6. Transportation Systems

6.1. Introduction

Transportation systems are critical to our daily lives. People use various systems of transportation on a daily basis to travel to and from work, school, visits to family and friends, attend business meetings, and medical emergency sites. However, the transportation network meets much more than just an individual's needs. Businesses use trucks, ships, trains, and airplanes to transport goods from their point of production to their point of use or consumption. For example, food is often transported from the producer (e.g., a farm) to a processing and packing plant, then a regional or national distribution center, and finally to the local stores where it can be purchased by consumers. All of these steps in this example of product distribution rely heavily on the transportation system.

Traditionally, people think about the transportation system as using roads and bridges to move both goods and people. While roads and bridges are a critical part of the transportation network, communities[1] also rely upon other systems of transportation, including:

- Airports to transport people and goods long distances in a short period of time
- Passenger and freight rail lines to transport people and goods regionally/nationally
- Subway lines or light rail corridors in large urban centers (e.g., New York, DC, Chicago, Los Angeles) to transport people to/from work and entertainment/leisure activities
- Harbors and ports to import/export goods from/to the globally and distribute them on inland waterways
- Ferry terminals and waterways to transport the workforce to/from work (e.g., San Francisco, New York)
- Pipelines[2] to transport natural gas and petroleum nationally and regionally to utilities and refineries

The transportation system is a very complex system with multiple modes each with their own complexities that make coordinating activities to build resilience of the system and the communities they support very challenging. Examples of the complexity include:

- Within a small geographical area (i.e., a community) there may be many stakeholders responsible for the design, operation, maintenance and funding of the road network including federal, state, and local public agencies, as well as private operators of toll ways.
- The rail system includes private freight networks that are key to supporting economic activity and passenger rail services operating within cities and across states with multiple stakeholders.
- Marine transportation includes domestic and international movement of passengers and goods across regions that may have their own standards and guidelines for design, operation and maintenance. In the case of passenger ferries, a lack of standardization limits the transferability of vessels to support recovery from hazard events.
- The aviation system includes public and private airports of varying sizes that support air freight and commercial air passenger services.

Many people rely on multiple modes of transportation (i.e., intermodal transportation) every day. Businesses use multiple systems of transportation to move goods efficiently and cost effectively.

[1] For the purposes of this framework, a community is defined as an area under the jurisdiction of a local governance structure, such as incorporated cities and counties.
[2] Pipelines are included in the transportation chapter because they are regulated by the Department of Transportation. Water pipelines are discussed in Chapter 9.

Similarly, goods may be imported using ships; however, to get the goods from the ship to the next step in the supply chain requires trucks or rail. More discussion on intermodal transportation is in Section 6.1.2.

This chapter addresses disaster resilience of the transportation system. 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 provides an exemplary performance goal table. Communities can also use the performance goals table to identify the anticipated performance of existing infrastructure and their largest resilience gaps, and 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, infrastructure owner, 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 own performance goals by the time needed for its critical infrastructure to be restored following a hazard event for three levels of hazard: routine, expected, and extreme, as defined in Chapter 3.

Transportation systems are a large part of our daily lives in the United States and are often taken for granted. While not all natural hazard events can be forecasted, the transportation system is even more important when a natural hazard event has advanced warning (i.e., hurricane) and after of a natural hazard event. When a hazard event is forecast, transportation systems permit:

1. Parents to convey their children home from school or daycare
2. Residents in evacuation zones to travel to shelters or distant safe communities
3. State officials to close transportation systems that pose a danger to travelers during a hazard event

Following a hazard event, the community has short-term (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 for emergency responders (firefighters, paramedics, police) to reach people in need
2. Access for those that restore critical infrastructure (energy, communications, water/wastewater)
3. Access to facilities for shelter, medical care, banks/commerce, and food
4. Egress/evacuation from a community immediately after a hazard event, if needed
5. Ingress of goods and supplies immediately after event to provide aid

However, when addressing resilience, communities must also consider any inherent vulnerability in the transportation network that may seriously affect the ability of the community to achieve full recovery in the longer term and also consider improving the level of transportation network performance in the next hazard event. The intermediate and longer term needs of communities for the transportation infrastructure include:

1. Ability of public sector employees who run government, direct traffic, respond to emergencies, run transit systems, and teach/work in schools to get to their posts
2. Ability for citizens to get to work, school, and sports/entertainment facilities
3. Ability to re-establish access to businesses (both small and large), banks, retail, manufacturing, etc., so they can serve their customers
4. Ability to re-establish access to key transportation facilities (airports, ports/harbors, railway stations), so goods can be transported and supply chain disruption is limited

5. Need to restore, retrofit, and improve transportation infrastructure and rolling stock, so they will not be damaged or fail in the same way in a future event
6. Strengthen mass transportation, such as airports, passenger and freight rail, subways, light rail, and ferry systems to relieve stress on the roads and bridges components of the transportation network

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 more people on the already-congested road network, or worse, at home).

6.1.2. Interdependencies

Chapter 4 details the interdependencies of all critical infrastructure systems 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 other infrastructure systems. Hospitals, fire stations, police, and other emergency response systems depend on transportation before, during, and after a hazard event. 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 dependencies on the transportation system include:

1. ***Power Energy*** – A significant number of power plants rely on bulk shipments of coal or fuel via barge and freight rail for their operation. Gas fired plants rely on natural gas pipelines. Resource recovery plants rely on bulk shipments of refuse via truck. Interruption to barge, freight rail, and truck routes from a hazard event can affect power generation if fuel at these power plants is not stockpiled in advance.
2. ***Communication and Information*** – As fiber networks are expanded, many are routed through leased conduits over bridges and through tunnels to cross waterways or other geographic features**.** This makes them vulnerable to damage of those transportation assets in a hazard event from flooding, earthquakes, or storm surge, which can knock out portions of the fiber communications network. Postal services delivering letters, documents, and packages are also entirely reliant on the transportation network.
3. ***Buildings/Facilities*** – Large transportation terminals or stations, airline terminals, and port cargo facilities cease to function when transportation systems are shut down by a hazard event. Mixed use transportation facilities that are integrated with retail, businesses, and hotels are also impacted when transportation stops.
4. ***Water/Wastewater*** – The pipelines used by these systems are considered part of the transportation system.

Specific interdependencies of transportations systems with the other infrastructure systems 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 could not operate, which hindered both evacuation and 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, moveable bridges, vehicular tunnels and ports rely on electric energy for

lighting, functionality of mechanical components (e.g., loading equipment at a port), fire/life safety and for functionality of the buildings themselves (see Chapter 5). Regional passenger rail, subways, and light rail rely on electric energy to function as well as for fire/life safety inside the tunnels. However, the energy industry also relies on transportation systems, so repair crews can reach areas where failures have occurred and bring services online quickly. The logistics of deploying repair crews after disasters often starts with filling in washouts and clearing debris and fallen trees from roads to provide access to utility repair crews.

Transportation systems also include natural gas and petroleum pipelines that feed the power/energy fuel storage, generation, and distribution systems. Pipelines also transport jet fuel to major airports. Most pipelines in the continental United States are buried beneath the ground and can rupture from earthquakes or wash out by flooding.

2. ***Communication*** – The communications system relies on roads and bridges so repair crews can get into areas with failures of telephone and cable lines, cell towers, and fiber optic networks to repair services. Conversely, transportation systems depend on communications to relay information. Airports use communications for instrument-controlled aircraft operations 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. Highways depend on Intelligent Transportation Systems (ITS) to monitor traffic levels, direct traffic around areas of congestion, and respond to accidents and emergencies. ITS cameras, sensors, and variable message signs are supported on fiber networks, some owned and some leased by DOTs. Tolled highways and bridges rely on communication systems for electronic toll collection.
3. ***Building/Facilities* –** Buildings are rendered useless if people cannot reach them. Transportation systems allow people to travel to critical facilities, businesses, and to other homes/facilities to check on the safety of friends, family and vulnerable populations. When transportation systems are not available to get citizens to buildings and facilities, such structures cannot also contribute to the recovery.
4. ***Water and Wastewater* –** Water and wastewater lines are often buried beneath 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 system (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, 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 period. 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 will not be any goods for the rail system to transfer 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, banks, etc. People who work in large cities often rely on mass rapid transit, such as bus transit for most of their commutes. However, to get to their bus stop or rail station, or final destination, individuals may rely on the roadway system, including buses, taxis, bicycles or walking.

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

Freight transportation systems in the U.S. have less redundancy than systems that transport people. The freight rail lines currently have little redundancy with detours of hundreds of miles around certain critical routes that follow river beds and cross large rivers. With the reduced number of freight trains and the high costs for maintaining the right of way of freight tracks, railroads have abandoned redundant lines and many have been converted to recreational paths for pedestrians and cyclists.

Freight transportation by barge moves very large volumes at relatively low energy costs but has very limited system redundancy since it is dependent on navigable waterways. River flooding or a damaged or collapsed river crossing can lead to major delays of large volumes of freight.

Freight transported by truck has more redundancy than rail or barge freight; however, the national highway system has certain critical river crossings, which if damaged in a hazard event, can lead to long detours and heavily congested highway bottlenecks.

6.2. Transportation Infrastructure

Transportation systems in the United States are 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
- 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 used in the past to successfully mitigate failures. The first four sections deal with systems of the larger transportation network used to move both people and goods. The fifth section, Pipelines, discusses a system used to move resources alone (e.g., natural 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 three 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. 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. A loss of a road, bridge, or tunnel can dramatically increase the time it takes for emergency responders to get to the disaster area or reduce the ability for citizens to evacuate immediately following a disaster.

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 initial and secondary hazards (e.g., uprooting of a tree or other debris falling on a power or communication line). For example, flooding can result in undercutting road beds. In Figure 6-1, a pipe (an example of interdependency) that lay directly underneath the road shoulder was vulnerable to damage as a result of road failure.

Figure 6-1: Road undercutting in the aftermath of Hurricane Irene (FEMA, Photo by Elissa Jun, 2011)

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 transportation infrastructure (tunnels, bridges, railways, etc.), whereas 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. 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. Flash flooding in mountain communities where roads typically follow river beds with multiple bridge crossings have left entire communities cut off when roads and bridges collapsed from scour. For example, a dozen towns in Vermont were completely cut off from emergency aid in 2011 when Hurricane Irene dumped 11 inches of rain over a weekend that washed out roads and bridges. Similarly, in Boulder, Colorado search and rescue teams were prevented from reaching stranded communities after 6 inches of rain fell over 12 hours in September 2013, cutting off mountain towns after recent wildfires depleted the terrain of vegetation. 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

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

locations where their assistance is needed.

Ice storms, as previously discussed, can also cause road blocks by tree fall, 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, because they traverse significant geological features such as canyons, rivers, and bodies of water that interrupt the roadway path. Bridge structures are the most costly part of a roadway or railway system to build and maintain, so they are strategically placed and the temporary closure of one may lead to significant detour travel distances. 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 the harshness of their respective environmental conditions (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 hazard 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).

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. Flooding and wave action from hurricane storm surge (or tsunamis) can also damage bridges in other ways. For example, during Hurricane Katrina, wave-induced forces pushed multiple spans of the I-10 twin bridges over Lake Pontchartrain off their bearings (Figure 6-3) (FHWA 2010). Earthquakes in San Fernando Valley, Loma Prieta, and Northridge, CA showed that bridges can collapse due to failure of piers and decks (FHWA 2010).

Figure 6-3: Bridge sections slid off their supports during Hurricane Katrina due to wave action (FEMA, 2005)

Longer bridges tend to have relatively lightweight superstructures (decks and girders), so they can span long distances. Historically, their relatively low natural frequencies 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 (FHWA 2011). Moreover, some older long span bridges were tested and retrofitted to ensure that they were not vulnerable to wind failures.

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, they should 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 the road network, an area of the community that has many businesses and critical facilities, the bridge should be designed for the "extreme" event, as defined in Chapter 3. However, given that bridge failures are not common even in hazard 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 hazards 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 of tunnels through mountains (Meyer et al. 2014). Tunnels beneath rivers are not affected by moisture through the walls but by surrounding flooding through the tunnel portal. During long-term inundation inside a tunnel, corrosion is a major mode of damage, especially to any ventilation, electrical, or communications systems within in the tunnel structure. 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 (U.S. DHS 2013).

6.2.2. Rail

Rail systems consist of mass transit systems, such as subways, that operate within large high-density cities, regional commuter rail systems, which connect suburban communities to the city core, intercity passenger rail systems, like Amtrak, and freight rail systems that transport cargo both regionally and across the nation. Also included are light rail systems that operate within cities and airports.

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. Freight 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 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 failure (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 U.S. about $200 billion annually, or 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 that would increase redundancy in the system.

Another example of the lack of redundancy of the national freight rail system was the replacement of the critical 120-year-old Burlington Bridge in Iowa. It was determined that the two-track bridge – which had loading restrictions – was one of the three most important freight rail bridges spanning the Upper Mississippi River, based on train volume. The bridge is also part of Amtrak's national intercity passenger rail network and a key route for major coal traffic that brings low sulfur coal to the east, enough to supply electricity to nine million households annually.

Freight rail systems in the U.S. also play an important role in the intermodal transportation of containerized cargo and imported automobiles from ports on both coasts to points in the Midwest. Containers are double stacked on rail cars and transported to interior distribution hubs that then transfer cargo to trucks and taken to their final destinations.

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 in 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 hazards. Relocating transit lines to newer tracks that are placed with more consideration of natural hazard 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).

***Figure 6-4: A railroad bridge in New Orleans is washed out by flooding** (Photo by Marvin Nauman)*

Rail systems have other vulnerabilities. Most regional and intercity passenger rail systems either rely on electrified overhead catenaries or on third-rail traction power. While overhead catenary systems are more vulnerable to damage in storms from winds, falling trees, and branches, both are vulnerable to flooding, ice storms, and blizzards. Passenger rail in rural areas is powered by diesel locomotives and is more resilient. Some railroads have invested in hybrid locomotives that can be powered by diesel or electricity and be redeployed to restore limited service to lines where there may be loss of electric power. Freight rail cargo is transported by diesel powered locomotives that are not dependent on the energy grid and are less affected by storms, ice and flooding. Freight trains are more dependent on moveable bridges, which require electric power and are used for freight rail lines, because fixed bridges require elevated approaches to achieve higher under clearances.

