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## **6. Transportation Sector**

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### **6.1. Introduction**

The transportation sector is critical to our daily lives. People use various methods of transportation on a daily basis to travel to and from work/school, visit family and friends, attend business meetings, and provide assistance in a medical emergency. However, the transportation network is used for much more than just personal needs. Businesses use trucks, ships, trains, and airplanes to transport goods from the source/manufacturer to communities. For example, food is often transported from the source (e.g., a farm) to a processing and packing plant, then a regional or national distribution center, which in turn sends the food to the local stores where it can be purchased by consumers. All of these steps, to get food from the source to the consumer's home/business, rely heavily on the transportation sector.

Traditionally, people think about the transportation sector as using roads and bridges to move both goods and people. While roads and bridges are a critical part of the transportation network, communities also rely upon other methods of transportation, including:

- Airplanes to transport people and goods long distances in a short period of time
- Passenger and freight rail to transport people and goods regionally/nationally
- Subways or light rail in large urban centers (e.g., New York, DC, Chicago, Los Angeles) to transport people to/from work and entertainment/leisure activities
- Ships to import/export goods to the international community
- Ferries to transport the workforce to/from work (e.g., San Francisco)

Although these other methods of transportation provide additional ways to move people and goods efficiently, they cannot be used alone. Many people rely on multiple methods of transportation (i.e., intermodal transportation) every day to travel to business meetings, and visit loved ones. Businesses use multiple methods of transportation to move goods efficiently and cost effectively. For example, businessmen and woman often travel long distances for meetings using air transportation, but also use a vehicle to get from their home or place of business to the airport, and then from the airport to their meeting location. Similarly, goods may be imported using ships. However, to get the goods from the ship to the next step in the supply chain requires using either trucks or rail. More discussion on intermodal transportation is in Section 6.1.2.

Transportation systems are a large part of our daily lives in the United States and are often taken for granted. The transportation sector is even more important in the aftermath of a natural disaster to permit:

1. Emergency repair crews for other sectors (energy, communications, and water/wastewater) to access areas where there are failures so they can be repaired and their services can be brought back online
2. Emergency response crews (firefighters, paramedics, police) to reach people in need
3. Parents to convey their children from school or daycare
4. People to attend to the needs of vulnerable family members (e.g., the elderly/ill) and friends

However, when addressing resilience, communities must also consider the longer term and improving transportation network performance in the next disaster event. The intermediate and longer term needs of communities, in terms of the transportation infrastructure, include:

1. Ability for citizens to get to work, school, and sports/entertainment facilities
2. Re-establish access to businesses (both small and large), banks, retail, etc. so they can serve their clients
3. Re-establish access to key transportation facilities (airports, ports/harbors, railway stations) so goods can be transported and supply chain disruption is limited
4. Restoration, retrofits, and improvements for damaged infrastructure so it will not fail in the same way in a future event

5. Re-establish airports, subways, and light rail so mass transportation can be used to relieve stress on other components of the transportation network, such as roads and bridges.

This chapter addresses disaster resilience of the transportation sector. To address resilience of their infrastructure, communities need to first identify the regulatory bodies, parties responsible for the condition and maintenance of the infrastructure, and other key stakeholders. Communities should work with the stakeholders to determine the performance goals of the transportation infrastructure, evaluate the existing infrastructure, identify weak nodes and links in the network, and prioritize upgrades to improve resilience of individual network components and, consequently, the transportation network as a whole. This chapter identifies and discusses recommended performance goals for components of the transportation network through the use of a performance goals table. Communities can also use the performance goals table to identify the expected performance of existing infrastructure and identify their largest resilience gaps/prioritize improvements.

### **6.1.1. Societal Needs and System Performance Goals**

As discussed in Chapters 2 and 3, the social needs of the community drive the performance goals to be defined by each community and its stakeholders. The social needs of the community include those of citizens, local businesses, supply chains of large national and multi-national businesses, industry, and government. Each community should define its performance goals in terms of the time it takes for its critical infrastructure to be restored following a disaster event for three levels of hazard: routine, expected, and extreme, as defined in Chapter 3.

The community has short (0-3 days), intermediate (1-12 weeks), and long term (4-36+ months) recovery needs. Currently, communities think about recovery in terms of emergency response and management goals. For transportation these include:

1. Access to facilities for shelter, medical care, banks/commerce, and food
2. Access to areas where failures in other sectors (energy, communications, water/wastewater) require repair
3. Egress/evacuation from a community before or immediately after a disaster event, if needed
4. Ingress of goods and supplies immediately after event to provide aid

However, as discussed in the introductory section, communities must think about the longer term when addressing resilience. The intermediate goal of a community is to get back to normal in terms of their daily routine, including traveling to work and school, visiting local retailers and banks, and re-establishing their typical method transportation whether by car, bus, subway, light rail, or some combination of these methods.

In the long term, communities should strive to go beyond simply recovering by prioritizing and making improvements to parts of the transportation network that failed in the disaster or were the source of stress on the network (e.g., failure of the subway system in New York City, puts millions of people on the already congested road network, or worse, at home).

### **6.1.2. Interdependencies**

Chapter 4 details the interdependencies of all critical infrastructure sectors in a community. As the built environment within communities grows more complex and different systems become (more) dependent on one another to provide services, addressing the issue of interdependencies becomes an increasingly critical aspect of resilience.

Transportation systems play a critical role in supporting each other as well as critical services and infrastructure systems of other sectors. Hospitals, fire stations, police, and other emergency response systems depend on transportation before, during, and after a disaster. Evacuation depends on the capacity of roads, waterways, airports, and rail, as well as the government's ability to manage them. Relief efforts are hindered until damage to transportation systems is repaired.

Specific interdependencies of the transportation sector with the other sectors addressed in this framework include:

1. **Power/Energy** – The transportation system depends on the power and energy grid. Gas stations need electricity for vehicle owners to access fuel. As seen in Hurricane Sandy, without power, gas stations, utilities, and other entities that fuel transportation vehicles cannot operate and, therefore, hinder recovery. Electric energy is also needed for traffic signals to function. As seen during the northeast blackout of 2003, New York City’s 11,600 traffic signals were inoperable due to the loss of power, resulting in mass gridlock (DeBlasio et al. 2004). Airports, rail stations and ports rely on electric energy for lighting, functionality of mechanical components (e.g., loading equipment at a port), and for functionality of the buildings themselves (see Chapter 5). Subways and light rail rely on electric energy to function as well as for lights inside the tunnels. However, the energy industry also relies on the transportation sector so repair crews can reach areas where failures have occurred and bring services online quickly.
2. **Communication** – The communications sector relies on roads and bridges so repair crews can get into areas where there have been failures so that services can be repaired. Conversely, transportation systems depend on communications to relay information. Airports use communications to relay logistical and scheduling information to passengers (e.g., flight status times, gate changes, etc.) and to communicate with other air traffic via air traffic control. Light rail, train, and bus stations rely on communication systems to coordinate and schedule inbound/outbound times for users.
3. **Building/Facilities** – Buildings are rendered useless if people cannot reach them. The transportation system allows people to travel to critical facilities, businesses, and to other homes/facilities to check on the safety of friends, family and vulnerable populations.
4. **Water and Wastewater Sector** – Water and wastewater often passes underneath roads (i.e., below grade). Consequently, access to roads is needed to access points of failure. Moreover, leaks and failure of waterlines under roads can damage road foundations, and sinkholes may form. Conversely, critical facilities in the transportation sector (e.g., airports, bus, train, subway, and light rail stations) require water and wastewater for maintenance, sanitation, disposal, and emergency services (e.g., firefighting).

