Credit: NYCDOT

Transportation

Stillwell Avenue subway station in Coney Island

Credit: Zev Starr-Tambor

It carries one-third of all transit riders and two-thirds of all rail riders in the nation. It includes the nation's busiest rail hub and the largest bus and rail car fleets. It encompasses 6,000 miles of streets, 12,000 traffic signals, and nearly 800 bridges (including more than a couple of famous ones).

And, of course, it boasts the one and only Staten Island Ferry.

This complex behemoth is the New York region's transportation network. It encompasses the largest public transportation system in America, made up of subway networks, bus networks, commuter railroad networks, and ferry networks. And each of these networks is, in and of itself, staggeringly large.

Under normal conditions, the interconnected networks work together, adding up to an extraordinary supersystem, upon which New Yorkers—and the economy of the city, region, and nation—all depend. Day and night, millions of New Yorkers and visitors use this system to travel to and from work, school, shops, and cultural events, while goods move around the region by road, rail, and water. The city that never sleeps fittingly has a transportation system that never sleeps—until, with Sandy, nearly every element of New York's transportation system shut down.

Sandy's storm surge flooded vehicular tunnels, subway stations, roads, and airports. Transportation outages followed, impairing mobility and access to, from, and within the city and the region, and affecting 8.5 million public transit riders, 4.2 million drivers, and 1 million fliers.

Even after Sandy had departed, damage and power outages prevented restoration of the subway system for several days, with key sections shut for a week or longer. Responding quickly, City and State officials instituted a series of interim solutions to fill the transportation gap—including sending hundreds of buses to carry commuters back and forth across East River bridges and adding ferry service. However, damage to various elements of the system was severe—totaling many billions of dollars. In fact, as of the writing of this report, some elements still are not fully functional and will not be for months or even years.

The storm not only caused disruption; it demonstrated the centrality of the transportation system to the city's economy and overall ability to function. It also laid bare the vulnerabilities of various parts of the system to extreme weather and pointed to challenges that the region faces in increasing resiliency, given the size and complexity of its transportation system.

But these challenges must be tackled. In keeping with the broad goals of this report—which are to minimize disruptions caused by climate change and to enable New York City to bounce back when extreme weather events strike—the City will work to make the transportation system more resilient. It will seek to protect critical elements of the system from damage, maintain system operations during extreme events, and put in place plans for backup transportation options to increase mobility until regular services can be restored.

How the Transportation System Works

Transportation in New York City is complex due to the many different modes of travel, the ways they interact, and the grand scale of it all. And New Yorkers use this system in overwhelmingly large numbers, with 7.6 million daily subway and bus riders, close to 850,000 daily commuter rail riders, and almost 2 million people crossing the region's major bridges and tunnels every day. This network is busy for much of the day and night—not just during traditional commuting hours—with freight moving around the region by truck, hospital workers going to and from their shifts, and local residents and tourists visiting the city's many attractions.

The area of Manhattan south of 60th Street—the business center of the region and the nation—draws commuters to jobs from all over the New York area and beyond. Over 3.6 million travelers enter this district every weekday, with 1.4 million of those entering during the three-hour morning peak. Public transportation is absolutely critical to this travel, since 75 percent of those trips into the central business districts are made by public transit. Of those who do drive into this area, the majority depend on crossing a bridge or tunnel to do so, including 220,000 entering from Brooklyn, 175,000 entering from Queens, and 115,000 entering from New Jersey.

Travel within and among the outer boroughs is more varied. The use of buses is significant outside of Manhattan—with 2.1 million daily bus users in the other boroughs—as is the use of private vehicles, particularly for longer trips between the outer boroughs, where driving is generally faster and more direct. Many outer borough trips also require a major bridge crossing, and trips to and from Nassau and Suffolk Counties must pass through New York City. Close to a million trips pass between Nassau County and Queens every day, and over 500,000 trips cross the major bridges that connect between the outer boroughs every day.

While the city's transportation system is highly interconnected, it also does not exist in isolation. Instead, it is one network among the many that keep New York running. For example, the transportation network in the city depends on the power network to function; electricity is needed to run subways and trains, to switch on traffic signals, and to light tunnels, stations, and terminals. And, in turn, many of the city's other critical networks rely, wholly or in part, on the transportation network to run properly; this is especially true in times of emergency, when first responders and those bringing key supplies (such as food and fuel) must be able to reach individuals and communities that are in desperate need.

However, due to historical development patterns and operational needs, many parts of the city's transportation infrastructure are located near the waterfront or in low-lying areas, making them particularly vulnerable to the effects of climate change. This is true for many rail yards, which require large, flat expanses of land of the type frequently found near rivers and the shoreline. Similarly, by definition, ferry terminals must be at water's edge and close to the level of the water. Other assets are on the waterfront because that is where land was available or could be created through fill—this is how, for example, New York's airports were sited.

Some transportation assets, meanwhile, are not just at sea level, but are actually built below sea level. This is the case for the large segments of the city's transportation network that were built underground (including tunnels for vehicles and trains), designed both to span water bodies and to provide higher speed and greater capacity connections through dense and congested areas.

Transportation Networks

The first formal transportation elements to develop in New York City were its roads, which, under the Dutch and later the English, evolved from a network of Native American trading paths. In fact, Broadway, the oldest north-south thoroughfare in the city, was designed to connect the street network in Lower Manhattan (initially used by people on foot and on horse) to the northern reaches of the borough—and on into the Bronx and beyond. The Commissioners' Plan of 1811 laid out what is today perhaps the most distinctive aspect of New York's City's street network: Manhattan's modern street grid.

New York's ferry system, too, has a long pedigree. New Yorkers always have used the waterways to get around. Since the city's earliest days—especially before the development of long-span bridges—ferries have provided key water crossings, connecting Brooklyn, Queens, Staten Island, and New Jersey to Manhattan, both as stand-alone services and as links from rail terminals.

Over time, as New York City grew, it became increasingly important to link the soon-to-be consolidated boroughs effectively. Accordingly, in the late 19th and early 20th centuries, the City undertook a major program of bridge-building, completing some of the city's most iconic spans, including the Brooklyn and Manhattan Bridges over the East River. With the same goal in mind, New York City also worked with the Interborough Rapid Transit (IRT) Company to create its initial underground connections, opening the first subway line in 1904. The subway system has since expanded to become the largest in the world, with 659 miles of track and 468 stations, playing a critical role in making New York the global city it is today.

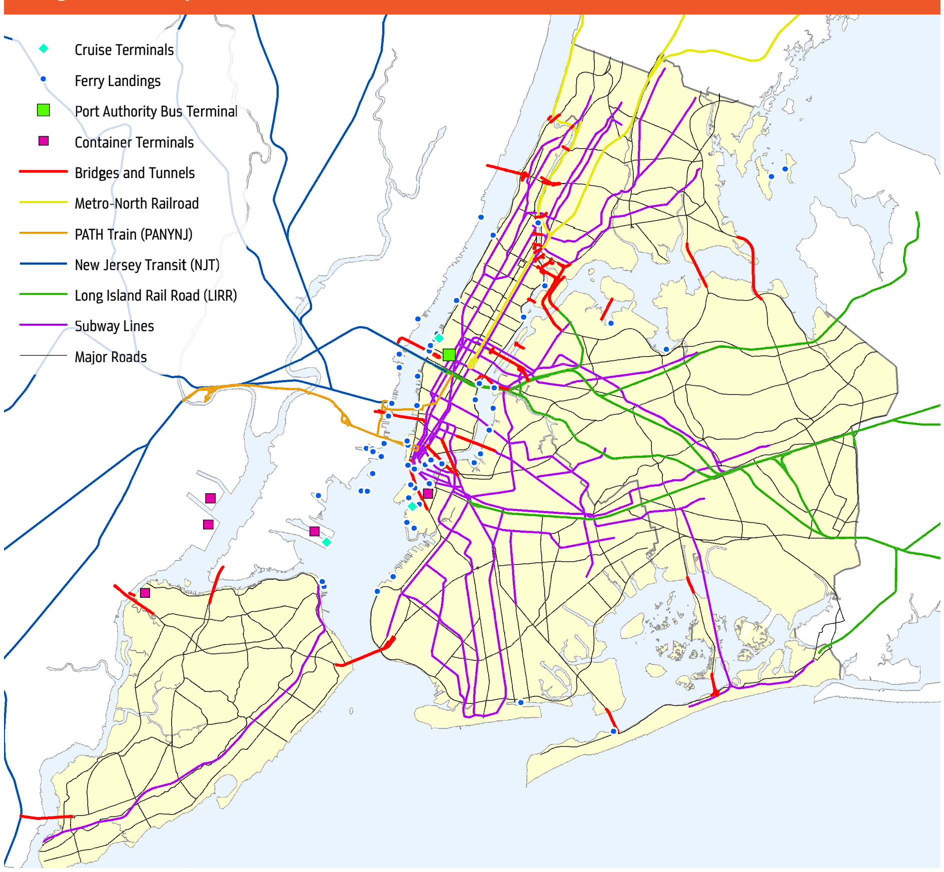
As the city continued to expand through the 20th century, New York's water-spanning tradition was picked up by the Port Authority of New York and New Jersey (the Port Authority) and the Triborough Bridge and Tunnel Authority (which subsequently became part of the Metropolitan Transportation Authority, or MTA). These two agencies built four bridges, and two tunnels connecting New Jersey to New York City, and seven bridges and two tunnels within the city. Meanwhile, in the latter half of the 20th century, the region's three major airports, including Kennedy and LaGuardia in Queens, became international gateways that, together, host more passenger traffic each year than the airports in any other metropolitan area outside of London.