A focus on early warning systems prior to a hazard event, whether that system is implemented by the weather service or by the rail companies, is essential if trains are to be moved to safer locations to protect train cars from flooding, which damages electrical components. As with other forms of transportation, adding forms of damage assessment will enable better prioritization of resources and lead to 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.

RESILIENCE EXAMPLE: The New York City Transit (NYCT) subway 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 empowered leadership throughout the system, critical decision making was fast and unhindered by a chain of command. Trains were rerouted around the disrupted area, 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).

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 subways 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 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 to involve representatives of the energy industry in decision making, because of subways' strong dependence on the power supply

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.

Airports are a key component of supply chain for e-commerce activities. Internet purchases result in tons of overnight air cargo transferred to trucks at airports and delivered to communities. There is a great interdependency between airports and roadway systems for timely delivery of high priority and perishable goods. Airport closures cause re-routing to other airports with longer truck travel times, delaying goods.

Large airports are communities in themselves; there are many people employed there, significant retail business and real-estate development, such as hotels. When an airport is closed, it does not just impact air travelers. People employed there are significantly affected and may be out of work until it reopens.

There are many dependencies between airports and other modes of transport. Passengers access airports via roadways or rail. Freight services and the provision of fuel to airports are reliant on roadways. In addition, when airports are disrupted, people and cargo are typically re-routed to road and rail networks.

Military airbases support the use of aircraft for operations by branches of the armed forces. An airbase typically has facilities similar to those of a civilian airport, such as traffic control and firefighting. Airbases are widespread throughout the U.S. and its territories and they provide a variety of services for the military such as refueling, storage and maintenance, training centers, and mission launch points. As with civilian air infrastructure, military air infrastructure provides the fastest way to transport personnel, cargo, arms, supplies, and other physical assets. As such, airbases play a critical role in supporting national security.

Disaster response is not a primary role of the armed forces; however, after major disasters, military airbases may double as launch points and staging areas for disaster recovery operations. As federal, state, and local agencies respond to disasters, the military is often called on for air support. Increased air transportation capabilities are particularly needed after hazard events that hinder ground transportation, such as floods, earthquakes, and major snow storms, or after hazard events in areas with prohibitive terrain. Common disaster response-related uses for military aircraft, include evacuation, search and rescue, supply delivery, and personnel mobilization. Airbases are governed by the branch of the military they serve, though assets may be provided to civilian governments under civilian control after a disaster.

Unfortunately, airports are more sensitive to disruptions than other forms of transportation infrastructure. Seventy percent of airport delays are due to severe 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, valuable lessons can be learned from past disasters.

Flooding, debris, snow, lightning strikes, wind, 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 disruptions. Their equipment could only clear a runway one hour after de-icer 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, although typically they have a lower degree of tolerance regarding safe condition for use. 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). Apart from storm events, heat waves can cause the tarmac to buckle under the heavy loading caused by takeoff and landing.

Figure 6-5: Flooding closed the Chester County Airport and moved planes (FEMA, Photo by Andrea Booher, 1993)

The airport terminals are vulnerable to the same hazards as other buildings, as discussed in Chapter 5. Energy, fuel, communications, water, and wastewater services are all critical to the safe operation of airports. Refer to Chapters 7, 8 and 9, respectively, for discussion on the resiliency of these infrastructure systems.

Airports play an integral role in moving people and supplies before and after a hazard event. Any major disaster is likely to lead to increased traffic from evacuation. Additionally, if 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 needed when they are most vulnerable – directly before and after a hazard event. Therefore, increasing disaster resilience in airports is essential to increasing overall community resilience.

6.2.4. Ports, Harbors, and Waterways

Ports, harbors, and waterways are used largely for import/export of goods and materials. The U.S. 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 U.S. 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).

Maritime infrastructure also allows for waterborne transportation of passengers and vehicles, which is another important component of domestic trade (MARAD 2015). Ferries provide a safe and reliable link across bodies of water for commuters in major metropolitan areas where tunnels and bridges are not available or are less reliable and more congested. Additionally, ferries can serve in emergency evacuations of metropolitan areas when other transportation networks are inundated, gridlocked, or otherwise non-functional. According to the Bureau of Transportation Statistics, there were 23 ferry operators across 37 states and territories in 2009. It is estimated that U.S. ferries carried close to 103 million passengers and over 37 million vehicles in 2009 (RITA 2015). In New York City, the Staten Island Ferry carries approximately 70,000 passengers on a typical weekday (NYC DOT 2015).

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 the risk of storm surge damage. Strengthening the structures themselves and strengthening the ground adjacent to the water, where soil may be weak, can be beneficial. Early warning systems for ship owners and port authorities also give facilities and watercraft time to prepare or evacuate (The World Bank 2012).

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

Hurricanes, storms, and other heavy precipitation events can lead to extreme flooding and overtopping via precipitation and storm surge. These damage structures, dislodge containers (see Figure 6-6), undermine foundations, and destroy buildings outright. When hazardous chemicals are transported, there is a risk of hazardous spills in addition to the risk of oil spills. Flooding can also deposit silt and debris, which may restrict or disable navigable channels. Overwhelmed or failed drainage systems can cause flooding in areas that would otherwise be unaffected by a storm surge or riverine flooding. This represents a vulnerability caused by existing infrastructure. High winds associated with these types of events can damage critical equipment, such as cranes and structures (URS 2012). Drought conditions contributing to reduced levels in waterways may affect the ability to move goods and people.

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, which are both forces that far exceed 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 during or after a hazard event. 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).

Drought can also stress shipping routes and maritime infrastructure. Inland waterways are particularly susceptible to drought; as water recedes during a drought, the navigable portion of a waterway may be restricted or completely cut off. Shriveling waterways create bottlenecks for shipping traffic, which creates congestion (U.S. FTA 2013). Even when drought-affected waterways remain navigable, reduced depth may require shipping vessels to reduce loads and speed, which hampers efficiency and increases shipping costs. Drought can also threaten commercial and municipal infrastructure that is specifically designed for fresh water. As freshwater discharge from a river's mouth decreases, coastal salt water can encroach on upstream areas that are typically freshwater (NPR 2013).

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).

As with other transportation modes there are many interdependencies For example, road and rail infrastructure is used to transport goods and people to and from ports and harbors to their final destination. Ferries can also be used as a temporary replacement for bridge infrastructure that may fail as a result of a hazard event. However, the lack of standardization across the industry can limit the transferability of vessels and infrastructure to support efforts following a hazard event.

Inland navigable waterways are crucial to the health of the U.S. trade economy. Shallow draft navigation (e.g., barges) serves 87% of all major U.S. cities, which accounts for 79% of all domestic waterborne freight (MARAD 2015). In 2005, inland waterways handled over 624 million tons of freight valued over $70 billion (MARAD 2007). The U.S. Maritime Administration estimates that if inland waterways became unavailable for transport, truck traffic on rural highways would increase by approximately 33% (58 million truck trips annually) and rail transport, by tonnage, would increase by 25%. Increases of these magnitudes would put tremendous stress on land-based infrastructure, resulting in increased maintenance costs, fuel consumption, congestion, and decreased safety. As waterways are maintained and improved, resilience to lasting drought conditions should be a chief consideration.

Inland waterways in the U.S. are relied upon to move large volumes of bulk cargo through a system of rivers and lakes interconnected by locks. As shown in Figure 6-7, one barge which can carry 1,500 tons of cargo moves the equivalent tonnage of 15 jumbo freight rail hopper cars or 58 large semi-trucks. A large barge tow consisting of 15 barges can transport the equivalent of 870 large semi-trucks. When the inland waterways flood, or there is a bridge collapse blocking a key river on their route, there is tremendous delay to bulk cargo movement that cannot be made up by other modes of freight transportation (Iowa DOT).

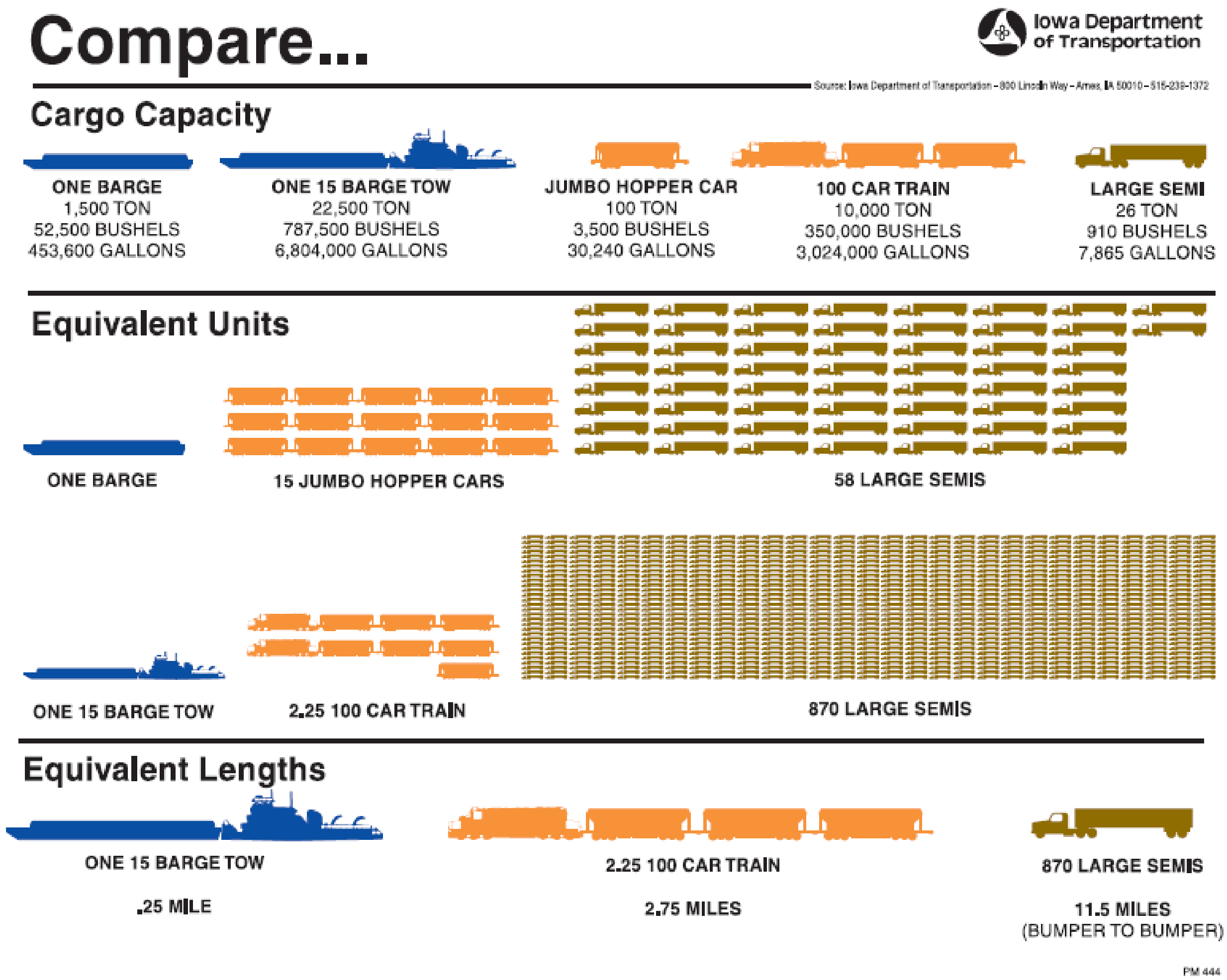

Figure 6-7: Iowa DOT Comparison Chart.

6.2.5. Pipelines

Pipelines are a key lifeline of the U.S. transportation and energy supply infrastructure, delivering natural gas, crude oil, refined products, such as gasoline and diesel, and natural gas liquids, such as ethane and propane. Because the engineering standards for pipeline safety and design are administered by the U.S. Department of Transportation's Pipeline and Hazardous Materials Administration (PHMSA), pipelines needed to transport natural gas and liquid fuels are discussed here as part of the transportation system.

The regulation and enforcement of pipeline safety for all types of pipelines are the responsibility of the PHMSA. A combination of federal, state, and local agencies are responsible for siting pipelines and their economic regulation (rates and tariffs).

Pipelines are generally grouped into three categories based on function: gathering (small pipelines in an oil or gas production area), transmission (larger, longer pipelines transporting products from supply areas to market areas), and distribution (pipelines delivering the product to residential, commercial or industrial end users). Including both onshore and offshore lines, there are approximately 300,000 miles of natural gas transmission pipelines, and 2.1 million miles of distribution pipelines in the U.S., delivering over 26 billion cubic feet of natural gas. Over 190,000 miles of liquids pipeline delivered nearly 15 billion barrels of crude oil and petroleum products in 2013. Over the last 10 years, liquids pipeline mileage is up 25,727 miles or 15.4%, with crude oil pipeline mileage growing 11,647 miles or 23.6% since 2004 (AOPL 2014).

The vast majority of liquid and gas pipelines are located underground, on land, or offshore; however, portions of the liquid pipeline network are located above ground along the Trans-Alaska Pipeline System, for example, which transports crude oil (DOT 2014).

Pipelines connect to compression/pumping stations, processing facilities, production platforms, wells, and storage facilities upstream and to end users, such as power plants and residential/commercial customers, downstream. Figure 6-8, showing the critical elements of the supply chain for oil, is equally illustrative of other types of pipeline systems and shows how these systems are inter-related with energy and other transportation systems. Short-term disruptions of the pipeline system by natural hazards complicate, hinder, and prolong disaster response and recovery. Long -term disruptions have a negative impact on the national economy, national security, and ecology.