**Intermodal Transportation.** Due to the nature of our large, diverse transportation network and how it is used today, intermodal transportation is a key consideration for communities. Intermodal transportation varies by community, depending on the community’s size, needs, structure, and complexity. Individual citizens in some communities may function well using only the road network on a daily basis. However, the community needs access to the larger transportation network, and thus other methods of transportation are needed to get food and supplies to local retailers in these communities.

In today’s global environment, goods are often imported via airplane, ship (i.e., barge), truck, or train. If goods are imported by airplane or ship, they are then loaded onto either trains or trucks. Depending on the goods being transported, the next stop in the supply chain may be a manufacturing or processing plant, national/regional distribution center, or a warehouse. Retailers often use warehouses or regional distribution centers to manage their products and provide goods to local stores via truck in a short time frame. Therefore, coordination is needed between the different methods of transportation used by businesses to ensure that their products can be delivered to the customer. If one of the systems fails, there may not be a need for the others (e.g., if ships can’t import goods, there may be no need for the rail system to transfer those goods to the next stop in the supply chain).

People also use multiple methods of transportation on a daily basis, particularly in large urban centers, to get to/from work, school, entertainment facilities, homes of loved ones, banks, etc. People who live and work in large cities often rely on mass rapid transit, such as light rail or subways, for most of their commutes. However, to get to their individual final destinations, they may rely on the roadway system, including buses, taxis, or walking.

Although several methods of transportation are available to citizens and businesses and, hence, have redundancy built into the overall network, failures in one of the systems can put significant stress on other transportation systems. For example, loss of use of the subway system in Chicago, New York or DC would cause significant congestion and gridlock in the roadway network.

## 6.2. Transportation Infrastructure

The transportation sector in the United States is extremely large and complex. This section is divided into five main categories:

- Section 6.2.1 – Roads, Bridges, Highways, and Road Tunnels
- Section 6.2.2 – Rail and Subway Systems
- Section 6.2.3 – Air
- Section 6.2.4 – Ports, Harbors, and Waterways
- Section 6.2.5 – Pipelines

These sections discuss the components of their network, potential vulnerabilities, and strategies that have been used in the past to successfully mitigate failures. The first four sections deal with systems of the larger transportation network that are used to move both people and goods. The fifth section, Pipelines, discusses a system used to move resources alone (e.g., gas).

### 6.2.1. Roads, Bridges, Highways, and Road Tunnels

**Roads and Highways.** Roads and highways are vital to the nation's transportation infrastructure. The nation's four million miles of public roadways endured 3 trillion miles of vehicle travel in 2011 (ASCE 2013). The large network of roads and highways serves as the primary transportation infrastructure used by most people and businesses on a daily basis. Although other methods of transportation, such as subways and airplanes, which are discussed later in this chapter, are used to move mass amount of people and goods to specific hubs (i.e., nodes in the transportation network), roads and highways are used to get people and goods to their final destinations.

When considering the road network, communities need to think about not only cars and trucks, but other methods of transportation, including buses, bicycles, and pedestrians. Locally, communities (particularly large communities with a stressed road system) should develop a long-term transportation plan that encourages citizens to use other methods of transportation (e.g., bicycles and buses) in addition to personal vehicles. Bicycle lanes, for example, can be added by widening the road in a planned construction project by approximately 4 feet. It is noted, however, that the usefulness of making such changes will vary by community based on average commute time and accessibility to alternative methods of transportation. Regardless, the goal of a road system for a community should be to encourage and support as many methods of transportation as possible to make it more efficient, rather than relying on just cars and trucks.

In addition to moving people and goods on roads and highways, essential utilities distribute services either along-side, above, or below the grade of roads. Therefore, when roads and highways fail, it not only disrupts the ability to move people and goods – it can leave the necessary utility services vulnerable to both the initial and possible secondary hazards (e.g., a tree or other debris falling on an exposed gas or water pipe). For example, flooding can result in undercutting roads. In Figure 6-1, a pipe (an example of an interdependency) that lies directly underneath the road was also vulnerable to damage as a result of road failure.



**Figure 6-1: Road undercutting in the aftermath of Hurricane Irene.**

Roads are also susceptible to damage from earthquakes. The force of earthquakes can cause roads to split, as seen after the Loma Prieta earthquake (FHWA 2010). Moreover, secondary effects of earthquakes, such as landslides and fires can also damage roadways. In fact, liquefaction is a major vulnerability for all of transportation infrastructure (tunnels, bridges, railways, etc.), but roads are especially susceptible to landslides (Meyer et al. 2014).

Failure or loss of service of individual roads does not typically cause a major disruption for a community because redundancy is built into the road network (i.e., alternate routes can be used). Major disruptions occur when a significant portion or critical component of the road/highway network fails such that people and goods cannot get to their destination. Large areas of the road/highway system can be impacted by debris from high wind events (hurricanes, extra-tropical storms, tornadoes), flooding as was seen in Hurricane Sandy, earthquakes, and ice storms. In the short term, tree fall (see Figure 6-2) on roads slows-down emergency response and repair crews from getting to locations where their assistance is needed.



*Figure 6-2. Local Road Blocked by Fallen Trees after Remnants of Extra-tropical Storm Struck Kentucky (Kentucky Public Service Commission 2009)*

Ice storms, as previously discussed, can also cause tree fall and thus, road blocks, as seen after the January 2009 ice storm in Kentucky (Kentucky Public Service Commission 2009). However, ice itself can also shut down the road network because even relatively small amounts of ice make driving conditions dangerous, particularly in areas of the United States where communities are not well prepared for snow and ice storms due to their infrequent occurrence. In states that are well prepared for these events and experience them regularly, ice storms or large snowfall events do not typically cause significant disruptions to transportation.

