Transportation System Resiliency and Disaster Response and Recovery: A Review on U.S. Metropolitan Long-Range Transportation Plans (TRBAM-22-00866)

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Abstract
Natural disasters pose a threat to the proper functioning of transportation systems, and their risks and impacts may intensify as a result of climate change, making it critical for cities and regions to enhance their transportation systems and emergency response operations to better withstand and respond to future threats. This study analyzed whether metropolitan planning organizations across the U.S. incorporate the concepts of transportation system resiliency and disaster or emergency response and recovery into the guidance statements (vision, goals, and objectives) and performance measures (metrics and targets) of their long-range plans. The study evaluated 20 long-range plans and focused on the Portland, Oregon metropolitan region as a case study. Overall, most plans recognize the need for more resilient transportation systems yet lack performance measures intended to ensure that the MPOs are actually increasing the resiliency of their systems. Disaster and emergency response and recovery showed up minimally in both the guidance statements and performance measures of the plans. The Portland, Oregon metropolitan region has done extensive work with disaster recovery, and the region's MPO plans to incorporate resiliency and recovery work in the next version of the region's long-range transportation plan.

1. Introduction

Transportation systems play a fundamental role in connecting people to jobs and services and facilitating daily societal activities. The normal functioning of transportation systems is susceptible to disruptions caused by disasters, both natural and manmade, that can negatively impact the people that depend on them. Improving the resiliency of transportation systems is a critical part of emergency response and recovery after disasters. Post-disaster actions depend on a stable, functioning, and connected transportation network to operate. A durable and resilient system can better withstand the threat of natural disasters and continue to function during disasters or after disaster strikes. The concepts of transportation resiliency and disaster response and recovery are not new, but they are becoming increasingly relevant as the risk of natural disasters has become greater in recent years and may continue to grow as a result of climate change (Schwartz 2016; Wuebbles 2016).

Over the past several years, the frequency and impact of extreme natural disasters on transport infrastructure has grown significantly, and it is expected that climate change will intensify these impacts (Rozenberg et al. 2019). According to the National Centers for Environmental Information (NCEI), over the past 40 years, the U.S. has experienced 258 weather and climate disasters that have cost at least, if not more than, $1 billion dollars in damages (Smith 2020). The years 2016-2019 have each experienced more than 12 different billion-dollar disasters, increasing the frequency of billion-dollar disasters from an annual average of 6.5 events over a forty-year span to an annual average of 13.8 events between the years 2015 and 2019 (Smith 2020).

One way to better prepare for regional disruptions and mitigate the impacts from natural disasters is through the long-range transportation plans (LRTPs) that are developed by

metropolitan planning organizations (MPOs). MPOs are regional transportation policy making organizations in the US that must represent any urbanized area with populations over 50,000 (Federal Transit Administration 2019). LRTPs typically look 20 years into the future and are used to guide transportation planning, operations, funding decisions, and project prioritization based on a set of goals and objectives (Federal Highway Administration 2020). Since LRTPs guide future development, it is essential for MPOs to anticipate any changes that may occur, such as the impacts of climate change. Recent costly and damaging natural disasters, like Hurricane Sandy and droughts and wildfires in Texas, California, and Colorado, have proven that planning for the future should involve accounting for severe damage from natural disasters (Baglin 2014). MPOs should plan future designs of roadways and other transportation infrastructure to withstand potential extreme weather events rather than simply maintain the existing transportation system and continue to develop LRTPs in the same fashion as before.

Historically, the idea of transportation system resilience and disaster response and recovery was largely missing from regional plans, but in recent years, these concepts are beginning to show up in these types of plans. One study from 2007 examined the plans of state departments of transportation (DOT), MPOs, and transit agencies in 20 regions across the U.S. to assess how well these agencies address emergencies (Bailey 2007). The study found that the majority of the MPOs had minimal plans set in place for disaster response and recovery, such as the lack of accounting for communicating emergency information to the public, and the failure to plan for communicating or coordinating activities, such as evacuation, with vulnerable populations (Bailey 2007). In 2018, a study found that MPOs better incorporated resiliency versus state DOTs into plans and planning process (FHWA 2018). MPOs also began identifying resilience strategies, even if they have not conducted a formal vulnerability assessment or developed resilience-specific evaluation criteria. The focus of the review was on resiliency efforts and not on evacuation, response, and recovery.

1.1 Research Questions

Our goal is to assess how MPOs are incorporating resilience into their LRTPs, and if these agencies are accounting for response and recovery needs after disasters. This paper will evaluate 20 regional transportation plans from MPOs across the country. In addition to the content analysis, this paper will focus on a case study of the Portland, Oregon metropolitan region. This case study will highlight work done by the Regional Disaster Preparedness Organization (RDPO) and Metro, the MPO for the Portland regional metropolitan area, regarding the designation, tiering, and operationalization of Regional Emergency Transportation Routes (RETRs). The paper seeks to answer the following research questions:

- How do the plans frame the idea of resiliency?
- How is transportation system resiliency, recovery, and response represented in regional plans' goals, objectives, and performance measures?
- How can transportation resiliency, recovery, and response be better incorporated into LRTPs?