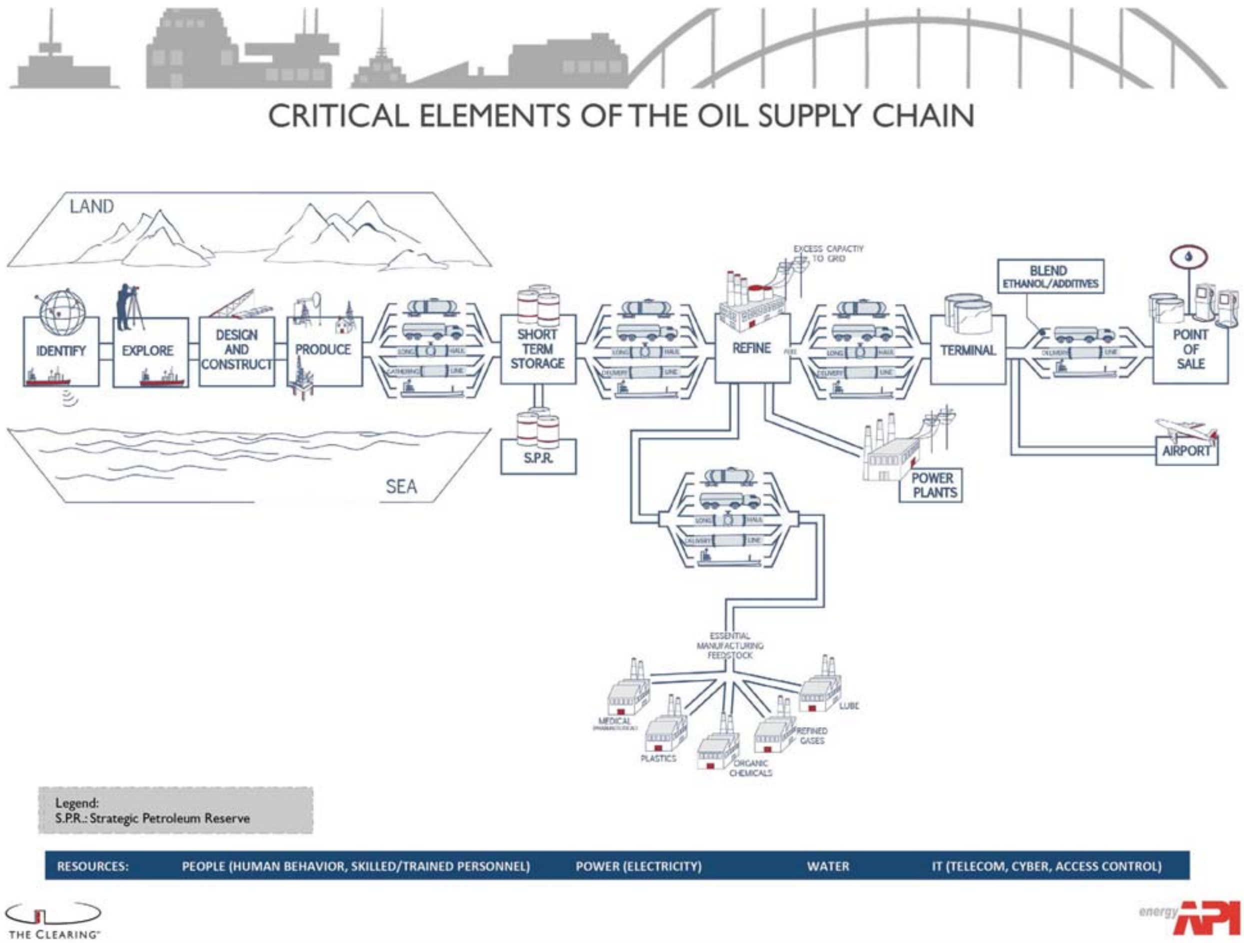

Figure 6-8: Critical Elements of the Oil Supply Chain

Pipelines and their associated aboveground 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 for the transportation system 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 offshore natural gas facilities that resulted in releases of gas from damaged or leaking pipelines in 72 locations (DNV 2007, 29). Damages to fuel refining and natural gas processing facilities caused by Hurricanes Katrina and Rita resulted in a loss of about 8% of the nation's capability to refine andprocess fuels, which significantly reduced the domestic supply (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 the East Coast to New Jersey and New York, creating a supply chain problem in New Jersey and New York. Yet, this delay 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) causing additional property damage (Ballantyne 2008, 1). Figure 6-10 shows an example of property damage caused by fire from broken gas lines.

Figure 6-9: Natural gas crew shuts off gas after Hurricane Sandy (Photographer: Liz Roll, 2012)

Figure 6-10: Fire damage from broken gas lines (Photographer: Christopher Mardorf, 2014)

The PHMSA 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 first step toward resiliency. Knowing where pipelines are located and making that information available is important to comprehensive and hazard mitigation planning, and preparedness, response, and recovery activities. Redesign or realignment of pipes to avoid liquefaction zones, faults, areas of subsidence, and floodplains are only possible if 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 provide an extra 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 help to mitigate damages to pipes due to earthquakes. These measures include replacing older pipes 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).

The American Lifelines Association (ALA 2005) identified the high-level performance measures and performance metrics for pipeline systems shown in Table 6-1.

Table 6-1: The American Lifelines Association High-Level Performance Measures and Performance Metrics for Pipeline Systems (ALA 2005).

Desired Outcomes (Performance Targets)	System Performance Metrics					
	Capital Losses ($)	Revenue Losses ($)	Service Disruption (% Service Population)	Downtime (hours)	Casualties (Deaths, Injuries)	Lost Product
Protect public and utility personnel safety					X	X
Maintain system reliability			X	X		
Prevent monetary loss	X	X	X	X		X
Prevent environmental damage						X

A qualitative ranking of hazards to typical pipeline system components and facilities from the ALA (2005) study is reproduced in Table 6-2.

Table 6-2: Qualitative Ranking of Hazards to Typical Pipeline System Components and Facilities (ALA 2005).

Hazards	Degree of Vulnerability									
	Transmission Pipelines	Pump Stations	Compressor Stations	Processing Facilities	Storage Tanks	Control Systems	Maintenance Operations Buildings and Equipment	Pressure Regulations / Metering Stations	Distribution Pipelines	Service Lines or Connections
Natural Hazards										
Earthquake Shaking	L	M	M	M	H	M	H	L	L	M
Earthquake Permanent Ground Deformations (fault rupture, liquefaction, landslide and settlement)	H	-	-	-	L	-	-	L	H (Buried)	M
Ground Movements (landslide, frost heave, settlement)	H	-	-	-	L	-	-	L	H (Buried)	M
Flooding (riverine, storm surge, tsunami and seiche)	L	H	H	H	M	H	H	H	L	M
Wind (hurricane, tornado)	L (Aerial)	-	-	-	-	L	L	-	-	-
Icing	L	-	-	-	-	-	-	-	L	-
Collateral Hazard: Blast or Fire	M	H	H	H	H	M	L	L	L	M
Collateral Hazard: Dam Inundation	L	H	H	H	M	H	H	H	L	M
Collateral Hazard: Nearby Collapse	-	L	L	L	-	L	L	L	M	L
Human Threats										
Physical Attack (biological, chemical, radiological and blast)	M	M	M	M	-	M	M	-	M	-
Cyber Attack	-	L	L	L	-	H	L	-	L	-

Note: Degrees of vulnerability: H = High, M = Moderate, L = Low. When a component or system is located within a building the vulnerability of both the building and component should be considered. For example, where there is a potential for building collapse or mandatory evacuation, the equipment housed within is at risk. The entries in Table 4-2 assume that the component is of recent vintage, i.e., post 1945.

It should be noted that over the last several years cyber security issues with pipeline systems have become an increased concern. Federal agencies, including the Department of Homeland Security, work with companies to improve security of computer-based pipeline control systems.

6.3. Performance Goals

Performance goals in this framework are defined by how quickly the functionality of the infrastructure systems recover after a hazard event. Minimizing downtime can be achieved during design or by developing and implementing a well prepared recovery plan (ideally both). [3]

Performance goals for the transportation system 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 infrastructure systems (e.g., power and water/wastewater). Community stakeholders include representatives of the transportation system users, including commuters, school districts, emergency response services, local businesses, and other private and commercial property owners. Transportation stakeholders come from the state DOT, city DOT, township engineer, transit authorities, highway authorities, airport authorities, Amtrak, freight and short line railroads, independent taxi, bus, marine, airline and truck operators, USACE, FHWA, FAA, FRA, FTA, USCG, state, city and township code officials, AASHTO, AREMA, state, city and township OEMs, and others, as applicable. Additional stakeholders from local critical facilities, businesses, and users of the transportation system should be included establishing performance goals. For transportation systems, in particular, it is imperative that other infrastructure industries are involved in establishing the performance goals, because several systems have strong interdependencies with transportation systems, as discussed in Section 6.1.2. For example, both overhead and underground distribution lines for the power transmission and communication systems are often within the right-of-way of roads and bridges, thus are subject to DOT requirements. Likewise, water, gas, wastewater utilities with buried lines beneath streets should also be involved. In the case of passenger and light rail, the method of transportation is heavily reliant on energy systems. Once a panel of stakeholders is established, they can work to establish the performance goals for transportation system of their community. Table 6-3 through Table 6-5 present examples of performance goals for the routine, expected, and extreme events (defined in Chapter 3) for the fictional community of Centerville, USA. These example performance goals are intended to be generic so that they can be used for a hurricane, earthquake, flood, etc. Although the loading on the infrastructure and failure modes will differ depending on the type of hazard event, the social needs that drive the establishment of performance goals remain the same. However, it is noted that the social needs, and thus performance goals will vary by community.

The matrices provide 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 hazard event. 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. A full discussion of the definitions of each level is provided in Chapter 3.

Recovery times are broken down into three main phases: Short-term, Intermediate, and Long-term. The short term phase (0-3 days) includes the needs/goals to support immediate recovery of the community in the wake of a hazard event. The intermediate recovery phase (1-12 weeks) includes the needs/goals to support to support citizens and businesses returning to their daily functionality. The long term recovery phase (4-36+ months) performance goals support the need to rebuild, retrofit, and strengthen the transportation network to become more resilient for future hazard events.

[3] A detailed discussion on performance goal metrics is provided in Chapter 3.

Table 6-3 through Table 6-5 can be used as guides by communities/owners to evaluate the vulnerabilities of their transportation infrastructure at the various hazard levels (routine, expected, and extreme). The tables should be used by communities/owners to establish performance goals based on local social needs. Tables similar to Table 6-3 through Table 6-5 can be developed for any community (rural or urban), and any type of hazard event.

The performance goals in Table 6-3 through Table 6-5 were based on the performance seen in previous disaster events, such as Hurricanes Sandy and Katrina. Although these performance goals are provided as an example, it is up to the individual community to prepare their own set of performance goals for their given hazards and infrastructure.

The affected area of a given hazard event 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 the infrastructure owner to consider because it will impact how much of the infrastructure may be damaged which will impact the duration of the recovery process.

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

In the individual rows of Table 6-3 through Table 6-5 an “X” shows how an infrastructure owner can indicate the anticipated performance and recovery of the infrastructure in their evaluation. As seen in these tables, there are significant gaps between the desired level of performance and what is seen in reality. This difference is a resilience gap. Once a community completes this table based on their local social needs and current anticipated performance, they can prioritize which gaps to address first.

Example performance goals for pipelines during the expected event in Centerville, USA are presented in Table 6-6. These example performance goals are similarly based on the performance seen in previous hazard events. The portions of the pipeline system most likely to have community impacts are liquid fuels and natural gas distribution systems, rather than production or transmission. This is because the interconnectivity of the pipeline grid is generally sufficient to adjust to localized incidents. Further, because natural gas and oil serve similar functions as electricity in the residential and commercial markets, the functional categories listed in Table 6-6 are essentially the same as the corresponding performance goal tables for electric transmission and distribution in Chapter 7. Much of the current infrastructure and response efforts managed by larger utilities may meet the 90% restored metric identified and therefore the blue shaded box is marked with 90% are to show that they are “overlapping.”

To establish performance goals for transportation systems, it is necessary to first prioritize the transportation systems and components that are most critical to community response and recovery. Next, set the highest performance goals for those systems. Corresponding performance goals of a lesser degree will then be set for systems and components that play a lesser role. This will insure that efforts to improve resiliency will be focused first on actions that can bring the most benefit to the community. The priority for each transportation system to support ingress, egress, and community transportation is based on the degree the system contributes to the performance of that role for the community. The ability of each system to effectively serve these functions is a balance of the volume of people or goods that the system has the capacity to move and the interface of the system with the local community it serves. For example, highways are designed as networks for evacuation/egress. Local streets feed state county routes, which feed state highways, which feed interstate highways. The capacity of each branch is commensurate with the demand. If a local street is blocked, a detour to another street can be found and the impact on traffic congestion is small. If a major interstate highway is blocked, the consequences are significant since traffic jams will create gridlock, because the detour routes require large traffic volumes to take local routes that cannot handle them.

In turn, design standards for highways are the highest for interstate highways, because they are the most critical for the movement of people and goods. They are graded to be above flood plains, trees are cut back from the shoulders, rock slopes are well back of shoulders, and they are well maintained. State highways are next in the level of performance standards and numbered county routes follow.

Highway bridges and road tunnels are part of the highway infrastructure and cannot be prioritized separately from the highway they connect. Bridges on interstate highways are more important than bridges on state highways and county routes when it comes to egress and ingress. Similarly, bridges or tunnels that are part of a subway or rail system that relies on them cannot be prioritized separately.

1. Designated evacuation routes and emergency access routes should have highest priority. They were designated such, because they can function as a network collecting vehicles from local streets, to county routes, state highways, and interstate highways, moving travelers to higher ground or away from other hazards such as a nuclear power plant alert. Highways may have intelligent transportation systems (ITS) to alert travelers of travel times, detours, and potential traffic congestion that can be avoided. Evacuation plans may reverse the direction of highways, so that all travel lanes are outbound, away from the hazard. ITS devices like cameras, sensors and variable message signs let traffic command centers communicate with travelers in vehicles to direct them.
2. Interstate Highways are next, since they are constructed to higher standards. They also carry the highest volume of vehicles, which makes them critical in evacuations.
3. State Highways are next for similar reasons to the above.
4. Numbered County Routes should be next (they are numbered parts of complete systems).
5. Pipelines serving power and energy systems in the community are next. In the short-term phase, ruptured natural gas, fuel, water, and wastewater lines need to be repaired to support recovery.
6. Buses use all the highway routes described above. Bus fleets should be protected, fueled, and strategically located and staged to support egress. They can move the greatest volumes of people, especially those in communities who do not own vehicles or have people they can rely on for a ride. In the short-term phase, they can also move the largest volume of relief and recovery workers to a disaster area. In evacuation planning it is preferable to have people who do not have access to automobiles to use buses instead of taxis or livery vehicles, since it results in less highway congestion.
7. In large cities subway mass transit systems are generally designed to collect commuters traveling to the city center from their local community via walking, bicycle, bus, regional rail, park and ride lots, and livery vehicles. The subway lines also connect at transfer stations, which serve as hubs to allow commuters to get to the specific destination station closest to where they work. At the end of the business day they perform these functions in reverse. Subway systems are capable of moving large volumes of people for egress purposes away from a hazard in the city center. When used for ingress purposes, the subway routes will likely allow passengers to use the transfer stations to get to a point close to their destination if their normal destination station is closed due to a disaster. Subways may not be useful for egress or ingress for disasters other than those described here. For this reason they are placed after buses in priority order.
8. Large ferry vessels are capable of moving significant volumes of people across bodies of water that otherwise would require long travel distances by other modes of transportation. Examples are the ferry system in San Francisco and the Staten Island Ferry in New York City. They can perform this function well on an emergency basis for egress or ingress. Their operation; however, is limited in storm conditions when they are required to shut down. Large ferry systems have robust ferry terminal docking systems that are less likely to suffer damage during an expected storm event; however, for more extreme storm events they may suffer significant damage.