In recent years, the City has expanded its transportation network by promoting a range of alternatives to driving, thus increasing the flexibility and efficiency of the system. For example, the City has expanded its pedestrian and bicycle networks. Walking has always played an important role for all manner of local trips and to gain access to the transit network, and cycling volumes in the city continue to grow. In addition, the City has maximized inter-modal connections and added several Bus Rapid Transit (BRT) routes (known in New York as Select Bus Service), or dedicated bus corridors that improve the speed, reliability, and attractiveness of bus service. Additionally, after many years during which the use of private ferries waned as new bridges and tunnels were built, the City, over the last 15 years, has helped bring about a renaissance in this transit mode, spurred by rising congestion on other networks and redevelopment of the waterfront neighborhoods of New York City and New Jersey. (*See map: Regional Transportation Network*)

Transportation Operators

All of New York's various transportation networks and services are linked in many ways, allowing a New Yorker or a visitor to the city to connect easily from one mode to another. So, for example, a marketing executive from Philadelphia might take an Amtrak train to Penn Station, then transfer to a subway, only to get off several stops later to hustle through the

Regional Transportation Network



busy streets of Lower Manhattan to her destination. In addition to shifting from one locale to another and from one transportation network to another, in making this trip, this visitor is also passing through multiple jurisdictions, from a system run by a Federal corporation, to one that is run by an authority under the control of the State, to one that is run by the City.

As illustrated in this example, many agencies manage different elements of New York's transportation system. For example, the New York City Department of Transportation (NYCDOT) has responsibility for roads and certain highways in the five boroughs, as well as over 12,000 traffic signals and 787 bridges. These bridges include the famous East River spans and 25 movable bridges that open and close to allow marine traffic to pass. NYCDOT also runs the Staten Island Ferry (SIF) and regulates all construction work on roadways and sidewalks, including work related to underground utilities. Additionally, since the launch of PlaNYC in 2007, NYCDOT has successfully expanded the city's bicycle network. It also has played a critical role, in partnership with the MTA, in creating multiple Select Bus Service (SBS) routes that make bus service faster and more reliable around the city.

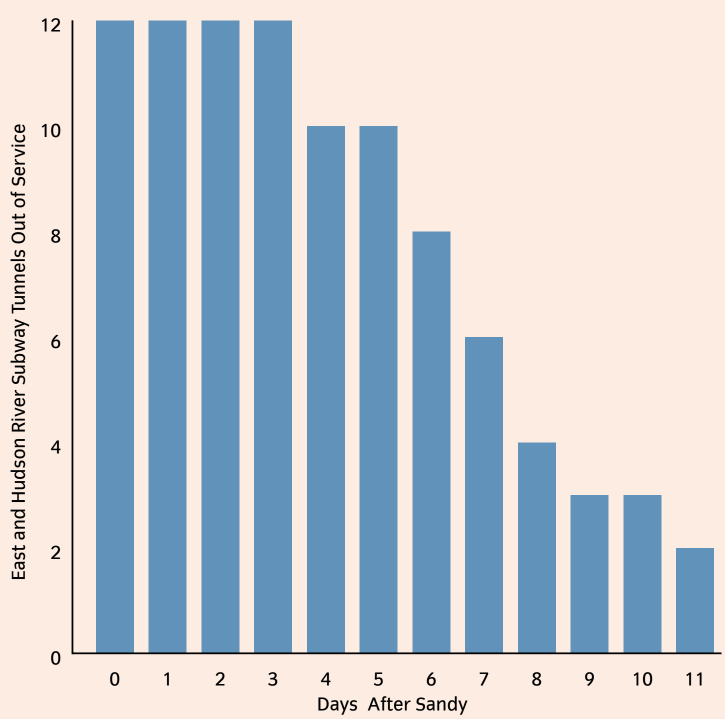
Two other important transportation agencies in New York City are the MTA and Port Authority. The MTA, a State authority, operates the nation's largest transit network and is responsible for the city's subway system, most of its buses, the Long Island Rail Road and Metro-North Railroad, and the tolled bridges and tunnels within New York City. Meanwhile, the Port Authority—an entity controlled jointly by the States of New Jersey and New York—is responsible for the city's airports, the bridges and tunnels connecting New York City to New Jersey, regional bus terminals, the Port Authority Trans-Hudson (PATH) rail system, and major parts of the region's ports infrastructure.

Other agencies that play central roles in transportation in New York City include the following:

- New York City Economic Development Corporation (NYCEDC), which is responsible for the East River Ferry, certain private ferry terminals, the City's cruise ship terminals, two heliports, parts of the region's port infrastructure, and portions of the city's freight railroad lines;
- New York State Department of Transportation, (NYSDOT) which is responsible for certain highways within the city and manages major highway construction improvements;
- New Jersey Transit (NJ TRANSIT), which operates rail and bus service between the city and New Jersey;
- Amtrak, which operates intercity rail service to and from New York City, the non-subway rail tunnels under the Hudson River and the East River, as well as Pennsylvania Station, the busiest transit hub in the country; and
- the Federal government—which, through various agencies, including the Department of Transportation—provides major capital funding for many of the region's transportation systems.

Finally, a variety of private entities play roles, both large and small, in the city's transportation system. These include the operators of taxi and black-car fleets, private ferries, commuter vans, local and intercity buses, maritime freight terminals and vessels, and airlines.

Subway Tunnel Closures After Sandy



Source: NYCDOT, MTA, and Port Authority of NY & NJ

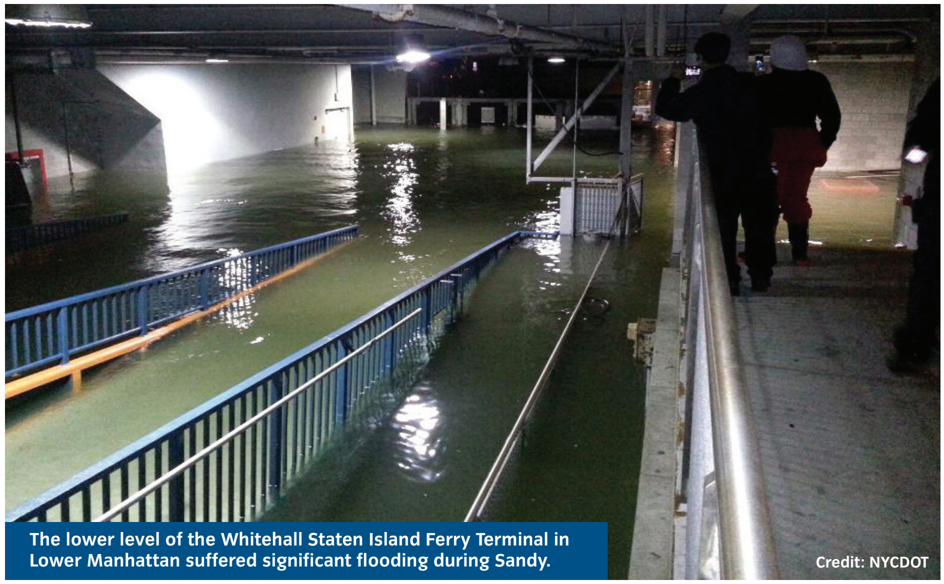
What Happened During Sandy

Sandy had a massive impact on the transportation system within New York City and the surrounding region, with the greatest impact felt on those elements located underground and close to the shoreline. The storm caused extensive damage and impaired the ability of the system to move people in and around the city and region.

