and they highlight that its analysis remains a central component in numerous studies on urban and territorial dynamics.

Accessibility continues to be a fundamental aspect, such as in the analysis of transport-related social exclusion (Páez, 2009; Scott and Horner, 2008), the evaluation of service areas for healthcare facilities (Apparicio et al., 2008; Horner and Mascarenhas, 2007; Páez et al., 2010a), the identification of functional commuting zones (Reggiani et al., 2011), and the effect of public

transport on labor outcomes (Blumenberg and Shiki, 2003). Therefore, if distance continues to represent a barrier to mobility, accessibility will remain a key factor in transport-related studies.

Building on the theoretical social mobility approach proposed by Tadeusz and Kazimierz (1986), this study proposes a reinterpretation of these dimensions as applied to transportation accessibility: real accessibility [objective and measurable conditions], perceived accessibility [subjective experience of road users or the community], and designed accessibility [transportation systems designed in synchronization with the needs and aspirations of end users]. This adaptation enables a deeper understanding not only of how people access transportation, but also of how they perceive that access and how they believe it should function within a fair and inclusive system.

Accessibility measures in transportation are typically composed of two key elements: the cost associated with travel, which depends on the spatial distribution of travelers and opportunities, and the quantity or quality of those opportunities. These two elements can be combined in different ways to create accessibility indicators that are either location-based or person-based, depending largely on the available details regarding network conditions, transportation modes, and individual mobility differences.

Moreover, accessibility can be assessed from the perspective of the origin or generator of potential trips, or from the standpoint of the destination or purpose of those trips. Islam et al. (2008) describe this distinction as the "*supply of opportunities*" versus the "*demand of participants*".

Examples in the literature illustrate various ways of conceptualizing accessibility:

- A location-based approach from the perspective of the trip origin, that involves calculating the average number of supermarkets within a 1000-meter radius of each census tract, adjusted by population (Apparicio et al., 2008).
- A geographic, origin-based perspective, evaluates whether at least one dentist is accessible within a 10-mile radius of a given county (Horner and Mascarenhas, 2007).
- A personalized, origin-based approach, considers the number of grocery stores located within the typical travel range of individuals with a specific profile, centered on their place of residence (Páez et al., 2010b).

A resilient transportation network has the ability to maintain its functionality during and after extreme events (Pregnolato et al., 2016), which require analyzing the vulnerability of

transportation networks by identifying road segment disruption during a disaster event and their impact on society, such as reducing emergency accessibility (Jenelius and Mattsson, 2015). When a road is flooded, the effects of its closure can cascade throughout the network system and affect people, businesses, emergency response, and the flow of traffic. For example, a school bus may not be able to access an area because of flooded roads. Also, flooded roads may prevent people from obtaining essential supplies [e.g., food] or reaching their work. During flood events, people requiring treatment may have to travel to remote hospitals or outpatient services. Therefore, it is crucial to determine the critical facilities at risk of flooding and how changing conditions alter their accessibility. Floods can prevent hospitals from operating efficiently and consistently. For example, during a 2008 flood event in Iowa, the Mercy Medical Center in Cedar Rapids was flooded, and 183 patients were evacuated (Alabbad et al., 2021).

There are now metrics that quantify the operational efficiency and quality of service of the transportation network under disrupted conditions, such as:

- Network Capacity and Traffic Flow Stability: The reduction in network capacity directly quantifies the severity of a disruption. Analyzing traffic flow stability helps understand the network's ability to handle traffic efficiently after a hazard, as disrupted flows can severely hinder emergency vehicles (Nogal et al., 2016).
- Total Network Travel Time (TNTT) and Total Network Flow (TNF): TNTT measures the sum of all vehicle travel times across the network, serving as a time-based performance criterion that accounts for physical deterioration and travel pattern variations. TNF refers to the fraction of satisfied demand in the post-disaster stage, indicating the degree to which user needs are met (Konstantinidou et al., 2019).
- Traffic Efficiency and Safety: These are critical performance indicators used to evaluate the network's state during post-disaster recovery, particularly after events like earthquakes (Yangyang et al., 2024).

Workforce Development for Coastal Transportation Resilience

The transportation industry is currently facing several challenges, including the adoption of new technologies, workforce transitions, economic constraints, and increasing resilience planning requirements. The need to strengthen workforce competencies in areas such as data analytics, statistical analysis, technology implementation, and interdisciplinary decision-making was

identified in NCHRP Report 1008: Workforce 2030 (NASEM, 2022). The report further notes that US-DOTs must increasingly incorporate environmental considerations and resilience principles into the planning, design, construction, operation, and maintenance of transportation infrastructure to ensure long-term safety and reliability. According to the report, "*a limited number of staff have the required skills [e.g., forecasting and modeling] to engage in discussions over designing, constructing, and maintaining the new standards.*" The report also highlights the need to improve communication practices and develop tools that effectively document the rationale supporting transportation planning and infrastructure investment decisions.

The report identified resilience planning as one of the emerging areas that will significantly influence future workforce needs. Transportation professionals will increasingly be required to understand climate adaptation, infrastructure resilience, risk assessment, and long-term asset management practices as part of their everyday responsibilities. Civil engineers have started to identify strategies and practices to enhance the sustainability and resilience of transportation corridors (Webb et al., 2019). The US-DOT has developed scoring tools to assist professionals in the assessment of the risks and vulnerabilities of transportation assets to ensure multi-modal transportation system reliability and resiliency (FHWA, 2024). The vulnerability of transportation assets is a function of exposure, sensitivity, and adaptive capacity and its assessment focuses on how existing or planned transportation facilities may fare given current and future hazards to enable better prioritization in the decision-making process and the identification of feasible solutions and more effective adaptation measures.

Moreover, the effective application of these assessment strategies requires the development of the technical capacity of professionals that can be able to identify and analyze different perspectives and contexts of the coastal communities, the stressors, hazards, and related vulnerabilities, the specific needs of the local residents and visitors, and what are the most effective solutions and strategies to provide.

This approach requires proper identification of coastal vulnerabilities, including assessing geographic and demographic variables, which will help in the decision-making process for enhancing economic drivers of coastal communities. This also requires the familiarization of the subjects with the definitions and resources available and the use of Geographic Information Systems (GIS) to visualize and analyze strategies. Results include the development of modules for

professionals and for the general community, which will get educated on the benefits of the Blue Economy and the potential from its implementation for coastal communities.

In addition, Workforce 2030 highlights the growing importance of interdisciplinary collaboration, resilience planning, and technology adoption across transportation agencies. The report indicates that future transportation professionals must possess competencies that integrate engineering, environmental stewardship, risk management, stakeholder engagement, and data-driven decision making. Furthermore, concerns regarding workforce retirements and the transfer of institutional knowledge underscore the need for educational initiatives, training resources, mentoring programs, and professional development activities capable of preparing the next generation of transportation professionals. These findings are particularly relevant for coastal regions, where transportation resilience requires coordination among multiple disciplines, organizations, and stakeholders (NASEM, 2022). CREATE aims, among other goals, to educate communities and professionals to close the existing gaps in technical and policies knowledge.

Applications of Virtual Reality in Education and Natural Disaster Response

In addition to traditional training methods, emerging visualization technologies such as virtual reality offer new opportunities for transportation education, risk communication, and workforce development. By creating a simulated environment that accurately replicates the experience of being in a flooded area, virtual reality (VR) offers a safe and controlled space in which individuals can develop a deeper understanding of the associated challenges and risks. Immersion in a realistic flood scenario allows for a more impactful communication of the situation's severity and increases awareness of the potential consequences of flood-related hazards.

In recent years, simulation and VR technologies have been widely applied to improve disaster preparedness and response. Ooi et al. (2019) developed an educational VR training system focused on fire disasters and concluded that the time required to initiate fire extinguishing was reduced by ten seconds from using the system. In the field of disaster risk management, VR has proven useful in various applications such as the assessment of vulnerable infrastructure, public awareness of natural hazards, and emergency response training (Khanal et al., 2022; Wu et al., 2017; Zhu & Li, 2021; Sermet & Demir, 2019).

Thanks to its digitization and visualization capabilities, VR technology enables the recreation of representative scenarios of various catastrophic events, such as floods, fires, earthquakes, terrorist attacks, radiation, or thunderstorms, within real urban environments (Zhu & Li, 2021). Multiple studies have shown that immersion in these virtual environments significantly improves participants' learning and self-efficacy, outperforming traditional non-interactive training methods such as instructional videos (Zhu & Li, 2021; Lovreglio et al., 2021; Çakiroğlu and Gökoğlu, 2019). Furthermore, VR has been explored across the different phases of the disaster risk management cycle prevention, response, and recovery leading to the development of practical tools and educational simulations aimed at strengthening the capacities of various population sectors (Alene et al., 2023; Skinner, 2020; D'Amico et al., 2023).

An illustrative case of VR application in safety and behavioral analysis is the work conducted at the University of Puerto Rico at Mayagüez under the SAFER-SIM (Safety Research Using Simulation) UTC. One of its projects developed a VR-based roadway crossing experiment to study pedestrian behavior at uncontrolled urban crossings (Figueroa et al., 2020). The simulation assessed gap acceptance and walking speeds under varying traffic and street conditions, offering insights into how different groups (by age and gender) make crossing decisions in potentially hazardous scenarios. The study demonstrated the potential of VR to measure real-life human factors in a safe, controlled setting and supported its use to identify at-risk pedestrian populations and evaluate innovative safety countermeasures. This work exemplifies how VR is not only a tool for disaster response training but also a valuable instrument for understanding human behavior in risk-laden environments, contributing to the development of safer, more resilient communities.

STUDY METHODOLOGY

The CREATE research program at UPRM consists of multiple interconnected activities designed to be implemented over several years. Phase I focused on establishing the conceptual and technical foundation of the project through literature review, stakeholder engagement, community surveys, case study selection, and the preliminary development of research frameworks and tools. While baseline assessment activities produced the results presented in this report, other components, including transportation vulnerability assessment, transportation network analysis, virtual reality [VR] development, and educational module design, were initiated during Phase I and will continue through subsequent project phases. The project seeks to better understand transportation vulnerability, accessibility, resilience, and workforce development needs in coastal communities exposed to multiple hazards. Figure 8 presents the principal research activities conducted and initiated during Phase I and their relationship to future CREATE research efforts.

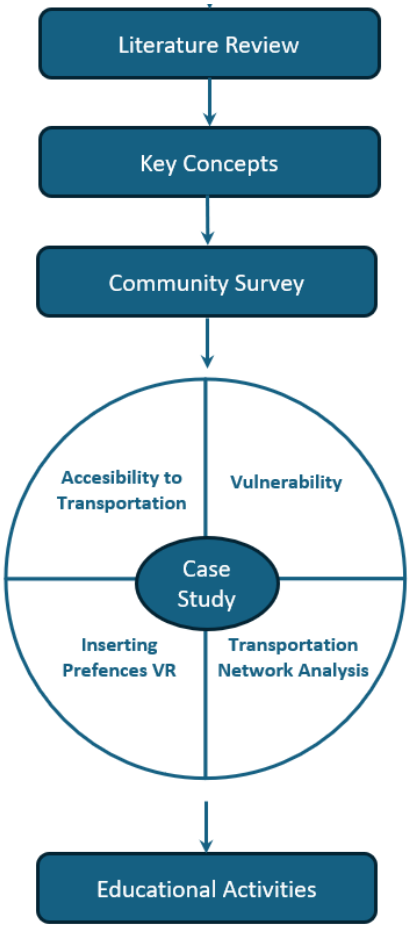


Figure 8. Phase I Research Activities and Multi-Phase Methodological Framework

The initial activity consisted of a literature review that included topics related to the vulnerability of coastal infrastructure, access to transportation, and the blue economy. Based on the review results, the study developed an online survey instrument to identify experience from extreme natural events and their impact on the transportation network. The survey collected information regarding perceptions of transportation vulnerability, accessibility, and preparedness related to natural hazards. The survey also inquired about mode choices, travel times, and opinions about the importance of blue economy activities. By identifying the type of community, comparisons were made of the perceptions and opinions received from coastal and non-coastal respondents in Puerto Rico.

The study developed a case study from the local coastal community of the Autonomous Municipality of Isabela to examine the transportation network challenges for the community, vulnerability assessments of flooding events, and collect perceptions of residents. The research activities will include the development of methodologies for analyzing vulnerability, transportation system operations, accessibility, and the use of virtual reality simulations to reflect flooding scenarios on the coastal corridor. Finally, educational activities will be developed in subsequent phases to raise awareness and support informed decision-making regarding risk in the face of natural hazards.

The adoption of the case study responds to the need to examine complex phenomena within a real and specific context. Coastal transportation systems are shaped by multiple factors, including natural, social, and infrastructural conditions, that cannot be fully understood through general or qualitative analyses. The case study provides significant methodological advantages, as it allows for a detailed examination of how local conditions such as risk exposure, social vulnerability, and roadway characteristics interact and influence community accessibility and resilience. It also enables the development of an interpretative framework regarding the impacts of flooding events on coastal mobility, which may serve as a foundation for future research. Furthermore, it supports the validation and expansion of existing theories by contrasting empirical findings with the literature on accessibility, vulnerability, and resilience, thereby enriching academic understanding of the phenomenon by incorporating feedback from the residents. Finally, it offers practical value by generating information directly applicable to infrastructure planning and the design of educational and mitigation strategies with local relevance.

In this sense, the case study becomes an essential methodological tool to bridge technical research with the social realities of coastal communities, producing results that not only strengthen theory but also inform decision-making in the pursuit of resilient transportation systems.

Multi-Dimensional Framework for Coastal Transportation Accessibility

Building on the research problem outlined in Chapter 1, the study adopts a methodological framework for assessing transportation accessibility and resilience in coastal communities through the integration of stakeholder perceptions, infrastructure vulnerability, and educational interventions. It is crucial to identify pertinent and quantifiable methods that enable feedback from stakeholders of coastal communities to establish assessment criteria for transportation resilience solutions. The pursuit of coastal road accessibility amidst and after natural hazards requires a multidimensional approach. Because transportation accessibility is closely linked to the long-term sustainability of the Blue Economy, the framework incorporates educational and community engagement components intended to support informed decision-making and resilience planning. This educational aspect is being supported by visualization strategies that allow for multidirectional analysis among the different states of accessibility.

The methodological concept looks to assess the transportation accessibility, focusing on coastal communities vulnerable to potential hazards [e.g., floods]. This model, referred to as the CREATE Accessibility Equilibrium Cycle, as shown in Figure 9, is based on three accessibility states or dimensions: perception [cognitive], reality [measured], and human-centered design [target]. Considering coastal transportation accessibility from these different dimensions offers a comprehensive framework for a desired outcome.

The framework is intended to bridge the gap between how transportation accessibility is experienced by communities, how it is measured through technical analyses, and how it can be improved through planning, education, and human-centered design.

The *perceived accessibility* dimension will be measured indirectly through online survey responses and future stakeholder engagement activities, including focus groups, related to the impacts of extreme natural events and the quality of the transportation network, as well to gather community perceptions and preferences regarding the state of their transportation accessibility.

The *measured accessibility* dimension will be evaluated during subsequent project phases using geospatial tools and transportation network micro-simulation models to compare the community perceptions with the outputs from typical performance measures [e.g., travel times, delays, etc.] used for roadway network analysis to quantify the "real" transportation accessibility.

The *human-centered accessibility* dimension will be promoted through the development and execution of the educational modules and the technology transfer activities resulting from the research products. With the use of educational modules at different levels [K-12, college, industry] and visualization tools, we will address the accessibility needs and the identification of potential solutions for communities and promote the transportation workforce development of blue economy topics and strategies.

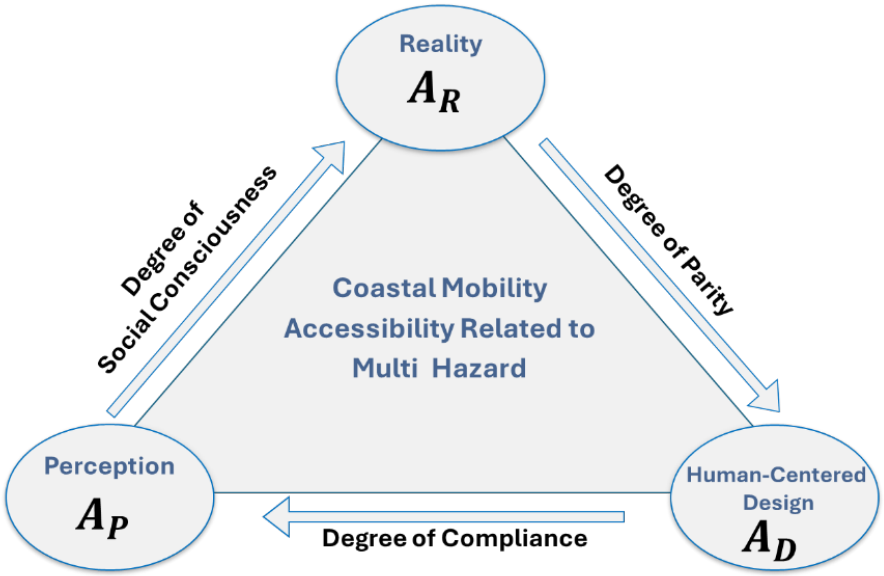


Figure 9. Accessibility Equilibrium Cycle for Resilient Coastal Transportation Systems

[Adapted from Krauze and Słomczyński, 1986]

It is essential to consider that educational components can be linked throughout every dimension of the model, ensuring its adaptability and transformative potential within its unique context. The collection of perceptions and opinions is embraced as the initial phase of the theoretical cycle, looking to help designers learn how to complement their design decisions and broaden their perspectives focused on community needs. This approach aims not only to propose solutions based solely on effectiveness and efficiency but also to propose tailored ones that meet

their genuine societal needs. Post-visualization, ongoing feedback remains pivotal to gauging sense of compliance and addressing emerging future needs. The engaged interaction of designers should encompass both the material and ideal perspectives, educating the community on maximizing the benefits of provided resources and highlighting the potential solutions. Now, in the equilibrium cycle, the educational direction is intended to address social perception by instructing the community on the actual accessibility state, therefore enhancing the possibilities for a more conscious design. This educational component nurtures the transformation of coastal communities focusing on the blue economy.

Community Survey Instrument

The cognitive or social dimension [i.e., *perceived accessibility*] pertains to the subjective perception community members hold about their situation. It is the filter through which they interpret their environment and perceive their available resources. This aspect of the model examines how the community views its own reality, feels about its surroundings, and perceives the opportunities and limitations they face. Puerto Rico residents were asked to share their opinions of transportation accessibility and infrastructure status post-heavy rainfalls, storms, or hurricanes within their area through an online survey instrument.

To support the objectives of the project, a web-based survey was developed and administered using Microsoft Forms. The survey, prepared in Spanish, was designed to collect data from adult residents of Puerto Rico regarding their transportation experiences, accessibility to daily activities, perceptions of transportation system quality, vulnerability to natural disasters, and the role of coastal activities in local economic development. The questionnaire also gathered demographic and geographic information to support statistical analyses across different population groups and regions of the island. The survey was anonymous, voluntary, and included an informed consent section approved for human subjects' research. Participants were informed that no personally identifiable information would be collected and that responses would be reported only in aggregate form. The questionnaire was estimated to require approximately 10 to 15 minutes to complete.

The survey instrument was specifically developed to support the Phase I objectives of the CREATE UPRM program by establishing a baseline understanding of stakeholder perceptions regarding transportation accessibility, vulnerability, resilience, and coastal economic activities.

The survey served as the primary mechanism for evaluating the perceived accessibility dimension of the Coastal Transportation Accessibility Framework shown in Figure 9. Although the survey did not directly assess workforce competencies, the information collected regarding transportation experiences, accessibility challenges, vulnerability perceptions, and the importance of coastal activities provide baseline information that will support future workforce development and capacity-building initiatives, educational initiatives, and decision-support tools for resilient coastal transportation systems.

The survey instrument consisted of five primary sections, as shown in Table 1. Section A identified the respondents' most frequent daily activities. Sections B1 and B2 collected information about the primary and secondary transportation modes used to access these activities, including travel times, transportation availability, and perceptions of infrastructure quality and safety. Section C examined transportation vulnerability to natural hazards and assessed the impacts of past disaster events on community mobility. Section D focused on the perceived economic importance of coastal activities and the condition of transportation infrastructure serving coastal destinations. Finally, Section E collected demographic, household, and residential information, including municipality, coastal proximity, household composition, and vehicle ownership.

Table 1: Survey Structure and Data Collection Themes

Sections	**Description /Focus**
A - Daily Activities Patterns	Characteristics of primary and secondary daily activities
B1-B2 - Transportation Modes and Accessibility	Preferred primary and secondary transportation modes
C – Transportation Vulnerability to Natural Hazards	Community perception and experience related to impacts from natural events
D - Coastal Activities	Coastal Activities and Blue Economy Perceptions
E - Demographic Characteristics	Basic socio-demographic information of respondents

The survey utilized several question formats to capture both objective information and subjective perceptions. These formats included single-choice questions, multiple-response questions, ranking and frequency scales, matrix-style evaluations, and numerical entries.

Section A. Daily Activity Patterns

Respondents were asked to identify their most frequent and second most frequent daily activities from a predefined list of destinations. Activities include employment, education, shopping, healthcare, banking, recreation, religious services, airports, and government or utility offices. These questions were presented as single-choice categorical selections.

Sections B1 and B2. Transportation Modes and Accessibility

These sections collected information regarding both the primary and secondary transportation modes used for daily travel. Respondents selected from six transportation categories:

- Personal motor vehicle
- Public transportation
- Walking
- Bicycle or e-scooter
- Ride-share (carpool)
- Taxi, Uber, Lyft, or equivalent services

Depending on the selected mode, respondents received mode-specific questions regarding travel conditions and accessibility. Examples of question types included: Travel Time Categories, Frequency Scales related to the Accessibility to Transportation, and Infrastructure and Safety Assessment Matrices. These evaluations addressed roadway safety, pavement condition, sidewalk quality, bicycle facilities, transit service quality, accessibility for individuals with disabilities, schedule reliability, and overall transportation safety.

Section C. Transportation Vulnerability to Natural Hazards

This section examined respondents' experiences and concerns related to natural disasters and transportation disruptions. A hazard concern matrix asked respondents to rate using a five-point scale their level of concern regarding:

- Hurricanes and severe winds
- Flooding
- Earthquakes
- Landslides

- Wildfires
- Drought
- Tsunamis
- Extreme heat

Additional questions assessed whether respondents' communities had experienced impacts from these events during the previous decade and whether transportation infrastructure or personal vehicles had been affected. Respondents also estimated the amount of time required to restore roadway access following various hazards and the additional travel time associated with alternative routes during transportation disruptions. A multiple-response question asked participants to identify all transportation options available during emergency situations, allowing more than one alternative to be selected.

Section D. Coastal Activities

Respondents evaluated the economic importance of several coastal activities within their municipality using a five-point importance scale ranging from 1 [Not Important] to 5 [Very Important]. Activities evaluated included:

- Tourism and beaches
- Cargo ports
- Cruise ports
- Fishing
- Water-based recreation
- Environmental conservation areas
- Marinas and nautical facilities

Participants also rated the condition of roadways used to access these coastal destinations using the A-to-F infrastructure quality scale. An additional "*Do Not Know*" response option was included for respondents unfamiliar with a particular activity or location.

Section E. Demographic Characteristics

The final section collected demographic and household information for statistical comparison purposes. Variables included:

- Age (numeric response)
- Gender
- Educational attainment
- Municipality of residence
- Neighborhood (barrio) of residence
- Residence within a coastal community
- Travel time to the nearest coastline
- Length of residency
- Household size
- Presence of individuals with limited mobility
- Number of motor vehicles in the household

Several of these questions used conditional branching logic. For example, respondents selecting a municipality were subsequently presented with a list of neighborhoods corresponding to that municipality. This approach allowed for greater geographic precision while maintaining a user-friendly survey experience.

The survey instrument combined travel behavior, transportation accessibility, infrastructure quality, hazard vulnerability, coastal economics, and demographic information into a single integrated data collection tool. The resulting dataset supports the evaluation of transportation resilience from both community and infrastructure perspectives while providing baseline information for future educational, workforce development, and community engagement activities within the CREATE UPRM program.

Preliminary Vulnerability Assessment Framework

This study builds upon the FHWA Vulnerability Assessment Scoring Tool [VAST] to evaluate transportation vulnerability within coastal communities. While VAST provides a systematic framework for assessing transportation assets based on exposure, sensitivity, and adaptive capacity, transportation resilience is influenced not only by the physical characteristics of the infrastructure but also by the characteristics of the communities that depend on it. Consequently, this project proposes the incorporation of community-related indicators into the

vulnerability assessment process to better understand how disruptions to coastal transportation corridors affect mobility, accessibility, and community resilience.