9. Light rail transit systems are often found to be a link between communities, the town center, and other modes of transportation, such as airports or passenger rail stations. They transport much lower volumes of passengers at lower speeds than mass transit systems, but provide more frequent service with shorter headways between trains. In general, light rail systems are not as resilient as other rail systems; they do not operate in high winds and have problems with icing, since they are either powered by overhead electric catenaries or have electric bus bars similar to, but less robust than, third rails.
10. Regional rail is generally designed to collect commuters traveling to the city center from local suburban communities via local stations or distribute them in the reverse direction. Travel to stations is by automobile, taxi, livery car, walking, or bicycle. Some stations are hubs with larger park and ride lots or garages. Regional rail usually feeds a multimodal train terminal station in the city or town center where passengers extend their trip to their ultimate destination by intercity rail, subway, bus transit systems, or taxis. Examples of regional rail are Penn Station in New York City and Union Station in Washington, DC. Regional rail can serve for egress or ingress; however, travelers evacuating from the suburbs need to be wary that the other transportation systems they will rely on for connections are functioning.
11. National or international airports can be used for egress of travelers who need to return to their home airport, or community residents evacuating to other cities. In the ingress mode, it can receive large volumes of emergency aid as air cargo and bring recovery workers from large distances unaffected by the hazard event. Airports are generally well connected to the regional highway network, which is likely to be the first local transportation system that is functioning after a hazard event. They may also be connected to regional rail, subway systems, or light rail systems.
12. Intercity rail, such as Amtrak, can be used for egress of travelers who need to return to their community, or residents evacuating to other communities. In the ingress mode, it can bring recovery workers from distant cities unaffected by the hazard event. Intercity rail stations are generally in the town center or city center and are well connected to the regional rail or local subway or bus transit system with taxi and rental car service.
13. Regional airports can function similar to national or international airports to serve communities that are outside of large cities. The highway networks that support these airports should be sized according to the lower volumes of cargo and passengers they transport.
14. Marine ports are comprised of docks, waterways, locks, and supporting upland facilities, which include cargo storage and distribution centers, cargo and container cranes, intermodal freight rail yards, and truck transfer and inspection facilities. Egress at these facilities involves scheduling large container ships and cargo vessels to divert to other ports, and diverting rail and truck exports to other ports. Ingress for recovery supplies and bulk and container cargo can only take place after restoration of the docks, waterways, locks, supporting upland facilities, and the connecting highways and rail yards.
15. Freight rail lines connect to major distribution centers in inland cities and to major port facilities on the coasts. Use for egress would include removal of debris and refuse. Use for ingress would include recovery supplies, bulk cargo, and heavy equipment.
16. Ferry terminals for smaller vessels carrying lower volumes of travelers do not have a big impact on egress, except where they may serve waterfront communities that are otherwise isolated (island communities). In addition, during the recovery phases, temporary ferry operations can be quickly established to serve communities cut off by bodies of water after the wash out of roads and bridges.

Table 6-3: Example Transportation Performance Goals for Routine Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Routine Event	Localized
	Disruption Level	Minor

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Routine Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Ingress (goods, services, disaster relief)		**A**									
Local Roads, Bridges and Tunnels			90%	X							
State Highways, Bridges and Tunnels			90%	X							
National Highways, Bridges and Tunnels			90%	X							
Regional Airport			60%	90%	X						
National/International Airport			60%	90%	X						
Military Airports			60%	90%	X						
Marine Port			60%	90%	X						
Ferry Terminal			60%	90%	X						
Subway Station			60%	90%	X						
Rail Station, Local			60%	90%	X						
Rail Station, Regional				30%	60%	90%	X				
Rail Station, National				30%	60%	90%	X				
Egress (emergency egress, evacuation, etc)		**1**									
Local Roads, Bridges and Tunnels			90%	X							
State Highways, Bridges and Tunnels			90%	X							
National Highways, Bridges and Tunnels			90%	X							
Regional Airport			60%	90%	X						
National/Int'l Airport			30%	60%	90%	X					
Military Airports			60%	90%	X						
Subway Station			60%	90%	X						
Ferry Terminal			60%	90%	X						
Rail Station, Local			90%		X						
Rail Station, Regional			60%	90%	X						
Rail Station, National			30%	60%	90%		X				
Community resilience											
Critical Facilities		**A**									
Hospitals			90%	X							
Police and Fire Stations			90%	X							
Emergency Operational Centers			90%	X							
Emergency Housing		**B**									
Residences			90%	X							
Emergency Responder Housing			90%	X							
Public Shelters			90%	X							
Housing/Neighborhoods		**B**									
Essential City Service Facilities			60%	90%	X						
Schools			60%	90%	X						
Medical Provider Offices			60%	90%	X						
Retail			60%	90%	X						
Community Recovery		**C**									
Residences			60%	90%	X						
Neighborhood retail			60%	90%	X						
Offices and work places			60%	90%	X						
Non-emergency City Services			60%	90%	X						
All businesses			30%	60%	90%	X					

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%	90%	
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
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

Table 6-4: Example Transportation Performance Goals for Expected Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Expected Event	Community
	Disruption Level	Moderate

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Expected Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-24	24+
Ingress (goods, services, disaster relief)		**A**									
Local Roads, Bridges and Tunnels			60%	90%	X						
State Highways, Bridges and Tunnels			60%	90%		X					
National Highways, Bridges and Tunnels			90%		X						
Regional Airport				30%	60%	90%		X			
National/International Airport			30%	60%	90%	X					
Military Airports			30%	60%	90%	X					
Marine Port				30%	60%	90%	X				
Ferry Terminal			30%	60%	90%	X					
Subway Station			30%	60%	90%		X				
Rail Station, Local			30%	60%	90%	X					
Rail Station, Regional				30%	60%	90%	X				
Rail Station, National				30%	60%	90%	X				
Egress (emergency egress, evacuation, etc)		**1**									
Local Roads, Bridges and Tunnels			60%	90%	X						
State Highways, Bridges and Tunnels			60%	90%		X					
National Highways, Bridges and Tunnels			90%		X						
Regional Airport				30%	60%	90%		X			
National/Int'l Airport				30%	60%	90%	X				
Military Airports				30%	60%	90%	X				
Subway Station			30%	60%	90%	X					
Ferry Terminal			60%	90%	X						
Rail Station, Local				30%	60%	90%	X				
Rail Station, Regional				30%	60%	90%	X				
Rail Station, National			30%	60%	90%	X					
Community resilience											
Critical Facilities		**A**									
Hospitals			60%	90%	X						
Police and Fire Stations			60%	90%	X						
Emergency Operational Centers			60%	90%	X						
Emergency Housing		**B**									
Residences			30%	60%	90%	X					
Emergency Responder Housing			30%	60%	90%	X					
Public Shelters			90%		X						
Housing/Neighborhoods		**B**									
Essential City Service Facilities			30%	60%	90%	X					
Schools			30%	60%	90%	X					
Medical Provider Offices			30%	60%	90%	X					
Retail			30%	60%	90%	X					
Community Recovery		**C**									
Residences			30%	60%	90%	X					
Neighborhood retail			30%	60%	90%	X					
Offices and work places			30%	60%	90%	X					
Non-emergency City Services			30%	60%	90%	X					
All businesses				30%	60%	90%	X				

Footnotes: See Table 6-3, page 22.

Table 6-5: Example Transportation Performance Goals for Extreme Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Extreme Event	Regional
	Disruption Level	Severe

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current

Functional Category: Cluster	(4) Support Needed	(5) Target Goal	Overall Recovery Time for Hazard and Level Listed								
			Extreme Hazard Level								
			Phase 1 – Short-Term			Phase 2 -- Intermediate			Phase 3 – Long-Term		
			Days			Wks			Mos		
			0	1	1-3	1-4	4-8	8-12	4	4-36	36+
Ingress (goods, services, disaster relief)		**A**									
Local Roads, Bridges and Tunnels					30%	60%	90%	X			
State Highways, Bridges and Tunnels					30%	60%	90%	X			
National Highways, Bridges and Tunnels				30%	60%	90%	X				
Regional Airport					30%	60%	90%	X			
National/International Airport				30%	60%	90%		X			
Military Airports					30%	60%	90%	X			
Marine Port					30%	60%	90%	X			
Ferry Terminal					30%	60%	90%	X			
Subway Station					30%	60%	90%	X			
Rail Station, Local					30%	60%	90%	X			
Rail Station, Regional					30%	60%	90%	X			
Rail Station, National					30%	60%	90%	X			
Egress (emergency egress, evacuation, etc)		**1**									
Local Roads, Bridges and Tunnels					30%	60%	90%	X			
State Highways, Bridges and Tunnels					30%	60%	90%	X			
National Highways, Bridges and Tunnels				30%	60%	90%	X				
Regional Airport					30%	60%	90%	X			
National/Int'l Airport				30%	60%	90%		X			
Military Airports					30%	60%	90%	X			
Subway Station					30%	60%	90%	X			
Ferry Terminal					30%	60%	90%	X			
Rail Station, Local					30%	60%	90%	X			
Rail Station, Regional					30%	60%	90%	X			
Rail Station, National					30%	60%	90%	X			
Community resilience											
Critical Facilities		**A**									
Hospitals			30%	60%	90%		X				
Police and Fire Stations			30%	60%	90%		X				
Emergency Operational Centers			30%	60%	90%		X				
Emergency Housing		**B**									
Residences					30%	60%	90%	X			
Emergency Responder Housing			30%	60%	90%	X					
Public Shelters			30%	60%	90%	X					
Housing/Neighborhoods		**B**									
Essential City Service Facilities					30%	60%	90%	X			
Schools					30%	60%	90%	X			
Medical Provider Offices					30%	60%	90%	X			
Retail					30%	60%	90%	X			
Community Recovery		C									
Residences					30%	60%	90%	X			
Neighborhood retail					30%	60%	90%	X			
Offices and work places					30%	60%	90%	X			
Non-emergency City Services					30%	60%	90%	X			
All businesses					30%	60%	90%	X			

Footnotes: See Table 6-3, page 22.

Table 6-6. Example Pipeline Performance Goals for Expected Event in Centerville, USA

Disturbance		
(1)	Hazard	Any
	Affected Area for Expected Event	Community
	Disruption Level	Moderate

Restoration times		
(2)	30%	Restored
	60%	Restored
	90%	Restored
(3)	X	Current (note: 90% used if desired equal to anticipated)

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+
Pipelines											
Distribution											
Critical Response Facilities and Support Systems											
Hospitals, Police and Fire Stations				30%	60%	90%					
Emergency Operations Centers				30%	60%	90%					
Disaster debris/recycling centers				30%	60%	90%					
Related lifeline systems				30%	60%	90%					
Emergency Housing and Support Systems											
Public Shelters (General Population, Animal, etc.)					30%	60%	90%				
Food distribution centers					30%	60%	90%				
Nursing homes, transitional housing					30%	60%	90%				
Emergency shelter for response/recovery workforce				30%	60%	90%					
Related lifeline systems				30%	60%	90%					
Housing and Neighborhood infrastructure											
Essential city services facilities							30%	60%	90%		
Schools							30%	60%	90%		
Medical provider offices							30%	60%	90%		
Houses of worship/meditation/ exercise											
Buildings/space for social services (e.g., child services) and prosecution activities											
Food distribution from local grocery stores (location known by community)						30%	60%	90%	X		
Community Recovery Infrastructure											
Residential housing restoration							30%	60%	90%		
Commercial and industrial businesses							30%	60%	90%		
Non-emergency city services							30%	60%	90%		
Community Recovery Infrastructure											
Residential housing restoration							30%	60%	90%		
Commercial and industrial businesses							30%	60%	90%		
Non-emergency city services							30%	60%	90%		
Related lifeline systems							30%	60%	90%		

Footnotes: See Table 6-3, page 22.

6.4. Regulatory Environment

There are multiple regulatory bodies at the various levels of government (federal, state, and local) that have authority over the transportation system. The transportation system is not regulated by a single regulatory body, even within a single transportation mode. This section discusses regulatory bodies of communications infrastructure at the federal, state, and local levels.

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 maintain the safety and security of infrastructure and operations. As the transportation industry features a diverse range of methods and operating environments, is overseen by a myriad of regulatory agencies, and funded by disparate streams that are subject to variability in direction of different political administrations, efforts to assess and address resilience across the transportation industry varies in scope. Some of the key regulatory agencies are discussed in the following sections.

Table 6-7 presents a summary of the methods of transportation used and the oversight authorities involved in their regulation.

Table 6-7: Transportation Infrastructure Code and Standards Governing Agencies

Industry	Infrastructure	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
	Roads, Bridges and Tunnels	Passenger	Inter-City Motor coach	X	X	X	X	X	X			X	X	X				X
			Intra-City Bus/Motor coach	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

6.4.1.1. U.S. Department of Transportation

The United States Department of Transportation (DOT) is a federal agency concerned with transportation. It was created in 1966 and governed by the U.S. Secretary of Transportation. Its mission is to "Serve the

United States by ensuring a fast, safe, efficient, accessible, and convenient transportation system that meets our vital national interests and enhances the quality of life of the American people, today and into the future." The following agencies are housed within the DOT:

- National Highway Traffic Safety Administration
- Federal Aviation Administration
- Office of Inspector General
- Federal Highway Administration
- Pipeline and Hazardous Materials Safety Administration
- Federal Motor Carrier Safety Administration
- Federal Railroad Administration
- Saint Lawrence Seaway Development Corporation
- Federal Transit Administration
- Surface Transportation Board
- Maritime Administration

6.4.1.2. Federal Highway Administration

The Federal Highway Administration (FHWA) is an agency within the U.S. 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 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 improves the transfer area of the Fairbanks, AK Freight Yard, so trucks can make pick-ups/drop-offs in a shorter period (FHWA 2009). The current pick-up/drop-off location does not provide enough room for the trucks to get to the trains, thus creating bottlenecks even without a hazard event occuring.

