University Transportation Research Center - Region 2

Final Report

Lessons from Hurricane Sandy for Port Resilience

Performing Organization: Stevens Institute of Technology

December 2013

Sponsor:
University Transportation Research Center - Region 2

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The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

Technology Transfer

UTRC's Technology Transfer Program goes beyond what might be considered "traditional" technology transfer activities. Its main objectives are (1) to increase the awareness and level of information concerning transportation issues facing Region 2; (2) to improve the knowledge base and approach to problem solving of the region's transportation workforce, from those operating the systems to those at the most senior level of managing the system; and by doing so, to improve the overall professional capability of the transportation workforce; (3) to stimulate discussion and debate concerning the integration of new technologies into our culture, our work and our transportation systems; (4) to provide the more traditional but extremely important job of disseminating research and project reports, studies, analysis and use of tools to the education, research and practicing community both nationally and internationally; and (5) to provide unbiased information and testimony to decision-makers concerning regional transportation issues consistent with the UTRC theme.

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16. Abstract

New York Harbor was directly in the path of the most damaging part of Hurricane Sandy causing significant impact on many of the facilities of the Port of New York and New Jersey. The U.S. Coast Guard closed the entire Port to all traffic before the storm hit on October 28th. It was not fully reopened to vessel traffic until November 4th. Then, even though the waterways were open, numerous port terminals and maritime facilities did not resume their operations for several more weeks because of power failures and damages to the facilities and equipment. This study was conducted to identify lessons learned that could assist in restoring the Port and its contributions to the supply chain to service more rapidly in the future. The study used interviews of key port stakeholders to gather information, to understand events, and to identify the circumstances that led to the Port's storm-related impacts and operational recovery. The project reviewed the existing design codes for infrastructure and attempted to identify how building codes could be improved. It also examines the activities and processes that enhanced port resiliency.

There were several generalized principles that emerged from the interviews. They included:

(1) Safety of life is the prime consideration.
(2) Strong and redundant communication systems are needed.
(3) Current building designs and building codes must be re-evaluated.
(4) Conduct drills and tabletop exercises.

Most of the major damage was related to the inundation associated with the storm surge. Storms capable of having similar impacts will occur in the future. The following code recommendations are suggested:

(1) The building codes of New York and New Jersey should be updated to include uniform port specific sections.
(2) States should adopt ASCE 24 for siting of critical utility and mechanical equipment and for flood resistant design for all port facilities.
(3) The Port Authority should add a section to their lease agreements devoted to port specific structural considerations.
(4) The facility owners in the Port should adopt a reasonable and consistent methodology for incorporating sea level rise into their facility upgrades.

A simple framework was formulated for enhancing port resiliency. There are activities that can take place prior to a disruption or they can take place following the occurrence of an incident. These timeframes are divided into two categories: (1) issues primarily defined by infrastructure and organizational mandates and (2) issues that are characterized by human behavior. Many of the interviewees felt that one of the keys to their success in reopening the port fairly quickly was their ability to improvise and establish ad hoc processes that drew on their prior relationships, their shared experiences, and their trust in one another's professional expertise. Their cooperation and collaboration enabled the port open to maritime activity in a week -- but the landside continued to be mainly inoperable. The same organizing principles/behaviors that worked on the marine portion of the port did not seem to be present in the actions of the transportation stakeholders for the terminal facilities and other intermodal portions of the supply chain.

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Executive Summary

New York Harbor was directly in the path of the most damaging part of Hurricane Sandy causing significant impact on many of the facilities of the Port of New York and New Jersey. The U.S. Coast Guard closed the entire Port to all traffic before the storm hit on October 28th. It was not fully reopened to vessel traffic until November 4th. Then, even though the waterways were open, numerous port terminals and maritime facilities did not resume their operations for several more weeks because of power failures and damages to the facilities and equipment. This study was conducted to identify lessons learned that could assist in restoring the Port and its contributions to the supply chain to service more rapidly in the future. The study used interviews of key port stakeholders to gather information, to understand events, and to identify the circumstances that led to the Port's storm-related impacts and operational recovery. The project reviewed the existing design codes for infrastructure and attempted to identify how building codes could be improved. It also examine the activities and processes that enhanced port resiliency.

There were several generalized principles that emerged from the interviews. They included:

(1) Safety of life is the prime consideration.
(2) Make plans before hand to provide leadership across organizations with strong and redundant communication systems between the leadership team and the staff.
(3) The current designs and procedures must be re-evaluated given the frequency of storms.
(4) Conduct drills and tabletop exercises.