When assessing vulnerability, it is important to consider community characteristics when evaluating transportation infrastructure for several reasons. Communities with limited resources [low-income populations, older adults, etc.] often face greater challenges when recovering from transportation disruptions. By considering these characteristics, transportation planners can better identify which areas are more affected by a disturbance in the network. It can also help pinpoint areas with limited access to transportation systems or fewer adaptation options. This understanding supports the development of strategies that improve accessibility across different types of communities.

Transportation infrastructure is closely linked to public health outcomes, including emergency access to medical care. Including community characteristics helps to better address health and safety concerns during extreme events, such as identifying areas where people may be isolated from essential services during floods, hurricanes, or road closures.

Also, community characteristics influence economic outcomes. Transportation access affects employment opportunities, local vendors, and the delivery of goods and services. By identifying vulnerabilities in areas where residents have more restricted mobility, planners can help maintain economic stability and continuity during and after disruptive events.

To support this effort, FHWA VAST was selected as the foundation of the vulnerability assessment framework. Exposure measures the extent to which transportation assets are subject to climate stressors, such as how frequently and severely they are affected by hazards like flooding, heat waves, or storm surges. Sensitivity assesses how susceptible these assets are to damage when exposed to climate stressors. This includes evaluating the condition and age of the infrastructure, as well as its design specifications and materials used. Adaptive capacity gauges the ability of the transportation system to cope with, recover from, or adapt to the impacts of climate stressors. This involves considering factors such as the availability of alternative routes, the robustness of maintenance and repair systems, and the capacity to implement adaptation measures.

VAST encompasses a wide range of asset types, including rail, ports and waterways, airports and heliports, oil and gas pipelines, bridges, and roads and highways. It also considers various climate stressors such as increased temperature and extreme heat, precipitation-driven inland flooding, extreme high tides, storm surges, wind, drought, dust storms, wildfires, winter storms, changes in freeze/thaw cycles, and permafrost thaw.

Using VAST involves several steps: defining the scope of the assessment, selecting relevant indicators, collecting data on these indicators, and converting the raw data into vulnerability scores. To illustrate how vulnerability indicators can be translated into numerical values for assessment purposes, an example rating scale was developed and is presented in Table 2. The scale ranges from 1 [lowest vulnerability] to 4 [highest vulnerability] as shown in the illustrative example in Table 3. These scores help to rank the assets by their vulnerability levels or support further analysis. Table 3 shows an example of the final assessment calculation by combining the score with a set of weights, prioritizing both the categories and the indicator levels.

Table 2: Scoring Criteria Used in the Illustrative Vulnerability Assessment Example

Exposure

Model SLR Inundation Depth

No	1
Yes	4

USGS Coastal Vulnerability Index

1	=	1
2	=	2
3	=	3
4	=	4

Sensitivity

Past Experience

Yes, inundated	4
No, not inundated	1

Flood Protection

Yes	1
No	4

Adaptive Capacity

Replacement Cost ($)

0	1,000,000	=	1
1,000,000	10,000,000	=	2
10,000,000	100,000,000	=	3
100,000,000	+	=	4

Detour Length (km)

0	10	=	1
10	30	=	2
30	50	=	3
50	+	=	4

Table 3: Illustrative Example of a VAST-Based Vulnerability Assessment

Category	Indicator	Score	Weight	Score × Weight	Weight Total
Exposure	Modeled Surge SLR Inundation Depth	4	60%	2.4	40%
	USGS Coastal Vulnerability Index	3	40%	1.2	
Sensitivity	Past Experience	4	50%	2.0	40%
	Flood Protection	1	50%	0.5	
Adaptive Capacity	Replacement Cost	4	80%	3.2	20%
	Detour Length	2	20%	0.4	
				Vulnerability Score	**3.2**

By documenting the vulnerabilities of transportation assets, VAST enables better prioritization in transportation planning and facilitates more effective adaptation measures. Its versatility in addressing different types of assets and climate stressors makes it applicable across various regions of the United States.

While VAST evaluates vulnerability through exposure, sensitivity, and adaptive capacity indicators, the proposed CREATE framework extends this approach by incorporating community characteristics that influence the consequences of transportation disruptions on coastal populations. An analysis of community characteristics with the assessment of vulnerable infrastructure helps determine which areas are more likely to be affected by extreme natural events and how it affects the people that use that infrastructure. The methodology to achieve the project goals includes a 7-step process, as shown in Figure 10.

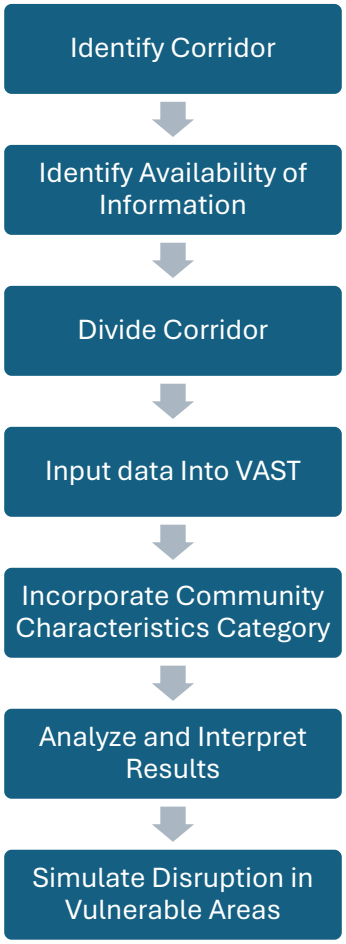


Figure 10. Vulnerability Assessment Methodology

The first step is to identify an important corridor within a coastal community. The selection is based on the corridor's relevance to daily mobility, economic activity, and its potential exposure to climate hazards. This step ensures the focus is placed on a transportation asset that is both critical and at risk.

The second step is to identify the availability of information for the three vulnerability indicators: exposure, sensitivity, and adaptive capacity. These indicators form the basis of the vulnerability framework.

The third step involves using Geographic Information System [GIS] analysis to divide the corridor into segments based on physical and geographical characteristics. These include FEMA flood zone maps, elevation, and roadway cross-sections. This spatial breakdown allows for a better analysis by recognizing the varying degrees of vulnerability across different segments of the corridor.

The fourth step is to input the segmented corridor data into VAST. Each road segment is characterized by its specific exposure, sensitivity, and adaptive capacity conditions. The indicators are then quantified on a scale from 1 to 4, with 1 representing low vulnerability and 4 representing a very high vulnerability. This scoring process provides a standardized method to assess and compare the vulnerability of each segment.

The fifth step is to incorporate a Community Vulnerability Category into the vulnerability assessment. This involves selecting social and demographic indicators from census data, such as income levels, disability status, vehicle access, and transportation mode availability. The inclusion of this category allows for the comparison of vulnerability scores with and without community characteristics, highlighting the influence of community vulnerability on resilience planning and transportation decision-making. The proposed community category represents an extension of the traditional VAST methodology and will be evaluated during subsequent phases of the CREATE project.

The sixth step is to analyze and interpret the results of the vulnerability assessment, focusing on identifying the most critical and vulnerable segments of the corridor. The comparison of scores with and without the community category provides insight into how social vulnerability influences

the overall robustness of the transportation network, helping to prioritize interventions that promote both infrastructure resilience and community resilience in the coastal area.

The final step will consist of simulating partial disruptions [lane reductions, bottlenecks, temporary blockages] and total disruptions [complete closures], to understand network operational impacts such as increases in travel time, traffic redistribution through alternative routes, increased fuel consumption, longer travel distances, changes in accessibility to essential services, traffic congestion, and road safety-related risks. The analysis will be conducted in a spatially differentiated manner, evaluating specific segments of the corridor. This will allow for comparisons of how the same type of event can affect different sections of the corridor in distinct ways.

Transportation Network Analysis Framework for Coastal Corridor Disruptions

While the vulnerability assessment framework focuses on identifying critical transportation assets and their susceptibility to hazards, the transportation network analysis seeks to understand how disruptions to those assets affect system performance, accessibility, and mobility within coastal communities. Together, these approaches provide complementary perspectives for evaluating transportation resilience.

Disruptions affecting a single roadway segment may generate cascading impacts throughout the transportation network by increasing travel times, reducing accessibility, and limiting access to essential services. The transportation network plays an important role in people's daily activities; at the same time, severe natural events [floods] frequently damage infrastructure and transportation networks. Understanding the vulnerability of transportation networks can improve prevention and response capabilities during disaster events and emergency incidents (Chen et al., 2015).

Studies have highlighted that, during a flood, the shortest distance to access essential services can double or even increase further compared to normal conditions (Alabbad et al., 2021). Therefore, having a method for analyzing traffic networks is useful for more effectively guiding more comprehensive transportation studies (El-adaway et al., 2016). Network analysis has been applied to address transportation issues, establishing itself as an ally in planning (Das et al., 2019). Simulation tools have established themselves as a valuable and appropriate resource for evaluating development and possible alternatives in transportation networks (Kozak et al., 2013).

The purpose of the transportation network analysis framework is to evaluate how disruptions affecting critical coastal transportation corridors propagate through the broader network and influence accessibility, mobility, and transportation system performance. The framework is designed to complement the vulnerability assessment methodology by quantifying the operational consequences of infrastructure disruptions and identifying potential resilience strategies for coastal communities.

In 2017, Hurricanes Irma and Maria severely affected Puerto Rico and transformed perceptions of their associated impacts. The Municipality of Isabela was included in Federal Disaster Declarations DR-4336 and DR-4339 due to the damage caused, which included disruption to roads and other types of infrastructure (Municipality of Isabela, 2020). Because of its exposure to coastal hazards and the importance of its transportation corridors for community mobility and economic activity, the coastal corridor and transportation network of the Municipality of Isabela were selected as the case study for this analysis.

To approach the analysis of the road corridor network in the event of flooding in a structured manner, a methodology consisting of six main steps is proposed, as shown conceptually in Figure 11. The framework integrates corridor characterization, disruption identification, scenario development, network simulation, performance evaluation, and resilience strategy formulation. These phases allow the problem to be addressed by combining technical analysis, local knowledge, and simulation tools.

This transportation network analysis framework supports the measured accessibility dimension of the Coastal Transportation Accessibility Framework presented in Figure 9 by quantifying how network disruptions influence travel behavior, mobility, and access to essential services.

Corridor characterization will be carried out in four sub-tasks:

- Definition of the corridor and data collection,
- Characterization of the population, travel patterns, and road infrastructure,
- Assessment of the importance of the corridor, and
- Collection of data and geospatial information relevant to the study.

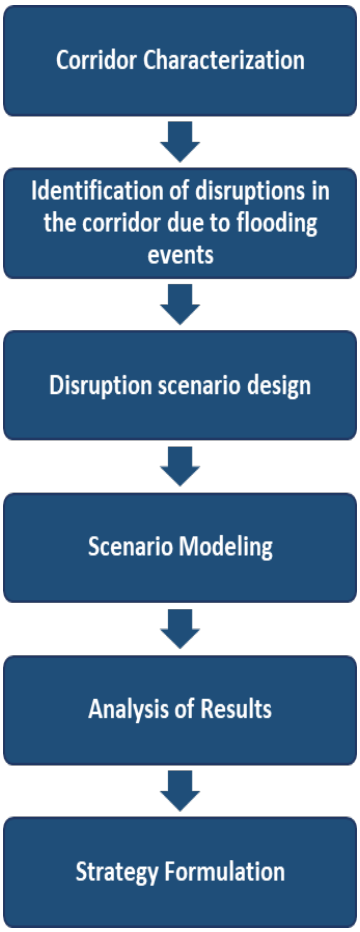


Figure 11. Proposed Transportation Network Analysis Framework

The identification of disruptions in the corridor due to flooding events will be obtained from primary and secondary sources. Primary sources will include interviews with residents, community users, and municipal officials who can provide qualitative and quantitative information on past disruptive events. Field inspections will also be conducted to assess locations that are likely to be affected. Secondary sources will include resources in the repositories of government agencies and academic institutions, such as reports from the Federal Emergency Management Agency [FEMA], the Puerto Rico Planning Board and the Land Use Plan, and the Municipality of Isabela's Disaster Mitigation Plan.

Disruption scenarios design will be based on the identification of historical events, documented evidence, local knowledge obtained through interviews, and physical characteristics defined from the data collected; the scenarios will be defined in three key dimensions:

- Cause of the event: why the disruption occurs [flooding];

- Type of disruption: whether it is total, partial, intermittent, or restricted traffic; and
- Severity level: how many lanes are affected, whether it affects both directions, and how long the impact will last.

Scenario modeling will consist of reproducing the scenarios defined in the previous phase using the simulation tool. The operational impacts generated by each type of disruption in the corridors will be quantified under controlled simulation conditions. The simulation will include partial disruptions [lane reductions, bottlenecks, temporary blockages] and total disruptions [complete closures].

In the phase of analysis of results, the data generated by the scenario simulation is interpreted to assess the operational impact of flood disruptions on the road corridor. Variations in travel times, congestion, and accessibility will be analyzed, identifying the most vulnerable points. These results will be compared with local knowledge and documentary sources to validate their accuracy and presented using maps and graphs to facilitate their application.

Formulation of strategies will be made based on the analysis of the results of the scenario simulations; strategies will be defined that can improve road operation in the event of disruptions caused by flooding. These strategies will be based on data obtained from the location of the impacts and the physical and functional characteristics of the corridor. Documented experiences from previous studies and solutions applied in similar contexts will be considered.

The results obtained through this framework will support future efforts to improve transportation resilience, enhance accessibility during disruptive events, and develop educational and workforce development resources for coastal communities exposed to multiple hazards.

Development of Scenarios for Natural Disaster Education and Preparation

While transportation vulnerability and network analyses provide quantitative measures of system performance, effective resilience planning also requires stakeholders to understand, visualize, and communicate transportation risks. Virtual reality [VR] technologies offer an opportunity to enhance risk perception, support community engagement, and improve educational outcomes by allowing participants to experience realistic hazard scenarios within a safe and controlled environment.

This project proposes a participatory methodology based on VR technology, with the objective of involving the community in understanding the risks associated with coastal flooding, as well as in the evaluation of various mitigation strategies. Through immersive simulations, residents are expected to visualize realistic impact scenarios. The main tasks of the experimental design can be seen in Figure 12, which outlines the methodological process step by step, from the initial literature review to the formulation of recommendations based on the analysis of results.

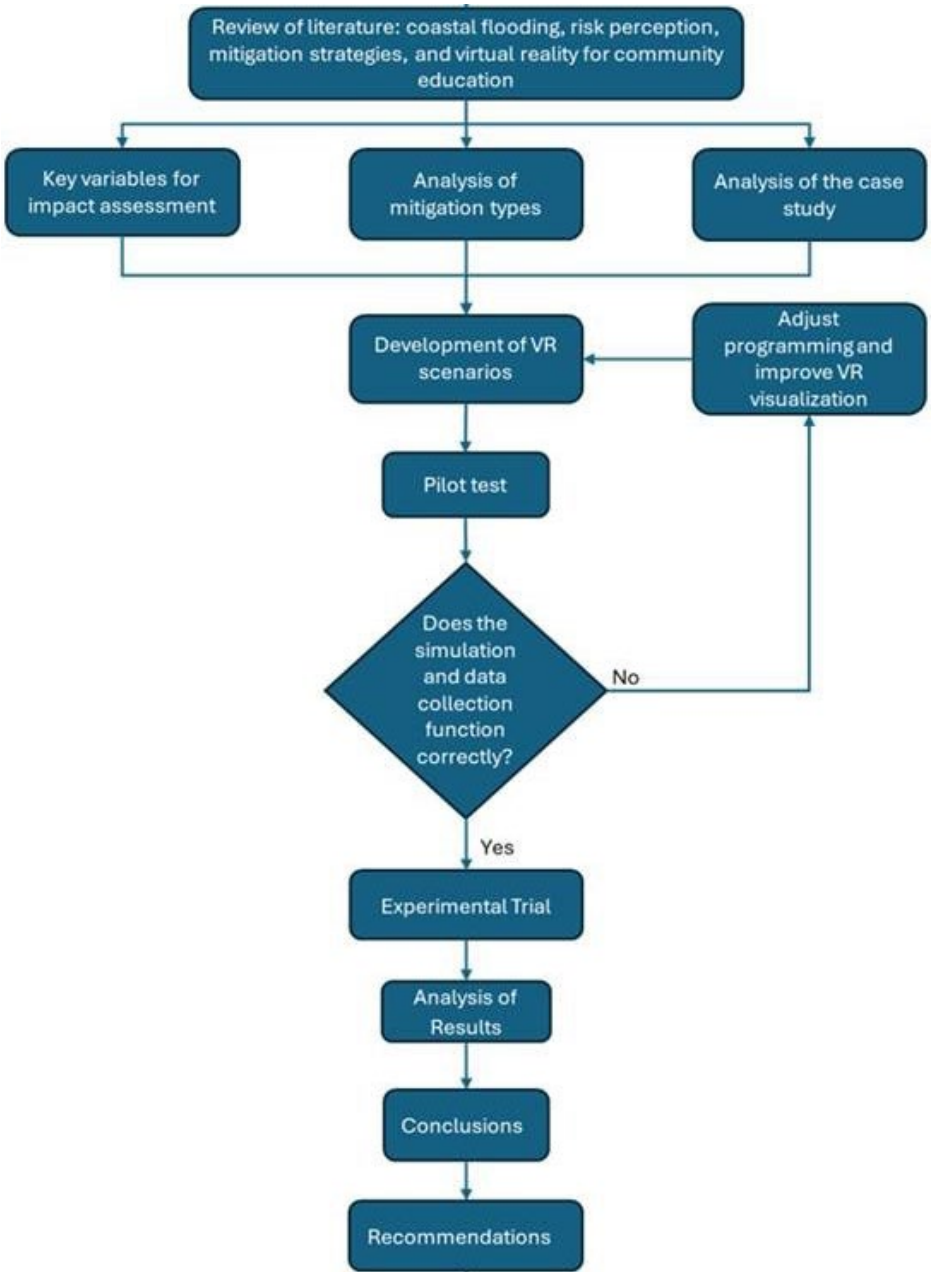


Figure 12. Proposed VR Experimental Design Framework

The VR experimental framework supports the human-centered accessibility dimension presented in Figure 9 by helping communities visualize transportation disruptions, understand resilience challenges, and participate in discussions regarding potential adaptation and mitigation strategies. Phase I focused primarily on the development of the methodology; the experimental protocol and virtual environments will be completed and used in future testing and evaluation activities in subsequent project phases.

The process begins with a literature review on coastal flooding, risk perception, mitigation strategies, and the use of VR in community education. This review serves to establish a conceptual framework that guides the design of the experiment.

Next, key variables are identified, including perceived transportation risk, accessibility perception, understanding of mitigation strategies, and participant responses to the simulated environments. With this conceptual and contextual foundation, the VR scenarios are developed.

These scenarios are subjected to a pilot test with residents to assess their comprehension, technological comfort, and the effectiveness of the virtual environment. If any issues are detected in the simulation or in data collection, the programming is adjusted and the VR visualization is improved.

Once the environments are validated, the experimental trial is conducted. Each participant interacts with the flooding scenarios sequentially, by observing the effect of different factors that affect flooded roadways and the perception of the risks involved.

Following the simulation, a post-simulation questionnaire is administered to collect information on risk perception, evaluation of mitigation strategies, emotional responses, and learning outcomes.

The collected data is then analyzed, allowing for conclusions to be drawn regarding changes in risk perception and the educational potential of VR. Finally, recommendations are formulated to strengthen participatory planning and environmental education in communities vulnerable to coastal events.

The experimental setup will be carried out using the Oculus Quest 2 VR headset, as shown in Figure 13. The equipment configuration includes a standalone VR headset, two Oculus Touch

controllers, a detachable handle, and over-ear headphones to replicate environmental audio effects, such as rainfall, rushing water, and emergency alerts during the simulation. Although the Oculus Quest 2 is designed for wireless operation, it will be connected to a desktop computer via Oculus Link (USB-C) to enhance visual rendering and processing reliability for the flood scenario. This hybrid setup enabled immersive, high-fidelity interactions while maintaining user safety and freedom of movement.



Figure 13. Oculus Quest 2 VR Headset

The Oculus Quest 2 employs inside-out tracking through four integrated cameras, supporting room-scale VR within an area of approximately 16.4 feet by 16.4 feet. This space was configured to simulate a flooded urban environment, including rising water levels, obstacle navigation, and virtual cues for evacuation behavior. The Guardian system helped define virtual boundaries and ensure participant safety throughout the experiment.

As part of the development of the immersive environment for coastal risk simulation, a series of preliminary virtual scenarios has been created using Unreal Engine 5.2. The main objective is to progressively depict a flooding situation in a coastal area resembling the site known as Villa Pesquera in the Municipality of Isabela. Figure 14 shows an aerial view of the Villa Pesquera location and a street view of the two-lane coastal road that will be used as model for the VR visualization.



Figure 14. Location and Street View of the Villa Pesquera Coastal Road
(Adapted from Google Maps)

During the VR scenario creation, some of the topography and characteristic elements of the site such as the beach, vehicular access points, and some representative structures will be digitally recreated to generate a realistic geospatial base on which flooded risk conditions will later be integrated, as shown in Figure 15 with the integration of standing and moving water into the virtual environment. This stage marks the beginning of the flood risk simulation, incorporating the sea and its interaction with the terrain. This addition not only enhances the visual realism but also prepares the conditions necessary for simulating extreme hydrometeorological events.



Figure 15. Preliminary VR Scenario of Flooded Roadway

This development process represents a significant step forward in the creation of educational and community awareness tools, as it enables controlled simulation of extreme events in vulnerable areas and thus helps strengthen risk perception and citizen preparedness.

The VR scenarios provide the visual foundation for future educational, stakeholder engagement, and workforce development activities aimed at improving awareness of coastal transportation risks and resilience strategies.

Research-to-Practice Framework for Coastal Transportation Workforce

The methodologies described in the previous sections are intended not only to improve understanding of transportation vulnerability and accessibility, but also to generate knowledge that can be translated into educational resources and professional development opportunities.

To address the knowledge gap in infrastructure design and community resilience, CREATE offers a research-to-practice framework for Blue Economy workforce development. As shown in Figure 1, the approach starts with community and infrastructure assessments focused on accessibility, risk, and needs. Data is gathered through public and expert engagement and is synthesized to develop educational modules delivered through seminars, posters, and interactive tools. Information collected through community surveys, stakeholder engagement activities, and future technical analyses will be used to identify priority topics for educational modules, professional training workshops, and workforce development initiatives.

The COVID-19 pandemic accelerated the creation of virtual learning systems like the Interactive Learning Hub (IL-HUB), developed by the Coastal Resilience Center [CRC] at UPRM (Lopez del Puerto et al., 2022). Hosted on Moodle, IL-HUB will serve as the primary platform for disseminating training materials, educational modules, webinars, case studies, and other technology-transfer products developed through CREATE. Through a partnership between CREATE and CRC, IL-HUB will expand its coverage to include Blue Economy and transportation resilience related topics, enhancing institutional capacity for education and stakeholder training.

CREATE will also facilitate technical outreach and stakeholder engagement activities to support the transfer of research results into practice. Information collected through underserved coastal community surveys will help identify perceived and actual risks associated with tourism, mobility, infrastructure, and socioeconomic factors. These findings will provide the basis for developing targeted educational materials, professional training opportunities, and capacity-building initiatives tailored to the needs of coastal communities and transportation practitioners. In this manner, the project seeks to strengthen both community awareness and the future transportation workforce needed to support resilient coastal transportation systems and the Blue Economy.

CASE STUDY

The methodologies presented in the previous chapter are applied and contextualized through the Bajura Borough case study in the Municipality of Isabela, Puerto Rico. The selection of a coastal case study allows the project to examine the interaction among transportation accessibility, infrastructure vulnerability, natural hazards, community resilience, and Blue Economy activities within a real-world setting.

The case study approach provides an opportunity to integrate the various methodological components of CREATE, including community perception surveys, transportation vulnerability assessments, transportation network analysis, visualization tools, and workforce development activities. By examining these elements within a specific coastal community, the project can better understand how local characteristics influence transportation resilience and how educational and planning tools can support informed decision-making. The community survey conducted during Phase I provides the baseline information necessary to understand local transportation perceptions, accessibility challenges, and stakeholder needs that will support future activities within the case study.