The FHWA 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). These programs 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 is especially helpful after a hazard event.

6.4.1.3. Federal Transit Administration

The Federal Transit Administration (FTA) is an agency within the U.S. Department of Transportation, which provides financial and technical support to local public transit systems (i.e., buses, subways, light rail, commuter rail, monorail, passenger ferryboats, trolleys, inclined railways, and people movers). FTA programs assist state, regional, and local transit operators in developing and maintaining 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 released 49 CFR Part 633 to cover system safety issues in design and construction of major capital projects. Later, after 9/11, the FTA developed requirements to cover security issues. However, these regulations did not cover the preponderance of transit systems that offered 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. These programs potentially cover climate change issues, since transit systems are required to perform design and operational risk assessments at this time.[4] However, the FTA does not have a systematic regulatory program to address climate change or resilience. Instead, the FTA has developed guidance and a pilot program for agencies to investigate the issues.

6.4.1.4. Federal Railroad Administration (FRA)

The Federal Railroad Administration (FRA) is an agency within the U.S. Department of Transportation responsible for heavy rail freight systems, commuter and inter-city passenger rail systems. The primary FRA programs organize around safety, rail network development, research and development, regulations, and grants and loans.

FRA’s core mission is railroad safety, and their programs reflect this focus. The safety programs address hazardous materials, motive power and equipment, operating practices, signal and train control, and track. FRA’s Track Division provides evaluation, direction, and technical advice for rail safety enforcement programs for FRA and State safety programs. The Track Division participates in accident investigations and directly investigates reports concerning track conditions. Most relevant to resiliency, the Track Division actively participates in development of industry and consensual standards useful for enhancement of railroad safety. Industry design standards relevant to resiliency are developed primarily by the American Railway Engineering and Maintenance-of-Way Association (AREMA). Additionally, for policy matters and operations-related standards, the leading organization is the Association of American Railroads (AAR).

FRA’s R&D mission is to ensure the safe, efficient and reliable movement of people and goods by rail through basic and applied research, and development of innovations and solutions. Safety is the DOT’s primary strategic goal and the principal driver of FRA’s R&D program. FRA’s R&D program also contributes to other DOT strategic goals because safety-focused projects typically yield solutions towards the state of good repair, economic competitiveness, and environmental sustainability goals.

FRA’s R&D program is founded on an understanding of safety risks in the industry. Hazard identification and risk analysis allows FRA to identify opportunities to reduce the likelihood of accidents and incidents, and to limit the consequences of hazardous events should they occur. Key strategies include stakeholder engagement and partnerships with other researchers, such as the AAR, prioritization of projects and conducting research through cost-effective procurement.

For roadway systems, federal regulation often leaves room for interpretation, while states often issue more specific guides and manuals building on federal regulation. For example, in each subsection of the FHWA’s Manual on Uniform Traffic Control Devices (MUTCD) there is a “Standard” section followed by multiple “Guidance” sections, providing further details that are recommended, but not required, depending on specific conditions. States are allowed, and even encouraged, to make modifications to the MUTCD that fit specific state needs. California found so many such modifications that it issues its own California MUTCD that supersedes the federal version.

6.4.1.5. Federal Aviation Administration (FAA)

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

[4] The latter is not a mandated and necessarily enforced by a standardized framework but the former is more so.

Administration (TSA) also has an active role in the security of air freight and commercial air passenger service.

The FAA supports public and private airports within the National Plan of Integrated Airport Systems (NPIAS) in the design, construction, and maintenance of the airport system with grants through the Airport Improvement Program (AIP). 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.

6.4.1.6. Federal Emergency Management Agency (FEMA)

FEMA is an agency of the United States Department of Homeland Security with a primary purpose to coordinate the response to a disaster that has occurred in the United States and that overwhelms the resources of local and state authorities. FEMA supports the recovery of infrastructure systems after a disaster event, including the transportation system, and the specific authorities and programs within the jurisdiction of participating departments and agencies.

As one of their mission is to recover from all hazards and provide funding for recovery and hazard mitigation, FEMA identifies transportation modes and capabilities for all populations, including individuals located in hospitals and nursing homes and individuals with disabilities and others with access and functional needs.

6.4.1.7. U.S. 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).

6.4.1.8. Transportation Security Administration (TSA)

The Transportation Security Administration (TSA), an agency within the U.S. Department of Homeland Security (DHS), is responsible for prevention of the intentional destruction or disablement of transportation systems in all modes of transport. Formed after the events of 9/11, TSA immediately imposed security oversight and regulation in the aviation community and subsequently established divisions in all other modes, including highway, mass transit, passenger and freight rail, pipeline and maritime where it shares oversight with the U.S. Coast Guard. TSA established direct interaction and partnerships with private and public transportation operators to review and assess modal security preparedness, training and enhancement through both regulatory and voluntary steps. TSA has focused its attentions on prevention of intentional disruption and improved resilience in all modal systems.

6.4.1.9. United States Corps of Engineers (USACE)

The USACE provides support in the emergency operation and restoration of inland waterways, ports, and harbors under the supervision of DOD/USACE, including dredging operations and assists in restoring the transportation infrastructure.

The USACE is a U.S. federal agency under the Department of Defense, with environmental sustainability as a guiding principle. By building and maintaining America’s infrastructure and by devising hurricane and storm damage reduction infrastructure, the USACE is reducing risks from hazard events.

The USACE regulates water under “Section 404 clean Water Act” and “Section 10 Rivers and Harbors” permits. As the lead federal regulatory agency, USACE assesses potential impacts to marine navigation in the federal-maintained channels in the USA.

USACE is addressing climate issues identified in the National Ocean Policy Implementation Plan (NOPIP) and taking actions. The USACE climate programs incorporate collaborative efforts to develop and disseminate methods, best practices, and standards for assessing coastal resilience in a changing climate. In response to Executive Orders 13514 and 13653, the USACE released its Climate Change Adaptation Plan and annual Strategic Sustainability Plan.

As it relates to the maritime industry, the USACE is working on the following actions in response to climate change related issues: **[3]**

- Develop an interagency plan for topographic and shallow bathymetric mapping to ensure comprehensive and accurate elevation information for coastlines that will eventually include acoustic bathymetry mapping.
- Provide and integrate county-level coastal and ocean job trends data via NOAA's Digital Coast to enable decision-makers and planners to better assess the economic impacts of climate change and ocean acidification.
- Support NOAA's Economics: National Ocean Watch (ENOW) will provide data on six economic sectors that directly depend on the resources of the oceans and Great Lakes: Living Resources (includes commercial fishing), Tourism and Recreation, Marine Transportation, Ship and Boat Building, Marine Construction (includes harbor dredging and beach nourishment), and Offshore Minerals (exploration and production, sand, gravel, oil, gas).
- Provide coastal inundation and sea-level change decision-support tools to local, state, tribal, and federal managers.
- Build on the USACE-developed sea level change calculator used in the interagency Sea Level Rise Tool for Sandy Recovery in the North Atlantic Coast. The USACE, NOAA, and FEMA are working on two pilot programs to test the application of this tool in the gulf coast and west coast. USACE, NOAA, and the Department of the Interior are working on a Sea Level Rise and Coastal Flooding Impacts Viewer and associated datasets including Digital Elevation Models. Being able to visualize potential impacts from sea level rise and coastal flooding is a powerful teaching and planning tool, and the Sea Level Rise Viewer, map services, and data brings this capability to coastal communities.

6.4.1.10. United States Environmental Protection Agency (EPA)

The EPA is an agency of the U.S. federal government created to protect human health and the environment by writing and enforcing regulations based on laws passed by Congress.

The Clean Water Act (CWA) establishes the basic structure for regulating discharges of pollutants into the waters of the United States and regulating quality standards for surface waters. EPA's National Pollutant Discharge Elimination System (NPDES) permit program controls discharges. These regulations are important from the perspective that most marine infrastructure design and construction process are required to comply.

The EPA's Program and Regional Offices produced a final Climate Change Adaptation Plan and the Climate Change Adaptation Implementation Plans. These plans describe how the agency will integrate considerations of climate change into its programs, policies, rules, and operations to ensure they are effective, even as the climate changes. On June 30, 2014, the EPA issued a new policy statement on climate change adaptation. This statement updates the initial policy statement issued in June of 2011. Climate Ready Estuaries is a partnership between EPA and the National Estuary Program to assess climate change vulnerabilities in coastal areas, develop and implement adaptation strategies, engage and educate stakeholders, and share the lessons learned with other coastal managers. **[4, 5]**

6.4.1.11. Council on Environmental Quality (CEQ)

CEQ was established within the Executive Office of the President by Congress as part of the National Environmental Policy Act of 1969 (NEPA) and additional responsibilities were provided by the Environmental Quality Improvement Act of 1970. NEPA assigns CEQ the task of ensuring that federal agencies meet their obligations under the Act. The challenge of harmonizing our economic, environmental and social aspirations puts NEPA and CEQ at the forefront of our nation's efforts to protect the environment. NEPA advanced an interdisciplinary approach to federal project planning and decision-making through environmental impact assessment. This approach requires federal officials to consider environmental values alongside the technical and economic considerations that are inherent factors in federal decision-making. They also require agencies to create their own NEPA implementing procedures. These procedures must meet the CEQ standard, while reflecting each agency's unique mandate and mission. Consequently, NEPA procedures vary from agency to agency. Further procedural differences may derive from other statutory requirements and the extent to which federal agencies use NEPA analyses to satisfy other review requirements. These include environmental requirements under statutes like the Endangered Species Act and Coastal Zone Management Act, Executive Orders on Environmental Justice, and other federal, state, tribal, and local laws and regulations.

6.4.1.12. National Ocean and Atmospheric Administration

Coastal Zone Management Act (CZMA) of 1972, administered by NOAA, provides for the management of the nation's coastal resources, including the Great Lakes. The National Coastal Zone Management Program works with coastal states and territories to address some of today's most pressing coastal issues, including climate change, ocean planning, and planning for energy facilities and development. The federal consistency component ensures that federal actions with reasonably foreseeable effects on coastal uses and resources must be consistent with the enforceable policies of a state's approved coastal management program. This also applies to federally authorized and funded non-federal actions.

6.4.1.13. Pipeline and Hazardous Materials Administration (PHMSA)

PHMSA is one of ten operating administrations within the U.S. Department of Transportation. PHMSA leads two national safety programs related to transportation. It is responsible for identifying and evaluating safety risks, developing and enforcing standards for transporting hazardous materials and for the design, construction, operations, and maintenance of pipelines carrying natural gas or hazardous liquids. PHMSA is also responsible for educating shippers, carriers, state partners and the public, as well as investigating hazmat and pipeline incidents and failures, reviewing oil spill response plans, conducting research, and providing grants to support state pipeline safety programs and improve emergency response to incidents. PHMSA also works with the Federal Aviation Administration (FAA), Federal Railroad Administration (FRA), Federal Motor Carrier Safety Administration (FMCSA), and U.S. Coast Guard to help them administer their hazardous materials safety programs effectively.

6.4.1.14. Federal Energy Regulatory Commission (FERC)

FERC is an independent regulatory agency for transmission and wholesale of electricity and natural gas in interstate commerce and regulates the transportation of oil by pipeline in interstate commerce. FERC also reviews proposals to build interstate natural gas pipelines, natural gas storage projects, and liquefied natural gas (LNG) terminals. FERC also licenses nonfederal hydropower projects and is responsible for protecting the reliability and cyber security of the bulk power system through the establishment and enforcement of mandatory standards.

FERC has comprehensive regulations implementing the National Environmental Policy Act (NEPA) that apply to interstate natural gas pipelines, natural gas storage facilities, and liquefied natural gas facilities. In evaluating applications for new facilities or modifications of existing facilities, FERC will issue an environmental assessment (EA) or environmental impact statement (EIS). If FERC approves the project and the routing, pipeline companies must comply with all environmental conditions that are attached to FERC orders.

6.4.2. Regional, State, and Local

Metropolitan Planning Organizations (MPO) were encouraged to review the safety and security of the regional transportation network, since the enactment of SAFETEA-LU in 2005. FHWA funded and encouraged MPOs across the U.S. to look into ways they can foster considerations of safety and security planning, including resilience efforts in the long-term capital plans that MPOs develop and fund.

For airports, FAA can accept state standards for construction materials and methods. Under certain conditions[5], the use of state dimensional standards that differ from the standards in FAA Advisory Circulars are not acceptable for federally obligated or certificated airports.

Many communities have zoning ordinances, building codes, and fire regulations that may place additional requirements on airport development and operations. For example, if a new hangar or other structure is to be built at an existing airport, approval and/or permits must be received from the local building department or planning authority (e.g., Borough of Lincoln Park, New Jersey has strict storm water management requirements due to high flood hazard potential).

State regulatory agencies oversee the ports, harbors, and waterways industry/infrastructure for methods of design and construction. Using New York as an example, the New York Department of State (NYSDOS) [6] regulates water under "Coastal Consistency Concurrence" permit. Coastal Zone Management Federal Consistency is a process that requires federal agencies to follow State coastal management policies when conducting a project or issuing a permit that could affect coastal resources. It also enables increased coordination between government agencies. The Department of State provides both technical assistance and grant funding to waterfront communities to facilitate disaster resilience.

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.

Roads, Bridges, Highways and Road Tunnels. Moving Ahead for Progress in the 21st Century (MAP-21) is a bill signed into law by FHWA in July, 2012. MAP-21 makes funds available for studies of climate change vulnerability, to improve the dissemination of research products, and to accelerate deployment of new technologies and ensure existing programs are kept intact. Authorization is given to create programs granting financial awards for transportation research. MAP-21 requires the USDOT to create a bureau of transportation statistics that will oversee a national transportation library, an advisory council on statistics, and a national electronic atlas database. Although climate change statistics are not specified, this act at the very least, gives the option for a centralized data center useful for transportation agencies gaining access to climate information and using this information for the development of codes and standards.