Most of the major damage within the port was related to the inundation associated with the storm surge plus a high tide. Storms capable of having similar impacts will occur in the future. The following building code recommendations are suggested:

(1) The building codes of New York and New Jersey should be updated to include port specific sections that are uniform for the entire harbor region.
(2) Specifically the states should adopt ASCE 24 for siting of critical utility and mechanical equipment and directly reference it for flood resistant design for all port facilities.
(3) The Port Authority should add a section to their lease agreements devoted to port specific structural considerations.
(4) The facility owners in the Port of New York and New Jersey should adopt a reasonable and consistent methodology for incorporating sea level rise into their facility upgrades.

Merging resiliency principles from the literature and the descriptions by stakeholders, a simple stepwise process was formulated for enhancing port resiliency. There are activities that can take place prior to a disruption (i.e., pre-event) or they can take place following the occurrence of an incident (post-event). The two timeframes are divided into two categories: (1) issues primarily defined by infrastructure and organizational mandates and (2) those issues that are characterized by human behavior. It was evident from the interviews that many stakeholders felt that one of the keys to their success in reopening the port quickly was their ability to improvise and establish *ad hoc* processes that drew on their prior relationships, their shared experiences, and their trust in one another's professional expertise. Their collaboration enabled the port open to maritime activity in a week -- but the landside continued to be mainly inoperable. What appeared to be missing was the same organizing principles that worked on the marine portion of the port did not seem to work in congealing the actions of the transportation stakeholders for the terminal facilities and other intermodal portions of the supply chain. Clearly, the relevance of human behavior in the achievement of system resilience deserves further research.

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Preface

The University Transportation Research Center's 2013 Theme was: "Planning and Managing Regional Transportation Systems in a Changing World". One of the three thematic areas was: "Responses to Change". Climate change is clearly an ongoing changing environmental condition. The severe disruptions that the New York – New Jersey metropolitan region suffered because of the impacts of Hurricane Sandy in October 2012 illustrate that the regional and even national responses to long-term changes in the environment must be considered more thoughtfully. Moreover, it appears that climate change, and particularly sea level rise, make the recurrence of a destructive weather events in the coming decades more likely.

This research study addresses the Response to Change thematic area and specifically investigates enhancing resilience for port infrastructure and supply chain transport operations following disruption by extreme events. The primary objective of the project was to develop a set of lessons learned that specifically could enhance port resilience. The study used interviews of key port stakeholders to identify and to elaborate on the steps that were taken to coordinate freight movements through the port's waterways and terminals during this time of severe stress caused by the storm's impact, particularly on existing navigation and terminal operating infrastructure. The researchers sought to identify opportunities for building greater resilience in the marine transportation system with respect to reducing port facility vulnerabilities and improving building design codes. Lessons learned with respect to potential improvements in building design and construction codes were a primary focus of the study's assessment; however, the findings also lead to new understandings with respect to the influence of human behavior in successful resilience activities following a significant disruptive event.

"*Preparing for climate change impacts has not been a priority concern for most U.S. ports. Ports have neither the data nor the methods to plan for climate change. In addition, many ports are assuming that climate change will not affect them any time soon. But some ports will inevitably experience impacts from climate change. As such, ports and their allies need to consider appropriate actions sooner rather than later.*"

U.S. Environmental Protection Agency, 2008

Chapter 1 – Marine Freight Transport

Today's global marketplace for durable and non-durable goods fully operates, in part, because of the availability and efficiency of the marine transportation system for the movement of international freight. The system's performance depends on speed to market, reliability, and cost-effectiveness as well as near-seamless intermodal connections for freight movement by transport service providers to its ultimate destination. These service providers (i.e., waterborne carriers, rail companies, trucking firms, and air carriers) depend on public and private infrastructure to enable their successful distribution of these goods in a timely manner.

More than 90% of world trade moves between the eastern and western hemisphere by ocean carriage (IMO, 2011). This transfer of cargo is accomplished by utilizing large oceangoing vessels carrying millions of containers. Landside access is provided through ports at the origin and at the destination locations. Ports are public and private enterprises that provide both navigation infrastructure (e.g., waterways, breakwaters, berths, etc.) and terminal facilities that enable the transfer cargo to and from the waterborne vessels. Terminals are also the point of transfer of cargo to barge, rail or truck for inland transport to some final destination in the port's hinterland. This logistical system of aquatic and land-based infrastructure and service providers has been identified by the U.S. Department of Transportation as the Marine Transportation System or MTS (USDOT, 1999).

The economic impacts from disruptions in the movement of freight have been documented to be substantial (Flynn, 2008). This vulnerability has demonstrated that the viability of the U.S. economy depends, to a significant degree, on the ability of the maritime system – and in particular on its ports (GAO, 2007; GAO, 2012a; GAO, 2012b). Secure ports enable the efficient flow freight through, into, and out of the U.S. land-based domestic freight transportation system (Zegart *et al.*, 2006; Young, 2009). In 2009, U.S. foreign trade accounted for some 16 percent of global waterborne trade, indicating the considerable potential for not only costly but also far-reaching impacts from U.S. seaport closures (AAPA, 2012). Compounding the potential vulnerability of the nation's transport system to disruptions is its concentration of freight in a limited number of ports. In 2011, the top ten ports accounted for 56 percent of oceangoing vessel calls (Maritime Administration, 2013).