2. Background

There is no standard definition for or measurement of resilience in transportation. The AASHTO–TRB Transportation and Security Summit in 2009 defined resilience in the transportation sector as "The ability of a system to provide and maintain an acceptable level of service or functionality in the face of major shocks or disruptions to normal operations," while the FHWA Order 5520 expanded the definition slightly to say, "The ability to anticipate, prepare for and adapt to changing conditions and withstand, respond to and recover rapidly from disruptions" (National Academies of Sciences, Engineering, and Medicine 2018). Though slightly different in scope, these two definitions highlight the need for a system to be able to respond to and recover from disruptions. Disruptions, both manmade and natural, and inadequate preparation for such disruptions, can prevent effective medical response,evacuation measures, or other necessary response actions. When Hurricane Rita threatened Houston, Texas in 2005, 3.7 million people attempted to evacuate the Houston region to avoid a similar situation to New Orleans during Hurricane Katrina (Domonoske 2017). Dozens of people died in the evacuation effort as a result of severe congestion in extremely high heat that lasted for several days. This example emphasizes the importance for cities and regions to properly plan for evacuations and other response and recovery activities.

The adoption of Asset Management in the public sector in 1995 ushered in a new approach to managing pavements, bridges, and other infrastructure, but this approach was based on maintaining a state of good repair and not on improving resilience, response, or recovery (AASHTO 2015). DOTs across the country modeled the new approach after principles used in the private sector. Around the 2000s, DOTs shifted focus towards improving the reliability of the transportation system through improved operations after the FHWA Office of Operations was created to provide a good foundation for improved operations work for DOTs. After 9/11, the role transportation plays in emergency response became clear. The National Response Framework (NRF), a guide developed by the Federal Emergency Management Agency (FEMA) on how nations should respond to disasters, stated, "The ability to sustain transportation services, mitigate adverse economic impacts, meet societal needs, and move emergency relief personnel and commodities will hinge on effective transportation decisions at all levels" (AASHTO 2015).

The federal government provides guidance for regions working to improve preparedness and recovery efforts for their transportation systems, as well as sets requirements for MPOs to adhere to, particularly when developing and enacting long-range plans. In 2011, FEMA first developed the National Disaster Recovery Framework (NDRF) as part of the National Preparedness System to guide and support MPOs with making decisions about incorporating recovery practices into transportation planning (FEMA 2011). The National Preparedness System integrates efforts across five preparedness mission areas—Prevention, Protection, Mitigation, Response, and Recovery. The goal of the report was to strengthen disaster recovery across the US. The report was updated in 2016 to expand on the other mission areas, prevention, protection, mitigation, and response. Together, the definitions for 'protection' – "the capabilities necessary to secure the homeland against acts of terrorism and man-made or natural disasters" –

and 'mitigation'– "the capabilities necessary to reduce loss of life and property by lessening the impact of disasters" – can provide an idea of what a resilient transportation system is capable of. All mission areas work together to create a transportation system that is more resilient to threats and disasters and safer for those who depend on it. Additionally, unlike previous funding bills, recent funding bills consider resiliency as part of transportation planning requirements. The Fixing America's Surface Transportation (FAST) Act, signed into law in 2015, "expands the focus on the resiliency of the transportation system as well as activities to reduce stormwater runoff from transportation infrastructure" (FHWA 2016). It newly requires MPOs to consider strategies focused on reducing the vulnerability of existing transportation infrastructure to natural disasters and other threats.

Climate change may play a greater role in transportation system resiliency and disaster recovery in the future. According to the International Panel on Climate Change, climate change is "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (United Nations 1992). Scientists expect natural disasters, like flooding, hurricanes, and wildfires, to be exacerbated by climate change, which can have major impacts on the functioning of transportation systems (Milman 2019; Rozenberg 2019; Schwartz 2016; Wuebbles 2016). The existing transportation system is designed for historic weather conditions, and often does not take into account global temperatures increasing at faster rates and changing weather patterns that can damage roadways and bridges. The long-term reliability and functioning of transportation systems will need to consider and plan for climate change and extreme weather events (Markolf 2019).

The Federal Highway Administration (FHWA) created the Vulnerability Assessment Framework, third edition, in 2017 to help transportation agencies conduct vulnerability assessments of their transportation infrastructure to extreme weather events. The Genesee Transportation Council (GTC), the MPO for the Genesee–Finger Lakes Region (Greater Rochester region) in upstate New York, provides an example of an MPO that has utilized the Framework to conduct vulnerability assessments and incorporate resilience initiatives into their agency. The project identified natural and manmade hazards, and the assessment studied the roadways, bridges, emergency response facilities, traffic and transit operation centers, highway garages, and fuel storage. According to the Council, "the major goal of the GTC vulnerability assessment was the development of a process to prioritize investments on transportation infrastructure projects that help to increase the resilience of the region" (National Academies of Sciences, Engineering, and Medicine 2018). Throughout the process, the Council learned of the importance of interagency partnerships and integration of the vulnerability assessments into decision-making processes (National Academies of Sciences, Engineering, and Medicine 2018).