Community Selection Process

A coastal community in Puerto Rico was selected as the focal point of this study to implement and evaluate the concepts and methodologies developed through the CREATE research program. The selection process was guided by five principal criteria:

- Exposure to coastal and flooding hazards.
- Importance of transportation infrastructure and accessibility.
- Presence of Blue Economy activities.
- Socioeconomic and demographic characteristics.
- Potential for community engagement, education, and implementation of resilience strategies.

The evaluation involved a comparative analysis of four candidate coastal communities:

- El Maní (Mayagüez)
- Islote (Arecibo)

- Piñones (Loíza)
- Bajura (Isabela)

Each community was evaluated using demographic, geographic, transportation, and hazard-related indicators. Demographic characteristics included population, poverty levels, and commuting patterns. Geographic considerations included coastal proximity, elevation, water bodies, FEMA flood maps, and exposure to coastal hazards. Existing economic assets such as ports, beaches, tourism activities, and commercial centers were also considered. In addition, transportation accessibility indicators from the American Community Survey [ACS], the NOAA Coastal Flood Exposure Mapper, and other GIS-based datasets were incorporated into the selection process.

El Maní, Mayagüez

The El Maní neighborhood in Mayagüez is a low-lying coastal community located adjacent to the Mayagüez Seaport, Eugenio María de Hostos Airport, La Boquilla Natural Reserve, and PR-2, one of the principal transportation corridors in western Puerto Rico.

The neighborhood spans the Sabanetas and Algarrobos sectors and has a combined population of approximately 8,562 residents, about 12% of the municipality's total population. Poverty rates range from 44% to 51% (U.S. Census, n.d.). The mean travel time to work ranges from 21.5 to 22.7 minutes, with 87 to 92% of trips taken by private motor vehicle, 0% by public transit, and only 2 to 4% by walking or biking. The community offers a combination of transportation significance, coastal exposure, and economic activity but also exhibits limited multimodal transportation options.

Islote, Arecibo

The Islote community in Arecibo is a rural coastal area with approximately 5,541 residents and a poverty rate of 53.4% (U.S. Census, n.d.). Residents commute an average of 30.3 minutes to work, with 95% relying on private motor vehicles, and no recorded use of transit or active transportation modes (walking or biking).

Accessibility is largely dependent upon PR-681, a single coastal roadway connecting the municipalities of Arecibo and Barceloneta. The community, adjacent to the Caño Tiburones Natural Reserve, supports tourism, recreation, and seafood-related economic activities, but its

transportation system exhibits a high degree of vulnerability because of its dependence on a limited number of transportation links and its frequent exposure to flooding events.

Piñones, Loíza

Piñones, a sector of the Municipality of Loíza located within the San Juan Metropolitan Area, contains approximately 2,058 residents and exhibits the highest poverty rate [58.6%] among the candidate communities (U.S. Census, n.d.).

The community is located adjacent to major tourism destinations, Luis Muñoz Marín International Airport, and several environmentally sensitive areas [the Piñones State Forest and the Piñones and La Torrecilla lagoons]. Although situated within the metropolitan region, transportation options remain heavily dependent on private vehicles, highlighting mobility challenges that persist even in highly urbanized coastal areas.

Bajura, Isabela

The Municipality of Isabela, located in the northwestern region of Puerto Rico, has a population of approximately 42,943 residents and a median age of 44.2 years, and supports a range of tourism, recreation, and coastal activities associated with the Blue Economy. Approximately 10.1% of the employed civilian population works in the accommodation, food services, and recreation industries, and the average commute time to work is 25.3 minutes (US Census, n.d.). Notable assets include the Paseo Lineal de Isabela, several internationally recognized beaches, and proximity to the Rafael Hernández International [BQN] Airport in the Municipality of Aguadilla.

Within the municipality, the Bajura sector emerged as a particularly suitable location for the case study. Bajura has a population of approximately 725 residents and an older demographic profile, with a median age of 66.1 years (U.S. Census, n.d.). The poverty rate [51.8%] exceeds the municipal average while the transportation system is highly dependent on private vehicle travel.

Selection of Bajura as the Case Study

Following the comparative evaluation, Bajura in Isabela was selected as the case study site because it offered the strongest combination of factors aligned with the objectives of CREATE. Figure 16 shows the location of the Municipality of Isabela, relative to Puerto Rico, and its Bajura Borough. Compared to the other candidate communities, Bajura presented:

- Significant exposure to coastal hazards and flooding risks.

- Dependence on a limited number of transportation corridors.
- Strong connections to Blue Economy activities, including tourism and recreation.
- Socioeconomic conditions that can influence community resilience.
- Opportunities for community engagement and educational implementation.
- Availability of local and municipal partners interested in resilience planning.



Figure 16. Boroughs of the Municipality of Isabela

An important consideration was the community's reliance on two primary road corridors:

- PR-466, which provides access to PR-2 and the regional transportation network.

- PR-4466, which connects Isabela with Rafael Hernández International Airport [BQN] and nearby coastal destinations.

Because transportation accessibility within the community depends heavily on these corridors, disruptions resulting from flooding or other hazards can significantly affect mobility, emergency access, economic activity, and community resilience.

The presence of active municipal participation and opportunities for community engagement further strengthened the suitability of Bajura as a living laboratory for testing transportation resilience, accessibility, educational outreach, visualization technologies, and workforce development strategies.

Bajura features coastal tourism amenities, such as the Shacks and Jobos Beaches and the Villa Pesquera sector (see Figure 17), access to open-air markets, and participation in both local and regional public-private partnerships aimed at infrastructure durability. Importantly, the area benefits from a cooperative municipal government already engaged in planning initiatives. The established civic and governmental framework enabled direct engagement with local social groups, opening opportunities for tangible educational outreach and feedback collection. These conditions made Bajura an ideal environment for demonstrating how Blue Economy principles and resilient transportation planning could be implemented in practice.

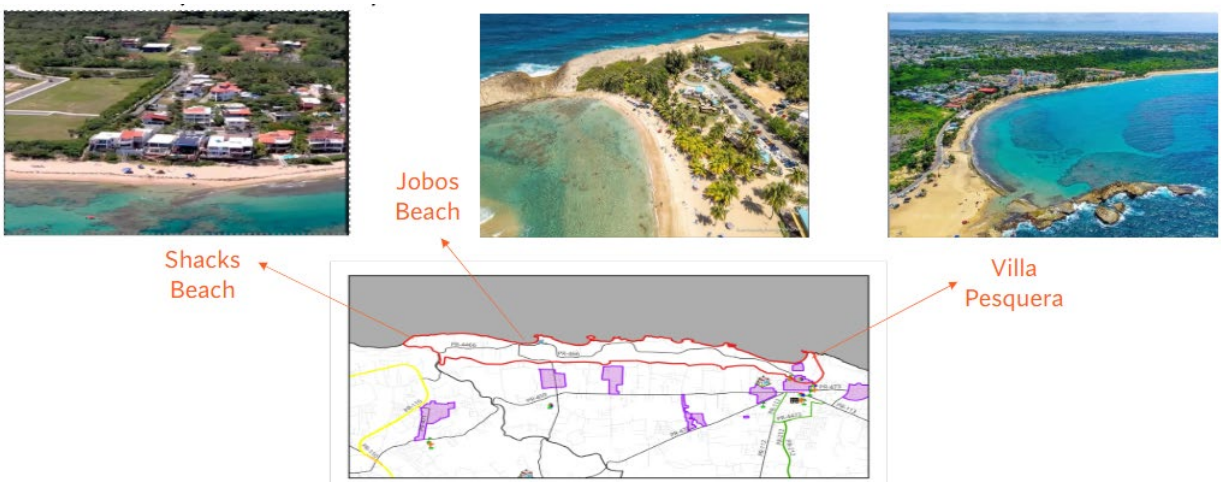


Figure 17. Beach Locations in the Coastal Community of Isabela

The Bajura case study provides a real-world environment in which the methodological components proposed in this research can be implemented and evaluated. The community offers

an opportunity to simultaneously examine transportation accessibility, infrastructure vulnerability, exposure to flooding hazards (Figures 18-19), transportation system operations, and the incorporation of community preferences into VR-based educational tools.



Figure 18. Flood Zones Map of Isabela
(Source: NOAA Coastal Flood Exposure Mapper)



Figure 19. Flood Hazard Composite Map of Isabela
(Source: NOAA Coastal Flood Exposure Mapper)

The selected case study will serve as the implementation platform for the transportation vulnerability assessment, network simulation analyses, virtual reality educational tools, and workforce development activities that will be conducted during subsequent phases of the CREATE project. These outputs are tailored for professional development and community outreach alike, intended to foster a deeper understanding of how coastal communities can leverage marine-linked economies to build resilience and improve local quality of life. As discussed by Webb et al. (2019), the transportation sector's role in this transformation is crucial, demanding the development of a well-informed professional workforce that can identify hazards, plan interventions, and foster access to economic opportunity.

ANALYSIS OF SURVEY RESPONSES

The primary objective of Phase I of the CREATE UPRM research program was to establish a baseline understanding of community perceptions regarding transportation accessibility, vulnerability, resilience, and coastal economic activities in Puerto Rico. The survey results presented in this chapter provide insight into transportation experiences, the impacts of natural hazards on mobility, and the perceived importance of coastal activities and the Blue Economy.

The analysis is organized around the principal themes addressed in the survey, including daily activity patterns, transportation mode choice, transportation accessibility, vulnerability to natural hazards, and perceptions related to coastal and Blue Economy activities. Comparisons between respondents from coastal and non-coastal municipalities are emphasized to identify differences in travel behavior, accessibility conditions, infrastructure perceptions, and resilience-related concerns. Consistent with the objectives of Phase I, these findings establish a baseline assessment of stakeholder and community perspectives that will inform future CREATE activities related to transportation vulnerability assessment, transportation network analysis, visualization tools, educational program development, workforce development, and capacity-building initiatives.

To gain insight into these topics, an online survey was conducted across Puerto Rico. The survey collected responses from 366 participants, all 18 years of age or older. Convenience sampling was used to capture perspectives from residents across multiple geographic and socioeconomic contexts throughout the island. Although the survey was not designed as a statistically representative sample of Puerto Rico's population, the responses provide valuable insight into transportation accessibility, vulnerability perceptions, and coastal-related issues.

Figure 20 presents the geographic distribution of survey responses across Puerto Rico. Responses were obtained from municipalities throughout the island, including both coastal and inland areas. For the purposes of this report, a coastal municipality is defined as one in which at least part of its territory lies within the legally established coastal zone, as shown in Figure 3. The classification of municipalities as coastal was guided by the official Map of Coastal Municipalities and Sectors.

Approximately three-quarters of the survey respondents with available municipality classifications resided in municipalities classified as coastal. This concentration is relevant to the objectives of the study because it provides substantial input from residents whose communities may be directly or functionally connected to coastal transportation corridors, coastal economic activities, and areas exposed to coastal hazards. Higher concentrations of responses were observed in several municipalities in the western, northwestern, and northeastern regions, providing the opportunity to examine perspectives across different geographic contexts. However, because the survey used convenience sampling and the coastal classification was applied at the municipal level, the distribution should be interpreted as a characteristic of the survey sample rather than as representative of the geographic distribution of Puerto Rico's population.

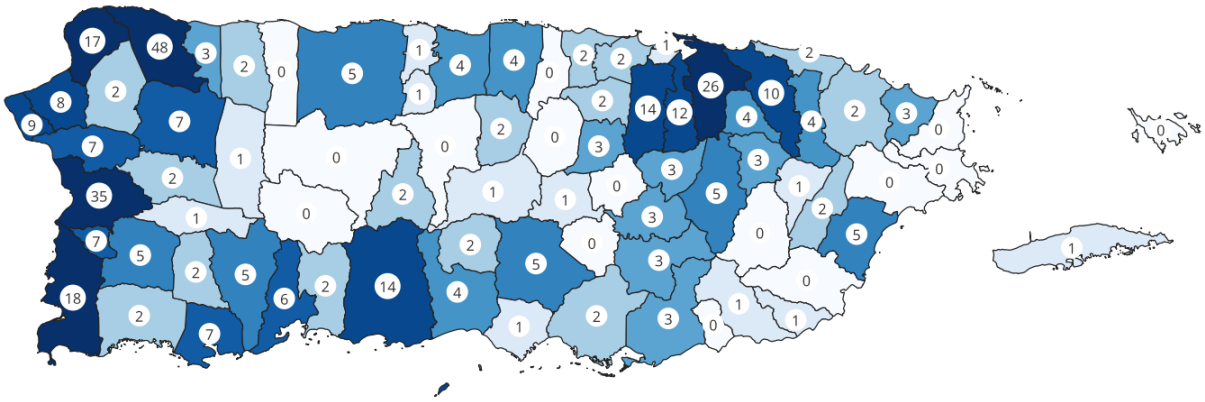


Figure 20. Survey Response by Municipality

The predominance of respondents from coastal municipalities strengthens the study's ability to establish a preliminary baseline of transportation experiences and hazard perceptions in coastal jurisdictions. Nevertheless, the unequal number of coastal and non-coastal respondents should be considered when comparing raw response counts between the two groups. Percentage distributions or within-group proportions were used to support comparisons rather than absolute frequencies alone.

The following sections present the survey findings and provide a baseline understanding of transportation behavior, accessibility perceptions, hazard-related concerns, and the perceived importance of coastal activities. Together, these results contribute to identifying transportation challenges, resilience needs, and opportunities for future research, education, technology transfer, and workforce development activities within the CREATE UPRM program.

Demographic Characteristics of Sample

Table 4 shows the distribution of survey respondents by gender and by municipality type. Female respondents represented approximately two-thirds of the sample [66.1%], while male respondents accounted for approximately one-third [32.8%]. The gender distribution was generally consistent across both coastal and non-coastal municipalities. Although the survey was not designed to be demographically representative of Puerto Rico, where females account for approximately 53% of the population (U.S. Census, 2025), the predominance of female respondents should be considered when interpreting perception-based results reported in subsequent sections.

Table 4: Respondents by Gender and Municipality Type

	Gender			
Municipality	**Female**	**Male**	**Other**	**No Answer**
Non-coastal	56	31	0	0
Coastal	184	87	1	1
Unknown	0	1	0	2
Total	**240**	**119**	**1**	**3**

Table 5 shows the distribution of survey respondents by household size and by municipality type. Household size is relevant to transportation resilience because disruptions may simultaneously affect the mobility needs of multiple household members, particularly when households depend on a limited number of vehicles or include individuals requiring mobility assistance.

Table 5: Respondents by Household Size and Municipality Type

	Household Size				
Municipalities	**1**	**2**	**3**	**4**	**5 or more**
Non-coastal	12	28	22	15	10
Coastal	47	97	64	48	18
Unknown	0	1	0	1	1
Total	**59**	**126**	**86**	**64**	**29**

The average household size for the sample was 2.7 people per household. As a comparison, the average for the territory is 2.5 people per household (U.S. Census, n.d.). Most respondents

lived in households with two to four residents, representing approximately 76.3% of respondents from coastal municipalities and 74.7% of those from non-coastal municipalities. These results suggest that transportation disruptions may affect multiple household members simultaneously.

Using five residents as a conservative value for the "*five or more*" category, the estimated average household size was 2.61 persons in coastal municipalities and 2.80 persons in non-coastal municipalities. Therefore, household sizes were generally similar across both geographic groups, although respondents from non-coastal municipalities reported a slightly larger average household size and a higher proportion of households with five or more residents. Because the survey used convenience sampling and the upper household-size category was open-ended, these differences should be interpreted descriptively rather than as statistically significant differences.

Table 6 shows the distribution of survey respondents by households with bedridden individuals and by municipality type. Approximately 15% of households surveyed in the sample reported the presence of at least one bedridden individual. Households with bedridden individuals in non-coastal municipalities had a slightly higher percentage with 18%. This finding is particularly relevant for transportation resilience and evacuation planning because mobility limitations can increase reliance on emergency transportation services and complicate evacuation and disaster recovery activities.

Table 6: Respondents by Households with Bedridden Individuals and Municipality Type

	Households with Bedridden Individuals		
Municipalities	**No**	**No Answer**	**Yes**
Non-coastal	72	1	15
Coastal	229	2	41
Unknown	1	2	0
Total	**302**	**5**	**56**

Table 7 shows the distribution of survey respondents by the number of vehicles in the household and by municipality type. Vehicle ownership levels were relatively high throughout the sample, with an average of 2.2 vehicles per household and with only seven respondents reporting no vehicle availability [1.9% of respondents]. These findings demonstrate a strong dependence on private motor vehicles, which is consistent with the transportation mode choices reported later in the survey results. As a comparison, the American Community Survey (U.S. Census, 2024)

estimates that about 2.3% of the population reported having no vehicle available and about 34% reported having 3 or more vehicles available.

Table 7: Respondents by Number of Vehicles in Household and Municipality Location

	Vehicles in Household					
Municipalities	**0**	**1**	**2**	**3**	**4**	**5 or more**
Non-coastal	2	19	36	17	10	3
Coastal	5	78	106	47	25	14
Unknown	0	1	0	1	0	1
Total	**7**	**98**	**142**	**65**	**35**	**18**

Vehicle ownership was high among respondents from both coastal and non-coastal municipalities. Using five vehicles as a conservative value for the open-ended "*five or more*" category, households in coastal municipalities reported an estimated average of 2.19 vehicles, compared with 2.26 vehicles among households in non-coastal municipalities. Nearly 70% of coastal households and 76% of non-coastal households reported owning two or more vehicles. The slightly higher vehicle ownership observed among non-coastal respondents may be partially associated with their larger average household size, estimated at 2.80 residents compared with 2.61 residents in coastal households. When considered relative to household size, however, vehicle availability was similar across both geographic groups.

These findings indicate a strong dependence on private motor vehicles throughout the sample, rather than a substantial difference between coastal and non-coastal municipalities. This widespread dependence on private vehicles has implications for transportation resilience because household mobility during emergencies may be constrained by roadway closures, fuel shortages, vehicle damage, or the absence of viable alternative transportation modes.

Table 8 shows the distribution of survey respondents by age and by municipality type. Respondents were predominantly middle-aged and older adults, with an average age of 51.4 years. A large proportion of responses originated from individuals between 45 and 69 years of age, while relatively few responses were obtained from younger age groups. Because transportation perceptions, travel behavior, and risk awareness may vary across age groups, this distribution should be considered when interpreting survey results.

Table 8: Respondents by Age Group and Municipality Type

	Municipality			
Age	**Non-Coastal**	**Coastal**	**Unknown**	**Total**
No Answer	26	69	1	**96**
18–19	0	2	1	**3**
20–24	4	6	0	**10**
25–29	0	8	0	**8**
30–34	3	10	0	**13**
35–39	7	9	0	**16**
40–44	5	20	0	**25**
45–49	6	32	0	**38**
50–54	8	28	0	**36**
55–59	9	29	0	**38**
60–64	10	25	0	**35**
65–69	6	22	1	**29**
70–74	3	10	0	**13**
75–79	1	4	0	**5**
80–84	0	1	0	**1**

Among respondents who reported their age, the estimated average age was 51.9 years for participants residing in coastal municipalities and 50.2 years for those residing in non-coastal municipalities. The difference of approximately 1.7 years indicates that both groups had generally similar age profiles, although coastal respondents were slightly older on average. Approximately 74.0% of coastal respondents and 67.2% of non-coastal respondents with valid age data were 45 years of age or older. Therefore, the survey primarily reflects the perspectives of middle-aged and older adults, a characteristic that should be considered when interpreting the findings related to transportation accessibility, mobility needs, and natural-hazard risk perceptions.

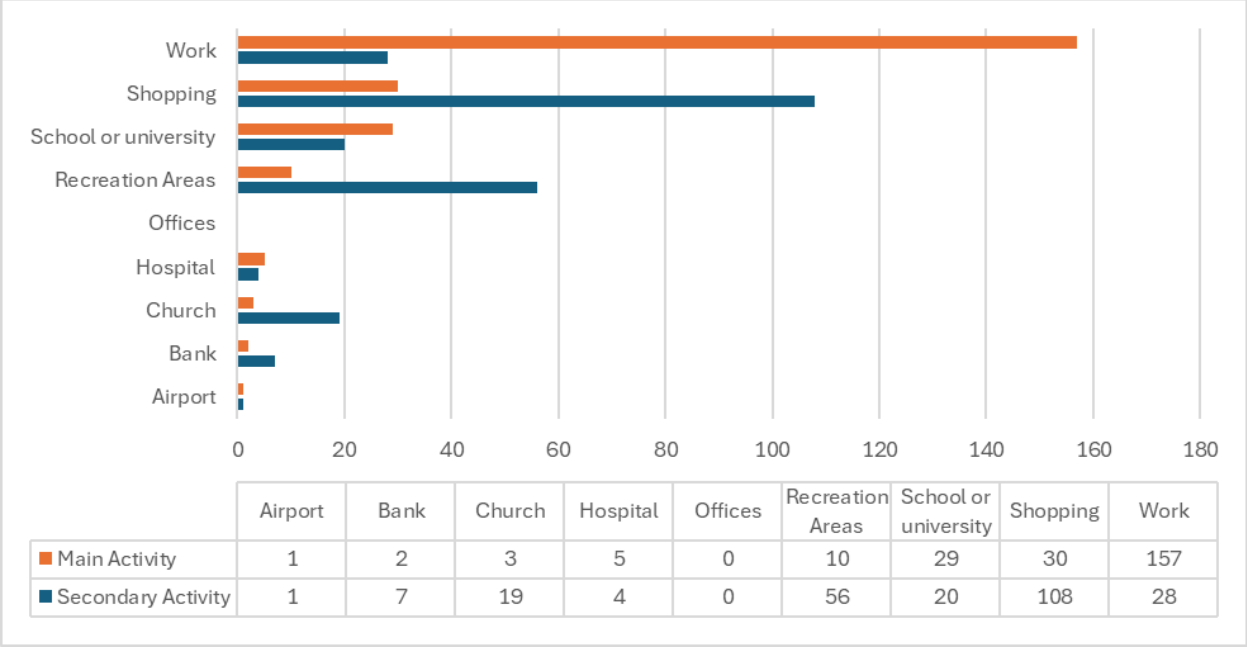
A total of 96 respondents did not provide their age, representing approximately 26% of the complete survey sample. Consequently, the age statistics describe only respondents who answered the question and should not be interpreted as representative of Puerto Rico's population.

Overall, the demographic characteristics suggest a population that is highly dependent on private vehicle transportation and includes a substantial proportion of older adults and households containing individuals with mobility limitations. Approximately 75% of respondents resided in municipalities classified as coastal, providing a strong basis for understanding transportation conditions and resilience-related perceptions in communities exposed to coastal hazards and Blue

Economy activities. These characteristics are particularly relevant when evaluating transportation accessibility, vulnerability to natural hazards, and community resilience, which are central themes of the research program. These demographic characteristics are also important when interpreting perceptions regarding evacuation, transportation accessibility, and adaptation needs during extreme natural events.

Principal Travel Activities

Figures 21 and 22 present the primary and secondary activities reported by respondents residing in coastal and non-coastal municipalities, respectively. Because the number of coastal respondents was substantially larger than the number of non-coastal respondents, comparisons between the two groups are based on within-group percentages rather than absolute response counts.