**Bridges.** Bridges are important components of the road/highway and railway networks. Bridges make the road network more efficient by shortening routes and travel time for drivers. The number of bridges, their length, and their location within a community depends on the local geography and social needs of the community. Bridges, like roads, are impacted by environmental conditions of the community (e.g., freeze thaw cycles). Traditionally bridges include expansion joints, which allow rainwater, ice, snow, and other debris to get beneath the road surface. Though this is a maintenance issue, water and debris infiltration leads to corrosion and deterioration of both the superstructure (i.e., beams and deck) and substructure (e.g., piers, bearings and abutments), which can impact bridge performance when a disaster event occurs. However, some short bridges (i.e., less than 300 feet) are now being designed using integral abutments so expansion joints are eliminated, reducing this deterioration in the future (Johnson 2012).

Bridges are designed to meet the criteria in AASHTO and/or local DOT requirements that supersede AASHTO. The primary design consideration for bridges is traffic. AASHTO specifies application of a three axle truck (i.e., the HS20 truck), which has a gross mass of 72,000 lbs, for design (Tonias and Zhao 2007).<sup>1</sup> Therefore, although loads from natural disasters such as earthquakes, wind, and flood, are considered in the design process, traffic loading often governs design. As a result, in the expected event, there should be few, if any, bridge failures. However, as seen in past disaster events, bridges do fail during natural disasters. During Hurricane Katrina, wave-induced forces pushed multiple spans of the I-

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<sup>1</sup> The HS20 truck is not representative of a real truck used to transport good. It is used to simulate the maximum loading (shear and bending) that a bridge must withstand (Tonias and Zhao 2007).

10 twin bridges over Lake Pontchartrain off their bearings (Figure 6-3) (FHWA 2010). Scour (i.e., erosion of bank material around bridge foundations) is a leading cause of bridge failures (FHWA 2011).

Scour is most often caused by flooding and wave action, but can also be caused by earthquakes. Earthquakes in San Fernando Valley, Loma Prieta, and Northridge, CA have also shown that bridges can collapse due to failure of piers and decks (FHWA 2010).

Longer bridges tend to have relatively lightweight superstructures (decks and girders) so they can span long distances. Historically, their relatively low natural frequencies have made some of these bridges susceptible to high winds because their low natural frequencies could be matched by the high winds. Thus resonance of the bridge could occur, producing large oscillations and failure in some cases. However, modern long span bridges are mostly subjected to aeroelastic wind tunnel testing to understand the dynamics of the structure and make changes in design (e.g., adding dampers or changing aerodynamic properties) to avoid failure during high wind events (FWHA 2011). Moreover, some older long span bridges have been tested and retrofitted to ensure that they are not vulnerable to wind failures.



*Figure 6-3: Bridge sections slid off their moorings during Hurricane Katrina due to wave action.*

Similar to roads, failure of an individual bridge causes a disruption to the local road network, but does not always cause a major disruption of an entire community's road network. Because there are often alternative routes, the driver's commute time might increase. Failure of a bridge puts additional stress on other parts of the road network locally because the bridge is a choke point, which could cause people to avoid certain areas and thus businesses. Therefore, when communities consider the design and functionality of their bridges, it is recommended that they consider the purpose of the structure and redundancy of the surrounding road network. For example, if the bridge is the only way commuters and goods can access, via road, an area of the community that has many businesses and critical facilities, it is recommended that the bridge be designed for the "extreme" event, as defined in Chapter 3. However, given that bridge failures are not common even in disaster events, most bridges should be designed and built for the "expected" event.

**Road Tunnels.** Road tunnels serve a similar purpose to bridges in the road network. They connect links of the road network by passing under water, through mountains, or under other roads/highways. In general, tunnels present more risk to life safety when failures occur than other transportation systems, which have easily accessible methods of egress. Fires in tunnels are the most deadly disasters because the enclosed space causes decreased oxygen levels, contains toxic gasses, and channels heat like a furnace (Meng and Qu 2010). Precipitation is another threat: flooding in surrounding areas can lead to dangerously high soil moisture levels that compromise structural integrity (Meyer et al. 2014). During long-term inundation inside a tunnel, corrosion is a major mode of damage, especially to any electrical or piping infrastructure that runs through. That said, there is value in letting some tunnels flood in urban environments to reduce infrastructure damage elsewhere. This concept is used in the design of the Malaysian SMART tunnel, which has lower and higher roadways and the capacity to flood its bottom half while allowing traffic flow to continue in the higher portion (ITS 2012). More resilient designs and different protection measures, such as inflatable tunnel plugs, may need to be employed to adequately mitigate the individual risk associated with tunnels (US DHS 2013).

### 6.2.2. Rail and Subway Systems

**Rail Systems.** Rail systems, which typically carry bulk commodities and assist in commuter services, have seen a boom in recent years. Amtrak reported more than 31.2 million passengers in 2012, double the reported figure from 2000. Railroads transport almost half the nation's intercity freight and approximately a third of its exports, with both numbers projected to increase. Freight and passenger railroads have increased investing in their infrastructure, even in the face of the recent recession, putting \$75 billion back into the tracks since 2009. In 2010, freight railroads renewed enough miles of track to go from coast to coast. This aggressive investment policy gives the rail system the capacity to meet future needs and represents an opportune time to build resilience into the system (ASCE 2013).

Since rail systems tend to be less interconnected than roadway systems, more key points serve as bottlenecks to different areas that could be severely affected by a disaster (Lazo 2013). One example is the failing Virginia Avenue tunnel in Washington D.C., through which 20 to 30 cargo trains travel each day. The tunnel, now 110 years old and facing structural issues that would cost \$200 million to repair, has a single rail line, forcing many freight trains to wait while others pass through. Bottlenecks like this cost the US about \$200 billion annually, 1.6% of GDP, and are projected to cost more without adding capacity along nationally significant corridors (ASCE 2013). Any disruption to these points in the system could cause significant economic disruptions, indicating a need to build in alternate routes and, thus, redundancy into the system.



*Figure 6-4: A railroad bridge in New Orleans is washed out by flooding.*

Railways do face similar natural hazards as roads (e.g., flood and earthquake). Moreover, the railway network has similar infrastructure, including bridges and tunnels. However, the railway network is not nearly as redundant as local road networks. Thus disruptions in the railway network can have a significant impact. During Hurricane Katrina, flooding caused railway tracks to be impassible and some railway bridges failed as shown in Figure 6-4. Careful planning can ensure that tracks are placed along high elevations and away from potential natural or artificial hazards. Relocating transit lines to newer tracks that are placed with more consideration of natural hazards and disaster risks reduces vulnerability, as does keeping older tracks in good repair for redundancy. Since railways, like roadways, are replaced every 20 years on average, resilience can be built into the system (Field et al. 2012).