3. Methods

We reviewed the long-range transportation plans for several MPOs to assess the state of transportation resiliency and recovery in practice around the US. We selected 20 MPOs based on their history of natural disasters and likelihood for future disasters. We also wanted to ensure that

a variety of regions across the US were represented. The regional plans for each MPO were collected from their respective websites. After obtaining plan documents, we performed a content analysis on the text data focusing on the following terms: ‘resilience’ or ‘resiliency,’ ‘hazard mitigation,’ ‘disaster recovery’, ‘disaster (or emergency) response,’ ‘emergency management’, ‘evacuation,’ and ‘extreme weather.’ These terms were chosen because of their relevance.

To better assess the content, we focused on two areas of the LRTPs: guidance statements and performance measures. Guidance statements are considered the language or overarching statements that guide plan development. Guidance statements were identified using these terms: ‘vision,’ ‘goal,’ and ‘objective.’ Performance measures are metrics that are used to evaluate how well the proposed projects and programs are performing. Performance measures were identified using these terms: ‘performance,’ ‘measure,’ ‘metric,’ and ‘target.’ We thoroughly scanned each of the plans to ensure no relevant section was missed during our initial word search.

We divided the guidance statements and performance measures into ‘Resiliency,’ ‘Recovery,’ and ‘Response’ to capture which themes were present for each (Table 2). The 2018 Regional Transportation Plan for Portland, Oregon defines resilience or resiliency as “[...] the ability to anticipate, prepare for and adapt to changing conditions and withstand, respond to and recover rapidly from disruptions (Metro 2018).” FEMA defines ‘recovery’ as actions done to “assist communities affected by an incident to recover effectively” and ‘response’ as actions meant to “save lives, protect property and the environment, and meet basic human needs after an incident has occurred” (FEMA 2016). In this analysis, resiliency encapsulates any action that responds to extreme weather or mitigates hazards; recovery includes roadway or bridge repairs, restarting transit services, and investments in new and improved infrastructure specifically after natural disasters; and response is defined as any action that involves medical response or emergency services, such as evacuations, following natural disasters. The terms mentioned earlier were divided among those three themes:

I. Resiliency: ‘resilience,’ ‘resiliency,’ ‘hazard mitigation’
II. Recovery: ‘disaster recovery’
III. Response: ‘disaster response,’ ‘emergency response,’ ‘emergency management,’ ‘evacuation.’

4. Results

This section will describe our main takeaways from the content analysis. Table 2 displays the presence of guidance statements and performance measures related to resilience, recovery, and response in the LRTPs. We will first summarize how MPOs incorporated resiliency, recovery, and response into the guidance statements of the LRTPs. We will then detail how each theme appeared in the performance measures.

4.1 Resiliency, recovery, and response within guidance statements

4.1.1 Resiliency

Only 15 of the plans referenced resiliency within guidance statements. The Southern California Association of Governments (SCAG) provides an example: Enhance the preservation, security, and resilience of the regional transportation system (Southern California Association of Governments 2020).

After analyzing all of the plans, it became apparent that most of the MPOs connect the idea of resilience to climate change or protection from weather related events. Eight of the plans explicitly mention climate change or climate protection. The LRTP from Portland, Oregon explicitly mentions natural disasters in one of its guidance statements: Reduce the vulnerability of regional transportation infrastructure to natural disasters, climate change and hazardous incidents (Metro 2018). In regard to climate change, MPOs either focus on mitigation strategies – strategies that lessen carbon emissions – or adaptation strategies – those that reinforce the existing transportation infrastructure to be more resilient to extreme weather events or other climate-related disasters. An example of a mitigation strategy is: Preserve and maintain the region's motor vehicle network system in a manner that improves safety, security and resiliency while minimizing life cycle cost and impact on the environment (Metro 2018). An example of an adaptation strategy is: Improve management of stormwater runoff and use green infrastructure solutions to mitigate the impacts of extreme weather and climate change (North Jersey Transportation Planning Authority 2017). A strategy from the Mid-America Regional Council (MARC)'s LRTP provides a good example of an MPO recognizing that resiliency can be approached through both mitigation and adaptation: Take a multi-pronged approach to building resilience and reducing climate risks to transportation infrastructure and area communities while also ensuring that the transportation system's impact on the climate decreases significantly over time (Mid-America Regional Council 2020). SCAG recognizes that climate mitigation and adaptation efforts are critical for supporting an integrated regional development pattern and transportation network. The agency understands that the greater the climate mitigation efforts in the short-term, the less adaptation will be needed in the long-term. One of SCAG's strategies is to support development of local climate adaptation and hazard mitigation plans that are separate from the regional transportation plan (Southern California Association of Governments 2020).

The Atlanta Regional Commission (ARC) and Regional Planning Commission (RPC) from New Orleans, Louisiana recognize the need for transportation systems to be resilient to both chronic stressors and present-day threats as well as period shocks and more extreme future

threats (Atlanta Regional Commission 2021; Regional Planning Commission 2019). The North Jersey Transportation Planning Authority (NJTPA) and Metropolitan Council from St. Paul, Minnesota strategize to reduce the transportation system's vulnerability to human-caused incidents and threats in addition to the changing climate and weather (Metropolitan Council 2018; North Jersey Transportation Planning Authority 2017).