Today's port is no longer an isolated node but instead is an integral part of the global logistics system or, as it is more commonly known, the global supply chain (Notteboom and Rodrigue, 2010). The global supply chain is the mechanism that enables international trade and is typically a crucial component of most nations' economic security. The global supply chain is actually a network of individual supply chains that follow specific trade routes (Sauser *et al.*, 2011). Each component of the supply chain, including the ocean carriers, ports, terminals, and intermodal service providers, are equally responsible for the success of the transportation services being delivered. If that service is interrupted or not acceptable to the cargo owner/shipper, they will shift their business to another logistics system, i.e., route and thus another port (Christopher and Peck, 2004).

For example, many firms were unprepared for the labor strike that shut down the six largest container ports on the West Coast in 2002, with an estimated cost to the U.S. economy running into the billions of dollars (Farris, 2008). Cargo concentration was again a concern. The six largest West Coast container ports were responsible for more than half of all foreign containers passing through U.S. ports, at a total worth was just over $300 billion (Farris, 2008). Cargo was shifted to Gulf and East Coast ports as a result of the interruption of services. Some freight returned to the West Coast after the dispute was resolved, but other cargo flows remained diverted (Gorton *et al.*, 2005). Terrorist actions as well as natural disasters (e.g. earthquakes, hurricanes, and tsunamis) can have similarly devastating impacts to people's lives, jobs, and our economy at-large. Whether a disruption is a natural or a human-caused event, the goal is to bring the port's freight transport services back on-line and to ramp-up throughput to the prior operating level rapidly, particularly before a costly and protracted delay can occur.

To protect the nation's trade-based economic security, it is important to know how the global supply chain operates, sources of capacity or constraints in the MTS, and demands for key mobility improvements (whether public or private enterprises). It is also essential to consider the mechanisms needed for enhancing business recovery in a post-disruptive situation and identify how to organize efforts across the system to restore commerce quickly and effectively (Barnes and Oloruntoba, 2005).

Port of New York & New Jersey

The Port of New York and New Jersey has been an international port for over three hundred years. Today, the port is the principal East Coast gateway for the United States' commercial trade with Europe, Latin America the mid-East, and other locations. It is the largest automobile and refined petroleum port in the United States and is the third largest container port (PANYNJ, 2013a). An expansive transportation and distribution network that connects local marine and petroleum terminals to three major airports, multiple rail connections with two railroads, and an expansive interstate highway system facilitates cargo movement. This network puts more than 90 million people in the United States and Eastern Canada within a 24-hour delivery time of the Port (PANYNJ, 2013a). For the region, the port and its attendant businesses are a primary employer (~279,000 jobs) and source of more than $37 billion of economic activity plus $5.3 billion in tax revenue (ASW, 2011).

There are six container terminals in the port that are located in both the states of New York and New Jersey. New York terminals include Howland Hook Marine Terminal and Red Hook Container Terminal as well as the South Brooklyn Marine Terminal (a bulk terminal) on the east side. The New Jersey terminals include the Elizabeth Port Authority Marine Terminal (APM Terminal and Maher terminal), Global Container Terminal, and Port Newark Container Terminal on the west side of the harbor. These terminals handle more than 5.5 million containers per year that are distributed throughout the nation. A map of the port is presented at Figure 1.

Figure 1: Map of the Port of New York and New Jersey

(Source: http://nyctransported.com/wp-content/uploads/2011/02/container-terminals-port-ny-nj.jpg)

The port is also a critical destination for liquid bulk products including various food oils and fruit juices, chemical stocks, and fuels, particularly petroleum products. The US Energy Information Administration states, “New York Harbor is the largest petroleum products hub in the Northeast, with bulk storage capacity exceeding 75 million barrels. Petroleum products delivered to the harbor are redistributed by truck or barge to smaller ports upstate along the Hudson River, and to Long Island, Connecticut, Rhode Island, and Massachusetts” (USEIA, 2013).” Tankers carrying crude oil from St. Johns, Nova Scotia or the West coast of Africa are almost a daily presence in the harbor (Walsh, 2011). The Bayway refinery, located on the harbor’s edge in Linden, New Jersey, is one of the largest on the East Coast and its production levels directly impact fuel prices in the region. Disruptions of marine deliveries of petroleum, crude and refined products, to these facilities can cause significant household hardship because of the region’s demand for home heating oil during the winter months and auto and jet plane fuels year round.