A focus on early warning systems prior to a disaster event, whether that system is implemented by the weather service or by the rail companies themselves, is essential if trains are to be moved to safer locations. As with other forms of transportation, adding forms of damage assessment will enable better prioritization of resources and, thus, faster recovery in a post-disaster environment (The World Bank 2012).

**Subway Systems.** Subway systems move mass amounts of people for work, school, entertainment events, or other leisure activities. Because subways are underground, flooding is especially problematic. During Hurricane Sandy, the New York City subway system experienced heavy flooding. Some tunnels filled up entirely. The subway's pumps were overwhelmed by the combined rainfall and storm surge. When power went out, the lack of redundancy in power supply stopped the pumps completely and left the subway unable to recover. The lack of protective measures leaves the system vulnerable to water, and the lack of pump capacity combined with a frail power supply makes it unable to recover quickly. These problems combined to severely inhibit the resilience of the subway system to the point that it will still take years for every station to reopen (City of New York 2013). Therefore, when attempting to achieve the performance goals set by the community's stakeholders, it is imperative that representatives of the energy sector be involved in decision making because of subways' strong dependence on the power supply.

**RESILIENCE EXAMPLE:** The New York City metro system, despite being one of the oldest transportation infrastructures in the city, showcased adaptability in its response to the 9/11 attacks. Decision making was dispersed throughout the system; station managers were used to closing down their stations and rerouting trains due to police action. As a result of leadership being empowered throughout the system, critical decision making was fast and unhindered by a chain of command. Trains were rerouted around the disaster, and when the nature of the event became clear, the subway was able to bring more trains onto outgoing tracks for evacuation. During the recovery, the system once again adapted to provide a means of transporting emergency personnel and supplies into and around the city (PWC 2013).

### 6.2.3. Air

The nation's air infrastructure provides the fastest way for freight and people to travel long distances. The airport system moves \$562 billion in cargo each year, in addition to providing 728 million passenger flights. Use of commercial planes increased by 33 million passengers from 2000 to 2011. By 2040, it is projected that cargo will triple and over a billion passenger flights will traverse the nation's skies. Studies already show that negative impacts to this massive system cause significant damage. The estimated cost of congestion and delays was almost \$22 billion in 2012 and is projected to rise to \$63 billion by 2040 if national spending levels on air infrastructure are stagnant (ASCE 2013). Only with additional investment can the aviation infrastructure rise to meet the demands being placed upon it.

Unfortunately, airports are more sensitive to disruptions than other forms of transportation infrastructure. Seventy percent of airport delays are due to extreme weather events, which are expected to become more frequent (ACRP 2012). This sensitivity is partly attributed to system complexity, which incorporates more opportunities to fail and more risks than are immediately obvious (PWC 2013). Thus, completely assessing all vulnerabilities in an airport is difficult. Nevertheless, we can learn valuable lessons from previous disasters.

Flooding, debris, snow, and ice can all force airport closure. In 2011, the area around the Dallas Fort Worth airport received 2.6 inches of snow before the Super Bowl. The airport was underprepared and suffered significant losses. Their equipment could only clear a runway one hour after deicer was applied, leading to cancellation of over 300 flights. In response, the airport invested over \$13 million in equipment to clear three runways of 2 inches of snow in 14 minutes. Although this is a great example of an aggressive response to creating a more resilient airport, it also showcases how easy it is for an unexpected weather event to cause disruptions (TRB 2014).



Runways are vulnerable to the same hazards as roads. Runways can be shut down by flooding (Figure 6-5), ice and snow. Additionally, runways are exceptionally vulnerable to soil liquefaction during seismic events (ACRP 2012). Even outside of storm events, heat waves can cause the tarmac to buckle under the heavy loading caused by takeoff and landing.

The airport terminals are vulnerable to the same hazards as other buildings, as discussed in Chapter 5.

As previously discussed, airports play an integral role in moving people and supplies before and after a disaster. Any major disaster will include increased load from evacuation. Additionally, if some airports in an area close, other airports must deal with redirected flights and increased loads (ACRP 2012). After a disaster, federal and state aid is most quickly administered by air. These factors mean that airports are most necessary when they are most vulnerable, directly before and after a disaster. Increasing disaster resilience in airports is, therefore, essential to increasing overall community resilience.



*Figure 6-5: Flooding closed the Chester County Airport and moved planes.*

#### **6.2.4. Ports, Harbors, and Waterways**

Ports, harbors, and waterways are used largely for import/export of goods and materials. The US Army Corps of Engineers estimates that over 95% of our trade, by volume, moves through our ports. In 2010, the ports helped export \$460 billion worth of goods and import \$940 billion. The US has over 300 commercial harbors that process over 2.3 billion tons of cargo per year, and over 600 additional smaller harbors. Although most ports are in good condition, the terminals need further investment due to the scheduled 2015 Panama Canal expansion. Due to the increasing size of commercial ships, many ports with shallow waterways are already inaccessible. Once the canal expansion is complete, even more ports will be unable to take advantage of the commerce boom from servicing new, larger ships that will be double the size of large cargo ships in use today (NOAA 2014). The need for further investment, as with the other transportation systems, means that this is the perfect time to make sustainable, resilient improvements to this critical infrastructure (ASCE 2013).

The very nature of water transportation systems demands that critical infrastructure be located in vulnerable areas. Although planning port placement will not generally avoid earthquakes, storms, landslides, and tsunamis, placing ports by shallow undersea slopes helps reduce storm surge damage. Also, strengthening the structures themselves and strengthening the ground adjacent to the water, where soil may be weak, can be beneficial. Additionally, focusing on early warning systems for ship owners and port authorities gives facilities and watercraft time to prepare or evacuate (The World Bank 2012).

Hurricanes, storms, and other heavy precipitation events can lead to extreme flooding and overtopping via precipitation and storm surge. This damages structures, dislodges containers (see Figure 6-6), undermines foundations, and destroys buildings outright. When hazardous chemicals are transported, there is a risk of hazardous spills in addition to the risk of oil spills. Flooded drainage systems cause flooding in areas that would otherwise be unaffected by a storm – not all areas and buildings are inundated by rainfall and wave action – representing a vulnerability caused by existing infrastructure. Finally, high winds associated with these types of events can damage critical equipment, such as cranes, and structures (URS 2012).