Three of the plans used pilot programs to guide plan formation and decision-making (Atlanta Regional Commission 2021; Broward County MPO 2019; Hillsborough MPO 2019). The ARC adopted a framework in 2018 that helps protect against long-term threats to the transportation system (WSP USA Inc. 2018). Using a grant from the FHWA Resilience Pilot Program, the MPO developed a GIS-based tool that allowed them to apply the framework to their decision-making processes and conduct a system vulnerability assessment. The results from the pilot program will continue to be used to improve the region's planning goals and objectives and incorporate resilience into future transportation plans (Atlanta Regional Commission 2021). Similar to the ARC, the Broward County MPO conducted two studies that determined the impact of extreme weather on the area's regional transportation network based on sea-level rise, storm surge, and precipitation-induced flooding, and identified vulnerable facilities and methods for treatments to protect the vulnerable facilities from those stressors (Broward County MPO 2019). The findings from both studies were incorporated into the LRTP. The Resilient Tampa Bay: Transportation Pilot Program Project evaluated adaptation strategies, or projects, for inclusion in the Hillsborough MPO's LRTP, and completed a cost-benefit analysis of potential investments for inclusion in the LRTP (Hillsborough MPO 2019). The project also prioritized critical infrastructure in the region.

The Puget Sound Regional Council (PSRC) and Sarasota-Manatee MPO also have efforts currently underway to enhance regional resiliency (Hillsborough MPO 2019; Puget Sound Regional Council 2018; Sarasota-Manatee MPO 2020). The investments in the PSRC's Regional Transportation Plan support their efforts for a resilient transportation system and continued public safety and economic vitality. For example, the work to better estimate and identify maintenance and preservation needs, and the focus in the plan's financial strategy to prioritize those investments, is critical to ensure the ongoing stability of the system (Puget Sound Regional Council 2018). Individual investments by the state and local jurisdictions are being designed to address resiliency and ensure long-term viability for those assets. The Sarasota-Manatee MPO developed the Tampa Bay Regional Resiliency Coalition (TBRPC) Memorandum of Understanding to support coordinated resiliency efforts in the region (Sarasota-Manatee MPO 2020).

4.1.2 Recovery

Only two plans referenced recovery in guidance statements. The LRTP for the Kittery Area Comprehensive Transportation System (KACTS) recommended that the MPO continue to collaborate with neighboring MPOs to "develop a regional all hazard transportation recovery plan that incorporates climate-related information and facilitates recovery and repair that enhances resiliency of transportation infrastructure" (Metropolitan Council 2018). The LRTP for

the Sarasota-Manatee MPO was more general and provided the objective to improve the transportation system for evacuation and recovery (Kittery Area Comprehensive Transportation System 2019). The Sarasota-Manatee MPO also referred to the All Hazards Recovery training that it received in 2017. This training taught the MPO the tools, knowledge, skills, and resources necessary to develop an emergency transportation recovery plan. The MPO documented those teachings for MPO staff and its jurisdictions, so that they can be incorporated into future planning efforts in order to enhance regional resiliency and recovery efforts (Kittery Area Comprehensive Transportation System 2019).

4.1.3 Response

Five MPOs discuss response activities in the guidance statements of their plans. Most of them focus on improving overall safety and security for the regions through the improvement of emergency response and management or promotion of evacuation planning. Three MPOs discuss strategies for improving communication between different agencies and emergency responders during hazards and extreme weather events (Regional Planning Commission 2019; Sarasota-Manatee MPO 2020; WSP USA Inc. 2018). The Metropolitan Council provides an example:

> Regional transportation partners should work with local, state, and federal public safety officials, including emergency responders, to protect and strengthen the role of the regional transportation system in providing security and effective emergency response to serious incidents and threats (Regional Planning Commission 2019).

The Metropolitan Council recognizes the importance of regional highways when responding to emergencies involving fire, ambulance, disaster, and evacuation (Regional Planning Commission 2019). The Broward County MPO (BMPO) included a strategy to identify and implement transportation projects that add alternate routes and connections (WSP USA Inc. 2018). The ARC and Coastal Region MPO discuss strategies to consider the location of key emergency evacuation routes, or promote evacuation projects (Mid-America Regional Council 2020; North Front Range MPO 2019).

4.2 Resiliency, recovery, and response within performance measures

4.2.1 Resiliency

Only three plans have metrics put in place to measure how well existing infrastructure is being adapted or protected in order to withstand future extreme weather events and function post-disaster. The Broward County MPO has a performance measure focused on the number of miles of public roads and rail forecasted to be permanently inundated by between one to two feet of sea level rise by 2045 (WSP USA Inc. 2018). The Hillsborough County MPO aims to protect 250 lane miles of highly vulnerable and critical roads from heavy rain and storm surge with shoreline protection, pavement hardening, and stormwater drainage improvements (Coastal Region MPO 2019). The Hillsborough County MPO also plans to invest $22 million per year to make highly vulnerable and critical roads resilient to flooding and storms and prevent up to $100

million in daily economic losses (gross regional product) from impassable roads after major weather events (Coastal Region MPO 2019). The Coastal Region MPO measures the reduction in the vulnerability of the transportation system based on the implementation of actively monitoring infrastructure, shoulder stabilization, battery backup for signals, and more (North Front Range MPO 2019).