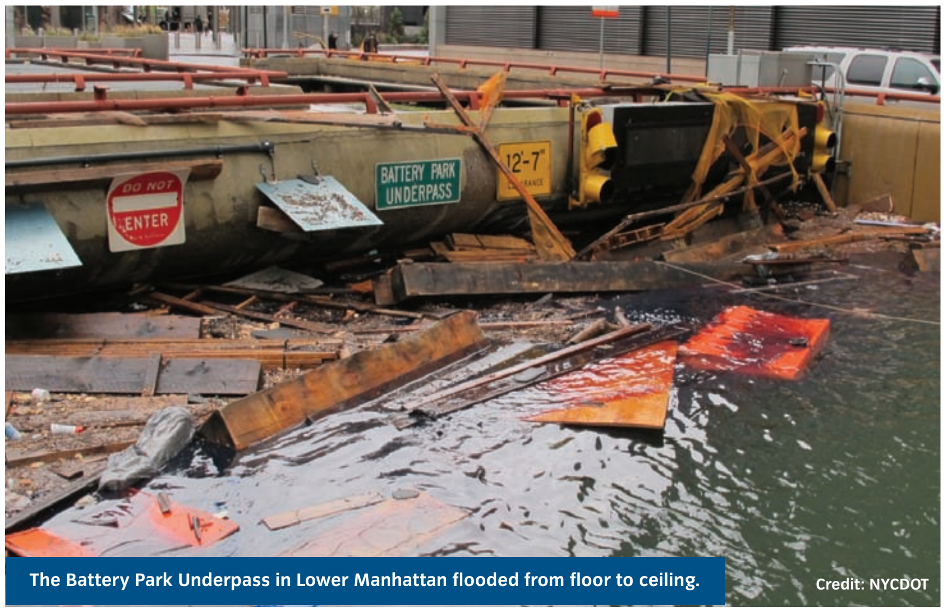
The storm had an impact on transportation in New York City even before it arrived. Starting the day before Sandy hit, most public transportation agencies made the decision to initiate an orderly shutdown of their systems to protect transit vehicles (often referred to as rolling stock) and critical infrastructure, and to ensure public safety. So, for example, the MTA installed plywood and sandbag barriers at critical station entrances and ventilation grates, while it also moved subway cars, buses, and trains to higher ground. At ferry landings and terminals around the city, gangways were removed to allow floating elements to move with the tide and expected storm surge without damaging buildings and facilities. SIF and private ferry service was halted. All seven active SIF vessels were then docked at the St. George Ferry Terminal on Staten Island, with more than 100 dedicated employees remaining on duty to protect the fleet.

Due to concerns about high winds and flooding, the Port Authority, MTA, and NYCDOT closed the city's major bridges and tunnels crossings, with the exception of the Lincoln Tunnel, the entrances to which were deemed to be high enough above the Hudson River to be at low risk of flooding. Meanwhile, airlines flew their planes out of harm's way, sheltering them at airports out of Sandy's path.

However, once Sandy arrived, its storm surge severely impacted many elements of the transportation system, including subway, railroad, and vehicular tunnels. Stormwaters



The lower level of the Whitehall Staten Island Ferry Terminal in Lower Manhattan suffered significant flooding during Sandy. Credit: NYCDOT



The Battery Park Underpass in Lower Manhattan flooded from floor to ceiling. Credit: NYCDOT

flooded tunnel entrances and ventilation structures in Southern Manhattan, Long Island City, Red Hook, Hoboken, and Jersey City. Vehicular tunnels that were knocked out of service were NYCDOT's Battery Park Underpass and West Street Underpass, the MTA's Queens Midtown and Hugh L. Carey (formerly Brooklyn-Battery) Tunnels, and the Port Authority's Holland Tunnel. Also inundated were all six of the subway tunnels connecting Brooklyn to Manhattan, the Steinway Tunnel that carries the 7 train from Queens to Manhattan, and the G train tunnel between Long Island City and Greenpoint. The PATH tunnels under the Hudson River also were flooded, with water entering via various entrances on both the New York and New Jersey sides, as were the railroad tunnels under the East River and the Hudson River. *(See chart: Subway Tunnel Closures After Sandy)*

Other elements of the subway system were impacted as well. For example, the A train viaduct connecting Howard Beach, Broad Channel, and the Rockaways was washed away in two locations, while the South Ferry subway station in Lower Manhattan was fully flooded to the mezzanine level.

In areas inundated by Sandy, roads similarly were affected, although these floodwaters typically receded within 12 hours. While 60 lane-miles of roadways were damaged severely and 500 lane-miles of roadways sustained minor damage, most roadways in inundated areas were undamaged. However, flooding did damage traffic signals controlling nearly 700 intersections when signal control boxes and underground conduits and cables were exposed to the corrosive effects of salt water.

Sandy's surge also affected maritime transportation, damaging landings and docks and inundating facilities on land (including both cruise terminals and both SIF terminals). The storm's winds and rising waters battered the SIF vessels, breaking mooring lines and submerging the docks. To prevent the ships from crashing into the shore, the captains of six ferries remained at the helm and successfully maneuvered the propulsion systems against the force of the storm. When the unmanned Alice Austen broke free of its moorings and lurched towards the Sen. John J. Marchi, crews developed improvised fenders, protecting both ships from damage.

Surge waters inundated rail yards and airports. Several low-lying rail yards were flooded, including the MTA's Coney Island Yard complex in Brooklyn and the LIRR's John D. Caemmerer West Side Yard in Manhattan. Meanwhile, the city's airports were flooded by waters from Jamaica Bay and Long Island Sound, but these waters did not reach the terminals, where the most sensitive and highest value equipment is located.

Sandy's surge thrust debris from the shore into the region's waterways, thereby necessitating a US Coast Guard shutdown of portions of the Harbor for five days. This decision hampered the movement of people and goods, including fuel as well as other supplies critical to recovery. Beyond the immediate impact of flooding, power outages from Sandy severely affected the transportation system. Lack of power meant that key equipment could not operate (e.g., train lines and tunnel ventilation equipment dependent on electricity). It also was a major impediment to the dewatering of the major tunnel infrastructure. Eventually, as power was restored, personnel from local agencies worked with crews from the US Army Corps of Engineers, Federal Emergency Management Agency (FEMA), US Navy, US Coast Guard, and National Guard to pump several hundred million gallons of water from these tunnels.

However, the fact that many tunnels were inundated for days exacerbated the impact of flooding and led to significantly greater water and corrosion damage to delicate equipment. For example, during the months following Sandy, this lingering damage resulted in more than 100 signal failures on the subway system, as well as ongoing problems with switches, power cables, and other infrastructure in the subways. Given the age and complexity of much of this equipment, obtaining replacement equipment proved both difficult and expensive. Despite the major disruptions and damage, much of the transportation system fared relatively well. For example, Sandy had a minor impact on the MTA's vehicles, thanks to the agency's successful relocation of this rolling stock out of harm's way. Meanwhile, the region's freight rail infrastructure also emerged from the storm with minimal damage, although some service disruptions did occur due to flooding and debris on tracks. Because wind speeds during Sandy were lower than earlier storms, the major bridges were able to reopen within 12 hours of the storm's conclusion, following safety inspections by engineers. *(See chart: Major Vehicular Bridge and Tunnel Closures After Sandy)*

However, the overall transportation system struggled to reopen, affecting millions of commuters. In the first two days following Sandy, for a variety of reasons, many people stayed at home and most businesses in impacted areas remained shuttered. However, by the third day after the storm, people started to attempt to return to their normal routines. With the subway and other major systems still partially out of service, New Yorkers were forced to improvise. In some cases, this improvisation turned mass transit users into bikers or walkers. In many other cases, however, these mass transit users turned to automobiles. The result was gridlock, especially on roads and bridges leading into Manhattan. In fact, during this period, average highway speeds dropped by as much as 71 percent, relative to speeds on normal weekdays. *(See chart: Highway Travel Speeds at Selected Locations)*