Port Disruptions

It is not just liquid bulk product deliveries that can cause problems if there is a disruption in the MTS activities. Because of the enormous number of containers that a single post-Panamax ship discharges during a port call, the Port requires an expansive network of waterway and landside infrastructure. Disruptions to waterways and landside infrastructure not only threaten the continuity of operations on the MTS but also have an adverse ripple effect throughout the U.S. economy (USCG, 2006; Pate *et al*., 2007; Park *et al*., 2008: Rice, 2009).

Today's streamlined supply-chain has strong links to providers, suppliers, and customers that minimized inefficiencies but simultaneously increased vulnerability (Park, 2008). The challenge is to reduce the risk of disruption and plan for an orderly recovery. Disruptions may be local, such as waterway closures resulting from a lock outage, or may be regional, such as the shutdown of East Coast or Gulf Coast ports from a significant weather event, like Hurricane Sandy (Rowan *et al*., 2012). Impacts from these disruptions can have national ramifications because the MTS is a critical component in the national supply chain (CMTS, 2011). The freight transport system must have the capability to respond quickly to disruptions of varying scales in order to return to normal operations (Lambert, 2001).

Chapter 2 – Hurricane Sandy

Hurricane Sandy developed as a tropical wave off the west coast of Africa on October 11, 2012 (Blake *et al.*, 2013). The system entered the eastern Caribbean Sea early on October 18th and by the 24th had become a hurricane with a well-developed eye centered 90 miles south of Kingston, Jamaica. As Sandy journeyed northward along the southeastern U.S. coastline, it intensified. It reached a secondary peak intensity of 97 mph before it swung towards the Mid-Atlantic States. Before making landfall near Brigantine, New Jersey, on the October 29th, Sandy weakened to a post-tropical cyclone with 80 mph maximum sustained winds (NOAA, 2013). However in the process Sandy increased in size tremendously, driving catastrophic storm surge and waves into the coasts of New Jersey and New York. An example of wave height is presented in Figure 2.

Figure 2: Waves during the height of Sandy

Sandy's storm surge and powerful waves devastated large portions of the coastlines. In fact, the extent of catastrophic damage along the New Jersey coast was unprecedented in the state's history, with the brunt of it occurring in Monmouth and Ocean Counties. About 5 million residences lost electrical power across this region, with power outages commonly lasting for several weeks. Approximately 345,000 housing units were damaged or destroyed in that state, with about 20,000 of those units uninhabitable, principally along the shoreline. The storm surge also pushed water into New York Bay and up the Hudson River, resulting in unprecedented urban flooding in Jersey City and Hoboken, New Jersey.

The highest storm surges and greatest inundation on land occurred in the states of New Jersey, New York, and Connecticut, especially in and around the New York City metropolitan area. In many of these locations, especially along the coast of central and northern New Jersey, Staten Island, and southward-facing shores of Long Island, the surge was accompanied by powerful damaging waves. Further, the surge was enhanced by low barometric pressure and the occurrence simultaneously of a high tide. On Monday afternoon (Oct. 29), the lowest barometric reading for an Atlantic storm that made landfall north of Cape Hatteras, N.C. was recorded (Sharp, 2012). Additionally, a full moon made the high tide 20 percent higher than normal and amplified Sandy's storm surge. This perfect storm caused flooding in normally dry areas of the port. Water was from 2 to 9 feet above ground level with waves on top of the standing water of 2 to 3 feet in some locations (Blake, 2013).

The National Weather Service determined that wave heights at two buoys were the highest recorded. At buoy 44025, located 35 miles south of Islip, Long Island wave heights built during the evening of Oct. 29 to a maximum significant wave height of 31.6 feet (9.65 meters) exceeding the previous recorded of 30.5 feet (9.3 meters) set during the December 1992 Nor'easter. The harbor entrance buoy reached a record wave height of 32.3 feet (9.86 meters) on October 30, exceeding the previous high recorded during Hurricane Irene by over 6 feet (26 feet or 7.95 meters). The tide gauges at the Battery (in Manhattan) and at Bergen Point West Reach (on Staten Island) recorded storm tide values of 9.0 feet and 9.53 feet above Mean Higher High Water (MHHW), respectively. In New Jersey, the highest storm surge measured by a tide gauge was 8.57 feet above normal tide levels at the northern end of Sandy Hook. The station failed during the storm and stopped recording prior to the peak; therefore, it is likely that the actual storm surge was even higher.

The New York Harbor was directly in the path of the most damaging part of the storm. There was a significant impact on many of the facilities of the Port of New York and New Jersey, particularly the facilities in the Arthur Kill (Figure 3) and Newark Bay (Figure 4). In fact, many of the port's facilities were severely damaged or even destroyed. The U.S. Coast Guard Captain of the Port closed the entire Port to all traffic before the storm on October 28th. It was not fully reopened to vessel traffic until November 4th. However, numerous port facilities, including container and oil terminals, did not resume full operations once waterways were open due to facility damage and lack of power.