4.2.2 Recovery

None of the regions explicitly provided metrics for disaster recovery work. Instead, most of the plans refer to incident management in their performance measures. For example, the Coastal Region MPO in Savannah, Georgia has a performance measure that reads as follows:

> Minimize clearance times during disruptive events to avoid secondary crashes (such as reductions in time to clear major crashes from through lanes, CHAMP clearance times) (North Front Range MPO 2019).

These performance measures seem to refer primarily to vehicular crashes, but could be applied to the clearance of debris or other obstacles after disasters. Since measures do not explicitly mention natural disasters, we did not consider any of the regions to have recovery performance measures.

4.2.3 Response

Only three plans mentioned metrics for measuring improvements to emergency response. The performance measure for Houston, Texas was extremely general. The plans for the BMPO and Coastal Region MPO were more specific and focused on evacuations (North Front Range MPO 2019; WSP USA Inc. 2018). The BMPO provides an example:

> Maintain or increase the number of lane miles of evacuation routes per 100,000 people by 2045 (WSP USA Inc. 2018).

5. Case Study

For a deeper example of work that MPOs are doing in relation to transportation system resiliency and disaster response and recovery in long range plans, we will discuss the activities in Portland, Oregon. The region's MPO, Metro, oversees three counties, which includes Clackamas, Multnomah, and Washington counties, and serves more than 1.5 million people living in 24 cities, including Portland.

The City of Portland's Mitigation Action Plan (MAP) recognizes a number of potential disasters that could affect the region, including severe weather, like thunderstorms, windstorms, and winter storms, moderate and high-intensity earthquakes, landslides, wildfires, flooding, and volcanic events (Hillsborough MPO 2019). Though each disaster could cause significant damage to the transportation system, one of the most substantial threats to the region is a major earthquake. The region is part of the Cascadia subduction zone, which is capable of producing very large earthquakes depending on the length of rupture during a seismic event (Tetra Tech 2016). . The Oregon Resilience Plan estimates that the current recovery period to restore

infrastructure damaged in a moderate to severe earthquake could take anywhere from weeks to years (Banse 2017). Likewise, a 2018 earthquake regional impact analysis from the Oregon Department of Geology and Mineral Industries (DOGAMI) for the Portland metropolitan region projects significant casualties and economic losses ranging from $23.5 to $83.4 billion dollars in the event of a major earthquake (Oregon Seismic Safety Policy Advisory Commission 2013). After earthquakes, the most likely and damaging disasters are landslides, wildfires, and floods. More than 89,000 people, $20 billion dollars worth of infrastructure, and 200 critical facilities in Portland reside in landslide hazard areas. Over 19,000 buildings and 68,000 people are estimated to live in wildfire hazard areas. Lastly, over 9,500 people live in 1-percent-annual-chance flood hazard areas.

We evaluated Metro's 2018 Regional Transportation Plan (RTP) as part of our content analysis. The 2018 RTP recognizes a number of opportunities for future regional collaboration in support of transportation preparedness for natural disasters making it clear that the MPO understands the future threat of natural disasters that needs to be addressed. One of these opportunities was the need for an update of the emergency transportation routes (ETRs) that were first designated in 1996. According to the RTP, "these routes are designated to facilitate all-hazards emergency response activities, including those of medical, fire, law enforcement, and disaster debris removal in the immediate aftermath of an earthquake or other major event" (FEMA 2011). The ETRs are intended to be updated every five years, yet the last update occurred in 2006. In the Portland metropolitan region, there are four distinct types of emergency transportation routes: Local Emergency Response Streets (Routes), Local Emergency Transportation Routes (ETRs), Regional Emergency Transportation Routes, and Statewide Lifeline Routes. Local ETRs, RETRs, and lifelines can be represented as a hierarchy (Figure 1). In Oregon, lifelines connect regions of statewide importance and are limited to a few key north-south and east-west routes; regional ETRs connect nodes of population and critical infrastructure within a region; and local ETRs connect regional nodes to destinations of local importance, such as populated areas, distribution centers, medical facilities, and fire stations (Bauer et al. 2018).

To update the RETRs, Metro partnered with the Regional Disaster Preparedness Organization (RDPO), which helps coordinate preparedness efforts around the metropolitan region, including Clackamas, Columbia, Multnomah, and Washington counties in Oregon and Clark County in Washington. RDPO is a partnership of government agencies, non-governmental organizations, and private-sector stakeholders, joined in a mission to "build and maintain regional disaster preparedness capabilities in the Portland Metropolitan Region through strategic and coordinated planning, training and exercising, and investment in technology and specialized equipment" (Shandobil & MacArthur 2019). The RETR project focused on creating regional connections for judications and essential locations and services under a large seismic event, though considerations for other natural disasters were also integrated into the data set to shape future recommendations (Regional Disaster Preparedness Organization n.d.). The updated RETR designations will be included in the next iteration of the RTP for the Portland metropolitan region in order to strengthen resilience and disaster recovery across the region. Beyond the

update, the project seeks to raise visibility of the RETRs, improve understanding of what is needed to recover quickly from disasters, and strengthen regional partnerships around resiliency and recovery.