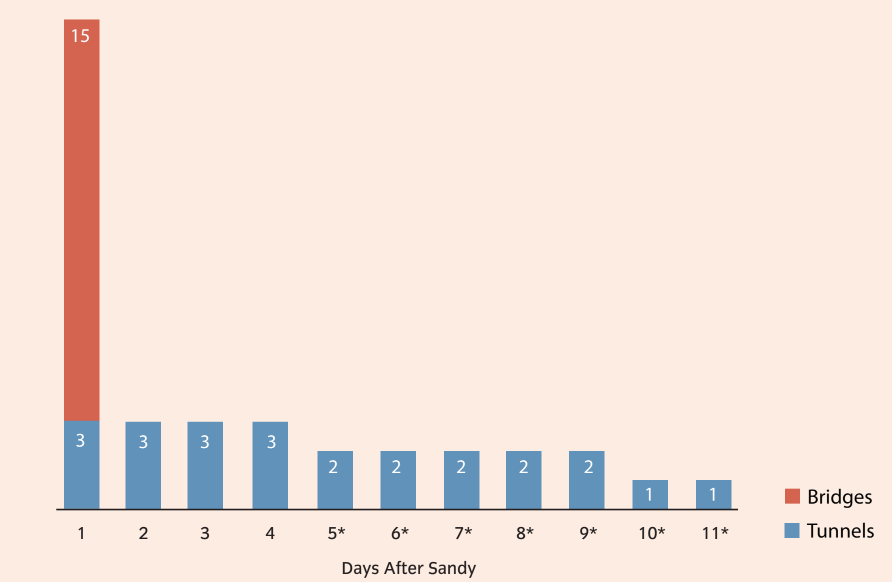
To maintain critical routes, City and State officials quickly implemented a series of temporary measures. Many of these measures were conceived on the spot immediately after Sandy hit. However, from temporary ferry routes, to bus bridges, to carpool requirements, together, they proved to be hugely successful in getting people moving again. *(See chart: East River Crossings Before and After Sandy; see sidebar: Temporary Services Help Restore Mobility After the Storm)*

As time progressed, much of the city's transportation network was brought back online. The ferry and marine transportation networks, for example, took between two days and a week to restore, while airports were back in operation within three days of the storm. The subways mostly were restored a week after Sandy, with vehicular tunnels taking closer to a week and a half to return to partial service due to damage to the ventilation equipment. By two weeks after Sandy, most of the city's transit network was functioning at or near normal capacity.

Certain elements took longer and in some cases, are still out of service as of the writing of this report, including portions of the subway system. For example, the Montague Street Tunnel used by the R train was restored eight weeks after Sandy (but will be taken out of service again for longer-term repairs), and the causeway that carries the A train connecting Howard Beach to the Rockaways was restored at the end of May 2013. Full restoration of South Ferry subway station in Lower Manhattan is expected to take several years.

In response to these longer-term transit outages post-Sandy–and generally to provide expanded mobility and access options—the following new and enhanced services were added:

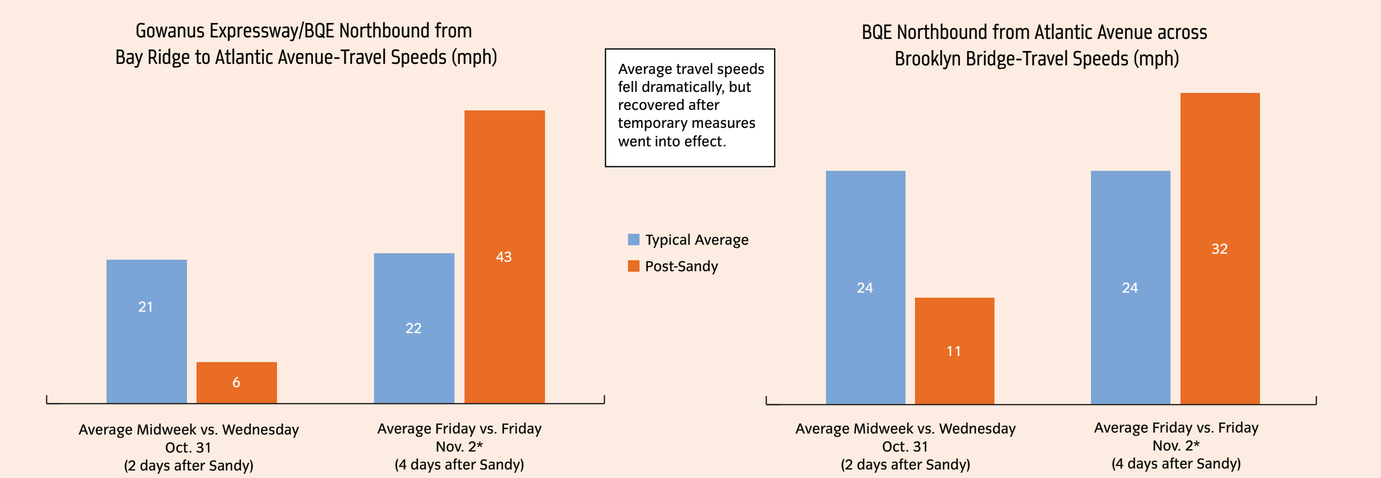
Major Vehicular Bridge and Tunnel Closures After Sandy



*partial tunnel closures continued due to ventilation system damage

Source: NYCDOT, MTA, and Port Authority of NY & NJ

Highway Travel Speeds at Selected Locations



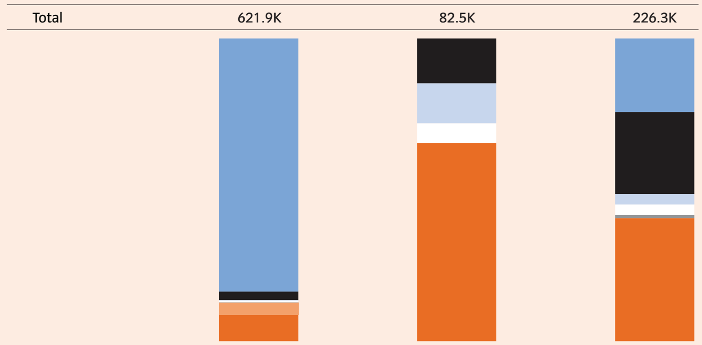
*Note: Bus bridges and HOV requirements were in effect on Nov. 2

Source: NYCDOT

- new ferry services from both the Rockaways and Staten Island to Lower Manhattan and Midtown to compensate for lost or constrained transit service;
- an H shuttle subway train, with an accompanying shuttle bus to the Howard Beach subway station through the Rockaways, to compensate for the loss of A train service across Jamaica Bay; and
- the reopening of the former South Ferry Terminal below the Whitehall Ferry Terminal, to allow 1 train service to the southern tip of Manhattan while the damaged South Ferry Terminal was being repaired.

Even as the city's transit system resumed most service, however, it was clear that Sandy's damage had been done. In total, close to 8.6 million daily public transit riders, 4.2 million drivers, and 1 million airport passengers were impacted by the shutdown of various systems. In addition, it is estimated that Sandy has resulted in a staggering $8 billion in physical damage to the region's transportation infrastructure, including $700 million in damage to NYCDOT's facilities and equipment.

East River Crossings Before and After Sandy



	Typical Weekday	Oct. 31 (2 days after Sandy)	Nov. 2* (4 days after Sandy)
Subways	**520,000**	0	55,000
Buses	**17,400**	12,200	61,300
Pedestrian	**1,100**	10,900	7,800
Bicycle	**3,500**	5,400	7,800
Ferries	**900**	0	2,400
Tunnels-Private Vehicles	**25,000**	0	0
Bridges-Private Vehicles	**54,000**	54,000	92,000

*Note: Bus bridges and HOV requirements were in effect on Nov. 2

Source: NYCDOT

What Could Happen in the Future

Looking to the future, the city's transportation system faces significant climate risks, including the risk of storm surge and flooding from coastal storms, heavy downpours, and sea level rise.