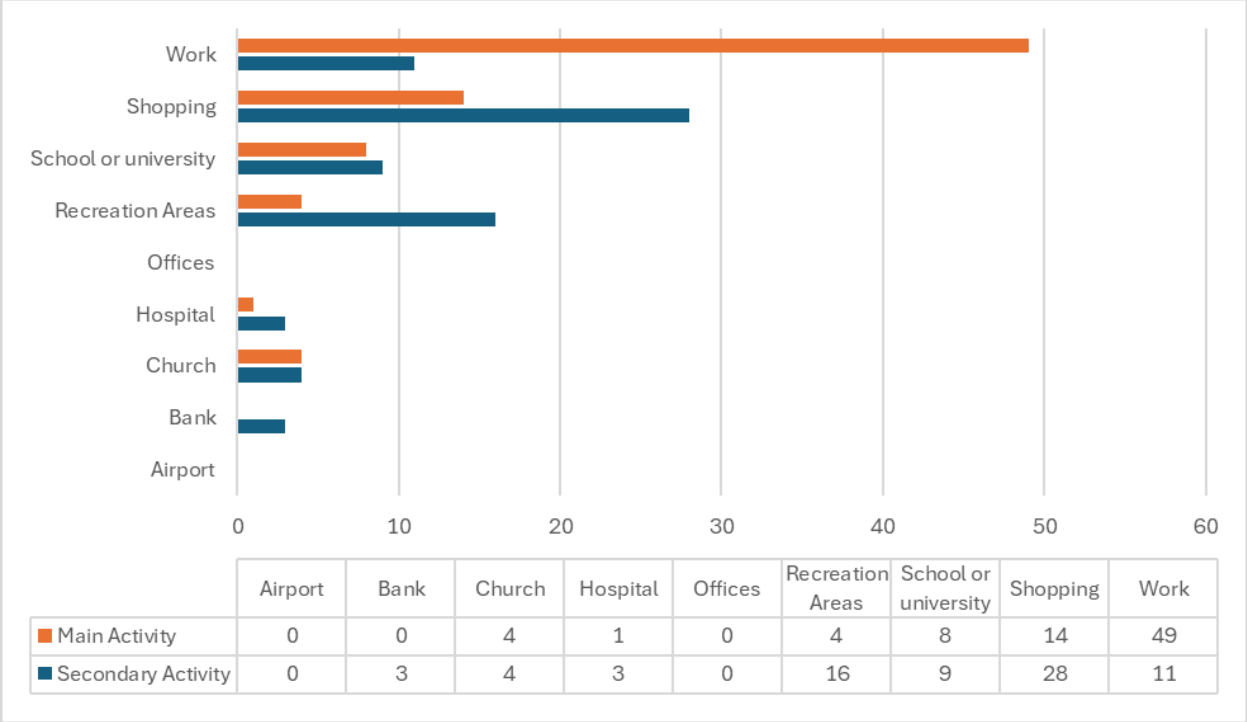


	Airport	Bank	Church	Hospital	Offices	Recreation Areas	School or university	Shopping	Work
Main Activity	1	2	3	5	0	10	29	30	157
Secondary Activity	1	7	19	4	0	56	20	108	28

Figure 21. Travel Activities for Respondents from Coastal Municipalities

Work was the most frequently reported primary activity in both geographic groups, accounting for 66.2% of valid primary-activity responses among coastal residents and 61.2% among non-coastal residents. Shopping and school or university followed as the next most frequently reported primary activities. Shopping accounted for 12.7% of primary responses in coastal municipalities and 17.5% in non-coastal municipalities, while school or university

represented 12.2% and 10.0%, respectively. These results indicate that employment was the dominant purpose of regular travel in both groups, followed by access to commercial and educational destinations.



	Airport	Bank	Church	Hospital	Offices	Recreation Areas	School or university	Shopping	Work
Main Activity	0	0	4	1	0	4	8	14	49
Secondary Activity	0	3	4	3	0	16	9	28	11

Figure 22. Travel Activities for Respondents from Non-Coastal Municipalities

Shopping was the most frequently reported secondary activity, representing 44.4% of valid secondary-activity responses among coastal residents and 37.8% among non-coastal residents. Recreation areas ranked second in both groups, accounting for 23.0% of coastal responses and 21.6% of non-coastal responses. These similar percentages suggest that shopping and recreation constitute important secondary travel purposes across both geographic contexts.

Education-related travel showed a mixed pattern. School or university was slightly more prevalent as a primary activity among coastal respondents, but it was more frequently identified as a secondary activity among non-coastal respondents. Other destinations, including hospitals, churches, banks, airports, and visits to service offices [e.g., medical offices, utilities, etc.], were selected less frequently. Their lower frequency should not be interpreted as indicating limited importance, particularly because access to healthcare, government services, and transportation terminals may become critical during emergencies.

Overall, the distributions reveal more similarities than differences between coastal and non-coastal respondents. Employment dominates primary travel, whereas shopping and recreation account for a substantial share of secondary activities. Maintaining reliable access to these destinations is important for economic continuity, access to essential goods, quality of life, and transportation resilience during and after natural hazard events.

These activity patterns provide insight into the destinations that residents consider most important in their daily lives. Understanding the functions supported by the transportation system is critical for identifying the potential consequences of transportation disruptions and for prioritizing resilience strategies that maintain access to employment, education, healthcare, commercial services, and coastal economic activities.

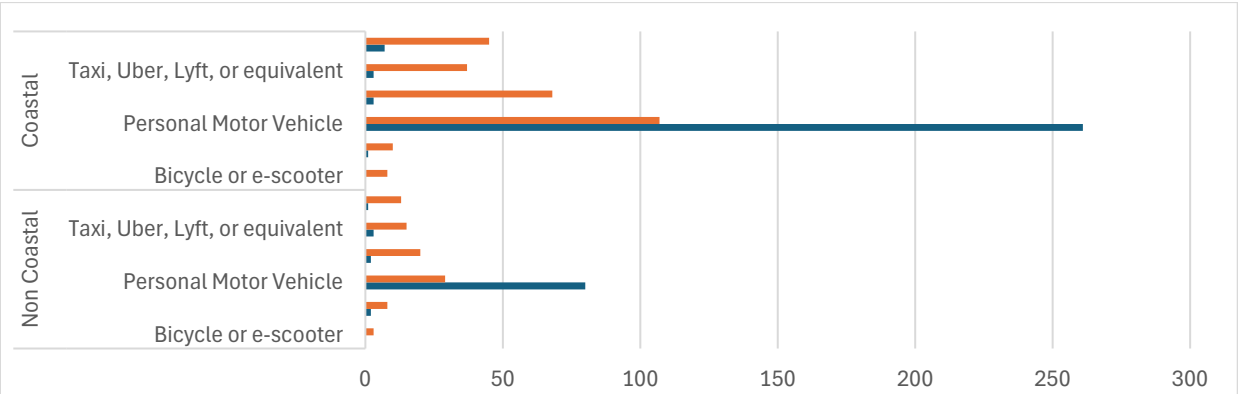
Preferred Transportation Mode

Analyzing not only the activities individuals engage in, but also the modes of transportation they use to access them is essential for a more comprehensive understanding of travel behavior, transportation accessibility, and system resilience. The survey asked respondents to indicate their preferred transportation mode for the primary and secondary travel activities. Figure 23 the primary and secondary transportation modes reported by respondents residing in coastal and non-coastal municipalities. Because the number of respondents differed substantially between these groups, the comparison is based on percentages within each municipality type rather than absolute response counts.

Percentages were calculated within each municipality group [coastal: n = 275; non-coastal: n = 88]. The figure presents stated main and secondary transportation modes and does not necessarily indicate that the secondary mode is available during a natural-hazard disruption.

The results reveal an overwhelming dependence on private motor vehicles for conducting the primary activities identified by respondents. In coastal municipalities, 94.9% of respondents selected the private motor vehicle as their primary transportation mode, compared with 90.9% in non-coastal municipalities. These findings are generally consistent with commuting patterns reported by the American Community Survey, which indicates that approximately 89% of workers in Puerto Rico travel to work either alone or accompanied in a motor vehicle (U.S. Census, 2024). The relatively small difference between coastal and non-coastal municipalities suggests that

automobile dependency is a characteristic shared across both geographic contexts rather than a condition unique to coastal communities. The ACS comparison should be interpreted cautiously because it applies specifically to journeys to work, whereas the CREATE survey considered travel to multiple activity types.



	Non Coastal						Coastal					
	Bicycle or e-scooter	Transit	Personal Motor Vehicle	Get a Ride	Taxi, Uber, Lyft, or equivalent	Walk	Bicycle or e-scooter	Transit	Personal Motor Vehicle	Get a Ride	Taxi, Uber, Lyft, or equivalent	Walk
Secondary mode	3	8	29	20	15	13	8	10	107	68	37	45
Main Mode	0	2	80	2	3	1	0	1	261	3	3	7

Figure 23. Preferred Transportation Modes for Principal Activities

Because the private motor vehicle overwhelmingly dominated the responses for the primary mode, the secondary transportation mode provides a more informative perspective regarding the mobility alternatives available to residents. In both municipal groups, the most frequently reported secondary transportation mode remained the private motor vehicle, accounting for 38.9% of coastal and 33.0% of non-coastal responses. This might imply that many respondents may rely on multiple vehicles available within the household. Beyond private vehicle use, "*Getting a Ride*" emerged as the second most reported alternative, representing 24.7% of responses in coastal municipalities and 22.7% in non-coastal municipalities. Walking also appeared as a relevant secondary option, accounting for 16.4% of responses among coastal residents and 14.8% among non-coastal residents.

Taxi and digital ride-hailing services represented 13.5% of secondary-mode responses in coastal municipalities and 17.0% in non-coastal municipalities. Public transportation accounted

for only 3.6% of coastal responses and 9.1% of non-coastal responses, while bicycles and e-scooters represented less than 4% in both groups. These findings do not indicate a greater proportional reliance on on-demand services in coastal municipalities. Instead, they reveal generally similar patterns across the two geographic groups, with greater differences appearing in the reported use of public transportation and taxi or ride-hailing services.

The relatively limited use of public transportation as either primary or secondary mode is consistent with longstanding transportation challenges in Puerto Rico. Outside the San Juan Metropolitan Area and a few larger municipalities, public transportation services are often limited in coverage, frequency, and availability. As a result, many residents have few practical mobility alternatives beyond the private automobile. In this context, the presence of walking as a secondary transportation option may be particularly significant. For some residents, walking may represent one of the few available alternatives when a private vehicle is unavailable, inaccessible, or cannot be operated. Similarly, reliance on rides from family members, friends, neighbors, or ride-hailing services suggests that people frequently depend on informal or on-demand transportation arrangements rather than formal public transportation systems.

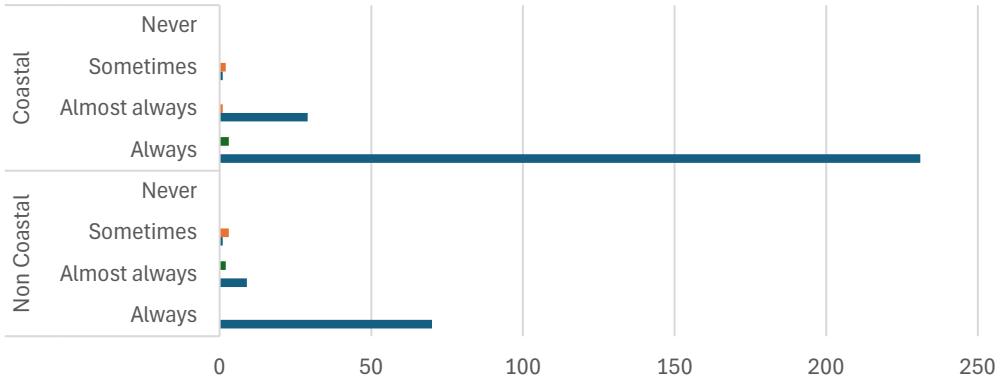
From a transportation resilience perspective, these findings indicate limited modal redundancy across the surveyed population. Even when respondents identified an alternative transportation option, most of those alternatives remained dependent on the roadway network through private vehicles, rides from others, or ride-hailing services. Consequently, disruptions affecting road infrastructure, fuel availability, or vehicle operations may simultaneously limit both primary and secondary mobility options available to residents. While walking, public transportation, micromobility, and ride-hailing services provide some degree of redundancy, their relatively limited use suggests opportunities for future planning efforts aimed at improving transportation accessibility, emergency mobility options, and overall community resilience.

Overall, the results indicate that transportation accessibility in Puerto Rico remains strongly dependent on private motor vehicles, while alternative modes play a complementary role. This dependence has important implications for resilience planning in coastal communities, where roadway disruptions caused by flooding, storm surge, landslides, or other natural hazards can directly affect access to employment, education, healthcare, shopping, and other essential activities.

Access to Transportation Modes

The survey included questions regarding the frequency with which respondents have access to the preferred transportation modes they commonly use for their daily activities. Understanding the availability of transportation options is important because accessibility depends not only on infrastructure and travel time, but also on whether users can reliably access the transportation modes required to perform everyday activities. The analysis focused on the individual motorized transportation modes that were identified as primary transportation modes [private vehicles, Get a Ride, and rideshared services] for both coastal and non-coastal municipalities.

Figure 24 presents the reported accessibility to the primary transportation mode. The results indicate overwhelmingly high levels of access to private motor vehicles in both coastal and non-coastal municipalities. Among respondents who identified private vehicles as their primary transportation mode, 88.5% of coastal respondents and 87.5% of non-coastal respondents reported that they always had access to a vehicle. These results suggest that the dominance of private vehicles observed in the previous section is supported not only by user preference but also by the widespread availability of automobiles throughout the sample.

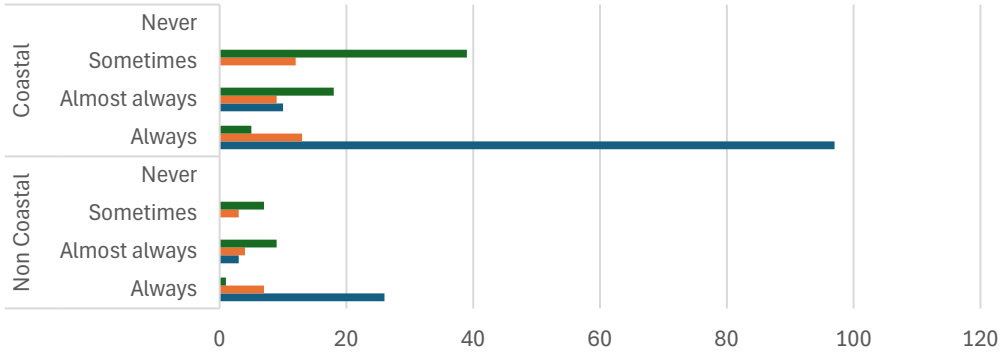


	Non Coastal				Coastal			
	Always	Almost always	Sometimes	Never	Always	Almost always	Sometimes	Never
Get a ride	0	2	0	0	3	0	0	0
Taxi, Uber, Lyft, or equivalent	0	0	3	0	0	1	2	0
Personal motor vehicle (car, motorbike, etc.)	70	9	1	0	231	29	1	0

Figure 24. Access to the Primary Mode of Transportation

Access to alternative motorized transportation options was considerably lower. Services such as "*Get a Ride*" and transportation network companies [Taxi, Uber, Lyft, or similar] were more commonly reported as occasional rather than permanent mobility options. None of these alternatives approached the levels of accessibility reported for private motor vehicles. These results reinforce the strong dependence on personal automobiles that characterizes travel behavior in Puerto Rico.

A different pattern emerges when analyzing access to the secondary transportation modes, as shown in Figure 25. Although private vehicles continued to be the most frequently available option, respondents reported a greater reliance on alternative mobility arrangements, particularly "*Get a Ride*" services and ride-hailing platforms. In coastal municipalities, 39 respondents indicated that they sometimes have access to transportation provided by another person, while 12 reported occasional access to transportation network company services. Similar patterns, although with lower frequencies, were observed in non-coastal municipalities.



	Non Coastal				Coastal			
	Always	Almost always	Sometimes	Never	Always	Almost always	Sometimes	Never
Get a ride	1	9	7	0	5	18	39	0
Taxi, Uber, Lyft, or equivalent	7	4	3	0	13	9	12	0
Personal motor vehicle (car, motorbike, etc.)	26	3	0	0	97	10	0	0

Figure 25. Access to the Secondary Mode of Transportation

These findings suggest that many residents rely on informal transportation networks, family members, friends, neighbors, or on-demand transportation services to complement their mobility needs. However, these alternatives remain highly dependent on roadway infrastructure and vehicle

availability. Unlike public transportation, walking, or micromobility, these modes do not represent independent mobility systems and may be affected by the same disruptions that impact private vehicle travel.

From a transportation resilience perspective, the results indicate that mobility redundancy remains limited. Most respondents have reliable access to private vehicles, but when alternative transportation is needed, the options most frequently identified continue to depend on motorized roadway travel. Consequently, disruptions associated with flooding, roadway closures, fuel shortages, vehicle damage, or severe weather events may simultaneously affect both primary and secondary transportation options. This pattern highlights the importance of strengthening multimodal transportation opportunities and developing alternatives that can continue supporting accessibility during disruptive events.

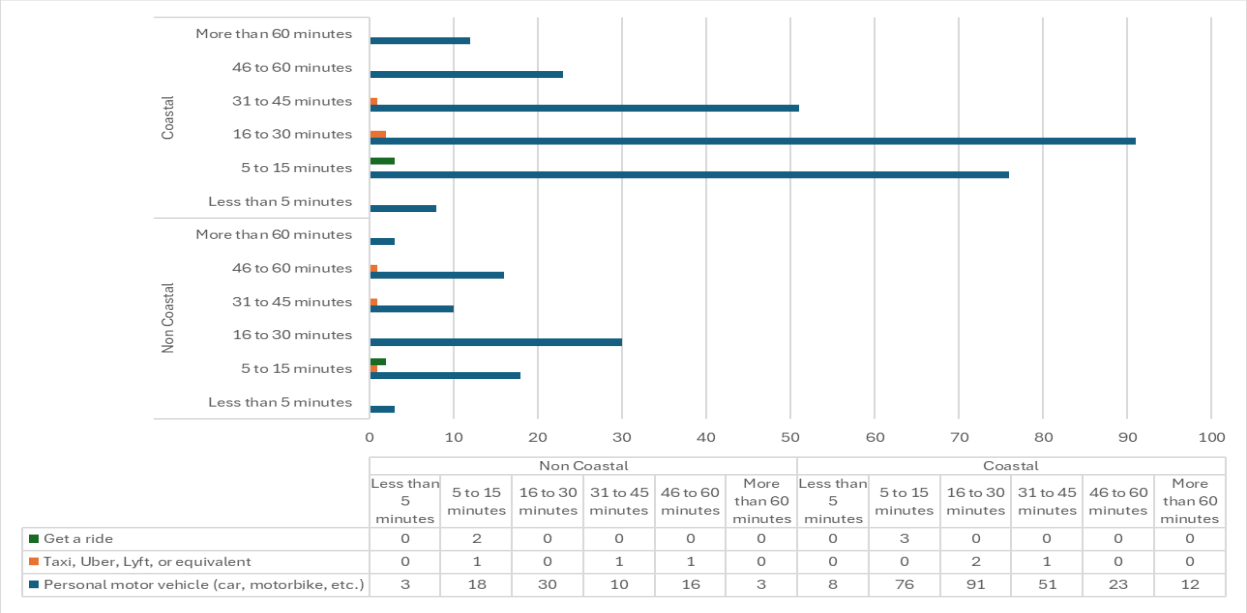
Overall, the findings confirm that transportation accessibility in Puerto Rico remains closely tied to automobile availability. The widespread access to private vehicles helps explain the strong dependence on motorized transportation observed throughout the survey, while the limited availability of independent alternative modes suggests potential vulnerabilities during emergencies and natural disasters.

Perception of Travel Time or Waiting Times to Destinations

The next questions in the survey asked about the travel time to destinations, either on vehicles or by walking, and the waiting times for the transit service [for those that selected transit as one of their preferred modes of travel]. The analysis of perceived travel times provides additional insight into transportation accessibility and the effort required to reach daily destinations. Figure 26 presents travel times associated with the primary transportation mode [for the personal motor vehicle, "*get a ride*", or rideshare modes]. In both coastal and non-coastal municipalities, most respondents reported travel times of 30 minutes or less [63.5% for non-coastal and 67.4% for coastal], suggesting that the transportation system generally provides reasonable access to employment, shopping, education, and other frequently visited destinations under normal operating conditions.

For non-coastal municipalities, the most frequently reported travel time range was 16 to 30 minutes, followed by 5 to 15 minutes. In coastal municipalities, travel times were more broadly

distributed across the 5 to 15 minute, 16 to 30 minute, and 31 to 45 minute ranges. This broader distribution may reflect differences in urban form, trip length, roadway conditions, destination distribution, or the need to travel longer distances to access employment centers, educational facilities, and services.

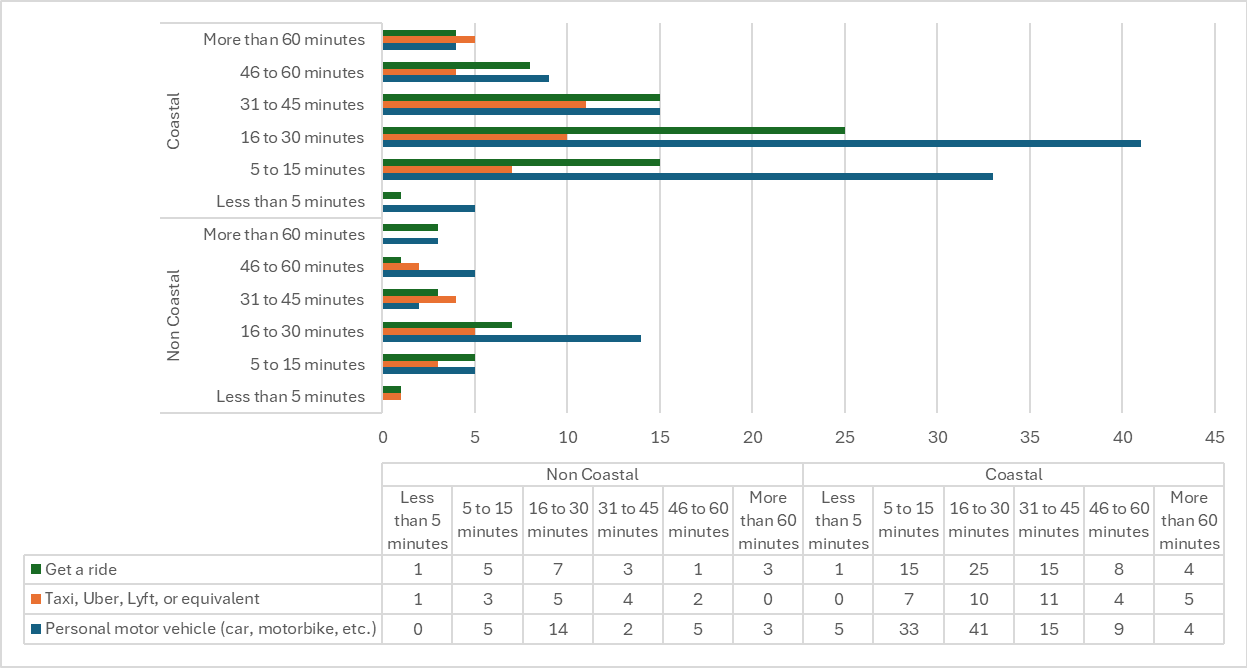


	Non Coastal						Coastal					
	Less than 5 minutes	5 to 15 minutes	16 to 30 minutes	31 to 45 minutes	46 to 60 minutes	More than 60 minutes	Less than 5 minutes	5 to 15 minutes	16 to 30 minutes	31 to 45 minutes	46 to 60 minutes	More than 60 minutes
Get a ride	0	2	0	0	0	0	0	3	0	0	0	0
Taxi, Uber, Lyft, or equivalent	0	1	0	1	1	0	0	0	2	1	0	0
Personal motor vehicle (car, motorbike, etc.)	3	18	30	10	16	3	8	76	91	51	23	12

Figure 26. Perceived Travel Times to Destination for the Primary Travel Mode

Figure 27 presents travel times associated with the secondary transportation mode [for the personal motor vehicle, "*get a ride*", or rideshare modes]. The travel-time distributions associated with secondary transportation modes reveal additional characteristics of mobility alternatives. Although private vehicles remained the most frequently reported secondary mode, respondents in non-coastal municipalities reported a greater presence of longer-duration trips, including trips lasting between 46 and 60 minutes and trips exceeding one hour. This suggests that secondary transportation arrangements are not always equivalent substitutes for the primary transportation mode and may require longer travel times or more complex trip-making patterns.

In coastal municipalities, secondary-mode trips were concentrated in the 5 to 15 minute and 16 to 30 minute categories. "*Getting a Ride*" and ride-hailing services displayed a similar pattern, with most trips concentrated in shorter travel-time ranges. These findings suggest that such services are primarily used to support specific trips or provide occasional mobility rather than serving as substitutes for routine long-distance travel.