An interview with port managers after hurricane Sandy revealed that storm surge was the biggest issue the ports faced. The storm surge, combined with debris, slammed facilities and equipment and made road and rail access impossible, even after the storm. Flooding was a major issue because all administrative offices were located on the first floors of buildings, so the water shut down the port management. In addition, flooding damaged new technology. The port had recently installed electric motors to move cranes in an effort to be more environmentally friendly, but these were all rendered inoperable. The loss of electric power shut down night lighting, nuclear detection for incoming and outgoing cargo, and traffic signals around the port. When power did slowly return, the presence of generators running a few critical systems combined with the grid voltage and repeatedly tripped circuit breakers. In parking lots, approximately 16,000 cars belonging to cruise passengers were flooded because there was nowhere and no one to move them. Piers and wharves performed well because they are designed to withstand a ship impact laterally and the weight of a shipping container vertically, both forces that far exceeded loads imposed by the storm. Although there was no loss of life during the storm, this interview illustrated the sheer number of things that can go wrong in a disaster situation. Details like moving offices to the second floor, raising crane motors up or constructing housing for them, and having a system for recovery coordination with key utilities are easily overlooked, yet can make a huge difference (Wakeman 2013).



*Figure 6-6: Shipping containers are displaced by high winds and storm surge.*

A unique vulnerability of maritime infrastructure is associated with sea level rise (SLR). Globally, the sea level is expected to rise by 7 to 23 inches by 2099. When combined with high tides and storm surges, this is the most probable threat to port infrastructure. Resulting changes in sediment movement lead to siltation along channel entrances, affecting accessibility for some ships. The risk of corrosion increases as more surface area comes in contact with the water. Some susceptibility to scour and flooding is ever present and is exacerbated by SLR, though it is usually accounted for in port design. This climate change impact has the potential to exact disaster-like tolls from the maritime infrastructure (Wakeman 2013).

### **6.2.5. Pipelines**

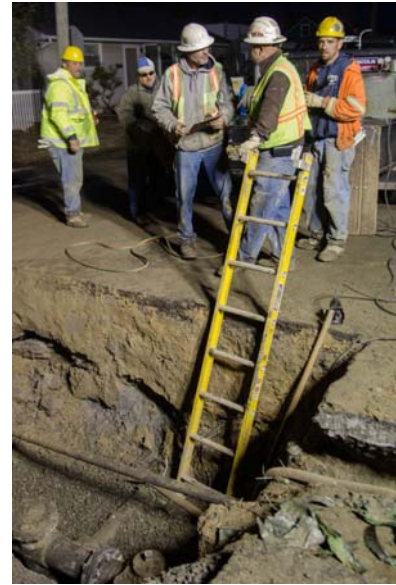
Pipelines are a key lifeline of the US transportation and energy supply infrastructure. Roughly two million miles of natural gas pipeline and more than 200,000 miles of pipeline carry crude oil and petroleum products throughout all 50 states (EIA 2007; FERC 2004). These pipelines transport more than 38 million barrels of crude oil and petroleum products a day; and the natural gas national network transports more than 40 trillion cubic feet of gas each year (EIA 2007; FERC 2004). The majority of hazardous liquid and gas pipelines are located underground on land or offshore; however portions of the hazardous liquid pipeline network are located above ground, for example along the Trans-Alaska Pipeline System, which transports crude oil (DOT 2014). Pipelines connect to compression stations, processing facilities, production platforms, wells, and storage facilities. Short term disruptions of the pipeline system by natural disasters complicate, hinder, and prolong disaster response and recovery. Long term disruptions have a negative impact on the national economy, national security, and ecology.

Pipelines and their equipment and facilities are vulnerable to damage by flooding and storm surge, impact from flood or windborne debris, and movement of land both on and offshore (earthquakes, subsidence, mudslides). Impacts to, or movement of, a pipeline can cause the line to rupture and that may ignite or explode into the air, soil or a body of water. Secondary effects of pipeline disruptions include delays and fuel supply loss to the transportation sector and natural gas to the energy infrastructure, which affects 1) the movement of responders and goods into affected areas and around the country if disruptions are

prolonged and 2) power distribution to residents, businesses, and industry, which delays recovery and causes additional distress and life safety threats to residents.

Hurricanes can cause offshore pipes to be displaced laterally or become exposed, which can cause leaks at clamps, welds, flanges, and fittings or be pulled apart, rupturing pipelines. Earthquakes damage pipes by ground deformation – landslides, liquefaction and lateral movement of pipes – and by wave propagation or shaking (Ballantyne 2008, 3). These types of impacts result in pipe compression or wrinkling, cracking and separation at joints, welds, flanges, and fittings, and bending and shear (Ballantyne 2008, 3).

Hurricane Katrina caused extensive damage to natural gas facilities and 72 spills from damaged or leaking offshore pipelines (DNV 2007, 29). Damages to fuel and natural gas processing and refining facilities caused by Hurricanes Katrina and Rita resulted in a loss of about 8% of the nation’s capability to refine/process fuels, which significantly reduced the domestic supply of refined fuels (DNV 2007, 28). In addition, the damages also caused the equivalent of nearly an 11% loss of an average day’s total gas consumption for the entire county (DNV 2007, 28). By comparison, Hurricane Sandy damaged petroleum refineries, not pipelines. Because the refineries were offline, although petroleum could still be moved through the pipeline, the movement was significantly slowed throughout the entire pipeline to compensate the loss of the supporting facilities, which affected areas from the Gulf Coast up to the East Coast, and New Jersey and New York, and created a supply chain problem in New Jersey and New York, but lacked the long term effects that Hurricane Katrina caused in 2005 (EIA 2012, 1). The Northridge (1994), Washington State (1997), and the Napa, California (2014) earthquakes damaged pipelines, which leaked natural gas that ignited resulting in a fire (Northridge, Napa) and an explosion (Washington State) that caused additional property damage (Ballantyne 2008, 1). Figure 6-8 shows an example of property damage caused by fire from broken gas lines.



*Figure 6-7: Natural gas crew shuts off gas after Hurricane Sandy (Photographer: Liz Roll, 2012)*

The DOT’s Pipeline and Hazardous Materials Safety Administration have identified five areas for local governments to develop mitigation strategies to improve protection of pipelines and increase the resiliency of the transmission system: 1) pipeline awareness (education and outreach); 2) pipeline mapping; 3) excavation damage prevention; 4) land use and development planning near transmission pipelines; and 5) emergency response to pipeline emergencies (DOT 2013, 3). Identifying pipeline locations and entering the information into the National Pipeline Mapping System is a key first step toward resiliency. Knowing where pipelines are located and making that information available is important to comprehensive planning, hazard mitigation planning, and preparedness, response, and recovery activities. Redesign or realignment of pipes to avoid liquefaction zones, faults, areas of subsidence and floodplains is only possible if a the location of both the pipeline alignment and the hazards are known and mapped. Similarly, local government can create a buffer zone around pipelines to increase the right-of-way to provide an extra



*Figure 6-8: Fire damage from broken gas lines (Photographer: Christopher Mardorf, 2014)*

margin of safety for nearby residents and businesses and to provide greater access for repair or emergency response equipment. In addition to non-structural mitigation, structural mitigation measures can be used to help mitigate damages to pipes due to earthquakes. These include: replacing older pipe with modern steel piping with electric arc welded joints; avoiding use of anchors to allow the pipe to move with the ground; installing a coating/covering over piping to minimize soil friction and allow easy pipe movement; installing an automated control system to allow quick shutdown of damaged pipeline systems; and constructing parallel pipelines to build redundancy in the pipeline system (Ballantyne 2008, 6).