Major Risks

The greatest future risk to the city's transportation network is storm surge—a risk that, as Sandy illustrated, is significant even today primarily because so many critical pieces of transit infrastructure are located within the 100-year floodplain, the area that has a 1 percent or greater chance of flooding in any given year. The recently released Preliminary Work Maps (PWMs) from the Federal Emergency Management Agency (FEMA) define the 100-year floodplain as an area that already includes approximately 12 percent of the roadway network, all of the major tunnel portals other than the Lincoln Tunnel, portions of both airports, a variety of commuter rail assets, all three heliports, and a number of subway entrances and vent structures, principally in Lower Manhattan. *(See map: Transportation Network in the 2013 PWMs 100-Year Floodplain)*

Going forward, the risks associated with storm surge will grow more severe, as rising sea levels increase the impact of those surges and turn minor surges into major events. According to projections from the New York City Panel on Climate Change (NPCC), described in Chapter 2 (*Climate Analysis*), sea levels are forecast to rise through the 2020s and 2050s. During this period, the floodplain will expand. By the 2020s, the floodplain is estimated to encompass 15 percent of the city's roadway network, and by the 2050s, it is expected to encompass 19 percent of that network. More and more of the City's airport infrastructure will be at risk as storm surges will move from

Temporary Services Help Restore Mobility After the Storm

On a normal day, the subway carries about 80 percent of the people crossing the East River into Manhattan. Following Sandy, however, with subway service across the river entirely shut down for a number of days, many people tried to commute by car. Gridlock ensued. It quickly became clear that the transportation network simply was not designed to handle the spike in drivers attempting to enter the central business district south of 60th Street.

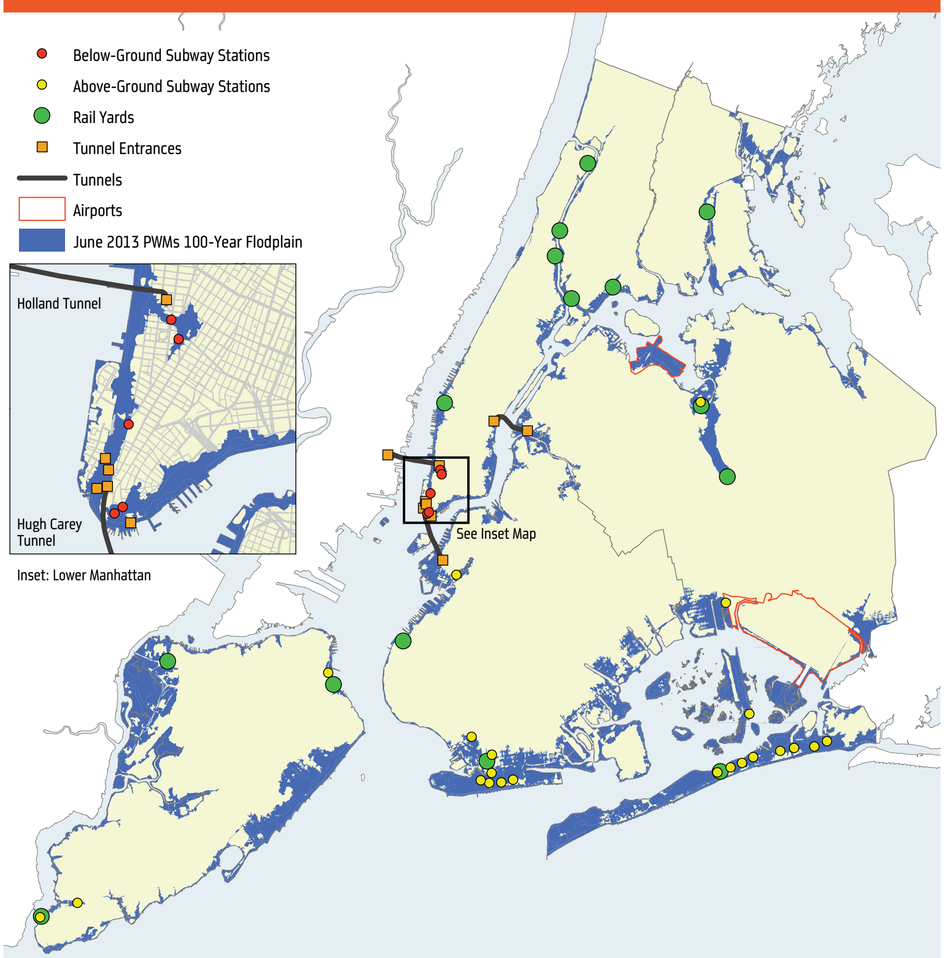
In response, the New York City Department of Transportation (NYCDOT), the New York City Police Department (NYPD), and the Metropolitan Transportation Authority (MTA) instituted a series of measures to limit the number of cars coming into Manhattan but still get people across the river. First, cars entering Manhattan's central business district were required to have three or more occupants. Second, the NYPD, NYCDOT, and the MTA implemented three new temporary, high-capacity, point-to-point bus routes (which quickly became known as "bus bridges"), connecting Downtown Brooklyn and Williamsburg with Midtown Manhattan, using 300 buses that the MTA diverted from other routes. Third, the East River Ferry service pattern was modified to increase capacity and provide faster service along routes with the highest demand, taking advantage of the infrastructure already in place and the vessels on hand.

The challenges inherent in communicating information about these temporary measures in the immediate post-Sandy environment initially led to some confusion among travelers—particularly those drivers who had to be turned away as they tried to enter Manhattan because they did not meet the occupancy requirements. However, these measures accomplished their desired goal, together enabling over 226,000 commuters to cross the East River—almost triple the number able to cross before these measures were in place.

The South Ferry Station in Lower Manhattan was flooded to the mezzanine level.

Credit: MTAPhotos

Transportation Network in the 2013 PWMs 100-Year Floodplain



Source: FEMA, CUNY Institute for Sustainable Cities

flooding outlying runways to threatening the terminal buildings, while additional subway stations will be at risk.

More intense downpours expected with climate change also pose a major risk to the transportation system. As with storm surge, heavy downpours pose the most significant challenge to subway and vehicular tunnels throughout the city, particularly in locations where tunnel entrances are located in low-lying areas or in areas with poor subsurface drainage. Examples of infrastructure matching this flood profile include the F train on Hillside Avenue in Queens and several subway lines in Lower Manhattan. Generally, heavy downpours are expected to pose only a moderate risk to roads and bridges, which may experience more frequent temporary flooding, but not more lasting damage.

Other Risks

High winds are likely to represent a moderate risk to the above-ground portions of the city's transportation infrastructure, such as traffic signals, signs, bridges, and street lights. They also could pose challenges to the aviation system, interfering with flight operations and, in the worst cases, creating safety hazards. Although high winds can cause power outages, which have serious impacts on the transportation network as a whole, it is not believed that these impacts will be greater than those facing the city today.

Heat waves, meanwhile, present a moderate threat to the city's ground transportation infrastructure, though it is not expected to become materially greater until the 2050s. Heat waves could create problems with opening and closing movable bridges and cause softening of asphalt roads. Heat waves also could become an issue for the subway system, increasing temperatures on platforms to levels that could turn what, today, is only a passenger comfort issue into a passenger safety issue. Moreover, heat waves could increase the potential for power outages, which affect transportation networks across the board.

Finally, sea level rise in and of itself is expected to pose a low risk to the city's transportation infrastructure for the next three decades. However, by the 2050s tidal flooding—already an issue for some low-lying areas—could become more widespread along the waterfront, including areas such as Southern Brooklyn and South Queens. Waterfront assets including the city's airports and ferry terminals could be placed at risk by this periodic flooding threat.