	Non Coastal						Coastal					
	Less than 5 minutes	5 to 15 minutes	16 to 30 minutes	31 to 45 minutes	46 to 60 minutes	More than 60 minutes	Less than 5 minutes	5 to 15 minutes	16 to 30 minutes	31 to 45 minutes	46 to 60 minutes	More than 60 minutes
Get a ride	1	5	7	3	1	3	1	15	25	15	8	4
Taxi, Uber, Lyft, or equivalent	1	3	5	4	2	0	0	7	10	11	4	5
Personal motor vehicle (car, motorbike, etc.)	0	5	14	2	5	3	5	33	41	15	9	4

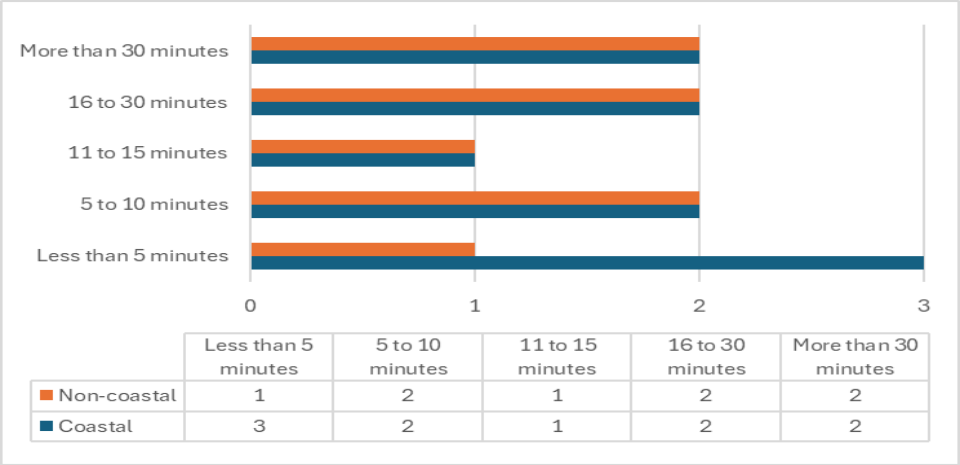
Figure 27. Perceived Travel Times to Destination for the Secondary Travel Mode

Because very few respondents identified public transportation as their primary transportation mode, travel-time analyses for transit focused on two indicators associated with perceived accessibility: the walking time to the nearest transit stop [Figure 28] and the waiting time for vehicle arrival [Figure 29].

Because relatively few respondents identified public transportation as a primary or secondary mode, the results should be interpreted cautiously. Half of the respondents who selected public transportation as a secondary transportation option generally reported short walking times to reach the nearest transit stop [10 minutes or less], suggesting that physical access to transit infrastructure may be reasonable for this subgroup of users. However, these same respondents reported substantial variability in waiting times, including waits exceeding 20 minutes and, in some cases, more than one hour [77.8% of respondents reported waiting times over 20 minutes].

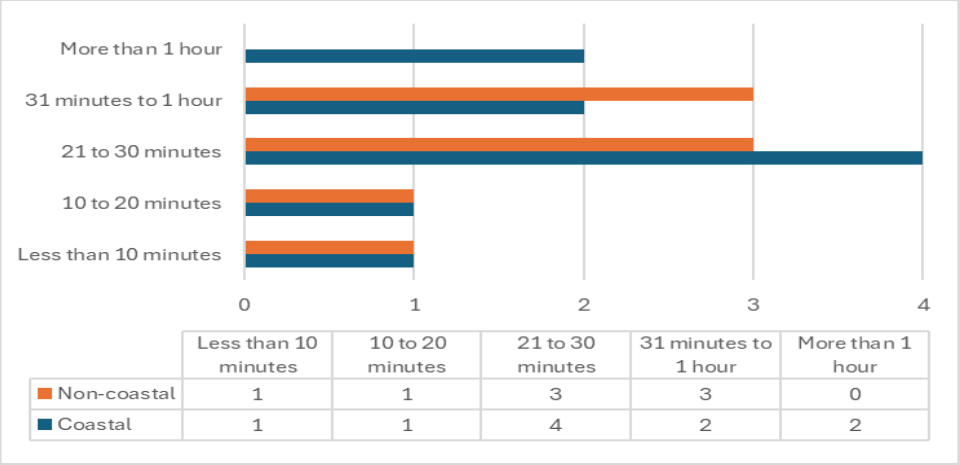
These findings indicate that service frequency and reliability may represent important perceived barriers among residents who already consider public transportation a viable option. At the same time, the results do not allow conclusions regarding the perceptions of individuals who never consider public transportation as an alternative mode. It is possible that some residents may not have convenient access to transit stops or may perceive public transportation as unavailable or

impractical for their daily travel needs. Consequently, both physical accessibility to transit infrastructure and service quality remain important considerations when evaluating transportation accessibility and resilience.



	Less than 5 minutes	5 to 10 minutes	11 to 15 minutes	16 to 30 minutes	More than 30 minutes
Non-coastal	1	2	1	2	2
Coastal	3	2	1	2	2

Figure 28. Walking time to the nearest public transit stop as a secondary mode

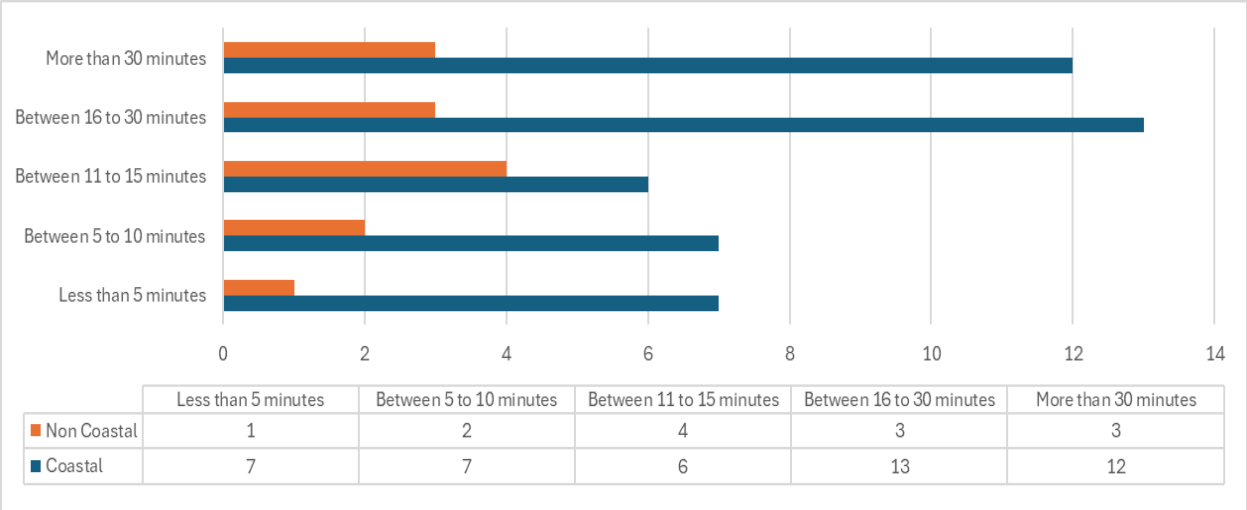


	Less than 10 minutes	10 to 20 minutes	21 to 30 minutes	31 minutes to 1 hour	More than 1 hour
Non-coastal	1	1	3	3	0
Coastal	1	1	4	2	2

Figure 29. Waiting time at the stop for the transport vehicle, as a secondary mode

From a transportation resilience perspective, both components are important. The proximity of transit stops influences whether public transportation can function as a realistic mobility alternative, while service frequency and waiting times influence its practicality during both routine travel and emergency situations. A transportation system may provide geographically accessible transit stops yet still fail to offer effective mobility alternatives if service intervals are long or unreliable.

Walking was rarely reported as a primary transportation mode but appeared more frequently as a secondary option. Figure 30 indicates that walking trips in both geographic contexts ranged from very short trips to trips exceeding 30 minutes. Coastal municipalities exhibited particularly high frequencies in the 16 to 30 minute and greater than 30-minute categories [55.6% of coastal respondents].



	Less than 5 minutes	Between 5 to 10 minutes	Between 11 to 15 minutes	Between 16 to 30 minutes	More than 30 minutes
Non Coastal	1	2	4	3	3
Coastal	7	7	6	13	12

Figure 30. Walking Time to Destination

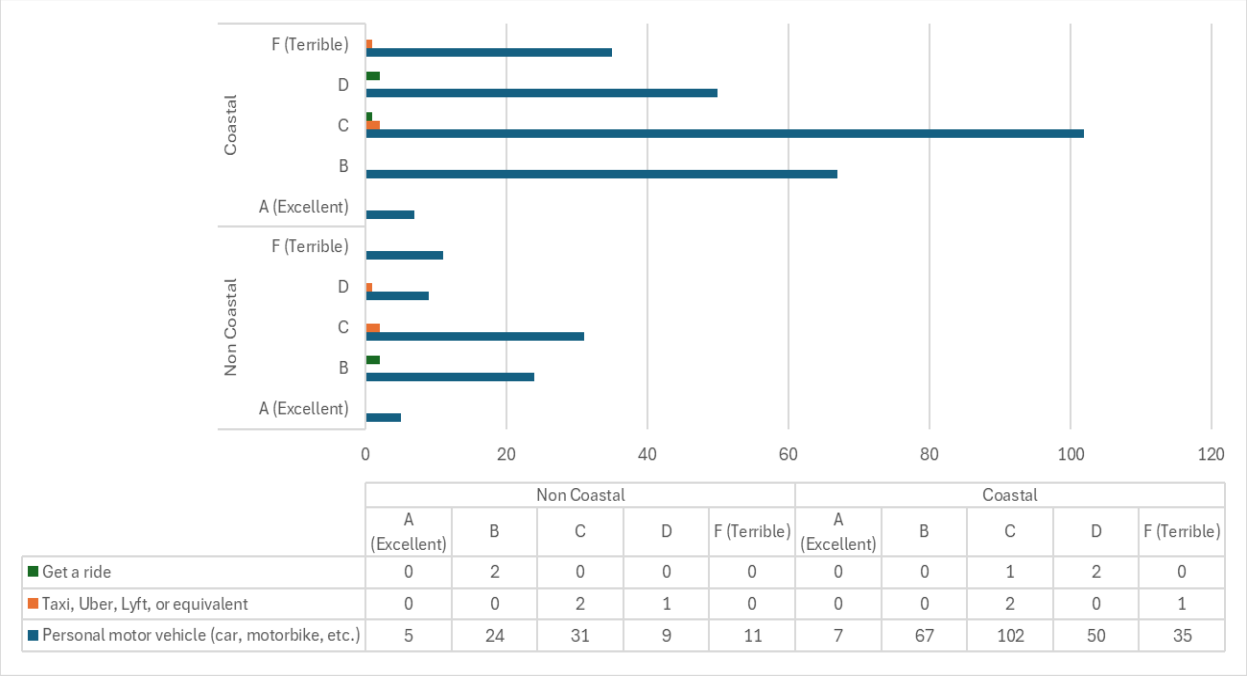
These findings suggest that some residents rely on walking to compensate for limited transportation alternatives. While this demonstrates a degree of mobility resilience, it may also indicate constraints in transportation availability. The ability to walk long distances, however, may not be feasible for all population groups, particularly older adults and households containing individuals with mobility limitations, both of which were represented in the survey sample.

Overall, the travel-time responses indicate that most respondents can access their primary activities within approximately 30 minutes under normal conditions. However, the strong dependence on private motor vehicles, combined with limited transit use and extended waiting times for public transportation, suggests relatively low transportation redundancy. While walking, ride-hailing services, and transportation provided by family members or friends offer some alternative mobility options, their effectiveness may vary across population groups and during disruptive events. These findings highlight the importance of transportation resilience strategies that maintain access to employment, education, healthcare, shopping, and other essential destinations when normal transportation conditions are compromised.

Perceived Safety of Preferred Transportation Modes

The survey asked to rank the perceived roadway safety when completing their trips on their primary modes. Understanding how users perceive the safety of the transportation system is important because safety perceptions directly influence transportation choices, accessibility, and the willingness to adopt alternative transportation modes. Respondents were asked to evaluate the safety of the roadway environment associated with their primary and secondary transportation modes using a grading scale ranging from A (Excellent) to F (Terrible).

Figure 31 presents the perceived level of roadway safety associated with the primary transportation mode used by respondents. Because private motor vehicles overwhelmingly dominated as the primary transportation mode in both coastal and non-coastal municipalities, the analysis primarily reflects perceptions of roadway conditions experienced by motor vehicle users.



	Non Coastal					Coastal				
	A (Excellent)	B	C	D	F (Terrible)	A (Excellent)	B	C	D	F (Terrible)
Get a ride	0	2	0	0	0	0	0	1	2	0
Taxi, Uber, Lyft, or equivalent	0	0	2	1	0	0	0	2	0	1
Personal motor vehicle (car, motorbike, etc.)	5	24	31	9	11	7	67	102	50	35

Figure 31. Perceived Roadway Safety for Primary Transportation Mode

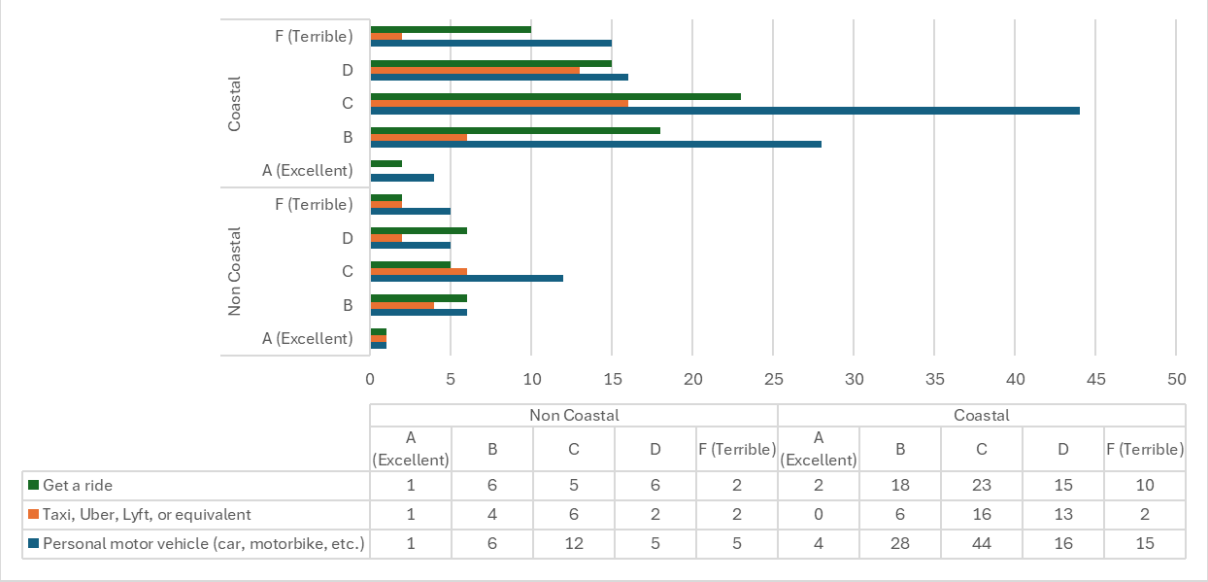
In both municipality types, the most frequently selected rating was C, followed by B, indicating that [65.6%] respondents generally considered roadway safety conditions to be fair or acceptable rather than excellent. Among non-coastal respondents, ratings were concentrated in the B and C categories, while approximately one-quarter of respondents assigned ratings of D or F,

suggesting that a meaningful segment of the population perceives deficiencies in roadway safety conditions.

A similar pattern was observed in coastal municipalities, where C remained the dominant response category. However, coastal respondents reported a somewhat larger proportion of lower safety ratings. Approximately one-third of respondents assigned D or F ratings to roadway safety conditions associated with their primary transportation mode. These findings suggest that roadway safety concerns may be somewhat more pronounced in coastal municipalities, possibly reflecting roadway conditions, traffic conflicts, roadway geometry, or exposure to environmental conditions that affect transportation infrastructure.

The limited number of responses associated with "*Get a Ride*" and "*Taxi, Uber, Lyft, or equivalent*" as primary transportation modes does not allow for reliable statistical interpretation. Nevertheless, the responses received were generally concentrated within the mid-range categories, reflecting a moderate perception of safety for these services.

Figure 32 presents the respondents' perceptions of roadway safety associated with their secondary transportation mode. Like the primary mode results, private motor vehicles continue to receive ratings concentrated in the B, C, and D categories.



	Non Coastal					Coastal				
	A (Excellent)	B	C	D	F (Terrible)	A (Excellent)	B	C	D	F (Terrible)
Get a ride	1	6	5	6	2	2	18	23	15	10
Taxi, Uber, Lyft, or equivalent	1	4	6	2	2	0	6	16	13	2
Personal motor vehicle (car, motorbike, etc.)	1	6	12	5	5	4	28	44	16	15

Figure 32. Perceived Roadway Safety for Secondary Transportation Mode

In non-coastal municipalities, the most common rating for private vehicles as a secondary transportation mode was C, followed by B and D. Coastal municipalities showed a similar pattern, with C again representing the most common response. However, coastal respondents continued to report a higher proportion of lower ratings [29%], including a notable number of F [Terrible] responses. This consistency between primary and secondary transportation modes suggests that respondents are evaluating broader roadway and traffic conditions rather than the transportation mode itself.

The safety perceptions reported for "*Get a Ride*" and "*Taxi, Uber, Lyft, or equivalent*" services were generally concentrated within the mid-range categories. Although sample sizes remain small, respondents rarely characterize these modes as exceptionally safe or exceptionally unsafe. Instead, they were generally perceived as moderately acceptable transportation alternatives.

Overall, the findings indicate that roadway safety remains an important concern regardless of whether respondents are using their primary or secondary transportation mode. The persistence of moderate-to-negative ratings across municipality types suggests that transportation resilience efforts should consider not only system functionality but also the perceived safety of the transportation environment.

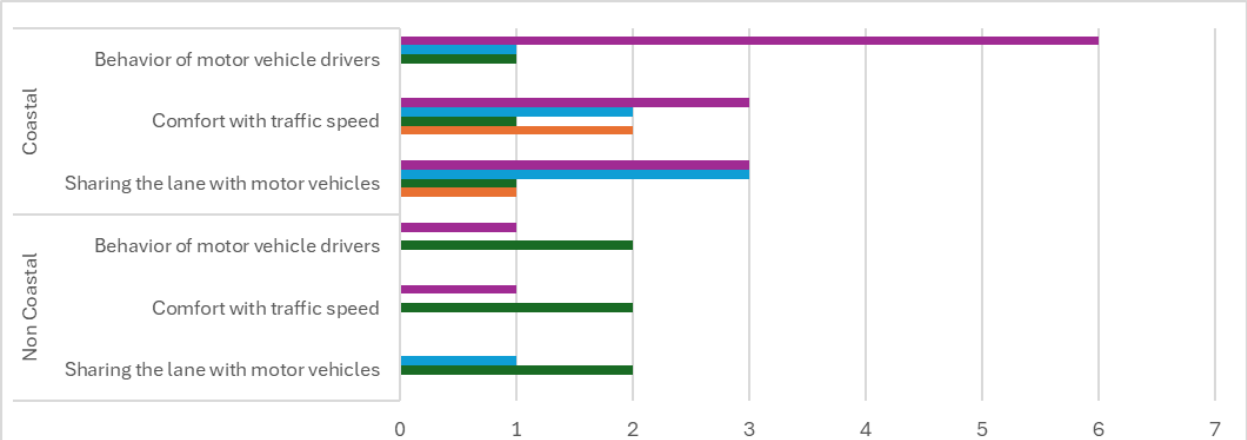
Even though bicycles and e-scooters were reported infrequently as primary transportation modes, an additional assessment was conducted to better understand the experiences of respondents who use these forms of micromobility. Participants evaluated three specific dimensions of safety:

- Comfort with traffic speed
- Behavior of motor vehicle drivers
- Sharing the travel lane with motor vehicles

Figure 33 reveals substantially lower safety perceptions for bicycles and e-scooters than those observed for motorized transportation modes. Respondents applied the same grading scale ranging from A (Excellent) to F (Terrible).

In non-coastal municipalities, most responses were concentrated in the C category, indicating a generally neutral perception. However, respondents also reported negative experiences

associated with traffic speed, driver behavior, and lane sharing, suggesting that active transportation users encounter safety concerns even in less densely populated settings.



	Non Coastal			Coastal		
	Sharing the lane with motor vehicles	Comfort with traffic speed	Behavior of motor vehicle drivers	Sharing the lane with motor vehicles	Comfort with traffic speed	Behavior of motor vehicle drivers
F (Terrible)	0	1	1	3	3	6
D	1	0	0	3	2	1
C	2	2	2	1	1	1
B	0	0	0	1	2	0
A (Excellent)	0	0	0	0	0	0

Figure 33. Perceived Roadway Safety for Micromobility Modes

The negative perceptions were considerably stronger among respondents from coastal municipalities. The behavior of motor vehicle drivers received the largest concentration [6 out of 8 responses] of F [Terrible] ratings, while traffic speeds [5 out of 8 responses] and sharing the roadway with automobiles [6 out of 8 responses] also received predominantly negative evaluations [D and F rankings]. Very few respondents assigned ratings in the positive categories, and no respondent selected A [Excellent] for any of the evaluated conditions.

These findings suggest that active transportation users perceive the roadway environment as significantly less safe than users of motorized transportation modes. The results also help explain the limited use of bicycles and e-scooters observed throughout the survey. If users perceive interactions with traffic as unsafe, they may be less willing to adopt these modes for daily travel, regardless of the potential benefits associated with active transportation.

From a transportation resilience perspective, this finding is important because communities with limited modal diversity may have fewer mobility options available when motor vehicle travel is disrupted. A transportation system that depends almost entirely on private vehicles has limited redundancy during floods, roadway closures, fuel shortages, or other emergency situations. Improving conditions for walking, bicycling, and micromobility could therefore contribute not only to transportation safety but also to overall community resilience and accessibility.

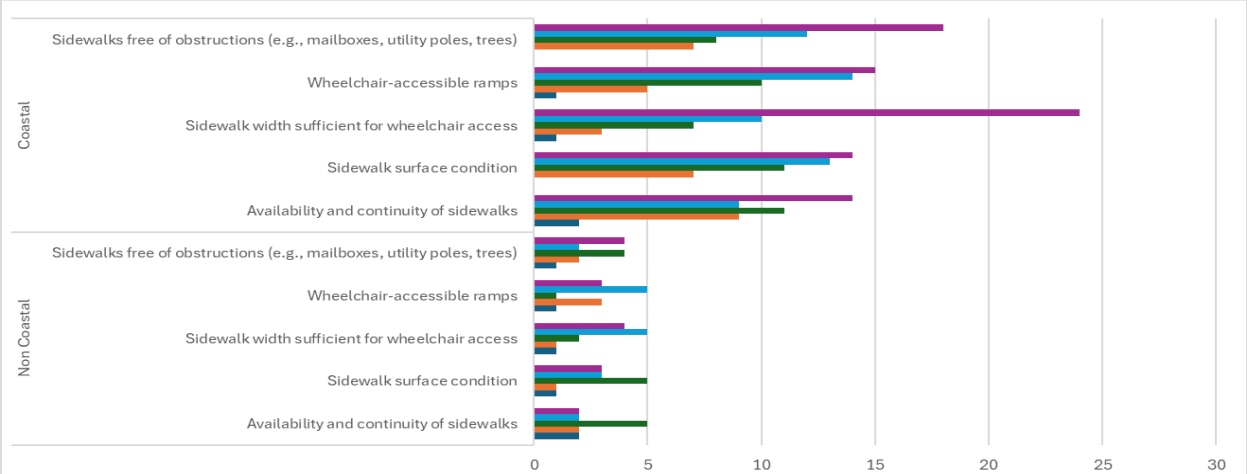
Overall, respondents generally perceived roadway safety for motor vehicle travel as fair to good, although a substantial minority reported poor or very poor safety conditions, particularly in coastal municipalities. The most significant concerns emerged from the evaluation of bicycles and e-scooters, where respondents consistently reported negative experiences associated with traffic speed, driver behavior, and lane sharing. If bicycling, e-scooters, and walking are perceived as unsafe, residents may have fewer practical mobility alternatives available during transportation disruptions resulting from natural hazards.

The heavy reliance on private vehicles observed throughout the survey may not only reflect transportation preferences and infrastructure availability but also concerns regarding the safety of alternative modes. These results suggest that perceived safety may be an important factor limiting the adoption of alternative transportation modes in Puerto Rico. Improvements in roadway design, traffic calming measures, bicycle and pedestrian infrastructure, and driver awareness could help increase transportation mode diversity, strengthen accessibility, and improve transportation resilience in both coastal and non-coastal communities.

Perception of Quality of Alternative Transportation Modes

Respondents also provided a ranking for their perceived quality of service of transportation infrastructure focusing on alternative modes. The quality of alternative transportation infrastructure plays an important role in transportation accessibility, modal choice, and community resilience. Respondents were asked to evaluate the perceived quality of facilities associated with walking, bicycling, e-scooter use, and public transportation using an A-to-F grading scale. The results provide insight into the conditions that may encourage or discourage the use of transportation alternatives beyond private motor vehicles.