Figure 3: Flooded New York Container Terminal

Figure 4: Blown over empty containers

The Storm's Impact

It cost the economy billions of dollars for the entire port to be closed for a week (Smith and Katz, 2013). Damages included impacts to terminal facility infrastructure, flooding of thousands of new cars, ruined yard equipment, closed channels, debris on roads and terminals, loss of power for equipment and road signals, berth damage, lost of Customs and Border Protection's radiological equipment, and damage to on-dock rail facilities. Even the Incident Command Center, where the agencies planned to conduct their recovery operations following the storm, was flooded (Python, 2013).

When the port was impacted, the regional supply chain was also disrupted. Unfortunately, this was the period when goods were arriving for the holiday season sales. As the storm approached and the port was closed, the import and export supply chains were broken and cargo stopped moving. The port, of course, is only one element in the supply chain. Not only do ships have to be able to land and pick-up cargo, but the intermodal connectors (i.e., trucks and trains) must be able to move cargo to the port and out of the port for cargo to reach its destination. If there is a break in the supply chain, cargo will be diverted to other ports so that freight can be discharged and sent on to its inland destination. During the period that the port was closed, containers that were bound for New York were diverted to both the Port of Halifax, Canada, and to the Port of Virginia, Norfolk. Containers were then trucked to their final destination including up to New York.

Following Hurricane Sandy, the Port needed several days to achieve a partial recover and a week to reopen for maritime commerce. The U.S. Coast Guard, U.S. Army Corps of Engineers, the Sandy Hook Pilots and others were quickly out on the water to survey the damage and were working to re-open the Port. Activities included the conduct of waterway surveys to ensure navigational aids were on station, locating and removing marine debris such as portions of buildings, locating floating shipping containers and making sure that the channels were cleared, and that shoaling had not created navigational hazards. In addition, there were two minor and a major oil spill in the Arthur Kill that demanded immediate clean-up to prevent the spread of oil in the estuary.

The Port remained closed from October 28th until November 4th, a full week later. There was a partial reopening beginning on November 1st for some ship traffic, but the supply chain remained off-line because of storm damage. Numerous facilities, including container and oil terminals, did not resume their normal operations for weeks. It is important to note that just because the waterways were open did not mean that things returned to normal. The regional freight platform concentrated at the port and its supporting transportation system responsible for delivering goods and fuel to the Northeast remained crippled due to a lack of electric power, facility damage, and limited intermodal capacity. However without an operating port, the rest of the facilities in the MTS supply chain are nearly irrelevant.

Seeking Lessons Learned

This study was conducted to identify lessons learned by the public and private stakeholders in the Port that could assist in more quickly returning the Port of New York and New Jersey as well as other ports to full service following future disruptions, like that caused by Hurricane Sandy. No two ports are the same nor are any two storms the same, but identifying areas of risk and establishing engineering standards for common port facility design may avoid structural failures in similar circumstances.

Hence, the objective of this project was to develop a set of lessons learned that specifically could enhance port resilience. The study used interviews of key port stakeholders to identify and elaborate on the steps that were taken to coordinate freight movements through the port's waterways and terminals during this time of severe stress caused by impact of the storm, particularly on existing navigation and terminal operating infrastructure. Lessons learned with respect to potential improvements in building design and construction codes were a primary focus of the study's evaluation. Resilience of port infrastructure would be enhanced if facility structural failures could be avoided in future storms.

Although the study focused on damage to port infrastructure and facilities, the supporting modes of transport were also considered (i.e., the highway, rail and waterway routes leading into and out of the port). The interviews were used to determine what activities took place that enhanced the recovery of port function after the event and what might have been done to accelerate port recovery. The catch-all term used for such efforts is port resilience – the ability of a seaport to withstand and bounce back from a serious threat to its ability to process freight in an efficient and cost-effective manner (Rice, 2009).

Chapter 3 – Resilience

"We must enhance our resilience -- which is the ability to adapt to changing conditions and prepare for, withstand, and rapidly recover from disruption." (Senior DHS Official, 2009)

The definition of "resilience" has been much discussed in multiple contexts (Mansouri *et al.*, 2010; Gallopi'n, 2006; Sheffi, 2005). At the website *Dictionary.com* the term "resilience" is defined as: 1) the power or ability to return to the original form, position, etc., after being bent, compressed, or stretched, and 2) ability to recover readily from illness, depression, adversity, or the like (http://dictionary.reference.com/browse/resilience). Resilience in the transportation sector is a more complex issue because of the diverse ownership of assets and infrastructure – a mix of private, public, and foreign owners. This ownership issue is further complicated by the fact that system capacity is a function of many factors beyond the marine conveyances and terminals.