Risk Assessment: Impact of Climate Change on Transportation

Major Risk | Moderate Risk | Minor Risk

	Scale of Impact			
Hazard	**Today**	**2020s**	**2050s**	**Comments**
Gradual				
Sea level rise	Minor Risk	Minor Risk	Moderate Risk	Some protection required, but most infrastructure is above future sea level
Increased precipitation	Minor Risk	Minor Risk	Minor Risk	Minimal impact
Higher average temperature	Minor Risk	Minor Risk	Minor Risk	Minimal impact
Extreme Events				
Storm surge	Major Risk	Major Risk	Major Risk	Increased flooding of key at-grade and underground infrastructure as storms worsen
Heavy downpour	Moderate Risk	Moderate Risk	Moderate Risk	Flooding of underground infrastructure possible during heaviest downpours
Heat wave	Minor Risk	Minor Risk	Moderate Risk	Movable infrastructure (bridges, switches) could be impacted, as well as safety/comfort on subway platforms INDIRECT: reduced electrical supply reliability impacts many aspects of infrastructure
High winds	Minor Risk	Minor Risk	Moderate Risk	General damage to infrastructure possible, as well as impact on aviation

Risk Assessment: Impact of Climate Change by Category of Transportation Asset

Major Risk | Moderate Risk | Minor Risk

	Asset Impacts				
Hazard	**Roads, Bridges, and Vehicular Transportation**	**Ferries and Marine Transport**	**Tunnels and Subways**	**Rail** (includes above-ground subways)	**Airports**
Gradual					
Sea level rise	Moderate Risk	Major Risk	Moderate Risk	Moderate Risk	Moderate Risk
Extreme Events					
Storm surge	Moderate Risk	Major Risk	Major Risk	Moderate Risk	Moderate Risk
Heavy downpour	Moderate Risk	Minor Risk	Major Risk	Minor Risk	Minor Risk
Heat wave	Moderate Risk	Minor Risk	Moderate Risk	Moderate Risk	Minor Risk
High winds	Moderate Risk	Moderate Risk	Minor Risk	Moderate Risk	Moderate Risk

Note: This chart excludes increased precipitation and higher average temperature because these are expected to have minimal impact on the transportation system

This chapter contains a series of initiatives that are designed to mitigate the impacts of climate change on New York's transportation system. In many cases, these initiatives are both ready to proceed and have identified funding sources assigned to cover their costs. With respect to these initiatives, the City intends to proceed with them as quickly as practicable, upon the receipt of identified funding.

Meanwhile, in the case of certain other initiatives described in this chapter, though these initiatives may be ready to proceed, they still do not have specific sources of funding assigned to them. In Chapter 19 (*Funding*), the City describes additional funding sources which, if secured, would be sufficient to fund the full first phase of projects and programs described in this document over a 10-year period. The City will work aggressively on securing this funding and any necessary third-party approvals required in connection therewith (i.e., from the Federal or State governments). However, until such time as these sources are secured, the City will only proceed with those initiatives for which it has adequate funding.

As outlined above, climate change could have a significant impact on the city's transportation infrastructure, ranging from short-term outages to direct damage—or even destruction of critical assets, in some cases. These impacts may make it difficult for commuters to travel to work and school and will hinder the economic and social life of the city.

To mitigate these impacts, the City and other transportation system operators will have to protect their critical assets—particularly those most vulnerable to damage and with the greatest economic and mobility value. However, they also will have to ensure both maximum system redundancy (offering transit users as many different routes as possible to their intended destinations) and that they are well-prepared to restore transportation services quickly, if and when extreme events breach defenses.

Strategy: Protect assets to maintain system operations

Given the range of potential climate change impacts on the transportation network and the criticality of the transportation network, the City will implement initiatives to protect the infrastructure that it controls from damage and loss of service and will call on other agencies to protect other transportation infrastructure critical to the city.

Sandy damaged many miles of City streets.

Credit: NYCDOT

Initiative 1
Reconstruct and resurface key streets damaged by Sandy

Sandy's waves and flooding caused significant damage to roadways. To address this damage, subject to available funding, the City, through NYCDOT, will reconstruct 60 lane-miles of streets that were severely damaged and conduct both subsurface and surface repairs. These newly-reconstructed streets also will include upgraded resiliency features to prevent future damage. In addition, NYCDOT will resurface 500 lane-miles of streets with damaged pavement but underlying structures that are in good condition. This initiative is already underway, with funding from Federal and City sources supporting rapid restoration of transportation services.

Initiative 2
Integrate climate resiliency features into future capital projects

The city's roadways are vulnerable to climate change threats in a variety of ways, including surface flooding from heavy downpours, wave action from storm surge, and asphalt damage from heat waves. These threats can have downstream impacts on other systems (including subways and utilities) and on private property. To mitigate the impact of these threats on streets and other infrastructure, subject to available funding, the City, through NYCDOT, will integrate a variety of climate resiliency features into future street reconstruction projects. This will include integrating storm water management best practices and tools. These features allow water captured on streets to soak into the ground rather than flow into the sewer system, resulting in lower drainage loads on both sewers and wastewater treatment plants. (see Chapter 12, *Water and Wastewater*)

While specific climate resiliency features will be designed for each location on a case-by-case basis, the range of tools could include raising street grades, installing bioswales (planted areas in the sidewalk designed to capture stormwater from the adjacent roadway) and/or pre-cast permeable concrete gutters, and adding or raising bulkheads. These features are already being integrated into active capital projects and this will continue in the future.

Initiative 3
Elevate traffic signals and provide backup electrical power

New York's traffic signals are vulnerable to damage from flooding, as well as to power loss from various extreme weather events. Either impact would reduce roadway network operational efficiency and could require the placement of New York City Police Department (NYPD) traffic agents to control traffic. The most vulnerable elements of the city's traffic signals are the signal controllers housing the electrical equipment that operates the traffic signal and communicate with the NYCDOT Traffic Management Center. Accordingly, subject to available funding, the City, through NYCDOT, will raise controllers at approximately 500 intersections in flood-vulnerable locations, placing the electrical hardware above the 100-year flood elevation. In tandem with this effort, the City also will install power inverters in approximately 500 NYPD vehicles, which will allow these vehicles to provide backup electrical power to critical traffic signals in the event that grid power is lost. These improvements will take place over the next three years and will increase the resiliency of this critical component of the transportation network.

Credit: The Elizabeth River Tunnel Project, Portsmouth, VA

Various technologies are available to seal tunnel entrances in the event of flooding such as the closeable flood doors on the Elizabeth River Tunnels in Portsmouth, VA.

Initiative 4

Protect NYCDOT tunnels in Lower Manhattan from flooding

The two tunnels owned by NYCDOT in Lower Manhattan—the Battery Park Underpass and the West Street Underpass—are vulnerable to flooding from both storm surge and heavy downpours, which would significantly disrupt Lower Manhattan's transportation network. NYCDOT, therefore, has evaluated a series of potential flood protection strategies, including installing floodgates and raising tunnel entrances and ventilation structures above flood elevations to provide specific protection for sensitive mechanical and electrical equipment, including ventilation, lighting, and safety systems. Subject to available funding, the City, through NYCDOT, will implement the most promising and cost effective strategies to provide this protection from water infiltration and damage. The goal is to begin work in 2014 and complete it within five years.

Initiative 5

Install watertight barriers to protect movable bridge machinery

The mechanical equipment that allows 25 of the city's bridges to move to provide a clear path for marine traffic is vulnerable to flooding. Damage to this equipment could impact marine and roadway traffic, if bridges were locked either open or closed. Subject to available funding, the City, through NYCDOT, will install watertight barriers to protect the bridges' mechanical equipment from flood damage to ensure that these critical crossings function properly.

Initiative 6

Protect Staten Island Ferry and private ferry terminals from climate change-related threats

New York City's ferry services are vulnerable to disruption and damage from flooding and wind that could lead to extended service suspensions and reduced mobility. To maintain service and allow for quicker service restoration, the City, through NYCDOT and NYCEDC, will continue to use Federal Transit Administration Emergency Relief funds to construct physical improvements to the floating infrastructure, loading bridges/gangways, pilings, and piers at both the Whitehall and Saint George SIF terminals and at additional ferry landings around the city. Within the next four years, NYCDOT and NYCEDC will protect critical aspects of these facilities by water-proofing certain equipment, relocating other equipment out of harm's way, and otherwise protecting electrical equipment from damage.

Initiative 7

Integrate resiliency into planning and project development

Climate adaptation and resiliency have not been critical considerations in prioritizing capital projects for either Federal or City funds, making it more challenging to fund projects that address critical climate change-related vulnerabilities in the city's transportation network. The City, however, already has begun working with other member agencies of the New York Metropolitan Transportation Council, which is responsible for prioritizing federal transportation funding in the New York region, to ensure that resiliency is a factor in such prioritization. Going forward, the City will advocate for similar changes in the planning and evaluation factors that are included in the next Federal legislation funding surface transportation.

At the same time, the City will call upon the various transportation agencies in the region to plan jointly for resiliency and adaptation, thus avoiding duplicative investment and unintended consequences.