Figure 34 presents respondents' perceptions regarding sidewalk infrastructure and pedestrian accessibility. Overall, respondents from both coastal and non-coastal municipalities identified deficiencies in several components of the pedestrian environment. However, the concerns reported by residents of coastal municipalities were consistently more severe.



	Non Coastal					Coastal				
	Availability and continuity of sidewalks	Sidewalk surface condition	Sidewalk width sufficient for wheelchair access	Wheelchair-accessible ramps	Sidewalks free of obstructions (e.g., mailboxes, utility poles, trees)	Availability and continuity of sidewalks	Sidewalk surface condition	Sidewalk width sufficient for wheelchair access	Wheelchair-accessible ramps	Sidewalks free of obstructions (e.g., mailboxes, utility poles, trees)
F (Terrible)	2	3	4	3	4	14	14	24	15	18
D	2	3	5	5	2	9	13	10	14	12
C	5	5	2	1	4	11	11	7	10	8
B	2	1	1	3	2	9	7	3	5	7
A (Excellent)	2	1	1	1	1	2	0	1	1	0

Figure 34. Perceived Quality of Walking Infrastructure

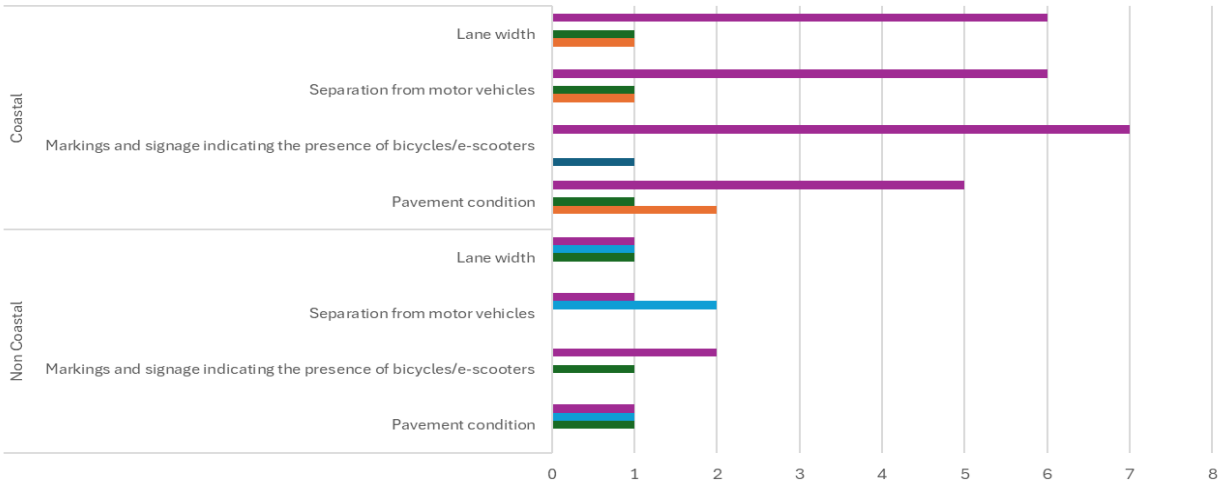
In non-coastal municipalities, half of the responses were concentrated within the B and C categories for sidewalk availability, continuity, and surface condition, suggesting that pedestrian facilities are perceived as moderately adequate. Nevertheless, accessibility-related elements received less favorable evaluations. Sidewalk widths suitable for wheelchair users [69.2%] and the availability of ADA-compliant ramps [65.4%] frequently received ratings in the D and F categories, indicating concerns regarding accessibility for individuals with mobility limitations.

The results from coastal municipalities reveal a more critical assessment of pedestrian infrastructure. More than three-quarters of respondents rated sidewalk widths suitable for wheelchair access and the availability of accessible ramps within the D and F categories. Similar concerns were reported regarding sidewalk continuity, surface condition, and the presence of

physical obstructions such as utility poles, mailboxes, trees, and other elements that restrict pedestrian movement. These results underscore systemic shortcomings in pedestrian infrastructure, particularly regarding universal design and the provision of barrier-free mobility environments.

These findings suggest that pedestrian infrastructure in many coastal communities may not adequately support universal accessibility. This result is particularly relevant given that approximately 15% of surveyed households reported the presence of bedridden individuals and many respondents were middle-aged or older adults. Deficiencies in pedestrian infrastructure may therefore limit mobility options not only under normal conditions but also during emergency situations requiring evacuation or access to essential services.

Figure 35 summarizes the perceptions regarding the quality of infrastructure available for bicycles and e-scooters. Respondents evaluated pavement condition, roadway width, separation from motor vehicle traffic, and the presence of markings and signage intended to support micromobility users.



	Non Coastal				Coastal			
	Pavement condition	Markings and signage indicating the presence of bicycles/e-scooters	Separation from motor vehicles	Lane width	Pavement condition	Markings and signage indicating the presence of bicycles/e-scooters	Separation from motor vehicles	Lane width
F (Terrible)	1	2	1	1	5	7	6	6
D	1	0	2	1	0	0	0	0
C	1	1	0	1	1	0	1	1
B	0	0	0	0	2	0	1	1
A (Excellent)	0	0	0	0	0	1	0	0

Figure 35. Perceived Quality of Roadway Infrastructure for Micromobility Use

The results indicate that bicycle and e-scooter infrastructure is generally perceived as inadequate in both coastal and non-coastal municipalities. Although sample sizes were relatively small, most responses [75%] were concentrated within the D and F categories, particularly for lane width, separation from motorized traffic, and signage.

The most negative evaluations were reported in coastal municipalities. Separation from motorized traffic and lane width were predominantly rated as F [Terrible], while roadway condition and pavement quality also received largely unfavorable ratings [75% of responses]. Signage and pavement markings, which are critical components for user guidance and safety, were similarly evaluated poorly.

These findings are consistent with the safety perceptions reported in the previous section. Respondents who use bicycles and e-scooters frequently reported concerns regarding motor vehicle speeds, driver behavior, and the need to share travel lanes with automobiles. Together, these results suggest that the current transportation environment does not provide conditions that encourage the adoption of active transportation modes.

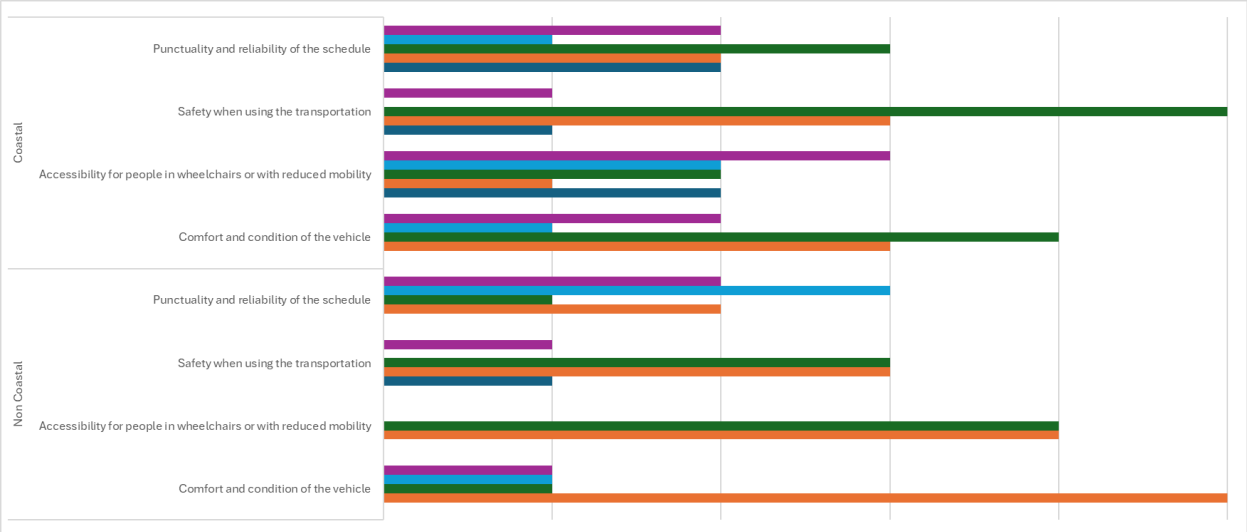
From a transportation resilience perspective, this finding is particularly important. Communities that rely almost exclusively on motor vehicles have limited transportation redundancy during roadway disruptions, fuel shortages, or emergency situations. The lack of safe conditions for bicycles and e-scooters may reduce the availability of alternative mobility options that could support accessibility during and after natural hazard events.

Figure 36 presents the respondents' perceptions of public transportation quality. Participants evaluated vehicle condition and comfort, accessibility for individuals with disabilities or reduced mobility, personal safety while using the service, and schedule punctuality and reliability.

Overall, public transportation received ratings concentrated within the B, C, and D categories, suggesting moderate levels of satisfaction but also room for improvement. Very few respondents [8.3% of all responses] assigned A [Excellent] ratings across any of the evaluated criteria.

Accessibility for individuals using wheelchairs or experiencing reduced mobility received more favorable ratings [all B or C responses] in non-coastal municipalities. Coastal municipalities

displayed a larger proportion of negative evaluations [50% of responses were D and F ratings], indicating concerns regarding the ability of the transit system to accommodate all potential users.



	Non Coastal				Coastal			
	Comfort and condition of the vehicle	Accessibility for people in wheelchairs or with reduced mobility	Safety when using the transportation	Punctuality and reliability of the schedule	Comfort and condition of the vehicle	Accessibility for people in wheelchairs or with reduced mobility	Safety when using the transportation	Punctuality and reliability of the schedule
F (Terrible)	1	0	1	2	2	3	1	2
D	1	0	0	3	1	2	0	1
C	1	4	3	1	4	2	5	3
B	5	4	3	2	3	1	3	2
A (Excellent)	0	0	1	0	0	2	1	2

Figure 36. Perceived Quality of Public Transportation Services

Safety while using public transportation was generally viewed as acceptable, with most responses clustered in the B and C categories in both municipal groups. In contrast, schedule punctuality and reliability emerged as recurring concerns [44% of responses at D or F ratings]. The variability previously observed in transit waiting times appears consistent with these perceptions and suggests that service frequency and reliability continue to represent significant challenges for public transportation users.

An important observation emerges when these results are considered together with the previous analysis of walking times and waiting times for transit users. Respondents who identified public transportation as a secondary transportation mode generally reported relatively short walking distances to access transit stops, suggesting that physical access to the network may be reasonable for some users. However, long and highly variable waiting times combined with concerns regarding reliability may reduce the attractiveness of public transportation as a practical mobility alternative.

It should also be recognized that the survey only captured perceptions from individuals who considered public transportation a viable mode of travel. Consequently, the findings do not necessarily represent the views of residents who never use or consider transit because service may be unavailable, inaccessible, or impractical in their communities.

Collectively, the results reveal that alternative transportation modes face important infrastructure and service-quality challenges across Puerto Rico. Sidewalk infrastructure, bicycle and e-scooter facilities, and public transportation systems all received moderate to poor evaluations, particularly in coastal municipalities. Accessibility-related features such as ramps, sidewalk dimensions, and accommodations for individuals with mobility limitations were consistently identified as areas requiring improvement.

These findings help explain the strong dependence on private motor vehicles observed throughout the survey. When walking environments are perceived as inadequate, micromobility facilities are viewed as unsafe, and public transportation is considered unreliable, residents may have limited practical alternatives to automobile travel. Improving the quality, safety, accessibility, and reliability of alternative transportation modes could therefore strengthen transportation accessibility, increase modal diversity, and improve community resilience during both routine travel and disruptive natural hazard events.

Definition of Coastal Communities

Puerto Rico is divided into 78 municipalities, 44 of which are classified as coastal. However, many residents of coastal municipalities live considerable distances from the shoreline and may not experience the same level of exposure to coastal hazards as residents of neighborhoods located directly along the coast [recall the identification of coastal inland sectors shown in Figure 3]. To better evaluate perceptions of vulnerability and transportation resilience, the analysis presented in this section uses a more refined geographic classification based on whether respondents identified themselves as residents of a coastal neighborhood.

Puerto Rico contains approximately 902 neighborhoods [barrios], of which 153 are located within coastal sectors or have direct access to the shoreline. Based on the respondents' self-identification, 80 survey participants reported residing in coastal communities, 253 reported living

in non-coastal communities, and 33 were unable to identify whether their neighborhood should be classified as coastal.

The use of neighborhood-level classification provides a more direct representation of potential exposure to coastal hazards such as flooding, storm surge, coastal erosion, and disruptions to coastal transportation corridors. As discussed in the previous chapters, vulnerability is influenced not only by infrastructure conditions but also by the characteristics and location of the communities that depend on that infrastructure. Therefore, evaluating perceptions at the community level may provide a more accurate understanding of transportation resilience challenges than broader municipal classifications. Figure 37 illustrates the geographic distribution of the survey responses according to both municipal and neighborhood classifications.



Figure 37. Survey Reponses in Coastal Neighborhoods and Municipalities

The questions included in the following sections focused on perceived vulnerability to extreme natural events, concerns regarding damage to homes and transportation infrastructure, mobility disruptions during emergencies, and the availability of alternative transportation options.

The responses will assist in identifying whether similarities or differences exist between coastal and non-coastal communities in several measures of risk perception and transportation disruption. Nevertheless, important differences emerge regarding exposure concerns, accessibility constraints, and dependence on transportation infrastructure. These findings provide valuable insight into how geographic location and proximity to coastal hazards may influence preparedness, mobility, and resilience within Puerto Rico's communities.

Stated Concern About Damage to Residences from Extreme Natural Events

Respondents were asked to indicate their level of concern regarding the potential damage that their residence could experience from several types of extreme natural events, including earthquakes, extreme heat, hurricanes and severe winds, floods, droughts, landslides, tsunamis, and wildfires. A five-point Likert-style scale was used to classify the perceptions from "*Extreme*" to "*None*". For purposes of this analysis, the *"Significant"* and *"Extreme"* response categories were combined to represent elevated levels of concern.

Figure 38 shows that concern patterns were generally similar among residents of coastal and non-coastal communities. Across all groups, earthquakes, extreme heat, and winds associated with storms and hurricanes generated the highest levels of concern, with more than half of respondents indicating *Significant* or *Extreme* concern regarding potential impacts to their homes. These findings suggest that residents are particularly sensitive to hazards that have recently affected Puerto Rico or that are perceived as widespread threats capable of causing substantial residential damage.

Flooding and drought were consistently perceived as hazards of moderate concern. While neither reached the concern levels associated with earthquakes, extreme heat, or hurricane-related winds, both hazards were identified by a substantial portion of respondents as potential threats. Flood-related concerns are particularly relevant given Puerto Rico's frequent exposure to heavy rainfall and tropical storm events that can affect both residences and transportation infrastructure.

In contrast, landslides, tsunamis, and wildfires generally elicited lower levels of concern among respondents. Although these hazards have the potential to generate significant localized impacts, they were less frequently identified as major threats to residential properties. This may reflect lower perceived exposure, lower frequency of occurrence, or reduced public awareness relative to more familiar hazards such as hurricanes, earthquakes, and heat events.

The results also reveal relatively minor differences between coastal and non-coastal communities. Coastal respondents reported slightly higher concern regarding hurricane-related winds and flooding, while non-coastal respondents displayed similar concern patterns for earthquakes and extreme heat. Overall, geographic location appears to influence the intensity of concern for certain hazards, but not the general ranking of perceived threats.

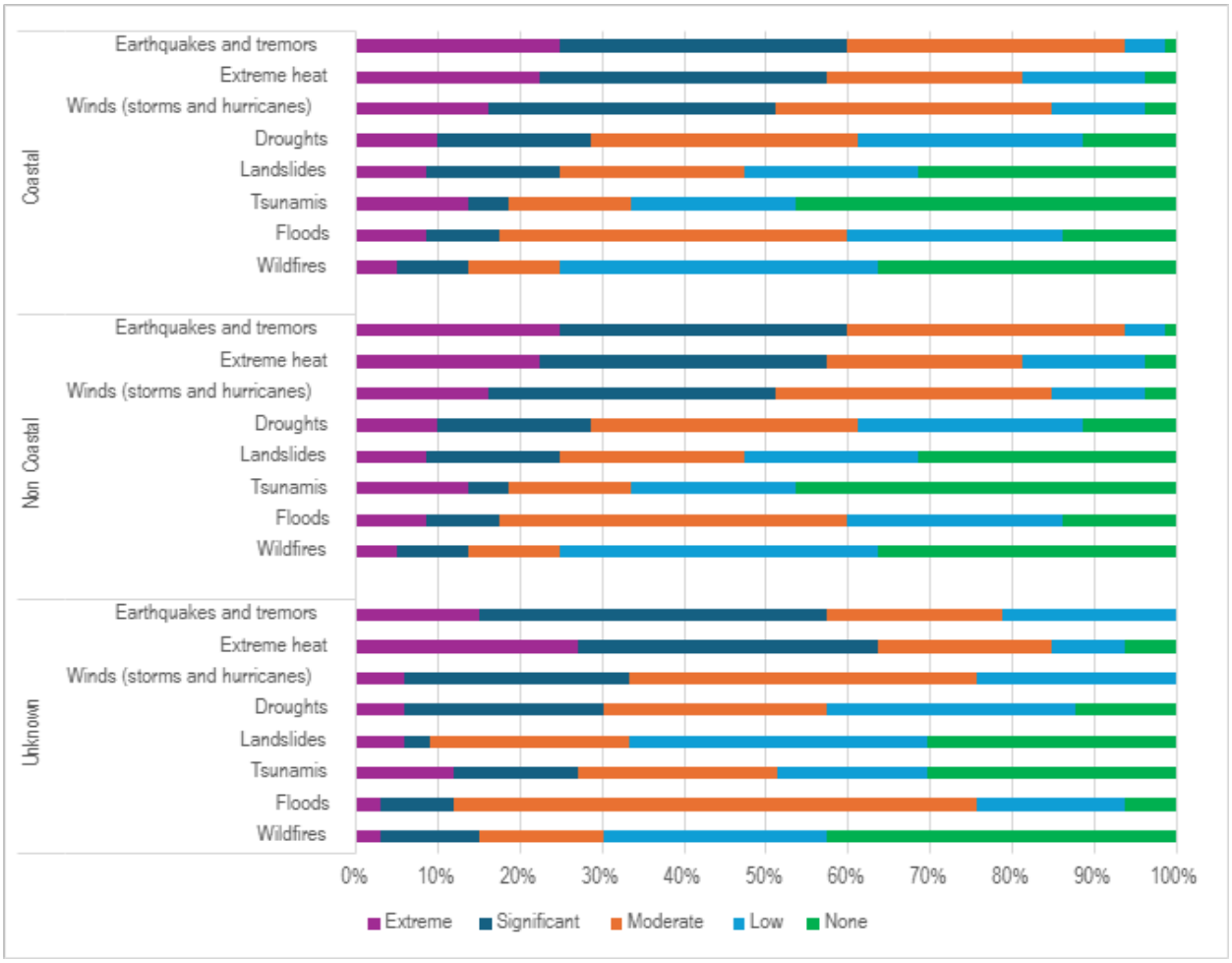


Figure 38. Concern Level Regarding Potential Residential Damage from Extreme Natural Events

From a transportation resilience perspective, these findings are important because they identify the hazards that residents perceive as most likely to affect their homes and communities. The prominence of earthquakes, extreme heat, hurricanes, and flooding suggests that future resilience, education, and capacity-building efforts should prioritize these hazards when developing transportation planning strategies, community outreach programs, and workforce development activities. The comparatively lower concern associated with landslides, tsunamis, and wildfires may also indicate opportunities for risk communication and public education regarding hazards that are less frequently perceived but may still affect community accessibility and transportation operations during extreme events.

The concern patterns observed in the survey appear to be reasonably consistent with the recent experience of Puerto Rico with major natural hazard events. Hurricanes Irma and María in

2017 produced island-wide impacts that affected housing, transportation infrastructure, power systems, communications, and community accessibility. María generated catastrophic flooding and triggered tens of thousands of landslides throughout Puerto Rico's mountainous interior, affecting a large portion of the population regardless of whether they resided in coastal or inland communities. As a result, the elevated concern associated with hurricane-related winds, flooding, and extreme weather conditions likely reflects lived experiences and direct observations of these widespread impacts. Similarly, the increased concern regarding extreme heat may reflect growing public awareness of climate-related risks and their effects on daily life, energy consumption, public health, and community resilience.

The high level of concern regarding earthquakes may also be influenced by the seismic sequence that affected southwestern Puerto Rico beginning in late 2019 and early 2020, commonly associated with the Punta Montalva fault system and surrounding seismic activity. Although the earthquake sequence caused significant structural damage and disruption in the southwestern region of the island, its impacts were not as geographically widespread as those associated with Hurricane María. Nevertheless, the event increased public awareness of seismic hazards across Puerto Rico and likely contributed to the elevated concern reported by respondents, even among residents located outside the most heavily affected areas.

An interesting finding is that perceived concern does not necessarily correspond to the physical severity of a hazard, but rather to the extent to which residents have experienced or observed its impacts. Hazards such as hurricanes, floods, and earthquakes have received extensive public attention due to their recent consequences in Puerto Rico, while tsunamis and wildfires tend to be perceived as lower-risk events despite their potential to generate localized transportation disruptions and accessibility challenges. These differences suggest opportunities for future risk communication, education, and capacity-building initiatives aimed at improving awareness of hazards that may be underrecognized by the public.

The relatively lower level of concern associated with landslides, despite their extensive occurrence following Hurricane María, may reflect differences in perceived exposure rather than a lack of awareness. While María triggered thousands of landslides throughout Puerto Rico's mountainous interior and generated substantial impacts on transportation accessibility, many residents may perceive landslides as hazards that primarily affect specific geographic areas rather

than the entire island. In contrast, hurricanes, extreme heat, and earthquakes are often perceived as hazards capable of affecting large portions of the population simultaneously, regardless of their location.

A similar interpretation may apply to floods. Although flooding was widely experienced and received significant media attention following major storm events, respondents may perceive its impact as more localized than those associated with hurricanes and earthquake events.

These findings suggest that perceived vulnerability is influenced not only by the historical impacts of extreme events but also by the degree to which residents believe that future events could directly affect their homes, mobility, and daily activities. Understanding these perceptions is important for developing effective risk communication, educational initiatives, and transportation resilience strategies.

Experience with Impacts from Extreme Natural Events

Respondents were asked whether their community had experienced impacts from a series of extreme natural events during the previous ten years. The objective of this question was to complement the previous assessment of perceived vulnerability by examining whether concern levels were consistent with respondents' recent experiences. Figure 39 summarizes the responses based on whether participants resided in coastal neighborhoods, non-coastal neighborhoods, or were unable to identify the location of their community.

The results reveal a remarkable degree of consistency across all three groups. Winds associated with storms and hurricanes, earthquakes or tremors, and extreme heat were the events most frequently reported as having affected respondents' communities during the previous decade. More than 70% of respondents in both coastal and non-coastal communities indicated that their communities had experienced impacts from these hazards. This widespread experience is consistent with Puerto Rico's recent exposure to major hurricanes, prolonged heat events, and the extensive earthquake sequence that affected the southwestern region of the island beginning in 2019.

Flooding due to rainfall occupies an intermediate position, with approximately half of respondents indicating that their communities had experienced impacts. While flooding has generated significant disruption throughout Puerto Rico, the responses suggest that residents may

perceive these impacts as more dependent on local conditions and geographic location than hazards such as hurricanes, earthquakes, or extreme heat. Similar patterns were observed for drought conditions, which were reported by a substantial share of respondents but not at the same frequency as the hazards receiving the highest levels of concern.