Nevertheless, it is paramount that an attempt to add resiliency where practical is undertaken so that the broader economy can regain its commercial transaction volumes as quickly as possible after interruptions or disruptions (Kruse and Protopapas, 2011; Robinson 2006). In the more limited port security area, the definition is focused to mean the ability of a port to return to its normal mode of operation after a disruption caused by a natural or human-initiated incident (Air et al., 2010; Barnes and Oloruntoba, 2009; AAPA, 2009). For the purpose of this study, a working definition of resilience is applied. Resilience is the capability of a port to provide and maintain an acceptable level of service in the face of major environmental changes or disruptions.

Increasing Port Resilience

How resilient a port is depends on a many different factors (Hultin *et al*., 2004; Handmer *et al*., 2013; Kong *et al*., 2013). From a purely physical processing standpoint this means ensuring that freight gets into, is suitably processed by, and get out of the port as expeditiously as possible (Chopra and Sodhi, 2004). Given the considerable expense of providing redundant cargo handling capacity, a key to effective disruption response and subsequent recovery is to identify the primary steps in the cargo moving, manifesting and storage processes involved, who is in charge of each processing step, who/which agencies need to be kept informed of progress, and who will have a decision-making role in changing operating rules and procedures when a disruption event occurs (Lane, 2009). This involves tracking of both the physical cargo from intermodal transfer, through storage and shipboard loading/unloading, and its associated administrative processes, includes both immediate responses to a disruptive incident, and a more protracted series of responses to port asset reallocations.

Most of the literature on port disruption effects is focused on economic impacts (ERD Group, 2012; CBO, 2006; Gordon *et al*, 2005; Hall, 2004; Rice and Caniato, 2003). This project moves the major point of interest to the physical impacts on facilities and the corresponding design codes for those facilities as associated with port supply chain disruptions. This discussion appears only sporadically in the literature (FEMA, 1996; FEMA, 2012).

Research Questions

This project reviewed the existing design codes for infrastructure and attempted to identify how building codes could be improved to mitigate failures. It identified lessons learned through stakeholder interviews regarding the circumstances that led to the port's closure. Lessons learned from the stakeholders were listed, and a tabulation of these findings and recommended approaches to mitigate these problems were made (i.e., guidelines that in some cases suggested additions to existing building codes). The overriding goal of the research was to make the New York and New Jersey port facilities and associated supply chain transportation operations more resilient in the future.

Admittedly, there are many other outstanding questions regarding port residence that could be asked including how currently evolving port security protocols impact resilience and recovery efforts (Hector, 2002). In considering port shutdown costs and associated security measures, Leamer and Thornberg (2006) suggest that labor issues are likely to be more limiting than physical limitations for some incidents such as terrorist attacks and that " the true limitation is the unwillingness of labor to work under potentially hazardous conditions". Moving from human factors to engineering practice raises other types of questions such as the utility of federal and state agency policy, plans and projects to adapting to climate change (Dalton *et al*., 2012). There are numerous additional questions that can be asked about port resilience challenges.

Questions are be formulated to address important issues that are difficult to predict in pre-event contexts, such as unique operational issues. For example, for freight transport operations to be restored, the debris on terminals and in waterways post-event must be removed and disposed of prior to these areas cleared for use (Kirby, 2008). These questions have been asked during past disruptions and need to be collected, analyzed, and responses formulated into useful guidelines (McEvoy *et al*., 2013; Chhhetri *et al*., 2013; Scott *et al*., 2013).

For this project, the pre-selected research questions were limited to a few civil engineering building and code issues:

- *Are the current design codes for coastal structures, particularly the kinds of structures found in commercial ports, adequate for current environmental conditions?*
- *Are these codes satisfactory for anticipated environmental conditions with anticipated climate change and sea level rise?*

Additional foundational questions about the port resiliency and recovery processes arose during the interview and analysis processes. Some of these questions are raised and addressed in the later portions of this document. However there are many questions that are beyond the scope of this study and will remain for study in the future.

Chapter 4 – Stakeholder Interviews

The researchers utilized informal stakeholder interviews to gather information, to understand events, and to identify the circumstances that led to the port's storm-related impacts. Particularly interesting to the researchers were any storm impacts that were related to existing design and building codes.

Interview Process

The interview methodology began with selecting overarching questions for the survey. It was decided to keep the questions limited to a few and to keep them simple. The three selected questions were:

- What was the big issue or issues?
- Were there any surprises?
- What were three lessons learned?