Initiative 8

Call on non-City agencies to implement strategies to address climate change threats

Many non-City agencies that own and operate critical portions of New York City's transportation system already have called for increased investment in resiliency and protection strategies appropriate for their

Adding System Flexibility

A number of projects that improve the flexibility of the transportation system and create redundant connections along critical corridors are currently in various phases of development:

- Amtrak's Gateway Project which seeks to add intercity rail capacity into New York City;
- extension of the MTA New York City Transit's 7 subway line to New Jersey or alternatives that would significantly expand cross-Hudson commuting capacity;
- transit improvements along the North Shore of Staten Island; and
- extension of Metro-North Railroad service to Penn Station.

LaGuardia Airport closed due to flooding on its runways.

Credit: Port Authority of NY & NJ

The LIRR's John D. Caemmerer West Side Yard during Sandy.

Credit: MTAPhotos

Temporary "Bus Bridges" (Non-Stop Bus Service) After Sandy

Source: NYCDOT

systems. Without comprehensive implementation of such actions across all transportation systems, critical assets could remain vulnerable to damage and disruption from future climate change-related events. Seeking to ensure that the city's entire transportation system is protected from climate change threats and is prepared for quick restoration following an extreme climate event, the City will call on these agencies to implement hardening and preparation measures, including those already outlined in plans such as the NYS2100 Commission Report. Infrastructure protection should include the following system elements:

- vehicular and rail tunnels, including the subway system;
- bus depots and terminals, and other facilities that are critical to providing bus service;
- rail and subway yards, and other facilities that are critical to providing rail service;
- airport facilities, including runways, lighting systems, navigation systems, and terminal buildings; and
- port and marine facilities, particularly those that handle critical supplies such as food, fuel, and building materials.

In addition, the City will continue to collaborate with Federal and State transportation agencies to support projects that expand the flexibility and redundancy of the transportation network. *(see sidebar: Adding System Flexibility)*

Strategy: Prepare the transportation system to restore service after extreme climate events

The city's transportation system is too large, too complex, and too old for it to be entirely "climate-change-proofed." In this vein, New York's experience after Sandy demonstrated the importance of maximizing modal redundancy within the system, of ensuring that—when systems are overwhelmed by extreme weather events—they are quickly brought back to regular service, and of being prepared to add temporary services to restore mobility while outages continue.

Therefore the City will implement the initiatives below.

Initiative 9
Plan for temporary transit services in the event of subway system suspensions

When major portions of the subway system are out of service, there simply is not sufficient capacity in the rest of transit network or the roadway system to carry the increased volume

Protected ferry landings can ensure rapid resumption of service.

of commuters and other travelers. To address this situation, the City, through NYCDOT, will continue to work with its transportation partners to develop and regularly update formal plans to provide temporary transportation services. These services could include temporary, high-capacity "bus bridges" of the type implemented during Sandy, temporary point-to-point ferry services, and dedicated bus lanes and necessary enforcement, among others. Identifying the range of potential threats to the transit network and the potential impacts of these threats will be critical to this effort, enabling agencies to determine the types of temporary services that may be necessary. Detailed strategies already have been developed and will continue to be refined and expanded by NYCDOT, the MTA, and other regional agencies. NYCDOT subsequently will acquire and store the traffic control, public information, and other ancillary materials necessary to implement these temporary services. *(See map: Temporary "Bus Bridges" (Non-Stop Bus Service) After Sandy)*

NYCDOT and NYCEDC will work with private ferry fleet operators, and with the MTA and private bus fleet operators, to investigate the level and type of support these companies could provide in the event of a public transit outage

Finally, NYCDOT will work with the MTA to investigate providing city residents with greater access to LIRR and Metro-North services during significant emergency events that lead to major transit disruptions, at fares comparable to those of the subway. This access would be limited to the periods of major disruption, providing an alternative mobility option similar to the type of "cross-honoring" of tickets that is often put in place on NJ TRANSIT buses, PATH, and NJ TRANSIT commuter rail following major disruptions of one of those services.

Initiative 10

Identify critical transportation network elements and improve transportation responses to major events through regular resiliency planning exercises

Many of the facilities critical to the City's ability to respond effectively to a disaster are vulnerable to disruption and damage, potentially impairing delivery of emergency services and supplies of food, fuel, and medicine, as well as impairing the restoration of critical non-transportation infrastructure and economic activity. To respond better to a variety of different possible transportation outage and restoration scenarios, the City, through NYCDOT, will begin immediately to work with a wide range of transportation agencies and other stakeholders around the region to identify the critical elements of the surface transportation network that need to be available quickly following different types of events. The key tool to identify these networks will be an ongoing series of detailed and multi-disciplinary resiliency planning exercises—and potentially even live drills—that will allow these agencies to understand where resources need to be focused before, during, and after an event. This will provide a basis for prioritizing resiliency investments, improving operational response, and disseminating guidance to transportation stakeholders about the routes that they can expect will be available following an event.

Initiative 11

Develop standard plans for implementing High-Occupancy Vehicle (HOV) requirements

During a number of different events—both natural and manmade—that have led to significant interruptions of subway service into and out of Manhattan, the volume of private vehicles trying to cross into Manhattan has overwhelmed available capacity and created gridlock in locations around the city. In response, the City has implemented requirements that vehicles entering the Manhattan central business district have three or more occupants. To improve the future implementation of these measures, the City, through NYCDOT and NYPD, is working to develop standard protocols for implementing HOV requirements, including the conditions under which these requirements will be implemented, and the tools that will be used to communicate this information to the public. NYCDOT, NYPD, and the City's Office of Emergency Management are working together to formalize any exemptions to the HOV requirements, including emergency response vehicles and potentially vehicles carrying key supplies such as food or fuel or emergency response personnel for private businesses. Detailed planning for this eventuality will be completed by the relevant agencies by the end of 2013.

Initiative 12

Plan for and install new pedestrian and bicycle facilities to improve connectivity to key transportation hubs

Subway service interruptions can cause New Yorkers to turn to walking and biking in large numbers, overwhelming the current capacity of pedestrian and bicycle paths, particularly those crossing the East River. To provide additional capacity in these situations, subject to available funding, the City, through NYCDOT and NYPD, will plan for the deployment of temporary pedestrian and bicycle capacity in the event of an emergency situation. This capacity could include special lanes on East River Bridges and their approaches, and lanes that provide access to ferry landings. These agencies will procure and store the materials necessary to implement these facilities quickly in the event of an emergency, with such materials likely including static signs, temporary traffic control devices, and electronic message signs. Planning for this effort will begin in 2013, with the goal to fully develop these capacity enhancements by the end of 2014.

The City, through NYCDOT, also will work with CitiBike/NYC Bike Share, which provides a transportation option that does not require grid electrical power, to explore future expansion of the bike share network to areas that are vulnerable to weather-related transportation interruptions and that are also adjacent to CitiBike's initial service area, including neighborhoods such as Red Hook, Greenpoint, and Long Island City. This process will begin after the full Citibike deployment is complete.

Initiative 13
Construct new ferry landings to support private ferry services

Emergencies and other events that disrupt subway or transportation service can create serious challenges to mobility within the city, with resulting economic, community, and social impact. To increase the availability of interim transportation services—particularly between the boroughs—subject to available funding, the City, through NYCEDC, will work to expand the network of ferry landings available for both regular and emergency use. To support the establishment of emergency ferry services, NYCEDC will design and procure two new ferry landing barges that are outfitted with the required equipment for providing basic ferry service, with a goal of completing these within three years. These barges will be stored in a secure and protected location. When the need arises, they will be deployed within 24 to 48 hours as temporary landings, allowing for the rapid establishment of interim service. As part of this exercise, NYCEDC will work with the New York State Department of Environmental Conservation to identify potential locations where these barges quickly could be deployed adjacent to neighborhoods that are vulnerable to climate-related transportation interruptions, in a manner that minimizes the impact on the natural environment.

In addition, subject to available funding, the City, through NYCEDC and NYCDOT, will work together to deploy four new permanent ferry landings. These strategic locations will be selected based on the results of the ongoing Comprehensive Citywide Ferry Study in (see Initiative 18 for details on the study). The landings will be designed to be mobile so that, in an extreme situation, they can be temporarily relocated to provide alternative transit services where needed. The goal is to begin design of these landings later in 2013, with deployment based on the results of the ferry study.