The project was divided into two phases. The first phase gathered background data and information. In the summer and fall of 2019, the Transportation Research and Education Center (TREC) at Portland State University prepared background research for the project to help shape the methodology used to identify the RETRs. The methodology was also informed by information gathered during the previous update as well as input from the RETR work group. The RETR work group included over twenty stakeholders that spanned multiple jurisdictions and departments. Representatives came from each of the five counties and the larger cities, including emergency management planning and operations, transportation planning and operations, public works, and staff from the Oregon Department of Transportation (ODOT), Washington Department of Transportation (WSDOT), and regional transportation agencies. In early 2020, RDPO and Metro developed a memorandum that outlines the criteria used to identify the best regional routes for emergency response during a seismic event. The criteria were connectivity and access, route resilience, and equity. This process generated updated RETRs as shown in Figure 2 (Thuy Tu Consulting 2021).

As part of the first phase, TREC distributed a survey to agencies across the Portland metropolitan region to explore the priorities, gaps, and barriers related to transportation resilience and recovery in the region. The survey received 16 organization responses from a variety of stakeholders, including representatives from different counties and transit authorities in the region. The survey revealed that most regional agencies have conducted vulnerability assessments for their local transportation infrastructure yet have not incorporated resiliency into their local transportation plans, maintenance activities, or system operations plans. According to respondents, the greatest barriers to incorporating resiliency and recovery into transportation plans are resource-based (i.e., the availability of personnel) and financial. The majority of respondents believe that determining the vulnerability of all assets in the regional transportation network and creating a prioritized list of the assets should be the region's highest priority in order to increase regional transportation system resiliency. This action could be integrated into the next long-range transportation plan. Though the second phase of the project has not yet started, respondents believe the region should conduct an engineering evaluation of the regional ETRs for seismic upgrades and integrate the regional ETRs into local plans and planning and investment decision processes. Prioritizing these projects based on resilience to seismic events and measuring how many seismic retrofit projects are completed could be a good performance measure for resilience.

In the survey, project stakeholders identified following priorities for additional future work:

1. Engineering evaluation of priority (tiered routes) for seismic upgrades
2. Integrate RETRs into other planning and investment decision processes
3. Integrate RETRs and LETRs into local evacuation planning
4. Develop equity-centered public messaging for transportation in emergencies

5. Evaluation of river routes for emergency response
6. Evaluate bike and pedestrian options for emergency transportation.

The second phase of the project beginning in 2022 will focus on prioritizing and operationalizing the RETR designations in order to inform investments and incident management. The project team will establish a tiering methodology and prioritization framework based on best practices research and discussion among stakeholders. This framework will develop and apply a GIS-based tiering methodology for comparing the different RETR segments, and designate which routes should be evaluated, cleared/fixed, and opened first, next, and last in a recovery scenario. The team will also establish operationalization guidelines and agreements that establish facility owner and operator roles and responsibilities and related coordination activities. There is potential for a memorandum of understanding (MOU) or intergovernmental agreement (IGA) to establish the prioritized routes and operational guidance for local jurisdictions. This would help provide consistency and clarity on coordination efforts in the region. To assist with these activities, TREC will help RDPO develop a series of workshops that facilitate discussion about transportation resiliency and recovery work and intergovernmental and interjurisdictional coordination.

6. Discussion

Federal planning factors largely influenced the plans we analyzed. Under the FAST Act, MPOs are required to outline performance measures to track their progress over time, as well as evaluate their assets and outline capital improvements and investments. The Federal Highway Administration (FHWA) established a rule in 2017 that requires MPOs to assess the condition of the following: pavements on the National Highway System (NHS) and interstate system and bridges carrying the NHS which includes on- and off-ramps connected to the NHS (Wilmington Urban Area MPO 2020). There are no requirements for reporting the proportion of pavements or bridges that are reconstructed to protect against damage from all hazards. It is important for MPOs to recognize that "[t]ransportation systems have largely been designed and operated for historical climate conditions that are now often exceeded," and that now, more robust infrastructure designs are needed to compete with the changing climate (Markolf et al. 2019). Noticeably, most of the plans did not develop performance measures to assess resilience beyond the basic federal requirements. Most of the plans focus on maintaining the quality of roadways and bridges rather than strengthening or adapting existing infrastructure to withstand extreme weather conditions or other hazards. Simple maintenance of current roadway and bridge designs, though important, may not be able to handle uncertain future conditions. Because of this, we decided not to consider adherence to the "State of Good Repair" and other federal requirements as 'resiliency' – only MPOs that provided measures beyond these requirements were considered to have performance measures related to resilience. Similarly, some transportation plans provide objectives that focus on reducing the transportation system's vulnerability to disasters, yet there are no performance measures set in place to measure outcomes or progress.

System reliability, or the efficiency of the surface transportation system, is connected to resiliency in one of the federal planning factors. In most plans, 'reliability' is referred to as dependable travel times and connections during 'normal' times, or standard use under fair weather conditions. Most plans do not intend reliability to mean dependability of the transportation system during extreme weather events or after natural disasters. In order to have resilient transportation systems, reliability should be expanded to include dependability during and after disasters. Additionally, dependability should not only pertain to infrastructure but emergency response and recovery activities as well.