Next step was the selection of approximately ten organizations that are central to port activities, to determine the best order to approach each, to make contact with each, and seeking an appointment for an interview with the appropriate person or persons. Regarding identifying the key organizations and players in the Port of New York and New Jersey, it was relatively well known that much of the routine port planning and operational decision-making in the Harbor is strongly influenced by two port-wide standing committees: the Harbor Safety, Navigation and Operations Committee ("Harbor Ops") and the Area Maritime Security Committee (AMSC). Many of the participants sit on both of these two groups, making them key stakeholders in the port. During and after Sandy, a small body of partners worked together through the Marine Transportation System Recovery Unit (MTSRU), which shares leadership between the U.S. Coast Guard (USCG) and the Sandy Hook Pilots. The MTSRU is based out of a subcommittee of the AMSC. The function of the MTSRU is to facilitate the reopening of the Port and the resumption of maritime commerce in the aftermath of a disaster. The researchers assumed that they would be major players in the response and recovery processes and were identified as desirable interviewees.

Eight organizations were interviewed for approximately 2 hours each. All face-to-face interviews were conducted between January and June 2013. In September 2013, a telephone interview with a representative of the U.S. Army Corps of Engineers (USACE) was conducted; also a written response to the interview questions from a second USACE representative was received in late September 2013. The organizational participants include two federal agencies (United States Coast Guard and U.S. Army Corps of Engineers), two state agencies (the Port Authority of New York and New Jersey and New Jersey Department of Homeland Security and Preparedness), a private sector service provider (the Sandy Hook Pilots), an industrial association (New Jersey Petroleum Council) and a private facility operator (Union Dry Dock, Incorporated). Details on the names and locations of each of these participants are presented at Appendix A. Additional interviews were sought with other port stakeholders but were not able to be arranged during the study period.

Finally, the responses from the agency and industry stakeholders that were interviewed for each of the questions were summarized by the researchers for comparison and evaluation. Lessons learned were analyzed to identify vulnerabilities and resiliency gaps.

Principal Findings

The following section presents a synthesis of responses to interview questions. It is not possible in this report to characterize all the impacts that were described much less all that occurred as a result of the storm – there were too many. This section is meant to capture the major issues that were discussed and give an overview of the principal suggestions presented during the stakeholder interviews so that the broader lessons learned can be extracted.

- <u>What were the BIG issues?</u>

The storm surge was the big issue. With a hurricane you might expect a wind event with some flooding. Instead we had a major flooding event with some wind damage. In fact, this issue was so significant particularly from the perspective of the problems potentially faced by ports from sea level rise, and particularly coastal flooding, that a Stevens Institute of Technology Master of Science student examined the problem and proposed guidelines for the New York-New Jersey port complex (Python, 2013). The other big issue was debris, which was a problem during the storm as objects slammed into fixed facilities and equipment. It was also a problem following the storm with respect to road and rail access and clean-up of the terminal areas.

Consider for impact mitigation: Build on-shore berms, sand dunes, breakwaters and other barriers to block water and debris movement and prevent debris deposition after flood water recedes with fencing, walls, etc.

The general flooding problem with 2 to 3 feet of water everywhere caused immediate shutdown of administrative activities for all the operations.

Consider for impact mitigation: Move all administrative activities off the ground floor to second floor or higher or, if vans were made available at preposition locations, business activities can begun more rapidly at these off-site locations.

- <u>What were the Surprises?</u>

1. The terminal operators have replaced their diesel motors with electric motors to run the container cranes because of air emission concerns. The motors are mounted near the wheels to move the cranes – about 4 feet off the ground. The motors flooded with saltwater, making them inoperable, and costing about $160,000 a piece to repair.

Consider for impact mitigation: Design the motor housing to protect the motor and to resist saltwater intrusion.

2. Electric power failed with the surge and remained out for 6 days. There were no traffic signals (17 intersections), overhead lighting for night operations, or equipment running that did

not have a generator connection. Without power the Nuclear Detection Portals at terminal gates could not operate. Hence trucks could not return to the terminals with containers nor could they remove containers from the terminals.

There was another power problem. Generators were being used to feed back into the grid, which cause the grid to keep being shutdown. As the utility brought the power grid back on-line, the circuit break would pop. There needs to be a mechanism to remove the generators from the grid as power is restored.

Consider for impact mitigation: Work with utility to minimize power failures and harden generators locations, electrical vaults, and other components to avoid flooding.

3. There was a public health problem.   The sewage lift stations flooded and sewage was distributed out of the facilities into public and terminal areas. The sewage had to be removed/cleaned-up prior to allowing people back onto the port. The surge also flooded the fire station causing failure of the control equipment and the pumping equipment (the pump station is necessary to raise the water pressure from 40 to 70 pounds to be able to fight fires in the port.

Consider for impact mitigation: Work with utility to protect water and wastewater systems from future inundation by flooding events.