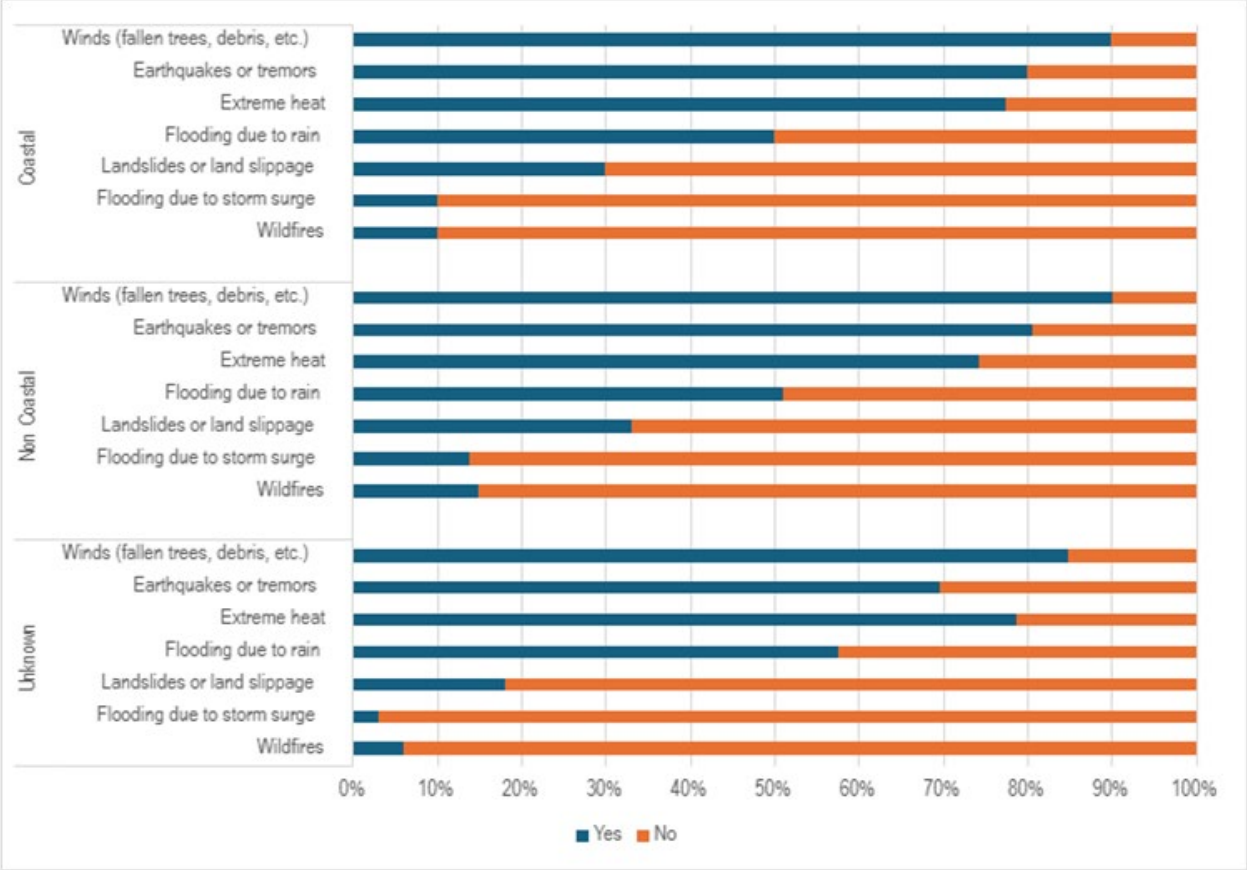


Figure 39. Stated Impacts from Natural Events During the Last Decade

Landslides, flooding due to storm surge, and wildfires were reported less frequently than winds, earthquakes, and extreme heat. However, these lower percentages should not be interpreted as indicating a lack of awareness. Following Hurricane María, thousands of landslides were documented throughout Puerto Rico and received extensive public attention because of their impacts on communities, transportation corridors, and infrastructure. Similarly, flooding and coastal hazards have been widely discussed due to their effects on housing, mobility, and economic activities. The results instead suggest that residents may perceive these hazards as affecting specific geographic areas more frequently than the whole territory.

The similarities observed between coastal and non-coastal communities are particularly noteworthy. Coastal respondents reported slightly greater experience with flooding-related hazards and storm surge, while non-coastal respondents exhibited broadly similar experiences regarding earthquakes, extreme heat, and hurricane-related impacts. This pattern suggests that many of Puerto Rico's recent hazard experiences have been shared across communities regardless of their location relative to the coast.

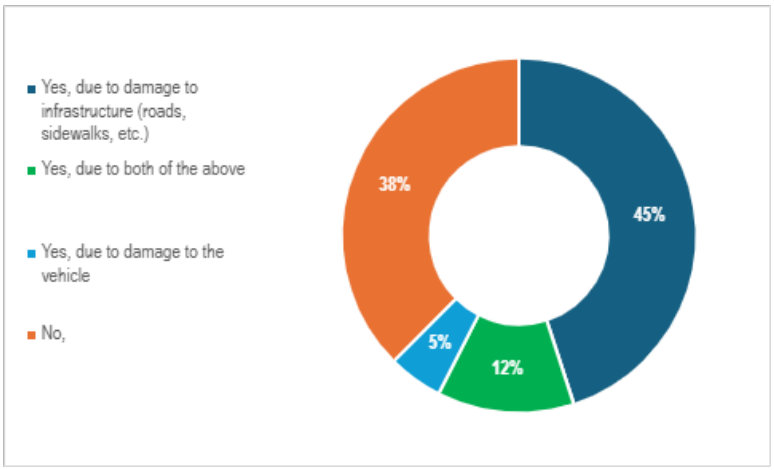
When compared with the previous question regarding concern about damage to residences, the results indicate a strong relationship between perceived vulnerability and lived experience. The hazards generating the greatest concern, earthquakes, extreme heat, and winds associated with storms and hurricanes, are also the hazards most frequently reported as having affected respondents' communities during the last decade. This finding suggests that perceptions of vulnerability are strongly influenced by direct experience with past events and their consequences.

From a transportation resilience perspective, the results highlight that the hazards most experienced by Puerto Rican communities are also those capable of generating widespread disruptions to transportation infrastructure and accessibility. Hurricanes and severe winds can damage transportation assets across large geographic areas, earthquakes can affect critical infrastructure and mobility networks, while extreme heat can influence transportation operations, public health, and energy systems. Understanding how residents perceive and experience these hazards provides valuable information for developing future resilience strategies, educational initiatives, and transportation planning efforts intended to reduce vulnerability and improve community preparedness.

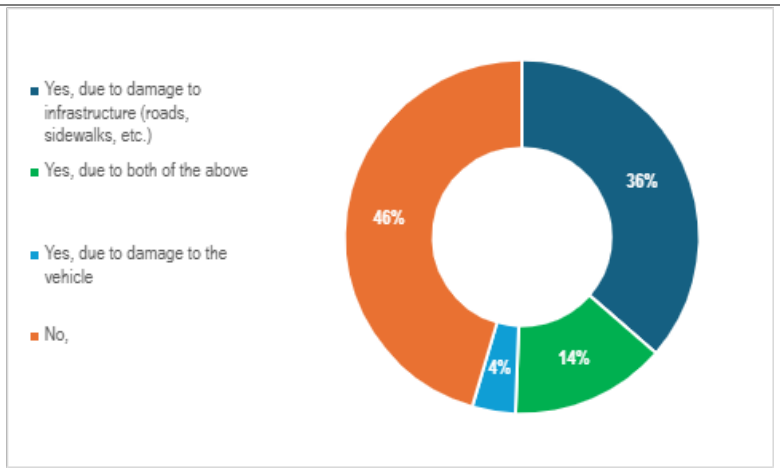
Impacts of Natural Events on the Primary Transportation Mode

Following the questions related to hazard exposure and community vulnerability, respondents were asked whether their primary transportation mode had been affected by any of the previously identified natural events. Participants could indicate whether the disruption resulted from damage to transportation infrastructure, damage to their personal vehicle, both factors, or whether no impact had occurred. Figure 40 shows the responses from coastal, non-coastal, and unknown zone groups.

(a) Coastal



(b) Non-Coastal



(c) Unknown

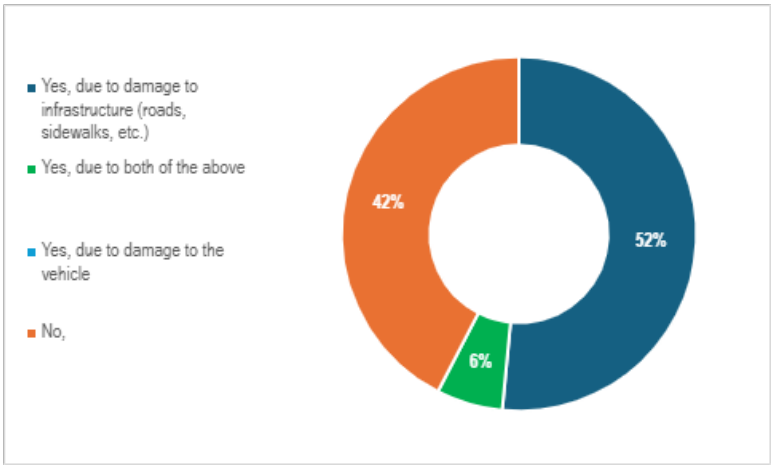


Figure 40. Stated Impact to Primary Transportation Mode

The responses indicate that natural hazards have had a substantial impact on the mobility of respondents throughout Puerto Rico. More than half of respondents reported that their primary transportation mode had been affected by one or more extreme natural events during the previous

decade. This finding is consistent with the widespread impacts generated by hurricanes, floods, earthquakes, and other disruptive events that have affected transportation systems across the island.

Among residents of coastal communities, approximately 62% reported experiencing some type of transportation disruption. The most frequently identified cause was damage to transportation infrastructure, accounting for approximately 45% of responses. Damage to roadways, bridges, sidewalks, and access routes appears to represent the principal mechanism through which natural hazards affect daily mobility in coastal areas.

A similar pattern was observed among residents of non-coastal communities. Approximately 54% reported that their primary mode of transportation had been affected by a natural event, with roadway and transportation infrastructure damage again representing the most common cause of disruption. Roughly 36% of respondents identified infrastructure-related impacts as the principal factor affecting their ability to travel.

Respondents whose community location was not classified also reported substantial impacts on mobility, with just over half indicating that their primary transportation mode had been affected. As in the other two groups, transportation infrastructure damage emerged as the dominant source of disruption.

These findings demonstrate that the principal vulnerability experienced by respondents is not necessarily the loss of the transportation mode itself, but rather the loss of access caused by disruptions to the transportation network. Regardless of whether individuals depend on private vehicles, ride-sharing arrangements, or other transportation options, mobility becomes constrained when roads, bridges, intersections, sidewalks, and other transportation facilities are damaged or rendered inaccessible.

The results are particularly important when considered alongside the findings presented in previous sections. Survey respondents reported high levels of access to private vehicles and strong dependence on motorized travel. However, the present findings suggest that vehicle availability alone does not guarantee mobility during or after extreme events. Even households with consistent access to vehicles may experience significant transportation limitations when critical transportation corridors are damaged or blocked.

From a transportation resilience perspective, these results reinforce the importance of protecting transportation infrastructure and maintaining network connectivity during disruptive events. The findings also highlight the value of identifying vulnerable transportation corridors, maintaining alternative access routes, and improving emergency transportation planning in both coastal and inland communities. Because infrastructure damage was consistently identified as the primary cause of mobility disruption across all geographic groups, future resilience strategies should prioritize measures that improve the reliability, redundancy, and rapid recovery of transportation networks following natural hazards.

One particularly noteworthy observation is that the differences between coastal and non-coastal communities are smaller than might be expected. Although coastal communities reported slightly higher levels of disruption, the results suggest that extreme natural events have affected mobility throughout Puerto Rico regardless of geographic location. This finding is consistent with previous survey responses showing that respondents across the island shared similar experiences with hurricanes, earthquakes, extreme heat, and other hazards. As a result, transportation resilience should be viewed not only as a coastal issue, but as a broader challenge affecting communities across Puerto Rico.

Duration of Transportation Disruptions Following Extreme Natural Events

Respondents were asked to estimate how long the roads in their communities remained unavailable following different extreme natural events. Response options ranged from roads not being affected to disruptions lasting several months. This question provides insight into the perceived duration of transportation disruptions and the recovery capacity of local transportation networks. Figure 41 shows the responses from coastal, non-coastal, and unknown zone groups for each of the natural events.

The results indicate that hurricane- and storm-related winds are consistently perceived as the natural hazard responsible for the most prolonged transportation disruptions across Puerto Rico. Respondents from both coastal and non-coastal communities frequently reported roadway closures lasting days, weeks, and in some cases, months following wind-related events. This finding is consistent with the widespread impacts experienced during major hurricanes, where fallen trees,

debris, utility poles, landslides, infrastructure damage, and power restoration activities can significantly delay the reopening of transportation corridors.

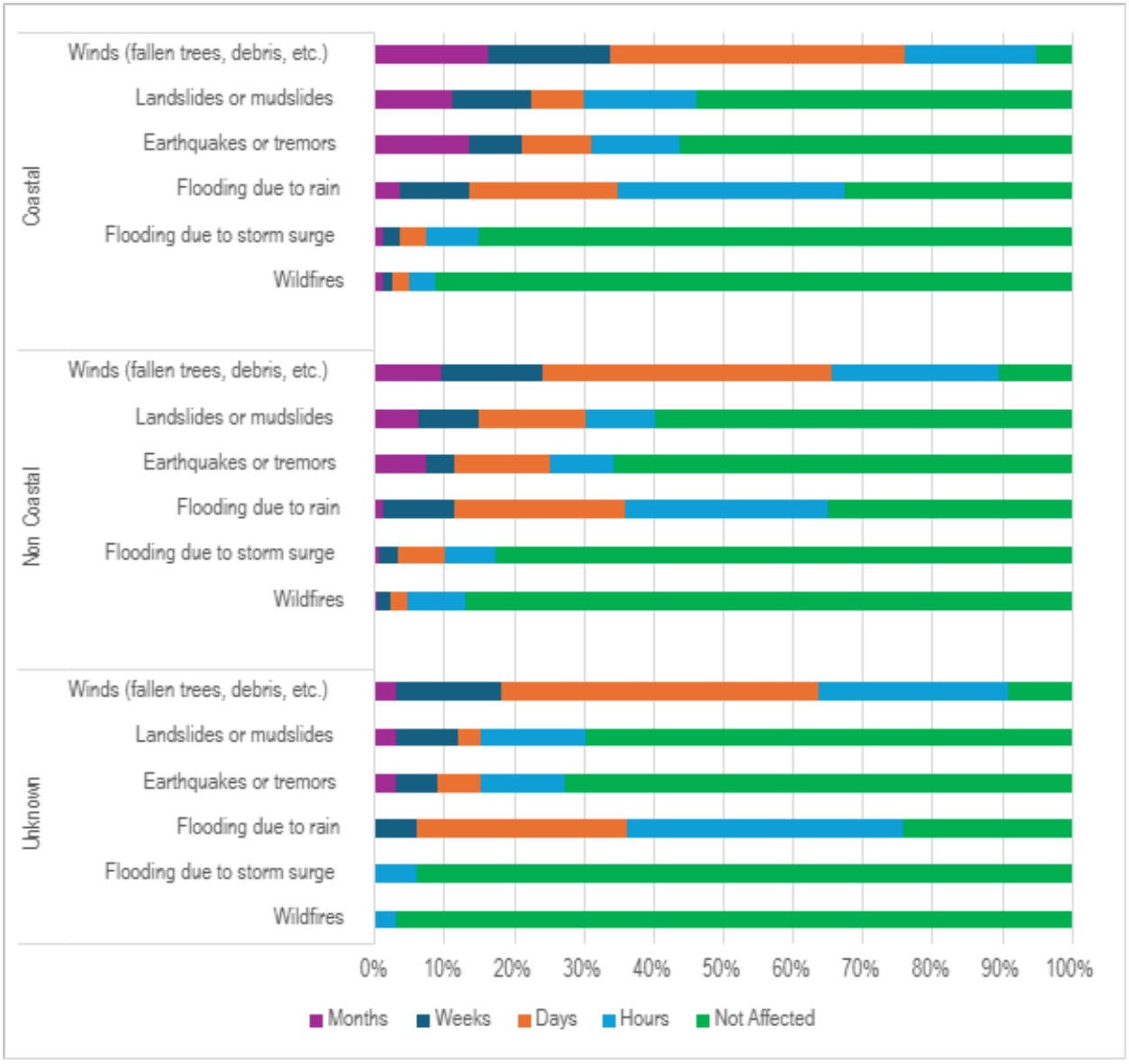


Figure 41. Stated Duration of Road Disruptions After Natural Events

Among residents of coastal communities, approximately one-third indicated that wind-related impacts resulted in roadway disruptions lasting weeks or months. No other hazard generated a comparable level of prolonged interruption. This suggests that hurricane-related events represent the greatest threat to long-term transportation accessibility in coastal areas.

Flooding due to rainfall presents a different pattern. While respondents frequently reported that roads became unavailable following flood events, the duration of these disruptions was generally shorter, typically ranging from hours to several days. This suggests that many flooding events affect mobility through temporary roadway closures rather than long-term infrastructure damage. Nevertheless, the frequency of these disruptions indicates that flooding remains an important accessibility concern for many communities.

Landslides and earthquakes occupy an intermediate position. Although fewer respondents reported impacts from these events, when disruptions occurred, they often extended beyond a few hours and occasionally required weeks for full recovery. These findings are consistent with the localized but potentially severe effects associated with slope failures and structural damage to transportation infrastructure. In Puerto Rico, landslides have received significant public attention due to their extensive occurrence following Hurricane María and their ability to isolate communities by blocking critical transportation corridors. Consequently, while landslides may affect fewer locations than hurricanes, the resulting impacts on accessibility can be substantial for the affected communities.

Flooding associated with storm surge and wildfires generated the lowest levels of reported disruption. Most respondents indicated that roads were either not affected or that impacts were relatively short in duration. This likely reflects the more geographically localized nature of these hazards compared with island-wide events such as hurricanes, earthquakes, and prolonged periods of extreme heat.

An important finding is that the differences between coastal and non-coastal communities are generally smaller than might be expected. Although coastal communities reported somewhat longer disruptions associated with winds and flooding, respondents across Puerto Rico shared similar experiences regarding the duration of transportation interruptions. This result supports findings presented in previous sections, where respondents from both geographic groups reported comparable exposure to major natural hazards and similar experiences with transportation disruptions.

From a transportation resilience perspective, the duration of roadway disruptions may be as important as the occurrence of the event itself. Even when communities have access to private vehicles and alternative transportation arrangements, mobility becomes severely constrained when

the transportation network is unavailable for extended periods. The results suggest that transportation resilience efforts should prioritize not only reducing physical damage to infrastructure but also improving the speed with which critical corridors can be reopened following extreme events.

Overall, the findings indicate that hurricane-related winds represent the most significant source of long-term transportation disruption in Puerto Rico. Flooding, landslides, and earthquakes also contribute to accessibility challenges, although their impacts tend to be more localized or shorter in duration. These results reinforce the importance of transportation network redundancy, emergency response planning, proactive maintenance, and rapid recovery strategies to preserve mobility and accessibility following future extreme natural events.

Additional Travel Time Caused by Roadway Disruptions

Following the questions related to transportation disruptions caused by natural hazards, respondents were asked to estimate the additional travel time required to reach their routine destinations when their primary travel route becomes inaccessible due to an extreme natural event. Figure 42 shows the responses from coastal, non-coastal, and unknown zone groups.

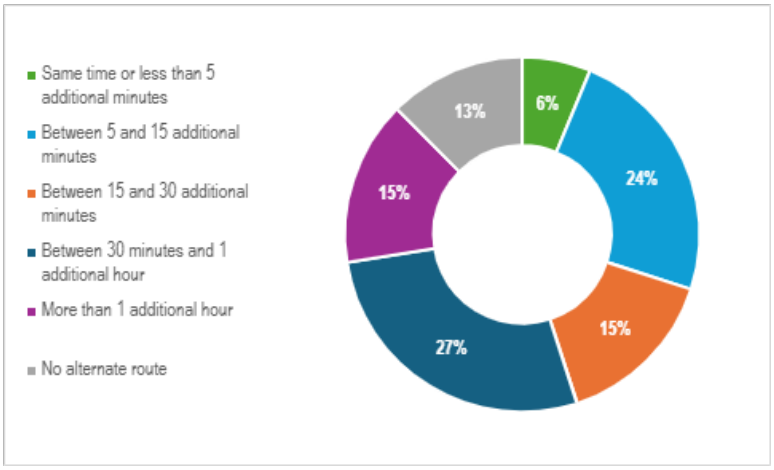
The results indicate that roadway disruptions generate substantial impacts on transportation accessibility across Puerto Rico. In both coastal and non-coastal communities, most respondents [70% or above in all groups] reported experiencing additional travel times exceeding 15 minutes when forced to use alternative routes following a natural event.

Among residents of coastal communities, approximately 57% reported that the loss of their primary route would increase travel times by between 15 minutes and more than one hour. Similarly, respondents from non-coastal communities reported comparable impacts, with approximately 60% indicating additional travel times within this same range. Respondents whose community location could not be classified reported similar experiences, with approximately 64% indicating travel time increases greater than 15 minutes.

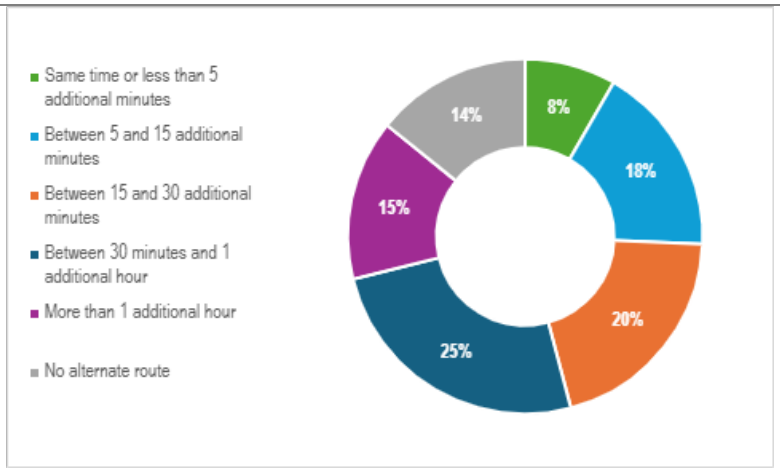
An equally important finding is that a notable percentage of respondents reported having no alternate route available. Approximately 13% of respondents in coastal communities and 14% of respondents in non-coastal communities indicated that they would be unable to identify an

alternative route if their primary route became inaccessible. This finding suggests that some communities remain highly dependent on a limited number of transportation corridors and may face significant accessibility challenges when those corridors are disrupted.

(a) Coastal



(b) Non-Coastal



(c) Unknown

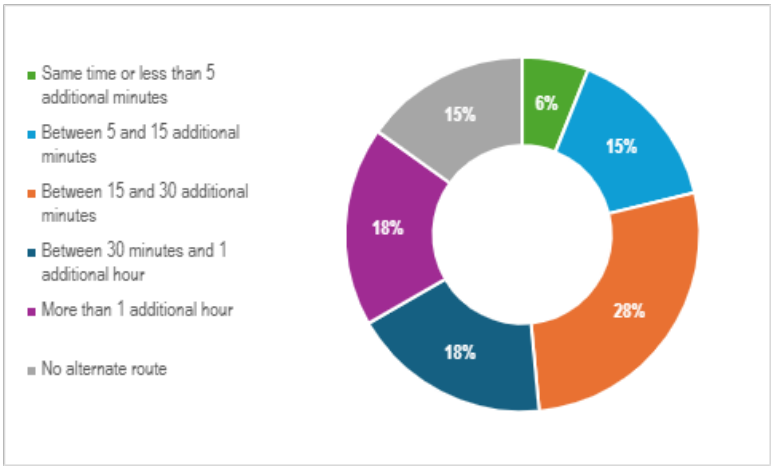


Figure 42. Added Travel Time from Alternate Route

The relatively small differences observed between coastal and non-coastal communities suggest that route dependency is not exclusively a coastal issue. Rather, transportation accessibility throughout Puerto Rico appears to rely heavily on a limited number of critical roadway connections that can become vulnerable during extreme events.

From a transportation resilience perspective, these findings are particularly significant. While previous survey results showed that most respondents have access to private vehicles, vehicle availability alone does not guarantee mobility during emergency situations. When primary transportation corridors are disrupted, travelers may experience substantial increases in travel time or may have no viable alternative route at all. Consequently, resilience depends not only on access to transportation modes, but also on the availability of redundant and reliable transportation networks capable of maintaining access to employment, education, healthcare, shopping, and other essential activities.