AASHTO is a standards-setting body that publishes specifications, test protocols, and guidelines used in highway and bridge design and construction throughout the United States. AASHTO specifications for design of bridges consider waterfront effects, since bridges often span waterways. Hence, the provisions of these specifications are often used in the design of similar waterfront structures.

Rail. The American Railway Engineering and Maintenance-of-Way Association (AREMA) authors a Manual for Railway Engineering (MRE) and a Communications and Signals Manual, among other guides. The MRE is updated annually with new design standards for fixed railway. Chapter 13 covers environmental aspects including water, air quality, and waste management and sites environmental acts

[5] Applies to airports with 10,000 passengers or less boarding per year and runways 5,000 feet or shorter, serving aircraft of 60,000 pounds gross weight and under, and standards not related to the safety of airport approaches or airport geometric standards. Reference AC 150/5100-13, Development of State Standards for Nonprimary Airports.

pertaining to regulations. For example, Section 404 of the Clean Water Act discusses the regulatory limit for tidal waters and states that a project including placement of fill material within a body of water between ordinary high water marks requires a Section 404 permit from the USACE (see 6.4.1.6). Additionally, Section 401 of the CWA pertains to water quality certifications and provides a statutory basis for federally-designated states to regulate their state's water quality. This flexibility of state-issued certification allows for a more tailored response to disaster resilience needs. For example, Section 401 regulatory limit for tidal waters extends to the mean high water limit, which is influenced by changing sea levels.

The American Society of Civil Engineers, ASCE, is a professional body representing members of the civil engineering profession worldwide. The following standards, published by ASCE are of interest to facilities with a risk of natural hazards. These standards do not include specific reference to adaptation/resilience policies.

- ASCE 24 Flood Resistant Design and Construction: This standard is also referenced by the International Building Code, with any building or structure proposed to be located in a flood hazard area is to be designed in accordance with ASCE 24. Also, the International Residential Code (IRC) allows homes in coastal high hazard areas to be designed in accordance with ASCE 24, as an alternative to the prescriptive requirements therein. [**12**]
- ASCE 7 Minimum Design Loads for Buildings and Other Structures: This standard is referenced by the International Building Code (IBC). It includes the consideration and calculation of flood loads.[**13**]
- ASCE 61 Seismic Design Standard for Piers and Wharves: This defines a displacement-based design method to establish guidelines for piers and wharves to withstand the effects of earthquakes.[**14**]

The American Concrete Institute, ACI, is a leading authority and resource for the development and distribution of consensus-based standards for individuals and organizations involved in concrete design, construction, and materials. The ACI codes typically used where the flood risk is greatest are:

- ACI 318 Building Code Requirements for Structural Concrete and Commentary: This covers the materials, design, and construction of structural concrete used in buildings and where applicable in non-building structures. The code also covers the strength evaluation of existing concrete structures.
- ACI 350 Code Requirements for Environmental Engineering Concrete Structures: This code provides design requirements more stringent than ACI 318 for concrete structures intended to contain highly corrosive liquids used for environmental engineering. Waterfront structures exposed to aggressive saltwater environments are often designed to meet these more exacting standards.
- ACI 357.3R Guide for Design and Construction of Waterfront and Coastal Concrete Marine Structures: This is a relatively new guide, covering durability and serviceability of concrete waterfront structures, as well as analysis techniques and design methodologies unique to them.

The American Institute of Steel Construction's (AISC) mission is to provide specification and code development, research, education, technical assistance, quality certification, standardization, and market development for steel construction. Most building codes reference American National Standards Institute (ANSI)/AISC standard 360, Specification for Structural Steel Buildings.

Air. The FAA regulates commercial service airports under 14 CFR Part 139, Certification of Airports. This regulation prescribes rules governing the certification and operation of airports in any state of the United States, the District of Columbia, or any territory or possession of the United States that serve scheduled or unscheduled passenger service. Advisory Circulars (ACs) contain methods and procedures that certificate holders use to comply with the requirements of Part 139.

FAA's AC 150/5200-31C, Airport Emergency Plan, provides guidance to the airport operator in the development and implementation of an Airport Emergency Plan (AEP) that should address essential actions in the event of possible emergencies, including natural disasters. The guidance includes mitigation, such as zoning and earthquake-resistant construction, as an important phase of comprehensive emergency management.

Ports, Harbors, and Waterways. Codes and standards are used by the ports, harbors and waterways to establish minimum acceptable criteria for design and construction. To mandate adequate robustness, each jurisdiction adopts appropriate codes and standards to set these minimum requirements. Climate change adaptation would be in the form of local regulations, independent of the codes and standards selected. These regulations would be similar for a project, such as a pier or bulkhead, whether it is proposed as part of development of upland property or to protect upland property from sea level rise for an extended period. Therefore, the application of regulations to maritime infrastructure would be similar to those developments mentioned above. In the purpose and need statement for a proposed project, the basis of design should state the standards and codes used, and the regulations and guidelines followed; that part of the justification for the project includes risk for natural hazard, if appropriate.

The World Association for Waterborne Transport Infrastructure, PIANC, provides expert guidance, recommendations and technical advice for design, development, and maintenance of ports, waterways and coastal areas. Two guidelines of frequent interest in port design are:

- Seismic Guidelines for Port Construction
- Guidelines for the Design of Fender Systems

The following organizations provide codes, standards, and guidelines commonly used in maritime infrastructure design and construction:

- American Association of State Highway Officials (AASHTO)
- Permanent International Association of Navigation Congress PIANC 2002
- American Society of Civil Engineers (ASCE)
- American Concrete Institute (ACI)
- USA Department of Defense (DoD)
- U.S. Army Corps of Engineers (USACE)
- American Institute of Steel Construction (AISC)
- British Standards Institution (BSI)
- Overseas Coastal Area Development Institute of Japan (OCDI).

The DoD initiated the Unified Facilities Criteria (UFC) program to unify all technical criteria and standards pertaining to planning, design, and construction, which was previously issued by individual Defense agencies. The following UFC documents are often used for waterfront design – none specifically refer to adaptation/resilience policies.

- UFC 4-150-06 Military Harbors and Coastal Facilities
- UFC 4-151-10 General Criteria for Waterfront Construction
- UFC 4-150-01 Design: Piers and Wharves
- UFC 4-152-07N Design: Small Craft Berthing Facilities
- UFC 4-159-03 Design: Mooring

The USACE published an extensive library of Engineering Manuals covering the design of a variety of major civil works. The manuals typically used for waterfront design include the following – none of which specifically incorporate adaptation policies regarding resilience. **[18]**

- EM 1110-2-2502 Retaining and Flood Walls
- EM 1110-2-2602 Planning and Design of Navigation Locks
- EM 1110-2-2504 Design of Sheet Pile Walls
- EM 1110-2-2503 Design of Sheet Pile Cellular Structural Cofferdams and Retaining Structures
- EM-1110-2-1614 Design of Coastal Revetments Seawalls and Bulkheads
- EM-1110-2-1100 Coastal Engineering Manual

The standards from this institution used for waterfront construction are contained in the following parts of BSI 6349, Maritime Structures.

- Part 1: General Criteria
- Part 1-4: Materials
- Part 2: Design of Quay Walls, Jetties and Dolphins
- Part 3: Design of Shipyards and Sea Locks
- Part 4: Code of Practice for Design of Fendering and Mooring Systems
- Part 8: Design of RO/RO Ramps, Linkspans and Walkways

Pipelines. The nation's pipeline safety programs are overseen by Congress and administered by PHMSA. However, PHMSA delegates the majority of these responsibilities for intrastate (generally the gathering and distribution pipelines) lines to the states. PHMSA retains the role as primary safety inspector for interstate pipelines (generally, the transmission pipelines), except in 11 states (Arizona, California, Connecticut, Iowa, Michigan, Minnesota, New York, Ohio, Washington, Virginia and West Virginia). State pipeline safety personnel represent more than 75% of the state/federal inspection workforce, although state employees account for less than 40% of the federal pipeline safety budget. This means that the bulk of the safety and inspection responsibility lies at the state level. Under existing law, states opt into this relationship with PHMSA. If a state decides not to participate, PHMSA does the safety inspection on its own. At present, this applies only to Alaska and Hawaii.

All state programs must certify to DOT that they will adopt regulations that are as stringent as the Federal Pipeline Safety Regulations. States are allowed to adopt pipeline safety regulations that are stricter than federal government regulations and the overwhelming majority of states do have more stringent requirements. State regulations were developed over the years based on specific results of state inspections, changing public priorities, and increased safety expectations of the local public. A 2013 report issued by the National Association of Pipeline Safety Representatives (NAPSR), with assistance and support from the National Association of Regulatory Utility Commissioners (NARUC), found that most states have adopted pipeline safety regulations more stringent than the federal regulations. The report also contains a compendium of state regulations and identifies those that exceed federal requirements. (NASPSR, 2013).

PHMSA has separate safety and design standards for natural gas and liquids pipelines (49 CFR Part 192 for natural gas and 49 CFR Part 195 for liquids). The regulations also provide guidance for proper management and operation of these pipelines. PHMSA employees also participate in more than 25 national voluntary consensus standards-setting organizations that address pipeline design, construction, maintenance, inspection, and repair. PHMSA then reviews and approves standards for incorporation by reference into its regulations. PHMSA currently incorporates by reference all or parts of more than 60 voluntary standards and specifications developed and published by technical organizations, including consensus engineering standards from the American Society of Mechanical Engineers (ASME), the American Petroleum Institute (API), the American Gas Association, the National Fire Protection Association, and the American Society for Testing and Materials. For example, ASME Standard B31.8S establishes risk assessment practices for identifying pipelines (primarily older pipelines) that could possibly be susceptible to material and construction-related integrity concerns. In addition, many agencies – federal, state and local – share responsibility for developing and enforcing other codes and standards applicable to pipeline infrastructure, such as erosion control requirements, noise ordinances, and building codes.

6.5.1. New Construction

Current federal and state project development guidelines require an environmental study at the early stages of transportation projects to identify potential environmental impacts and identify state and federal permitting requirements. The study must provide a sufficient level of understanding of the projected alignment of the facility to enable engineers and planners to identify likely impacts. If federal funding is to be used for the project, it will be subject to environmental review under the National Environmental Policy Act (NEPA). Projects go through a scoping process to establish general parameters of the work and the potential for impact. The scoping process leads to a Class of Action determination establishing whether the project is Categorically Exempt from NEPA review, or will need either an Environmental Assessment (EA) or the highest level of review, which is an Environmental Impact Statement (EIS).

Roads, Bridges, Highways and Road Tunnels. The interstate roads, bridges, highways, road tunnels system, and virtually all other state and local roadways and bridges in the United States are owned and operated by the public sector. Toll roads are typically owned and operated by public/private partnerships, but are subject to the same federal and state design standards issued primarily by FHWA and state Departments of Transportation. The state DOTs establish standards within the framework of the American Association of State Highway and Transportation Officials (AASHTO). AASHTO's most recent bridge design manual, the Load Factor and Resistance Design (LFRD) Bridge Design Specifications, incorporates a risk factor into load bearing calculations. This includes effects due to deflection, cracking, fatigue, flexure, shear, torsion, buckling, settlement, bearing, and sliding. Effects of climate change are able to influence the uncertainty variables in the load equation (Myers).

After Hurricane Katrina, FHWA began recommending a design standard for major interstate structures to consider a combination of wave and surge effects, as well as the likelihood of pressure scour during an overtopping event. Additionally, FHWA recommended that a flood frequency surge and wave action (500-year storm) be considered. (Myers). Some of the codes, standards, and guidelines for surface transportation are shown in Table 6-8.

Table 6-8: Surface Transport Codes, Standards, or Guidelines

Component	Organization	Codes, Standards or Guideline
General	AASHTO	Roadside Design Guide, 4th Edition, 2011
		A Policy on Geometric Design of Highways and Streets, 6th Edition, 2011
General	AASHTO	LRFD Bridge Design Specifications, 7th Edition, 2014
		AASHTO Highway Drainage Guidelines, 2007
	FHWA	Guide for Design of Pavement Structures, 4th Edition, 1998
		Design Standards Interstate System
		Highways in the Coastal Environment, 2nd Edition, June 2008
		A Policy on Design Standards – Interstate Systems, January 2005
Specific to Severe Weather/Hazards	AASHTO	Guide Specifications for Bridges Vulnerable to Coastal Storms (2008)
		Transportation Asset Management Guide, January 2011
		Integrating Extreme Weather Risk into Transportation Asset Management
	NCHRP	Climate Change, Extreme Weather Events, and the Highway System
	FHWA	Impacts of Climate Change and Variability on Transportation Systems and Infrastructure, The Gulf Coast Study, Phase 2, Task 3.2 (Aug 2014)
	United States DOT	2014 DOT Climate Adaptation Plan
	U.S. Global Change Research Program	National Climate Assessment

Rail. The rail network in the United States is primarily owned and operated by the private sector. The few exceptions are in densely developed urban corridors where Amtrak and public transit agencies operate over the privately owned freight lines under trackage rights. In some areas, such as the Northeast Corridor and cities with commuter rail service the tracks and other infrastructure may be owned and maintained by Amtrak, the regional transit authority, or its contract operator. In the railroad industry, AREMA establishes and updates design standards for track, structures, and facilities. Operating standards in the rail industry pertaining to safety are under the jurisdiction of FRA. Additionally, the industry trade organization AAR has a role in the development of operating standards and policies pertaining to railroad operations. Some of the codes, standards, and guidelines for rail are shown in Table 6-9.

Table 6-9: Rail Surface Transport Codes, Standards, or Guidelines

Component	Organization	Codes, Standards or Guideline
General	AREMA	Manual for Railway Engineering, 2014
		Communications and Signal Manual, 2014
		Portfolio of Track Work Plans
General	AREMA	Practical Guide to Railway Engineering
		Bridge Inspection Handbook
		Design of Modern Steel Railway Bridges
	AAR	Guide for Design of Pavement Structures
General	AAR	Design Standards Interstate System
		A Policy on Design Standards – Interstate Systems
Specific to Climate Change	AREMA	None identified
	AAR	None identified
	United States DOT	2014 DOT Climate Adaptation Plan
	U.S. Global Change Research Program	National Climate Assessment

Ports. As stated elsewhere in this document, new maritime construction needs to follow the local codes and standards for design and construction. Climate change impacts are usually incorporated by local authorities by utilizing the guidance documents issued by various local and federal authorities (such as USACE, IPCC). For example, the City of New York adopted specific guidelines in regards to climate change through an authorized panel, New York Panel on Climate Change (NPCC).