Disaster recovery and response are largely missing from guidance statements and performance measures. Though preparing transportation infrastructure for disasters is important, improving emergency services and post-disaster actions are just as critical. Some MPOs, such as the Cape Fear MPO, mention previous extreme weather events that highlight the need for a more resilient transportation system, yet make no mention of evacuation planning or other disaster response and recovery work within their guidance statements. Though a significant number of the MPOs connect the idea of transportation system resilience to protection from climate change or weather-related events, the guidance statements and performance measures that focus on climate protection and mitigation do not always tie in disaster response or recovery. Guidance statements and performance measures related to climate protection focus more on minimizing air pollution or habitat loss than protection against disasters and recovery and response activities. Most of the plans discuss improving safety and security, but this pertains mostly to reducing injuries and deaths from vehicular crashes or bicycle and pedestrian accidents, and not during or after natural disasters. Metro, the MPO for the Portland, Oregon metropolitan region, provides an example of how to incorporate recovery work into regional plans. The MPO plans to incorporate the emergency transportation route designations from the recent update project into the next version of the LRTP.

Overall, most plans recognize the need for more resilient transportation systems yet lack performance measures intended to ensure that the MPOs are actually increasing the resiliency of their systems or improving disaster response and recovery actions. This may be because the FHWA is still developing a metric to evaluate the resiliency of improvement projects, but MPOs must develop a way to assess its progress even without the guidance of federal agencies. Recovery and response are not as widely recognized as resiliency despite their shared importance.

A significant challenge to integrating resilience, recovery, and response into transportation systems is regional cooperation. A true partnership among transportation, emergency management, and other key stakeholders (including public, private, and nonprofit entities) is essential to improve communities' resilience and speed up recovery from disasters (FHWA 2017). MPOs can play a critical role in improving regional cooperation among necessary stakeholders by providing guidelines and standards in long-range plans that stakeholders can refer to. When integrating climate adaptation efforts into a regional transportation system, establishing a common framework can help facilitate broader discussion

among transportation agencies and their partners, especially emergency management agencies, in order to identify current adaptation barriers and opportunities for interregional and interagency collaboration (Matherly 2014).

7. Conclusion

In conclusion, resilience and disaster response and recovery are becoming increasingly imperative considerations for transportation planning departments, yet this is not reflected in many of the guidance statements or performance measures of long-range transportation plans across the country. It is important to not only recognize the importance of these but to also recognize the need to develop actionable steps that hold transportation agencies accountable for making necessary changes to their practices.

CRediT Authorship contribution statement

Jai Daniels: Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing.
John MacArthur: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Table A.1. Metropolitan Planning Organizations and their Long-Range Transportation Plans

Region	Regional Organization	Population (2010)	Plan Year	Horizon Year	Reference #
Atlanta, GA	Atlanta Regional Commission (ARC)	4,818,052	2020	2050	23
Fort Collins, CO	North Front Range MPO (NFRMPO)	433,297	2019	2045	31
Fort Lauderdale, FL	Broward County MPO (BMPO)	1,748,066	2019	2045	25
Houston, Texas	Houston-Galveston Area Council (H-GAC)	5,892,002	2019	2045	41
Kansas City, MO	Mid-America Regional Council (MARC)	1,895,535	2020	2050	23
Los Angeles, CA	Southern California Association of Governments (SCAG)	18,051,203	2020	2045	21
Nashville, TN	Nashville MPO	1,494,356	2021	2045	44
Newark, NJ	North Jersey Transportation Planning Authority (NJTPA)	6,579,801	2017	2045	22
New Orleans, LA	Regional Planning Commission (RPC)	1,057,709	2019	2048	27
Phoenix, AZ	Maricopa Association of Governments (MAG)	4,055,281	2020	2040	42
Portland, OR	Metro	1,501,596	2018	2040	18
Dover, NH	Strafford Regional Planning Commission (SRPC)	146,865	2017	2040	45
Sarasota, FL	Sarasota-Manatee MPO	700,837	2020	2045	30
Springvale, ME	Kittery Area Comprehensive Transportation System (KACTS)	48,680	2019	2045	29
Oakland, CA	Metropolitan Transportation Commission (MTC)	7,150,828	Ongoing	2050	43
Savannah, GA	Coastal Region MPO	276,406	2019	2045	32
Seattle, WA	Puget Sound Regional Council (PSRC)	3,690,866	2009	2040	26
St. Paul, MN	Metropolitan Council	2,849,557	2020	2040	28
Tampa, FL	Hillsborough County MPO	1,228,761	2019	2045	33
Wilmington, NC	Wilmington Urban Area MPO (WMPO)	253,077	2020	2045	46