### **6.3. Performance Goals**

Performance goals in this framework are defined in terms of how quickly the functionality of the infrastructure systems can be recovered after a disaster event. Minimizing downtime can be achieved during design or by developing and implementing a well prepared recovery plan – ideally both.

Performance goals for the transportation sector should be established by a panel of key stakeholders within the community, including owners, engineers, planners, regulators, codes and standards representatives, and representatives of other sectors (e.g., power and water/wastewater). For the transportation sector, in particular, it is imperative that other sectors are involved in making recommendations and establishing the performance goals because several sectors have strong interdependencies with the transportation sector as discussed in Section 6.1.2. For example, both overhead and underground distribution lines for the power and communication sectors are often within the right-of-way of roads and bridges, and thus are subject to DOT requirements. In the case of light rail, the method of transportation is heavily reliant on the energy sector. Once a panel of stakeholders is established, they can work to establish the performance goals for the transportation sector of their community.

Table 6-1 presents recommendations of performance goals for the “expected” event, whether it be a hurricane, earthquake, flood, etc. Although the loading on the infrastructure and failure modes will differ depending on the type of disaster event, the social needs that drive the establishment of performance goals remain the same.

The matrix provides three functional categories that equate to general services that transportation provides: ingress, egress and community transportation. Ingress refers to transportation of goods, services and first responders into a community immediately after a disaster and in the period of rebuilding and recovery from the event. Egress refers to the need to evacuate the population before and immediately after a disaster. The transportation network must be viable and sufficient to provide safe egress for all citizens of the affected community. Community transportation ensures that the community can withstand and come back, or be resilient, from the given disaster. It ensures that the transportation network is available to provide passage to the critical facilities directly after an event and is available to citizens when their businesses re-open several days or weeks after.

Recovery times are broken down into three main phases: Phase 1) Response, Phase 2) Workforce, and Phase 3) Community. Phase 1 (0-3 days) includes the needs/goals to support immediate recovery of the community in the wake of a disaster event. Phase 2 (1-12 weeks) includes the needs/goals to support to support citizens and businesses returning to their daily functionality. Phase 3 (4-36+ months) performance goals support the need to rebuild, retrofit, and strengthen the transportation network to become more resilient for future disaster events.

Table 6-1 is intended as a guide that communities/owners can use to evaluate the vulnerabilities of their transportation infrastructure. The table should be used by communities/owners to establish performance goals based on local social needs. Tables similar to Table 6-1 can be developed for any community (rural or urban), any type of disaster event, and for the various hazard levels (routine, expected, and extreme) defined in Chapter 3.

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The performance goals in Table 6-1 show 3 levels of desired restoration after an “expected” disaster event:

- Light orange boxes indicate the desired time to have 30% functionality
- Light yellow boxes indicate the desired time to have 60% recovery
- Light green boxes indicate the desired time to have 90% recovery

The performance goals in Table 6-1 were established based on the performance seen in previous disaster events, such as Hurricanes Sandy and Katrina.

The affected area of a given disaster can also be specified, which often depends on the type of hazard. For example earthquake and hurricanes typically have large affected areas, whereas tornadoes and tsunamis have relatively small affected areas. The affected area is important for a community to consider because it will impact how much of the infrastructure may be damaged which, in turn, will impact the duration of the recovery process.

The disruption level in the performance goals table is based on the current state of the transportation infrastructure system as a whole, and should be specified as usual, moderate, or severe.

In the individual rows of Table 6-1, an “X” is shown in some of the rows as an example of how a community can indicate the expected performance and recovery of the infrastructure in their evaluation. As seen in Table 6-1, there are some significant gaps between the desired level of performance and what is being seen in reality. This difference is a resilience gap. Once a community completes this table based on their local social needs and current expected performance, they can prioritize which gaps to address first.

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*Table 6-1: Transportation Performance Goals for Expected Event to be Developed by Community*

Disturbance			Restoration times		
(1)	Hazard	Any	(2)	30%	Restored
	Hazard Level	Expected		60%	Restored
	Affected Area	Community		90%	Restored
	Disruption Level	Moderate	(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Phase 1 -- Response			Phase 2 -- Workforce			Phase 3 -- Community		
			Days 0	Days 1	Days 1-3	Wks 1-4	Wks 4-8	Wks 8-12	Mos 4	Mos 4-36	Mos 36+
<b>Ingress (goods, services, disaster relief)</b>			<b>A</b>								
Regional Airport						90%		X			
National/International Airport					90%	X					
Marine Port						90%					
Ferry Terminal					90%	X					
Subway Station					90%		X				
Rail Station, Local					90%	X					
Rail Station, Regional						90%	X				
Rail Station, National						90%	X				
<b>Egress (emergency egress, evacuation, etc)</b>			<b>1</b>								
Bridge				90%	X						
Tunnel					90%	X					
local freeway			90%								
state freeway			90%								
National freeway				90%							
subway				30%		X					
Ferry				90%	X						
Regional Airport				30%				X			
National/Int'l Airport				30%		X					
Rail Local				30%		X					
Rail Regional					30%	X					
Bus			90%	X							
<b>Community resilience</b>											
<b>Critical Facilities</b>			<b>A</b>								
Hospitals			60%	90%							
Police and Fire Stations			60%	90%							
Emergency Operational Centers			60%	90%							
<b>Emergency Housing</b>			<b>B</b>								
Residences				60%	90%						
Emergency Responder Housing					90%						
Public Shelters			90%								
<b>Housing/Neighborhoods</b>			<b>B</b>								
Essential City Service Facilities							90%				
Schools					60%	90%					
Medical Provider Offices							90%				
Retail						90%					
<b>Community Recovery</b>			<b>C</b>								
Residences						30%		60%	90%		
Neighborhood retail					30%	60%		90%			
Offices and work places						90%	X				
Non-emergency City Services					30%	60%			90%		
All businesses						30%		60%		90%	

**Footnotes:**

- 1 Specify hazard being considered  
Specify level -- Routine, Expected, Extreme  
Specify the size of the area affected - localized, community, regional  
Specify severity of disruption - minor, moderate, severe
- 2 

30%	60%
-----	-----
- 3 

X
---

 Estimated restoration time for current conditions based on design standards and current inventory  
Relates to each cluster or category and represents the level of restoration of service to that cluster or category  
Listing for each category should represent the full range for the related clusters

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Category recovery times will be shown on the Summary Matrix  
"X" represents the recovery time anticipated to achieve a 90% recovery level for the current conditions