The following return periods from current industry standards can serve as a starting point to guide an agency towards a comfortable level of risk for current and projected scenarios. A return period or recurrence interval is an estimate of the likelihood of an event, such as a flood, to occur.

- Wind on facilities (ASCE-7): Varies depending on occupancy category – up to 1700 year return
- Coastal Flooding (USACE): 50 year return
- Inland Flooding (AASHTO): 100 year return plus a percentage depending on agency
- Inland Flooding for other facilities (ASCE-7): 100-year return

Pipelines. New pipelines are subject to current federal and state design and safety guidelines. Liquids pipelines and intrastate natural gas pipelines are regulated at the state level; therefore, regulations and risk evaluations for assessment of hazards will vary depending on location.

The failure modes discussed in this chapter may represent key vulnerabilities in the codes that are exposed during hazard events. Table 6-10 presents a summary of the methods of transportation used, whether they are used for public or private transportation, and the oversight authorities involved in their regulation.

Table 6-10: Transportation Infrastructure Code and Standards Governing Agencies

Industry	Infrastructure	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
	Roads, Bridges and Tunnels	Passenger	Inter-City Motor coach	X	X	X	X	X	X			X	X	X				X
			Intra-City Bus/Motor coach	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

6.5.1.1. Implied or stated Performance Levels for Expected Hazard Levels

When defining standards for hazards for roads, bridges, highways, and road tunnels, federal regulations tend to use general language for performance levels. For example, when describing Drainage Channels, the AASHTO Roadside Design Guide states that "channels should be designed to carry the design runoff and to accommodate excessive storm water with minimal highway flooding or damage." No specific levels are mentioned, leaving specific implementation up to state regulations and engineering judgment.

Although federal documentation does not give specifics on hazard mitigation levels for the entire country, it often gives guidance on how more locally-based regulation should be formed. For example, in Highways in the Coastal Environment, the FHWA gives three approaches for determining site-specific design water levels. These consist of 1) use of available analyses, 2) historical analysis, and 3) numerical simulations with historic inputs. These are only general guidelines, but they apply to all regions of the country and ensure the process is data driven.

AREMA provides more specific regulations than AASHTO in regards to hazard levels, but still leaves room for site-specific engineering. To continue the draining example, the Manual for Railway Engineering states that, "typically, the 100-year base flood elevation is the most commonly regulated storm water elevation associated with rivers, streams and concentrated flow areas." It goes on to describe how, "any change to the flood plain will generally result in extensive studies and computer modeling to be submitted for approval." Again, these regulations are not specific numeric regulations, but a guidance that ensures proper steps are taken by the appropriate agency to mitigate risk.

The National Cooperative Highway Research Program conducted a study on climate change adaptation strategies in 2013 that provided some specific examples of dealing with increasing severity of weather events. For example, precipitation events may consider estimating second -order recurrence intervals (if two 100-year storms happened in two consecutive years) and updating variables accordingly in the Clausius-Clapeyron relationship for relative precipitation increases (NCHRP 2013).

The Advisory Circulars (AC) define design criteria for most details of an ***airport's*** facilities – runway/taxiways, terminal buildings, lighting, and navigational aids. These documents define standard criteria for construction, but do not specifically address climate extreme weather events beyond potentially constructing drainage for a 50-year storm. The following is a subset of the available Acs.

- AC 150/5300-13A, Airport Design (9/28/12)
- AC 150/5370-10G, Standards for Specifying Construction of Airports (7/21/14)
- AC 150/5340/30H, Design and Installation Details for Airport Visual Aids (7/21/14)
- AC 150/5320-5D, Airport Drainage Design (8/15/13)
- AC 150/5345-53D, Airport Lighting Equipment Certification Program (9/26/12)
- AC 150/5345-28G, Precision Approach Path Indicator (PAPI) Systems (9/29/11)
- AC 150/5320-6E, Airport Pavement Design and Evaluation (9/30/09)
- AC 150/5200-30C, Airport Winter Safety and Operations (12/9/08)
- AC 150/5345-46D, Specification for Runway and Taxiway Light Fixtures (5/19/09)
- AC 150/5360-13, Planning and Design Guidelines for Airport Terminals and Facilities (4/22/88)

Performance levels addressed include a recommended 5-year storm event be used with no encroachment of runoff on taxiway and runway pavements when designing storm water drainage (including paved shoulders). Airport pavements should provide a skid-resistant surface that will provide good traction during any weather conditions (with provisions for frost and permafrost). And, airport terminal buildings should be structurally designed to appropriate seismic standards (Executive Order 12699, Seismic Safety of Federally Assisted or Regulated New Building Construction, January 5, 1990).

State and local legislative bodies are not obligated to adopt model building codes and may write their own code or portions of a code. A model code does not have legal standing until it is adopted as law by a legislative body (state legislature, county board, city council, etc.). When adopted as law, owners of property within the boundaries of the adopting jurisdiction are required to comply with the referred codes.

Because codes are updated regularly, existing structures are traditionally only required to meet the code that was enforced when the property was built unless the building undergoes reconstruction, rehabilitation, alteration, or if the occupancy of the existing building changes. In that case, provisions are included in the code to require partial to full compliance depending on the extent of construction. [ASCE Policy Statement 525 – Model Building Codes]. For example, New York City Building code describes the requirement for flood-resistant construction, referencing FEMA flood maps and ASCE 24 for "dry flood-proofing." The Design Flood Elevation for certain structures, such as terminals, air traffic control towers, and electrical substations, is the 100-year floodplain plus one-foot.

Except for wind and seismic loading, rail codes do not provide specifics regarding natural hazards (e.g., the codes may stipulate various flood levels for which a structure may need to be designed, but they will not specifically set what that level is). Rather, they set event-based criteria, e.g., 50 or 100-year event. Similarly for wave loads, various codes (e.g., USACE Coastal Engineering Manual) may advise that waves should be considered, but it's usually up to the design professional to determine what wave characteristics should be considered.

Each agency's tolerance for risk (note that risk tolerance could include interests beyond an agency's immediate jurisdiction particularly if other utilities within the asset right of way, such as water, sewer, or electrical may be impacted). An agency with a higher risk tolerance would plan for less extreme changes. An agency with a lower risk tolerance could be expected to plan for more extreme change.

Interstate natural gas infrastructure is regulated by FERC, which is responsible for compliance with NEPA. The NEPA document will address potential impacts of climate change: impacts resulting from the project and impacts on the project. As stated previously, impacts on pipelines are generally limited because they are buried, but aboveground facilities such as compressor stations could be affected by storm-related incidents. Input from state and local governments is a key component of the review process at FERC. Local knowledge of environmental conditions and concerns about inter-relationships with other critical infrastructure should be identified to FERC at the earliest point in any project review. For example, there may be resiliency and reliability concerns if a new pipeline's proposed route would be adjacent to a critical electric transmission line.

6.5.1.2. Recovery Levels

For roadway and rail transportation, no specific requirements were identified in codes or standards. However, at state and local levels there may be operational goals or performance standards. For example, a state may issue a severe weather warning, mandating that all drivers remain home until authorities deem roads are safe enough to be traveled. Similarly for rail, administrative and inspection personnel decide when a system is safe to operate.

There is minimal description of required recovery levels for extreme events for airports. Language for storm water drainage requires surface runoff from the selected design storm be disposed of without damage to facilities, undue saturation of the subsoil, or significant interruption of normal traffic. "The drainage system will have the maximum reliability of operation practicable under all conditions, with due consideration given to abnormal requirements, such as debris and annual periods of snowmelt and ice jam breakup."

Marine infrastructure is critical to the transportation industry (commercial, public, and private) and the full recovery will be necessary for proper functionality. However, no specific guidance or performance levels were identified.

6.5.2. Existing Construction

The design of transportation systems has been refined over time; however, incorporating resiliency into the design is a relatively new concept. For existing transportation systems, they are bound by the codes and standards for which they were initially designed. Typically, transportation infrastructure is not required to meet the new codes as they develop. As the codes and standards incorporate resiliency, a significant portion of transportation system will not be covered under these new more restrictive codes and standards.

For rail and roadways, documented codes or standards have not been identified specifically for existing construction.

Airport codes and standards do not address retrofitting existing construction to adjust for climate change or extreme weather events. Several advisory circulars outline procedures for maintaining existing facilities only.

- AC 150/5380-6C, Guidelines and Procedures for Maintenance of Airport Pavements (10/10/14)
- AC 150/5380-7B, Airport Pavement Management Program (PMP) (10/10/14)
- AC 150/5340-26C, Maintenance of Airport Visual Aid Facilities (6/20/14)
- AC 150/5200-33, Hazardous Wildlife Attractants on or Near Airports

In relation to Prevailing Design Standards for the maritime industry, only sections of the local or national codes and standards that govern design of the component would be required. Information collected will allow for the assessment of the existing asset to determine if it adheres to current design standards. This will assist in determining vulnerabilities and the selection and prioritization of adaptation strategies for the marine infrastructure in question.

Reviewing existing design codes and standards will guide the engineer to determine the design parameters required to perform a check of the condition of the marine infrastructure. Using the selected code or design standards and the parameter values to perform an engineering calculation to determine if the asset satisfies the requirements. The degree to which the component is affected by the stressor will serve to assist in determining appropriate adaptation strategies.

Figure 6-11 illustrates a comparison of transportation timeframes against the climate impacts. According to Moritz (2012), infrastructure planned and built with past climate and weather in mind may not be adequate for future resilience and operation. Hence, there is a strong need to re-consider or adopt the long-range transportation planning process.

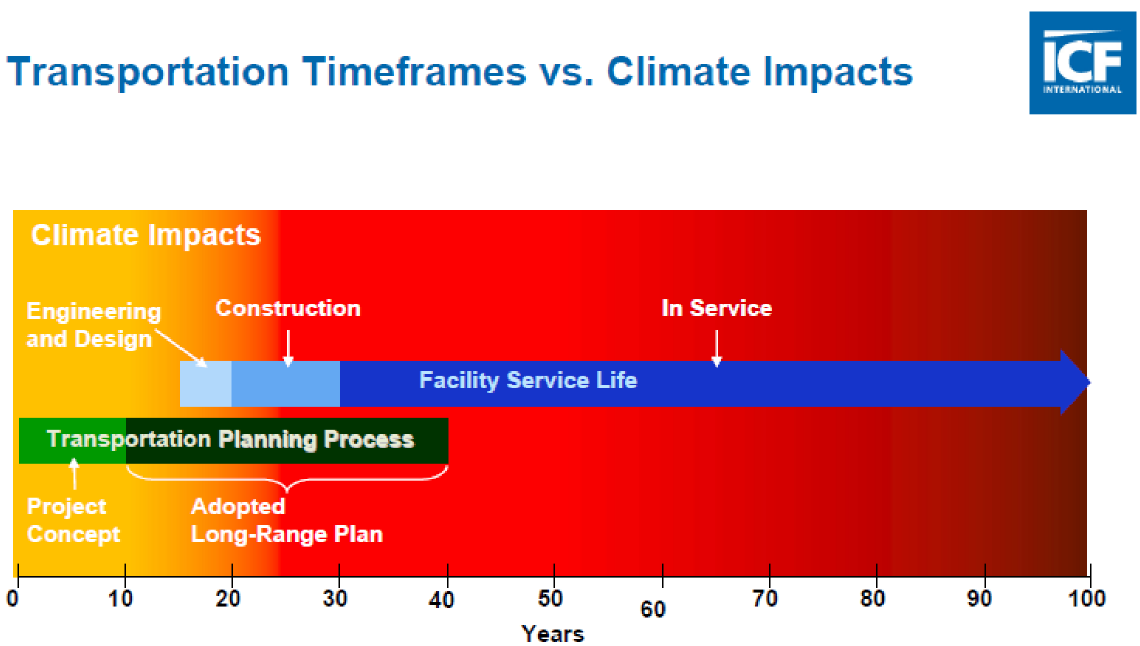

Figure 6-11: Procedures to Evaluate Sea Level Change Impacts, Responses, and Adaptation Corps of Engineers' Approach, Naval Facilities Engineering Command Port Hueneme, CA 24 October 2012

6.5.2.1. Implied or stated Performance Levels for Expected Hazard Levels

The performance levels for new/future and existing transportation infrastructure are anticipated to be the same. Therefore, the reader is referred to the previous discussion in Section 6.5.1.1.

6.5.2.2. Recovery Levels

Since the performance levels anticipated for new/future and existing construction are the same, the recovery levels are also anticipated to be similar. The reader is referred to the previous discussion in Section 6.5.1.2.

6.6. Strategies for Implementing Community Resilience Plans

6.6.1. Available Guidance

Section 6.2 describes the various components of the transportation systems and case studies of where these systems may have failed in the past. The performance of the transportation system is highly dependent on the age of the system, the type of natural hazard, the standard to which it was designed, and the basic decisions made immediately before and after the hazard event. Current engineering standards and guidelines provide tools to assess the performance of bridges and roadways, such as the (AASHTO) *Manual for Bridge Evaluation.* Similar standards exist for other transportation nodes, such as airports, rail, subways, etc.

AASHTO's Transportation Asset Management Guide applies to both roads and rail, as it encourages agencies to include operations and maintenance into state and local resource management programs. This includes considering life-cycle planning, including frequency of maintenance and repair based on weather conditions. The guide asks, "What allowance should be made for climate change when designing a new asset or facility with a long life? For example, should expanded storm water drainage capacity be provided, should route planning decisions consider the risks of sea level changes in coastal areas?" The guide goes on to recommend processes and tools for life cycle management, incorporating effects due to climate change. In addition to processes, it is necessary to continue to monitor the assets to continually improve the model's forecasting.