Table A.2. Resiliency, Recovery, and Response in Long-Range Transportation Plans

Region	Regional Organization	Guidance Statements			Performance Measures		
		Resiliency	Recovery	Response	Resiliency	Recovery	Response
Atlanta, GA	Atlanta Regional Commission (ARC)	✔	✔	✔	-	-	-
Fort Collins, CO	North Front Range MPO (NFRMPO)	-	-	-	-	-	-
Fort Lauderdale, FL	Broward County MPO (BMPO)	✔	-	✔	✔	-	✔
Houston, Texas	Houston-Galveston Area Council (H-GAC)	-	-	-	-	-	✔
Kansas City, MO	Mid-America Regional Council (MARC)	✔	-	-	-	-	-
Los Angeles, CA	Southern California Association of Governments (SCAG)	✔	-	✔	-	-	-
Nashville, TN	Nashville MPO	-	-	-	-	-	-
Newark, NJ	North Jersey Transportation Planning Authority (NJTPA)	✔	-	-	-	-	-
New Orleans, LA	Regional Planning Commission (RPC)	✔	-	-	-	-	-
Phoenix, AZ	Maricopa Association of Governments (MAG)	-	-	-	-	-	-
Portland, OR	Metro	✔	-	-	-	-	-
Rochester, NH	Strafford Regional Planning Commission (SRPC)	✔	-	-	-	-	-
San Francisco, CA	Metropolitan Transportation Commission (MTC)	-	-	-	-	-	-
Sarasota, FL	Sarasota-Manatee MPO	✔	✔	-	-	-	-
Savannah, GA	Coastal Region MPO	✔	-	✔	✔	-	✔
Seattle, WA	Puget Sound Regional Council (PSRC)	✔	-	-	-	-	-
Springvale, ME	Kittery Area Comprehensive Transportation System (KACTS)	✔	✔	-	✔	-	-
St. Paul, MN	Metropolitan Council	✔	-	✔	-	-	-
Tampa, FL	Hillsborough County MPO	✔	-	-	✔	-	-
Wilmington, NC	Wilmington Urban Area MPO (WMPO)	✔	-	-	-	-	-

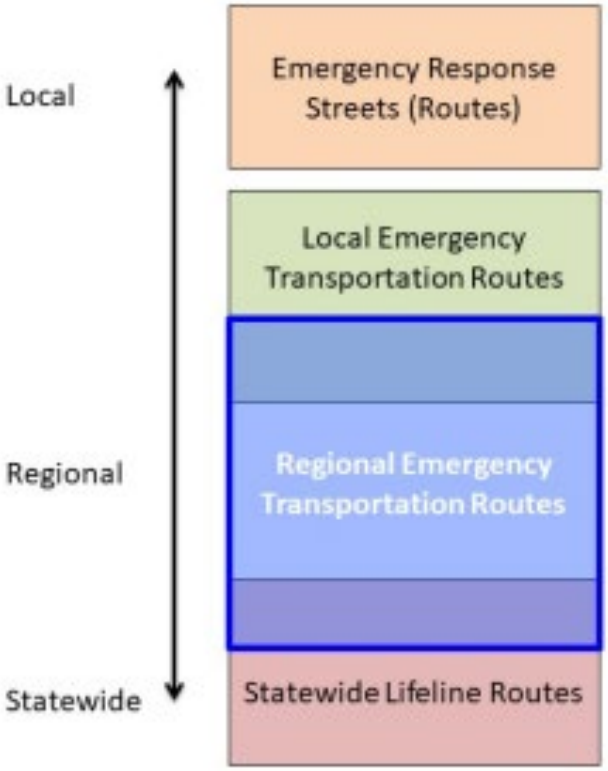

Figure A.1. Emergency Transportation Route Hierarchy

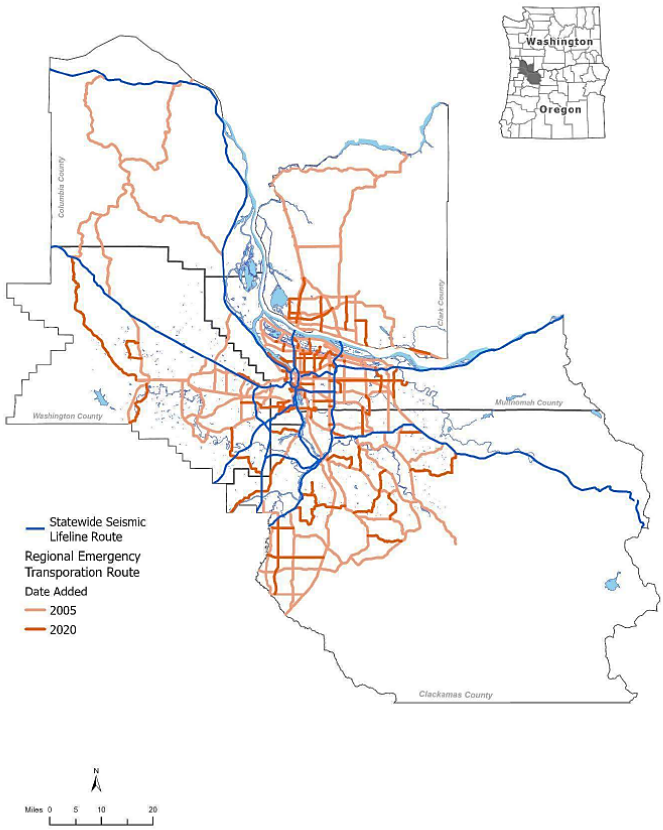

Figure A.2. Updated RETRs in the Portland Metro Region