- 4 Indicate levels of support anticipated by plan
- R Regional
  - S State
  - MS Multi-state
  - C Civil Corporate Citizenship
- 5 Indicate minimum performance category for all new construction.  
See Section 3.2.6

## **6.4. Regulatory Environment**

### **6.4.1. Federal**

Federal regulatory agencies oversee the transportation network and methods of transportation used within those networks. These agencies have promulgated policies and regulations that oversee the safety and security of infrastructure and operations. As the transportation industry features a diverse range of methods and operating environments and is overseen by a myriad of regulatory agencies and funding streams that are subject to variability in direction of different political administrations, efforts to assess and address resilience across the transportation industry vary in scope. Some of the key regulatory agencies are discussed in the following sections:

#### **6.4.1.1. Federal Highway Administration**

The Federal Highway Administration (FHWA) is an agency within the US Department of Transportation. The FHWA supports state and local governments in the design, construction, and maintenance of the roadway system. The FHWA provides funding to state and local DOTs to ensure that roadways remain safe and operable. It also conducts research and advances the technology of the transportation system including bridges, pavements, and materials through facilities such as the Turner Fairbanks Highway Research Center in McLean, Virginia.

The FHWA partners with state and local DOTs by funding pilot projects in an attempt to relieve congestion in the existing transportation network and improve commuter time for both citizens and business (FHWA 2009). One pilot program is the Freight Intermodal Distribution Pilot Grant Program, which has funded six programs around the country to make improvements to their infrastructure so that intermodal transportation of people and goods becomes more efficient (FHWA 2009). One of these six programs is to improve the transfer area of the Fairbanks, AK Freight Yard so trucks can make pick-ups/drop-offs in a shorter period of time (FHWA 2009). The current pick-up/drop-off location does not provide not enough room in the pick-up/drop-off area for the trucks to get to the trains, thus creating bottlenecks even before a disaster event occurs.

The FHWA has also attempted to relieve congestion in road networks by funding pilot programs in four cities that encourage non-motorized methods of transportation in the road network (i.e., walking and bicycles). The intent of these programs is to provide infrastructure for other forms of transportation in the road network and encourage people to use the infrastructure so the road network is more diverse (FHWA 2012). Increasing the diversity of how the road network is used relieves congestion, which can be especially helpful after a disaster event.

Climate change is another challenge to which the transportation network will be vulnerable. The FHWA has initiated 19 pilot programs around the country to evaluate the risk of the existing and planned transportation network to effects of climate change (FHWA 2014).

#### **6.4.1.2. Federal Transit Administration**

The Federal Transit Administration (FTA) is a federal agency within the US Department of Transportation that provides financial and technical support to local public transit systems (i.e., buses, subways, light rail, commuter rail, monorail, passenger ferry boats, trolleys, inclined railways, and people movers). Through financial support from the federal government, the FTA assists in developing new

transit systems and maintains existing systems. In addition, they oversee grants that fund research, management and support of local transit systems.

In 1990, the FTA promulgated 49 CFR Part 659, Fixed Guide way Rail State Safety Oversight, which mandated that rail transit agencies that do not run on the national railroad network develop a system safety management organization guided and documented in a System Safety Program Plan (SSPP), which covered revenue service operations. It later promulgated 49 CFR Part 633 to cover system safety issues in design and construction of major capital projects. Later, after 9/11, it developed requirements to cover security issues. However, these regulations did not cover the preponderance of transit systems out there that offered rubber tire transit bus and paratransit operations. Nor did these, in general, cover capital projects of under \$100M in value. Some of these capital design requirements do impact ferry grantees that operate under the USCG if the operation uses FTA grant funding. While these programs do potentially cover climate change issues, as transit systems are required to perform design and operational risk assessments (the latter is not a mandate and necessarily enforced by a standardized framework but the former is more so) at this time, the FTA does not have a systematic regulatory program to address climate change or resilience, but has developed guidance and a pilot program for agencies to investigate the issues.

#### **6.4.1.3. Federal Railroad Administration (FRA)**

The FRA covers heavy rail freight systems, commuter and inter-city passenger rail systems. Forty-nine CFR Parts cover various safety and security engineering, design and operational requirements of these agencies. The TSA also has an active role in the security of rail freight and inter-city passenger service.

#### **6.4.1.4. Federal Aviation Administration (FAA)**

The Federal Aviation Administration (FAA) is an agency of the US Department of Transportation that oversees all civil aviation in the country. The major roles of the FAA include regulating US commercial airspace, regulating flight inspection standards, and promoting air safety.

The FAA is currently assessing airport sustainability planning. They developed a Sustainable Master Plan Pilot Program that will be piloted at ten airports across the country. In addition, the FAA has undertaken a study to review facility, service, and equipment profile (FSEP) data and its vulnerability to various climate responses, such as storm surge. This data will result in publicly available climate models that will be accessible by airport operators and managers.

#### **6.4.1.5. US Coast Guard (USCG)**

The USCG covers the safety and security of the national waterways, overseeing commercial freight and passenger service, as well as public transportation (e.g., municipal ferry service, boaters, and kayakers). The USGS works to prevent import of illegal or unwanted goods that may harm communities, and provides escorts of exported cargo for national security (e.g., military cargo).

### **6.4.2. Regional**

Metropolitan Planning Organizations have been encouraged to review the safety and security of the regional transportation network since the enactment of SAFETEA-LU in 2005. FHWA has funded and encouraged MPOs across the US to look into ways MPO can foster considerations of safety and security planning – including resilience efforts – in the long-term capital plans which MPO develop and fund.

*[Note to reviewers: This section is under development. In a future draft, examples from Port Authorities will be included]*

### **6.4.3. State**

*This section is under development. Text to be provided in a future draft.*



#### **6.4.4. Local**

*This section is under development. Text to be provided in a future draft.*

#### **6.5. Standards and Codes**

Codes and standards are used by the transportation industry to establish the minimum acceptable criteria for design and construction. To maintain adequate robustness, each state and locality must adopt appropriate codes and standards as a minimum requirement. Although adoption of codes is important, enforcement is a key factor in ensuring compliance of the built environment with codes and standards.

The failure modes discussed in this chapter may represent key vulnerabilities in the codes that are exposed during disaster events. Table 6-2 presents a summary of the methods of transportation used, whether they are used for public or private transportation, and which oversight authorities are involved in their regulation.