ISO 31000:2009, *Risk management – Principles and guidelines*, provides principles, a framework, and a process for managing risk. It can be used by any organization regardless of its size, activity, or sector. Using ISO 31000 can help organizations increase the likelihood of achieving objectives, improve the identification of opportunities and threats, and effectively allocate and use resources for risk treatment. ISO 31000 cannot be used for certification purposes, but does provide guidance for internal or external audit programs. Organizations using it can compare their risk management practices with an internationally-recognized benchmark, providing sound principles for effective management and corporate governance. The guidelines for establishment of sound risk assessment programs can be applied to the development of resilience assessment and mitigation (http://www.iso.org/iso/home/standards/iso31000.htm).

FAA issued a memorandum titled "Considering Greenhouse Gases and Climate Under the National Environmental Policy Act (NEPA): Interim Guidance" (January 12, 2012). The memo indicates that an estimate of GHG emissions can serve as a "reasonable proxy for assessing potential climate change impacts" and provide information for decision-making. The amount of carbon dioxide and/or fuel burn from aircraft operations should be calculated for FAA NEPA evaluations. Consideration should be given to reducing GHG emissions as a part of the project; however, reduction is not mandated. The memo does not reference assessing vulnerability to extreme weather as a result of climate change.[6] FAA's AC

[6] CEQ recently issued the "Draft Guidance on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change" (December 2014), which suggests agencies focus quantitative greenhouse gas analysis on the projects and actions with 25,000 metric tons of CO2-equivalent emissions on an annual basis or more, and counsels

150/5200-31C, Airport Emergency Plan, provides guidance on conducting a hazard/risk analysis to help determine what hazards exist and how to address them. In addition, the scope of work for FAA's Airport Sustainable Master Plan Pilot Program included a baseline inventory or assessment of each defined sustainability category (which will vary by airport), establishment of measurable goals, and development of specific sustainability initiatives to help the airport achieve each goal.

Several of the larger airport authorities, such as Port Authority of New York and New Jersey (PANYNJ), Los Angeles World Airports (LAWA) and Philadelphia International Airport, have established assessment methodologies, either alone or as part of larger citywide or regional efforts. PANYNJ became involved in a climate change assessment led by New York City's Long-Term Planning and Sustainability Office, which was conducted between August 2008 and March 2010. The team was called the Climate Change Adaptation Task Force, and its work was part of a comprehensive sustainability plan for New York City called PlanNYC. The assessment process comprised six major tasks: defining the climate change variables and projections, developing asset inventories, assessing vulnerabilities, analyzing risks, prioritizing the assets, and developing adaptation strategies.

The Greater Toronto Airports Authority (GTAA) uses the PIEVC (Public Infrastructure Engineering Vulnerability Committee) Protocol from Engineers Canada to assess risk and identify preliminary needs (such as storm water facilities).

The ASCE and Coasts, Oceans Ports and Rivers Institute (COPRI) established special committees on climate change to identify, gather, and organize information on potential infrastructure impacts due to climate change; to develop partnerships and collaborations of relevant and interested committees and organizations for responsible understanding and planning of potential climate change impacts; to develop strategies and recommendations addressing climate change impacts [22]. The Sea Level Change Committee provides a more systematic approach to estimating and including sea level change in marine/coastal projects. [23]

6.6.2. Strategies for New/Future Construction

The Canadian Council of Professional Engineers developed a risk based vulnerability assessment framework to evaluate climate change risks in building, roadway asset, stormwater–wastewater systems, and water resource management infrastructures. The protocol involves project definition, data gathering and sufficiency, risk assessment, engineering analysis, and recommendations. It covers the categories of buildings, roads and associated structures, stormwater/wastewater, and water resource systems (PIEVC 2009).

In the United Kingdom, the Highway Agency has a Climate Change Adaptation Strategy and framework that addresses specific climate risks for highway infrastructure and agency practices (UK, 2009). Transport Asset Management Plans (TMAPs) are mandatory in the UK, and some incorporate specific sections on climate change (Myers).

Transit New Zealand has incorporated climate change into its asset management inventory. Standards for assets have the ability to change with newly developed climate change predictions. An economic analysis shows that existing assets with a lifespan of 25 years or less did not require changes in design or maintenance, but new construction can be modified as needed. Additionally, Transit NZ modified its bridge manual, including a new design factor for climate change (Myers).

Rail. The FTA advocates for designs including larger drainage capacity, stronger structures to withstand winds, and materials suited for higher temperatures. For subway systems, flooding is a primary climate change affected concern. Potential strategies include requiring flood gates, high elevation entrances, and

agencies to use the information developed during the NEPA review to consider alternatives that are more resilient to the effects of a changing climate.

closable ventilation gates (requiring new fan-driven ventilation). A FEMA-commissioned study determined that that flood protection savings are, on average, four times greater than prevention costs.

Localized flooding for transit and other transportation facilities can be prevented by establishing proper stormwater management. Best practices include rain gardens, stormwater ponds, increased vegetation, green roofs, rain barrels, and pervious pavements. These allow stormwater to be absorbed through natural processes, reducing, or preventing flooding altogether (FTA 2011).

Port Authority of NY and NJ, PANYNJ, has an organization-wide "Sustainable Infrastructure Guidelines" that is implemented for projects including terminal building construction, building demolition, electronics systems, communications systems, airfield construction or rehabilitation, and landscaping. The guidelines require the protection of the ecological health of wetlands, floodplains, and riparian buffers, protection and maintenance of absorbent landscapes, mitigation of the heat island effect, and implementation of stormwater best management practice strategies, implementation of sustainable landscape maintenance. LAWA's Sustainable Airport Planning, Design, and Construction Guidelines are similar, identifying many technical approaches to climate change adaptation planning such as increasing the capacity of stormwater conveyance and storage (e.g., design for 100-year and 500-year storms) and utilizing heat-resistant paving materials.

New buildings, particularly those adjacent to coastal resources or within a floodplain, should implement flood hazard mitigation as part of the design. PANYNJ sets forth an elevation of 18 inches higher than the current code requirements, based on an anticipated increase of the mean sea level, for the lowest floor of buildings to be considered for all project elements. If that is not feasible, then the standard should at least be met for all critical project elements (electrical equipment, communications, etc.).

San Diego International Airport has incorporated low impact development strategies (e.g., pervious pavement, infiltration storage chambers, bio-retention swales, modular wetlands, riprap energy dissipater) into their north side improvements in order to reduce flooding risks.

The American Society of Civil Engineers (ASCE) issued a series of policy statements (a list is provided at the end of this document for those relevant to this study) defining the Societies role in the industry by supporting the sustainable and resilient reconstruction of affected areas devastated by accidental, intentional and/or natural disaster events. Collaboration with ASCE and its technical Institutes would promote development of national codes and standards for the changing world.

ASCE specifically supports the following activities:

- *Redesign and reconstruction of disaster protection systems for affected communities at a level appropriate for protection of the population, critical infrastructure and the environment; and*
- *Reconstruction that incorporates appropriate studies, urban design, application of technology, land use, zoning, and utilization of natural systems to recreate communities that are resilient, sustainable, more livable and less vulnerable to accidental, intentional and/or natural disaster events.*

The challenges include evaluation of the prior conditions and effects caused by the hazard(s) to determine if reconstruction of the affected infrastructure is viable, feasible and beneficial to facilitate the task of protecting life, property, and national critical infrastructure.

To better protect American lives, property, and infrastructure, the affected areas cannot always be rebuilt to match prior conditions. Reconstruction and recovery includes consideration of the existing conditions, which may have facilitated the destruction. It also includes consideration of the principles of sustainability and resilience.

There are many federal, state and local agencies that have been working on strategies for the maritime industry, including USDOT (FHWA) USACE and ASCE. Additional research including a more detailed review of the TRB 2013 report, *Assessment Of The Body Of Knowledge On Incorporating Climate Change Adaptation Measures Into Transportation Projects.*

From a European perspective, resilience or adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage they can cause, or taking advantage of opportunities that may arise (EU Adaptation Policy).

Adaptation strategies are needed at all levels of administration: at the local, regional, national, EU and also the international level. Due to the varying severity and nature of climate impacts between regions in U.S. and Europe, most climate adaptation initiatives will be taken at the regional or local levels. The ability to cope and adapt also differs across populations, economic sectors and regions within Europe.

6.6.3. Strategies for Existing Construction

The Transportation Research Board, TRB, reviewed operation and maintenance practice to mitigate the effects of future climate change conditions. They cite the example of an airport operator purchasing additional snow removal equipment to minimize operational out-of-service time. Agencies should be prepared for increased extreme weather incidents of all types and obtain the necessary equipment to minimize the operational disruption time (TRB, 2013).

PANYNJ’s climate change assessment found that capital investments could take the form of permanent improvements that could include installing new flood barriers, elevating certain elements of critical infrastructure so that they would be above the projected flood elevations, moving entire facilities to higher ground, and designing new assets for quick restoration after an extreme event. Regulatory strategies could include modifying city building codes and design standards.

Key West International Airport in Florida is already vulnerable to hurricanes and sea level rise. They have been retrofitting existing infrastructure, such as installing flapper valves inside drainage structures to avoid standing water on runways and taxiways. In addition, they have had to adapt their wildlife hazard mitigation strategies to handle new animals that are encroaching on the airport as a result of changing habitat. Additional strategies are outlined in the “Monroe County Climate Action Plan” (March 2013).

Climate adaptation strategies in the maritime industry must be applied to existing buildings as well as new building projects. Borrowing from the ICLEI process, the steps below describe how a project team can integrate adaptation strategies to existing buildings and sites. **[24]**

1. Understand regional impacts: Identify climate impacts for the facility’s region.
2. Evaluate current operation and maintenance targets: Understand how the maintenance and operations perform under current peak climate conditions.
3. Conduct a scenario analysis: Analyze how the facility will respond to projected climate impacts, modeling different system options under a variety of climatic conditions. Implement adaptation strategies: Install adaptation strategies that provide passive or efficient responses to more extreme climate events in order to maintain occupant comfort while preventing increased energy use.

Similar to the process above, USACE employs a 3 tier process for screening out the projects (Moritz, 2012). Tier 1 Establish Strategic Decision Context, Tier 2 involves Project Area Vulnerability and Tier 3 for Alternative Development, Evaluation, and Adaptability. Future storm tides will reach higher elevations than past storms and will do so more frequently impacting both flooding and structural loading.

- As part of the Tier 2 process, structural loading and processes needs to be evaluated from technical perfective:
- Natural variability of loading factors
- Tidal and wave height range
- Local sea level change rate

- Extreme lows and highs
- Frequency of events
- Key project processes
- Short and Long-term erosion/recession
- Rate of change of exposure
- Cumulative impacts with other climate or natural Drivers
- Example of Inventory & Forecast Qualitative Matrix (describes study area's and parallel system's susceptibility to sea level change (Moritz, 2012)

Table 6-11: Risks from Sea Level Rise

Critical Resources in Study Area	Density of Resource (3=high, 2=medium, 1=low, X=none)	Relevance	Risk from Sea Level Rise (3=high,2=medium, l=low, X=none present)
Length and type of primary federal navigation	3	The length and type of navigation structure will determine stability and maintenance impacts.(age, last maintained)	3
Length and type of secondary federal navigation structures (groins, spur jetties,dikes, etc.)	2	The length and type of navigation structure will determine stability and maintenance impacts.(age, last maintained)	2
Length and type of federal shoreline protection structures	1	The length and type of shoreline protection structure will determine stability and maintenance impacts. (age, last maintained)	2
Channel length and authorized depth, mooring areas and basins	3	SLR may impact this favorably; SLF may require adjustments to authorized lengths and depths. Harbor and entrance resonance and performance issues may arise. (length, area)	1
Dredged material management sites	1	DMMP sites may become more or less dispersive and/or have changes in capacity. (number, area)	1
Port facilities- bulkheads, wharves, docks, piers	3	Performance of existing federal structures under modified ocean conditions will result in increased magnitude and frequency of impacts. (length, type, seasons of use)	3
Commercial Infrastructure	3	Performance of existing federal structures under modified ocean conditions will result in increased magnitude and frequency of impacts. (type, value)	2
Transportation infrastructure	2	Impacts to transportation infrastructure (roads, rail, etc.) can impact benefits realized. (length, type)	2
Utilities, drainage systems, communication	2	Connectivity and support systems may be affected resulting in decreased project benefits.(length, type)	2
Environmental and habitat areas	1	Assessment of any environmental systems in project area. (type, sensitivity)	1

The FTA identifies four categories pertaining to adaptation strategies. They are broad enough that they apply to a range of transportation facilities (FTA 2011):

- ***Maintain and manage*** – adjust budgets for increased maintenance cost and improve severe event response times. Utilize technologies that detect changes such as pressure and temperature in materials as a precaution against structure damage or rising water levels.
- ***Strengthen and protect*** – existing infrastructure should be retrofitted to withstand future climate conditions. Ensure facilities can stand up against high winds and extreme temperatures, and assure flood prevention and adequate drainage.
- ***Enhance redundancy*** – identify system alternatives in the event of service interruption and develop a regional mobility perspective that includes all transportation modes.

- ***Retreat*** – Abandon at risk infrastructure located in vulnerable or indefensible areas. Potentially relocate in a less vulnerable location.

In regards to subways, many strategies have been implemented to combat heavier rains that would otherwise result in flooding. Many cities have increased the number of pumps or pump capacity. New York City has implemented raised ventilation grates to prevent runoff into subway lines. Tokyo ventilation shafts are designed to close when a heavy rain warning is issued, and can be closed by remote control or automatically in response to a flood sensor. The Port Authority of New York and New Jersey raised the floodgates at the top of stairs leading to station platforms to account for sea level rise and sealed all gates below the 100-year floodplain.

For open railway, track buckling results from increased temperatures and are costly to the railroad industry as well as an important derailment safety hazard. Slow orders (mandated speed reductions) are typically issued on sections of track in areas where an elevated rail temperature is expected and risk of track buckling is increased. Replacement track has a higher lateral resistance to combat buckling forces. FRA has created a model for predicting rail temperatures, allowing proper replacement before an incident occurs (FRA 2014).

Increased temperatures also have an effect on electrical equipment, worker exhaustion, and passenger comfort. Increased ventilation and cooling rooms may be required to maintain adequate temperatures for electronics and computers. Workers may need better air conditioning or shorter shifts to combat heat exhaustion. Transit stops and other shelter facilities should be designed with proper shading and ventilation. Heat resistant materials and reflective paints should also be considered (FTA 2011).

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Note to reviewers. Numbered references will be cleaned up and clearly provided for the next draft.

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