Initiative 14
Deploy the Staten Island Ferry's Austen Class vessels on the East River Ferry and during transportation disruptions

During transit service disruptions that cause large numbers of commuters to use ferry services, the increased demand can outstrip the capacity of typical private ferry vessels. To supplement East River Ferry capacity during such times, NYCDOT will be prepared to deploy the SIF's Austen Class vessels for service along these routes, developing specific operational plans for different scenarios. The Austen Class ferries, due to their size and maneuverability, have been used on a number of occasions over the years to assist in emergencies. Each of the two vessels can carry 10 times the passenger volume of a typical East River Ferry and could, therefore, during major transportation disruptions, help meet sudden increases in ridership on the East River and potentially in other locations.

Initiative 15
Improve at all levels communications about the restoration of transportation services

During and immediately following an emergency situation, communication among agencies and with the general public can suffer from a lack of reliable information and clear communication channels, leading to considerable confusion. To improve the flow of accurate and reliable information, the City will use existing interagency working groups to develop standardized communications protocols for use during transportation disruptions. The plan will include a standard "playbook" for outreach to agency stakeholders and the public regarding system status and interim measures. Truck routes will be a particular focus, in order to provide accurate information to truck companies and drivers during emergencies, minimize the impact of trucks on the City's sensitive infrastructure, and facilitate the safe, fast, and efficient delivery of relief supplies.

Strategy: Implement new and expanded services to increase system flexibility and redundancy

During an emergency situation when subway service is disrupted, other transportation modes often are overwhelmed, crippling the city's mobility and economy. Greater system redundancy that adds flexibility to adapt to unexpected events would add to the resiliency of the transportation network. Beyond creating additional capacity and responsiveness on a daily basis, these investments will be particularly valuable during a variety of weather events and other emergency situations.

Existing and Proposed Select Bus Service Corridors

Source: NYCDOT

The City, therefore, will work with its transportation partners to develop and implement the new or expanded transit services described below.

Initiative 16

Expand the city's Select Bus Service network

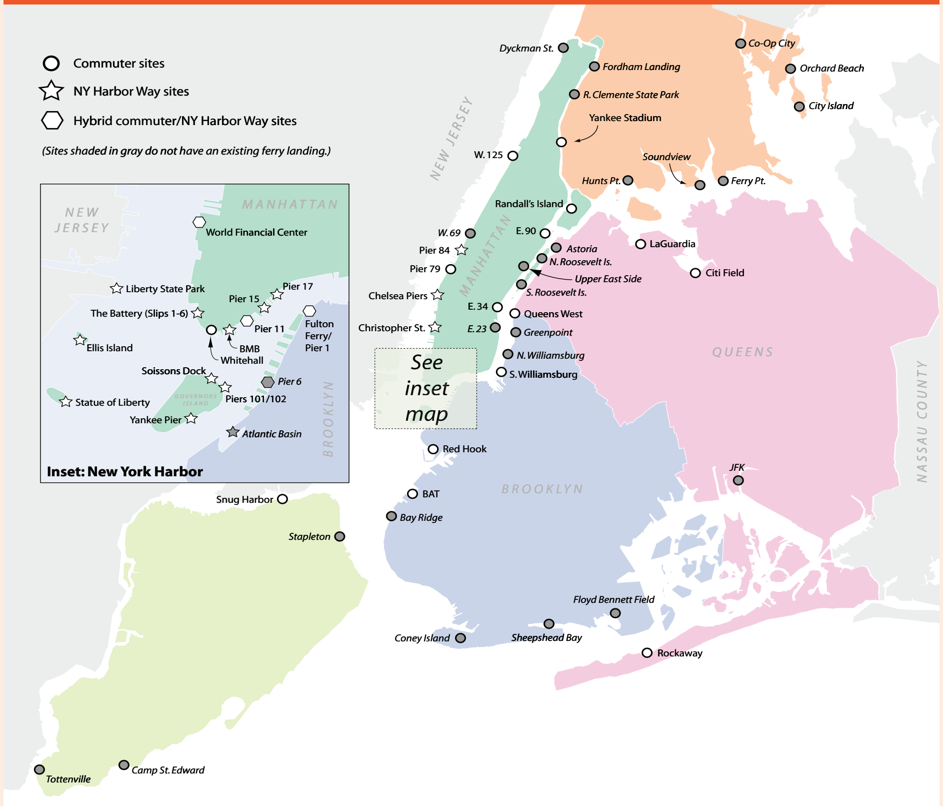
Subway disruptions or outages can create serious mobility challenges for many New Yorkers. As described above, since 2008 the City and the MTA have implemented four SBS Bus Rapid Transit routes to address general mobility challenges. These routes also can form the backbone of high-capacity bus service in the event of major subway outages. NYCDOT is working with the MTA to expand the city's SBS network significantly, building on a plan developed jointly in 2010 and reinforced in the New York State 2100 Report issued in January. Implementation of this plan has already begun, with three new SBS routes ready to launch shortly in Brooklyn, the Bronx, and Queens. Planning is underway for the Woodhaven Boulevard corridor in 2013, benefiting some of the Southern Queens neighborhoods impacted by Sandy. Subject to available funding, over the next five years NYCDOT will work with the MTA to implement four additional SBS routes. Also subject to available funding, the additional 12 routes included in the plan will be launched subsequently. *(See map: Existing and Proposed Select Bus Service Corridors)*

Initiative 17

Expand the network of bus priority strategies on arterial highways

During both normal and emergency situations, congestion on the region's highways can inhibit mobility and slow the city's recovery. As with the SBS routes, bus priority strategies for express, local, and intercity buses can improve this situation for both standard and emergency operations. Therefore, subject to available funding, the City, through NYCDOT, will work to expand its network of bus priority strategies. Over the next several years, the intention is to include 15 miles of bus priority corridors on major limited-access arterial highways, as these highways are improved or reconstructed in partnership with NYSDOT. This effort will focus on highways on which a variety of buses normally travel. Building on the State's Managed Use Lanes Study, these priority corridors will consist of lanes designed to help the impacted buses move through congested areas quickly and reliably. Types of treatments could include median bus lanes (similar to those on the Staten Island Expressway), contraflow bus lanes (such as contraflow lanes on the Gowanus Expressway and the Long Island Expressway), and use of shoulders for bus traffic (a technique that has been used successfully in other locations). The goal is to implement at least one new or expanded bus priority strategy within five years, with additional facilities added as opportunities arise.

Citywide Ferry Study



Initiative 18

Expand ferry services in locations citywide

The city's waterways present barriers to movement when key crossings are disrupted by a storm or other events. Ferry services provide a critical transportation option for connecting the city across these obstacles under a variety of conditions, including transit disruptions. To plan these services better, the City, through NYCEDC, is currently updating the Comprehensive Citywide Ferry Study (first published in 2011) to explore opportunities for expanding ferry service beyond the existing routes. Based on the results of this study, the City, subject to available funding, will work with its private-sector partners to provide additional service in appropriate locations throughout the city. Chapter 14 (*Brooklyn-Queens Waterfront*), Chapter 15 (*East and South Shores of Staten Island*), and Chapter 16 (*South Queens*) provide additional details on potential new or expanded ferry services in these respective neighborhoods. In addition, NYCEDC will use a Request for Expressions of Interest process to identify and validate the most promising opportunities for new ferry service. *(See map: Citywide Ferry Study).*

Staten Island Ferry Resiliency Upgrades

As was proved during Sandy, ferries are a critical lifeline during and after extreme weather events. This is, of course, true for the Staten Island Ferry, which provides a service that is directly threatened by climate change. Even as the City invests in waterfront and terminal infrastructure protections, ferry boats themselves face operational challenges and vulnerabilities during extreme weather events. Since three existing Barberi-class Staten Island Ferry boats are nearing the end of their useful lives, NYCDOT is preparing to replace these boats with new ferries with cycloidal propulsion systems. Cycloidal propulsion will improve ferry boat maneuverability and safety in high winds, rough waters, and during storm surges. NYCDOT has completed design of these boats and is seeking $300 million in federal funding to procure them. Accelerating these purchases will allow the ferries to be in operation by 2015, providing a resiliency benefit to the people of Staten Island and the city as a whole.