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*Table 6-2. Transportation Sector Code and Standards Governing Agencies*

Industry	Sector	Type	Method of Transportation	Public	Private	Oversight Authority													
						DHS	FEMA	NTSB	USDOT	FRA	FTA	TSA	FMCSA	FHWA	USCG	EPA	FAA	1+ state agencies	
Surface Transport	Rail	Passenger	Inter-City Rail (Amtrak)	X		X	X	X	X	X		X						X	
			Commuter Rail	X		X	X	X	X	X	X	X	X						X
			Subway	X		X	X	X	X		X	X							X
			Light Rail	X		X	X	X	X		X	X							X
			Inclined Plane	X		X	X	X	X		X	X							X
			Trolley/Cable Car	X		X	X	X	X		X	X							X
		Freight	Class 1 Freight Carriers		X	X	X	X	X	X		X						X	
	Rubber Tire	Passenger	Inter-City Motorcoach	X	X	X	X	X	X			X	X	X					X
			Intra-City Bus/Motorcoach	X	X	X	X	X	X		X	X	X	X					X
			Paratransit/Jitneys	X	X	X	X	X	X		X	X	X	X					X
			Taxis	X	X	X	X	X	X			X	X	X					X
			Personal Cars		X				X										X
		Freight	Commercial Trucking		X	X		X	X		X	X	X	X					X
	Maritime	Passenger	Ocean Lines		X			X	X			X			X	X			X
			Ferries	X		X	X	X	X		X	X		X	X	X			X
Commercial Boats				X			X	X			X			X	X			X	
Personal Boats				X			X	X			X			X	X			X	
Freight		Freighters		X	X	X	X	X			X			X	X			X	
		Barges		X	X	X	X	X			X			X	X			X	
Air	Air	Passenger	Commercial Airplanes		X			X	X			X					X	X	X
			Blimps		X			X	X			X					X	X	X
		Drones	X	X			X	X				X				X	X	X	
		Freight	Commercial Air Freight		X			X	X			X				X	X	X	

**6.5.1. New Construction**

*This section is under development. Text to be provided in a future draft.*

**6.5.1.1. Implied or stated Performance Levels for expected hazard levels**

*This section is under development. Text to be provided in a future draft.*

**6.5.1.2. Recovery Levels**

*This section is under development. Text to be provided in a future draft.*

**6.5.2. Existing Construction**

*This section is under development. Text to be provided in a future draft.*

**6.5.2.1. Implied or stated Performance Levels for expected hazard levels**

*This section is under development. Text to be provided in a future draft.*

**6.5.2.2. Recovery Levels**

*This section is under development. Text to be provided in a future draft.*

**6.6. Resilience Assessment and Mitigation Methodology**

*This section is under development. Text to be provided in a future draft.*

### 6.6.1. Assessment Methodology (current conditions, including dependence on sources outside the community)

*This section is under development. Text to be provided in a future draft.*

### 6.6.2. Strategies for new/future Construction

Several federal entities have begun recommending design practices that may increase resilience of the transportation system. FHWA recently published the “Framework for Improving Resilience of Bridge Design” with a fault tree methodology framework, where lessons from past bridge failures are used extensively to identify events that could lead to a bridge failure (FHWA 2011). An engineer can use the methodology in this document to design a bridge that is sufficiently devoid of the sort of weaknesses that might lead to bridge failure after a natural hazard event.

*[Note to reviewers: This section to be expanded in a future draft.]*

### 6.6.3. Strategies for Existing Construction

*This section is under development. Text to be provided in a future draft.*

### 6.6.4. Addressing Gaps in Resilience Plans

Several gaps exist in creating a truly resilient infrastructure transportation system, as noted by the DOT Climate Adaptation Plan (USDOT 2012):

- **Existing Infrastructure resilience:** The existing US infrastructure is owned and operated by different entities, including state, local, public, and private groups. This infrastructure varies in age and sophistication and has not been built to a consistent design standard. Currently, different owners choose whether to consider climate or natural hazard risk when making decisions regarding replacement or service life.
- **New Infrastructure Resilience:** New infrastructure is built to the best available codes and standards; however, many codes and standards do not currently consider climate change or natural hazard risk.
- **System Resilience:** Interdependencies of systems play a key role in transportation resilience. System resilience is best viewed across transportation modes and the many system owners. Many of these modes may be obvious, other dependencies may be less so. Thus, interdependencies may be hidden among the many variables.

There are multiple methods of transportation that have different operational, infrastructural, funding, policy and maintenance goals/needs, including:

- Methods of transportation that run on land, sea and in the air have distinct operational issues and risks.
  - Operational areas – rural, city, mountainous, elderly, millennial, earthquake prone vs. storm surge prone, etc., all require different kinds of needs for basic operations let alone to prepare for a specific type of incident/problem
- Rubber tire and ferries are generally, from an emergency management standpoint, much more resilient systems than rail and air systems (the latter because of the infrastructural and guidance system needs). All require fuel and communications, though rubber tire and ferries can withstand an initial impact better overall.
- Highway and road agencies provide the infrastructure for road operations – thus a completely different mandate and business model from providing passenger or freight carriage.
- Private and public sector foundations
- Transit bus operations, which make up the preponderance of transit in the country, can be large and small and serve completely different markets and clientele.
- Shippers work with the USCG, ports and terminal operations, rail carriers, storage and trucking companies, etc. to execute their operations.

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- Regulatory ownership sparks different issues that impact resilience planning. For example, within the transit industry alone:
  - The FRA covers passenger systems that operate on the national railroad system like Amtrak and commuter railroads, and freight operations.
  - Transit buses operate on roads, bridges, tunnels, and in terminals/stations built and operated by other agencies.

Many transportation systems rely on contracts or MOU for fuel, communications, parts, facilities, vehicles, operators, etc. These contractors can be weak links in recovery and provide difficulty when determining internal contingencies, especially if many other regions/industries are similarly impacted by a catastrophe, competing for assets, or unable to get assets in due to debris clearance/restoration operations of other agencies.

### **6.7. Tools Needed for Resilience**

A number of tools are needed to adequately define and quantify resilience of our transportation system. Based on the method of transportation and purpose of the transportation (ingress, egress, etc.), tools needed to adequately represent resilience vary.

Tools requested by transportation stakeholders include models that quantify the egress capacity of transit systems, roadways and other modes of transportation with the capability of adjusting in real time if a transportation system or mode goes down in a disaster event.

*[Note to reviewers: This section will be expanded in a future draft based on conversations with stakeholders.]*

The standards and codes for transportation systems can be expanded to account for performance-based design and the current inventory of transportation systems. A methodology to ensure that resilient design is incorporated into existing transportation infrastructure should be included.

#### **6.7.1. Standards and Codes**

*This section is under development. Text to be provided in a future draft.*

#### **6.7.2. Practice and Research Needs**

*This section is under development. Text to be provided in a future draft.*

### **6.8. Summary and Recommendations**

*This section is under development. Text to be provided in a future draft.*

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## DISASTER RESILIENCE FRAMEWORK

50% Draft for Norman, OK Workshop

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