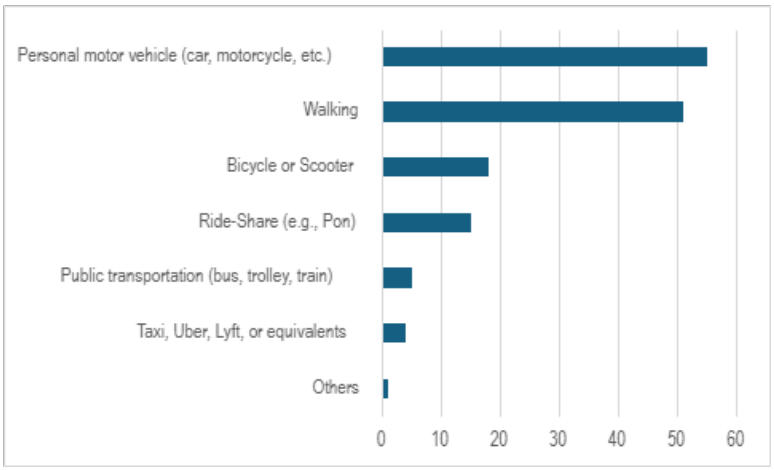
The results also reinforce findings from previous sections indicating that damage to transportation infrastructure is the principal mechanism through which natural hazards affect mobility. Even when alternative routes exist, the additional travel time required to reach routine destinations can represent a significant burden for households, emergency responders, workers, and businesses. These delays may become especially critical during evacuations, emergency response operations, and post-disaster recovery periods.

Overall, the findings suggest that natural hazards affect transportation accessibility not only by temporarily closing roads but also by increasing travel times and reducing network efficiency. The proportion of respondents reporting substantial delays or the absence of alternate routes highlights the importance of transportation network redundancy, corridor resilience, emergency access planning, and rapid recovery strategies as essential components of resilient transportation systems.

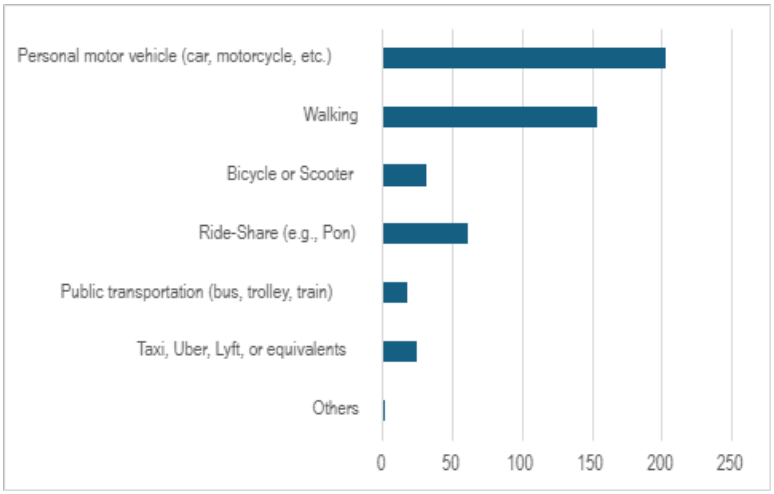
Transportation Options During Emergency Situations

Respondents were asked to identify the transportation options available to them during emergencies associated with natural events. The objective of this question was to better understand the level of transportation redundancy available to residents when normal mobility conditions are disrupted. Figure 43 shows the responses from coastal, non-coastal, and unknown zone groups.

(a) Coastal



(b) Non-Coastal



(c) Unknown

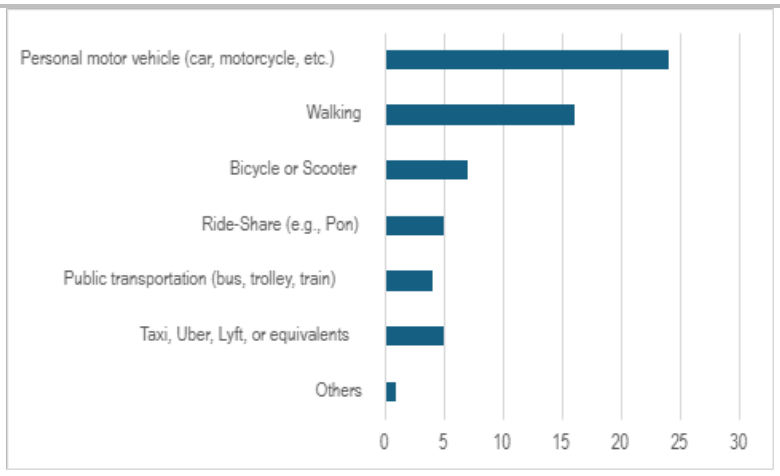


Figure 43. Transportation Modes Available in a Natural Event Emergency

The results reveal a relatively consistent pattern throughout Puerto Rico. Regardless of whether respondents resided in coastal or non-coastal communities, personal motor vehicles and

walking were identified as the most common transportation options available during emergency situations.

The predominance of private vehicles is consistent with previous findings from this survey, which showed high levels of vehicle ownership, frequent access to personal vehicles, and a strong dependence on motorized transportation for daily activities. These results suggest that most households view private vehicles as their primary resource for maintaining mobility during disaster-related disruptions.

Walking also emerged as an important emergency transportation option. While walking was not frequently identified as a primary transportation mode for daily activities, respondents reported it as a viable alternative during emergency situations. This finding may reflect the limited availability of transportation alternatives in many communities and suggests that residents may rely on walking when roads are congested or even disrupted, fuel is unavailable, vehicles are damaged, or motorized transportation becomes inaccessible.

At the same time, the results indicate relatively limited reliance on public transportation, micromobility devices, and other formal transportation alternatives during emergencies. This pattern is consistent with previous survey findings showing low utilization of public transportation and limited perceived quality of bicycle, e-scooter, and pedestrian infrastructure. As a result, transportation options available during emergencies appear to remain strongly dependent on the roadway network and the availability of private vehicles.

From a transportation resilience perspective, these findings suggest that mobility redundancy may be limited for many residents. Although most respondents have access to a private vehicle, many of the transportation alternatives identified during emergencies also depend on functioning road infrastructure. Consequently, communities may remain vulnerable when roadway corridors are blocked by flooding, debris, landslides, or other hazard-related disruptions.

The prominence of walking as an emergency mobility option also highlights the importance of maintaining safe and accessible pedestrian infrastructure. Sidewalk continuity, pedestrian accessibility, and the removal of physical barriers may become particularly important during emergency situations when residents are required to access essential services without vehicle transportation.

Overall, the results indicate that emergency mobility in Puerto Rico continues to rely heavily on private motor vehicles, with walking serving as one of the few broadly available alternatives. These findings reinforce the importance of developing transportation systems with greater modal diversity and redundancy to improve community resilience during and after extreme natural events.

Significance of Coastal Economy Activities and Accessibility Conditions

The final section of the survey examined the respondents' perceptions regarding the economic importance of coastal activities and the condition of the transportation infrastructure used to access those destinations. These questions were intended to better understand both the perceived contribution of Blue Economy activities to local development and the transportation conditions that support access to those activities.

Respondents were asked to evaluate the importance of seven coastal-related activities for the economic development of their municipality. Figure 44 presents the resulting perceptions for coastal, non-coastal, and unknown zone groups.

Overall, environmental conservation and tourism emerged as the two activities most frequently perceived as important for local economic development. More than half of respondents residing in coastal communities identified these activities as important or very important contributors to their local economy. Fishing also received relatively high importance ratings among coastal respondents, reflecting the historical and economic connection between many coastal communities and marine resources.

Residents of non-coastal communities expressed similar opinions, particularly regarding environmental conservation and tourism. Although some activities such as fishing, marinas, and other water-dependent activities were viewed as having less direct relevance to inland communities, respondents generally recognized the broader economic contribution of coastal resources and tourism to Puerto Rico's economy.

Respondents who did not identify the location of their community showed a similar pattern, consistently assigning high importance to tourism and environmental conservation. These results suggest that many residents view coastal resources not only as recreational assets but also as significant contributors to economic development and quality of life.

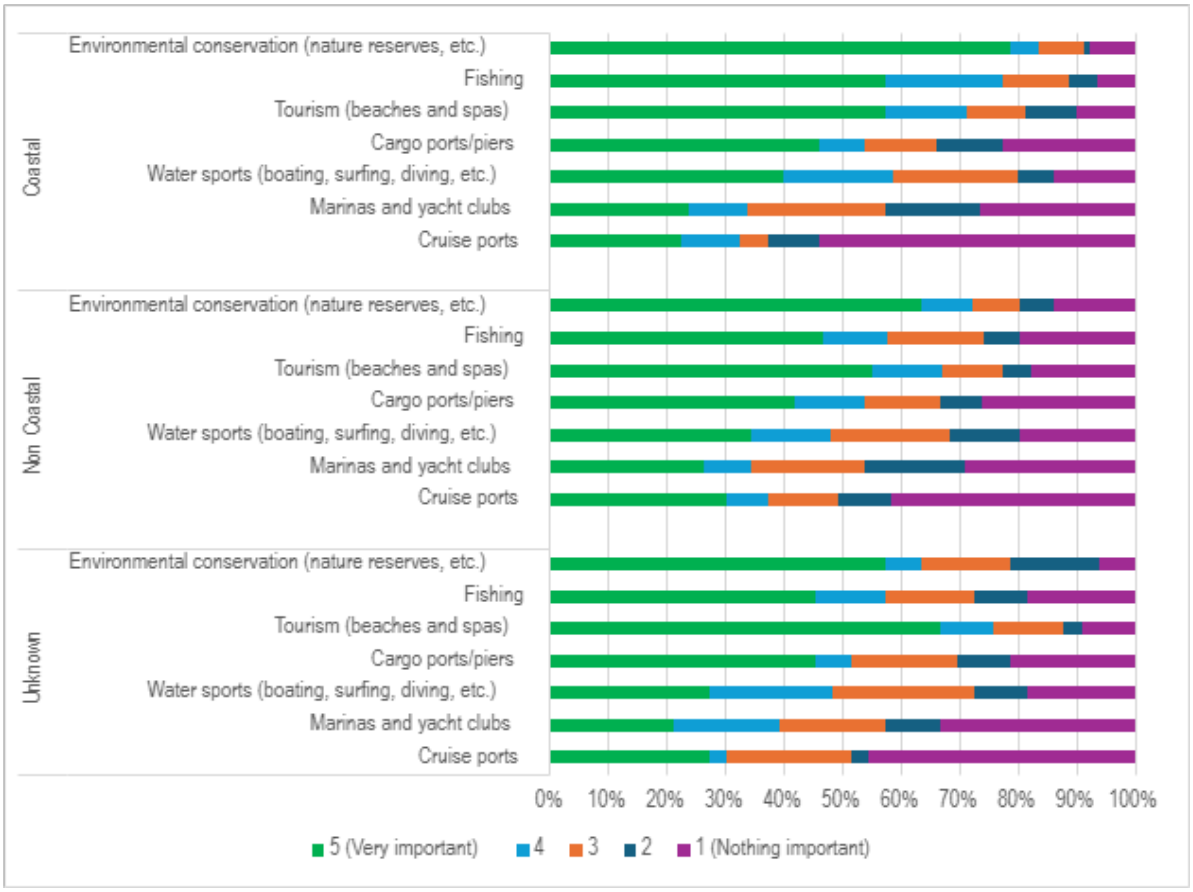


Figure 44. Perceived Importance of Coastal Activities

At the island-wide level, environmental conservation and tourism were consistently identified as the most important coastal-related activities for the economic development of the municipalities. This finding is particularly relevant because these activities depend heavily on the ability of residents and visitors to safely access coastal destinations. Consequently, transportation infrastructure plays a direct role in supporting the economic benefits generated by the Blue Economy.

Respondents were also asked to evaluate the condition of the roadways used to access various coastal destinations using the A-F rating scale. Unlike previous questions, participants were allowed to select "*Don't Know*" if they were unfamiliar with the roadway conditions associated with a particular activity.

Figure 45 shows that roadway conditions supporting access to coastal activities were generally perceived as *Fair* to *Poor*. Among respondents residing in coastal communities, many

roadway segments serving beaches, recreational areas, environmental reserves, and water-related activities received ratings concentrated in categories C, D, and F. These responses suggest concerns regarding the quality of the infrastructure that supports access to some of Puerto Rico's most important coastal destinations.

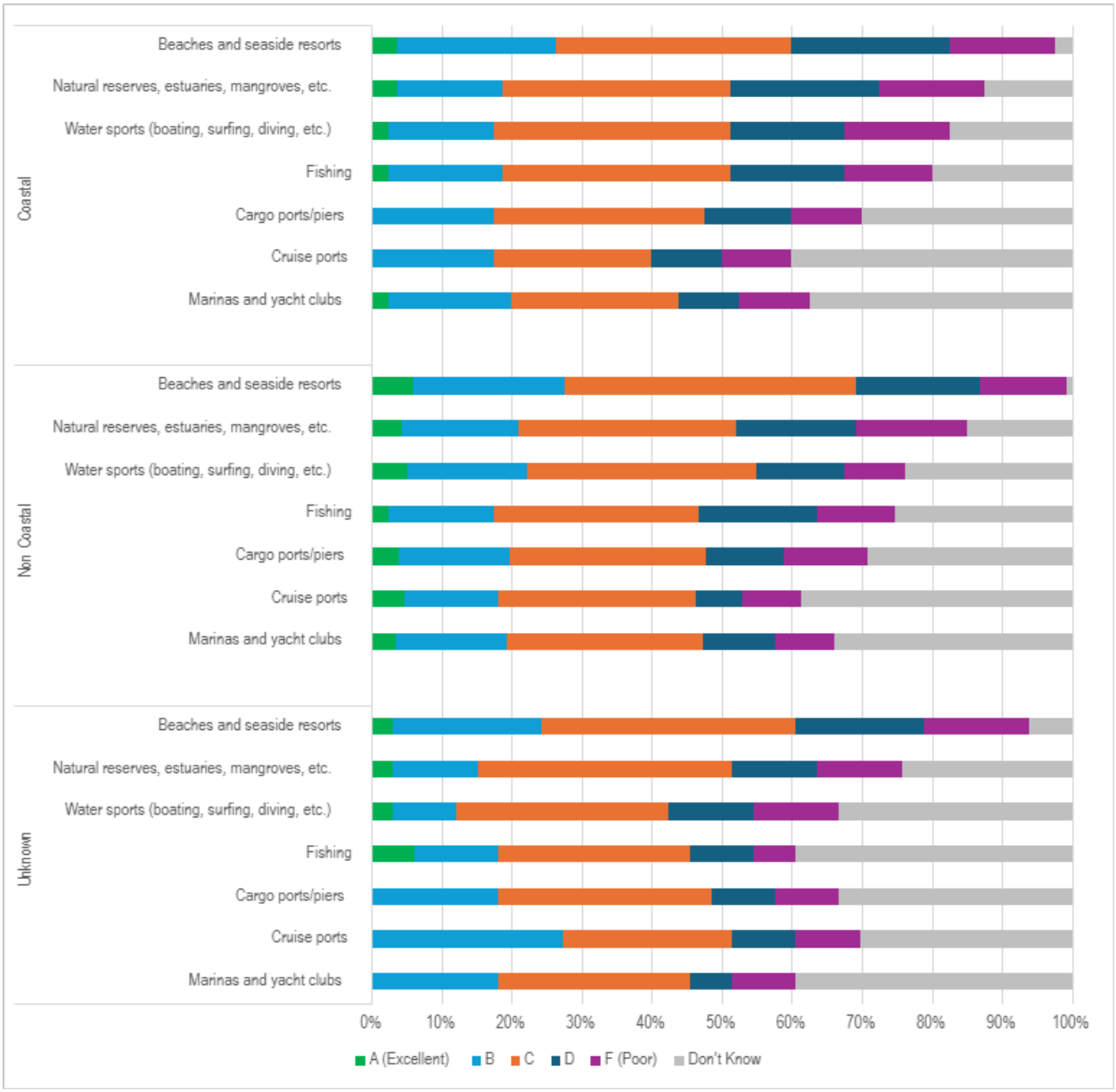


Figure 45. Perceived Roadway Conditions to Access Coastal Activities

Non-coastal respondents also tended to rate roadway conditions as *Fair*, particularly for destinations such as beaches and tourism-related locations that are more familiar to the general public. However, a greater proportion of respondents selected the "*Don't Know*" option for certain

coastal activities, likely reflecting less frequent use of those facilities or limited familiarity with the transportation corridors that serve them.

Respondents from the unknown-location group exhibited similar patterns, with roadway conditions generally rated as *Fair* while also showing a notable percentage of "*Don't Know*" responses.

An important observation is that the "*Don't Know*" responses provide useful information beyond simple nonresponse. In many cases, these responses may indicate limited interaction with specific coastal activities or unfamiliarity with the transportation infrastructure supporting them. Consequently, the results suggest that awareness and use of certain Blue Economy assets may vary substantially across geographic regions.

At the Puerto Rico level, roadway conditions supporting coastal activities were most rated as *Fair*, with a substantial number of respondents assigning *Deficient* [D] or *Poor* [F] ratings. The prevalence of these lower ratings suggests that transportation infrastructure may represent a constraint to the full utilization of some coastal economic opportunities.

Taken together, the results indicate that Puerto Rico residents recognize the importance of coastal resources and Blue Economy activities, particularly tourism and environmental conservation, as contributors to local economic development. However, respondents also reported concerns regarding the condition of the transportation infrastructure used to access many of these destinations.

From a transportation resilience and economic development perspective, these findings highlight the strong connection between coastal economic activities and transportation accessibility. The economic benefits associated with tourism, recreation, environmental conservation, fishing, and other coastal activities depend on reliable access provided by the transportation network. Consequently, improving roadway conditions and maintaining transportation accessibility to coastal destinations may support not only mobility and resilience objectives but also the long-term sustainability and growth of Puerto Rico's Blue Economy.

CONCLUSIONS AND RECOMMENDATIONS

The primary objective of Phase I of the CREATE UPRM research program was to establish a baseline understanding of community perceptions regarding transportation accessibility, transportation vulnerability, resilience, and coastal economic activities in Puerto Rico. The survey results successfully provided this baseline and generated insights that will guide future project phases focused on vulnerability assessment, transportation network analysis, educational initiatives, technology transfer, and workforce development.

The results indicate that transportation systems in Puerto Rico remain highly dependent on private motor vehicles. More than 90% of respondents identified personal vehicles as their primary transportation mode, while access to alternative transportation options was considerably more limited. Although some respondents identified ride-sharing arrangements, transportation network companies, or walking as secondary transportation options, most alternatives remain dependent on the roadway network. These findings suggest limited modal redundancy and reinforce the importance of maintaining transportation infrastructure functionality during and after extreme events.

The survey also revealed important differences in the perceived quality and safety of alternative transportation modes. Pedestrian facilities, bicycle infrastructure, and micromobility options were frequently rated as fair, poor, or very poor, particularly in coastal communities. Concerns related to sidewalk continuity, accessibility features, driver behavior, lane sharing, and infrastructure condition may contribute to the limited adoption of non-motorized transportation alternatives. These perceptions suggest that transportation accessibility in many of the local communities remains strongly tied to private vehicle ownership.

The vulnerability-related findings indicate that earthquakes, extreme heat, and hurricane-related winds represent the hazards generating the highest levels of concern among Puerto Rico residents. These concerns are consistent with the recent experiences of residents following Hurricanes Irma and María, the 2019–2020 earthquake sequence in southwestern Puerto Rico, and the increasing exposure to extreme heat events. Respondents reported that natural hazards have had substantial impacts on their mobility, with roadway and transportation infrastructure damage consistently identified as the primary cause of transportation disruptions.

Strong winds associated with storms and hurricanes were perceived as the hazard most likely to generate prolonged roadway disruptions, often lasting weeks or months. More than half of respondents reported travel time increases greater than 15 minutes when forced to use alternate routes following transportation disruptions, while approximately 13% to 15% reported having no alternate route available. These findings highlight the critical role that roadway redundancy plays in supporting transportation accessibility and community resilience.

The survey further revealed that environmental conservation and tourism are widely recognized as important contributors to local economic development. Respondents from both coastal and non-coastal communities identified these activities as among the most important Blue Economy sectors. At the same time, roads providing access to beaches, recreational areas, environmental reserves, and other coastal destinations were frequently rated as being in fair or poor condition. This suggests that transportation infrastructure may represent a constraint to expanding the economic benefits associated with Blue Economy activities.

The Bajura case study in the Municipality of Isabela was selected as an appropriate community for implementing the CREATE UPRM framework. The area's exposure to coastal hazards, dependence on limited transportation corridors, active tourism economy, and strong municipal engagement provide a suitable environment for future transportation vulnerability assessments, transportation network analysis, educational activities, and virtual reality applications.

Finally, Phase I successfully established the methodological foundations required for future project activities. The transportation accessibility framework, vulnerability assessment framework, transportation network analysis framework, virtual reality scenarios, and research-to-practice strategy were initiated and developed sufficiently to support implementation and evaluation during subsequent project phases.

Implications for Future CREATE Activities

The survey results provide valuable information for future CREATE UPRM tasks related to transportation vulnerability assessment and corridor analysis. The identified perceptions of risk, accessibility challenges, roadway dependency, and mobility disruptions can be incorporated into

the proposed expansion of the FHWA Vulnerability Assessment Scoring Tool [VAST] by including community-related vulnerability indicators.

Similarly, the findings support the transportation network analysis activities planned for the Bajura case study. The reported increases in travel time, dependence on limited roadway corridors, and lack of alternate routes reinforce the need to quantify accessibility reductions resulting from flooding and roadway disruptions.

The results also provide direct input for future workforce development and educational efforts. The reported concerns regarding transportation accessibility, mobility disruptions, and natural hazards identify priority topics for training modules, community outreach activities, and future educational materials to be delivered through CREATE and the Interactive Learning Hub [IL-HUB].

In addition, the survey findings provide contextual information that will guide the development of virtual reality scenarios and educational experiences focused on transportation resilience, accessibility, flooding impacts, and community preparedness.

Recommendations

The following recommendations are included in this report based on the results and focusing on the different aspects related to the CREATE UPRM project.

Transportation Planning and Infrastructure

- Prioritize resilience improvements for critical transportation corridors that provide access to coastal communities, employment centers, healthcare facilities, and Blue Economy destinations.
- Identify and strengthen alternate transportation routes for communities that currently rely on a limited number of roadway connections.
- Incorporate transportation resilience considerations into municipal transportation planning, emergency management plans, and infrastructure investment decisions.
- Improve monitoring and maintenance practices in locations vulnerable to flooding, landslides, coastal erosion, and hurricane impacts.

Accessibility and Alternative Modes

- Improve pedestrian infrastructure, particularly sidewalk continuity, accessibility ramps, obstacle removal, and pedestrian safety features.
- Expand infrastructure supporting bicycles and micromobility devices to provide additional transportation alternatives during everyday conditions and emergency situations.
- Evaluate opportunities to improve public transportation availability, reliability, and service frequency, particularly in municipalities with limited transportation alternatives.

Community Education and Outreach

- Develop targeted educational materials addressing hazards identified as high priorities by residents, including hurricanes, earthquakes, flooding, and extreme heat.
- Expand community awareness programs related to transportation preparedness, evacuation planning, and transportation resilience.
- Use visualization technologies such as virtual reality to support public understanding of hazard impacts and resilience strategies.

Workforce Development

- Develop professional development activities focused on transportation resilience, hazard mitigation, accessibility analysis, and Blue Economy transportation issues.
- Integrate transportation resilience, vulnerability assessment, and accessibility concepts into university curricula and workforce development programs.
- Create training materials that help transportation practitioners understand the interactions among infrastructure performance, community vulnerability, and accessibility.

Future Research

- Conduct larger and more representative surveys to further evaluate differences among communities, demographic groups, and geographic regions.
- Implement the proposed enhanced transportation vulnerability assessment framework and quantify the influence of community characteristics on transportation resilience.

- Complete the transportation network simulation activities for the Bajura case study and evaluate the impacts of flooding-related disruptions on travel times, accessibility, and emergency mobility.
- Implement and evaluate the VR experimental framework to determine its effectiveness for risk communication, transportation resilience education, and community preparedness.
- Expand future analyses to examine relationships among demographic characteristics, transportation choices, hazard perceptions, accessibility conditions, and resilience outcomes.

DATA AVAILABILITY STATEMENT

Survey data used in this study were obtained through an online questionnaire administered to 366 adult residents of Puerto Rico. The dataset includes responses related to transportation accessibility, transportation vulnerability, mobility impacts from natural hazards, and perceptions regarding coastal and Blue Economy activities. Because the survey contains information derived from human subjects and was collected under informed consent procedures, socio-demographic information from individual responses is not publicly available. Aggregated survey results, figures, tables, and summary statistics are included in this report. Requests for access to de-identified data for research purposes may be submitted to the project investigators and will be evaluated in accordance with applicable data privacy and human subjects' protection requirements. The dataset are available in the Zenodo Data Share repository with the identifier https://zenodo.org/records/23044763.

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