4. Approximately 16,000 vehicles (principally recently imported cars) were flooded because there was no where to move them. When the cruise line returned to Bayonne after the storm to discharge passengers, the passengers found that their private autos had all been flooded and were no longer suitable for travel.

Consider for impact mitigation: Construct a vertical parking garage to house the cars.

Generalized Lessons Learned

- *Safety of life is the prime consideration*. Thankfully, no lives were lost in the port during Sandy. Communications with decision-makers is critical. Need simple descriptions of what to expect including maps and simple drawings showing where flooding is expected and risks may emerge. These should be accompanied with explanations of the risk areas in simple terms so the decision-maker understands the priorities for re-locating assets and operations as well as shutting down equipment and utility systems to protect lives.

- *Have a designated person responsible for providing recovery before the disaster*. Make plans before hand to provide leadership across the organization and to have communications between the leadership team and staff. Recognize that local staff will be concern with their family and homes during and immediately after a disaster like Sandy. Staff should be supplemented with professionals from an outside firm (with no family worries in the stricken zone) that bring generators, stage supplies, provide temporary offices through their expertise that is knowledgeable about the potential impacts of the particular extreme event. Recovery is not only about recovering the infrastructure and other assets but also about restoring utility and other services to allow a return to some kind of normalcy.

- *Look at current designs and procedures going forward.* Clearly the number and severity of disasters have increased in recent years whether floods, blizzards, tornadoes, wildfires, heat waves, earthquakes, tsunamis, hurricanes and other natural or terrorist-caused events. These disasters can cause peoples' deaths, destroy property, disrupt transportation, interrupt economic activity, and cause social and political crisis locally, regionally and nationally. We must be more proactive to prepare for future extreme events.

- *Protect property and operations:* We can do what we already know is protective (by raising buildings, moving electrical systems up out of the flood zone, have staff operations on the first floor be mobile so it can move to higher levels if needed). We need to implement new building codes and standards that give greater protection from anticipated system failures, particularly in the life-line sectors.

- *Conduct drills and tabletop exercises:* We need to conduct exercises to practice our predetermined course of action in an emergency and to identify problems or challenges before the disaster strikes. These activities should be held at least annually to re-enforce our corporate procedures and cross-organization coordination, i.e., to plan > to train > to respond > to recover.

Impact on Port Components

A table of the facility failures discussed during the interviews for waterway, terminals and intermodal connectors was organized and recommended approaches to mitigate storm-related problems is presented. The consolidated comments are presented at Table 1.

Table 1: Chief Areas of Concern, Impacts and Mitigation

Area of Concern	Impacts on Port Elements	Post-Sandy Mitigation
Waterways	1. groundings & collisions from channel obstructions (debris, containers, shoals) 2. lack of or out of position channel markers 3. oil spills in water	1. Inspections by Pilots and NOAA and USACE hydrographic surveys 2. Buoy tender activities by USCG 3. USCG clean-up efforts
Terminals	1. lack of power (no stop lights or on port power) 2. public health and safety issues because of sewage overflows and debris scattered over port terminals 3. facilities damage because of saltwater inundation & debris	1. individuals used generators until fuel supplies ran out 2/3. clean-up efforts were limited to day-light hours
Intermodal Connectors	1. lack of fuel and/or power 2. road closures from flooding or debris on road or tracks 3. police barriers for public health and safety reasons	1. dependent on utilities to restore services 2. coordinate with highway departments to clear key roads

Chapter 5 – Port Design Codes

Structural Issues

Overall, Sandy had a relatively minor impact on the waterside structures such as piers and wharves within the Port of New York and New Jersey. Most of these waterside port structures are designed for loads well in excess of those imposed by storms such as Sandy. Piers and wharves in large ports such as the Port of New York and New Jersey are typically designed to withstand horizontal impact loads from fully loaded ships and vertical loads associated with containers and cargo handling equipment.

While most of the waterside structures made it through the storm unscathed, there were many instances of wave and surge related damage to ancillary structures, equipment, and cargo throughout the port. Most of the major damage within the port itself was related to the inundation associated with the 6-8 feet storm surge. Unfortunately the storm surge coincided with a spring high tide, which ultimately led to water levels of up to 12.5 ft above the North American Vertical Datum of 1988 (NAVD88) in Newark Bay and Upper New York Bay adjacent to Port Newark, Port Elizabeth and the Global Marine Terminal. While these water levels were unprecedented in the historical record, they are similar to the 100 year Base Flood Elevations recently redefined by Federal Emergency Management Agency (FEMA). FEMA is reviewing their flood maps, which depict the areas that are at risk of flooding, because they may be too conservative given recent extreme storm events. FEMA's flood maps for the Global Marine Terminal and the Port Newark areas are shown at Figures 5 and 6.

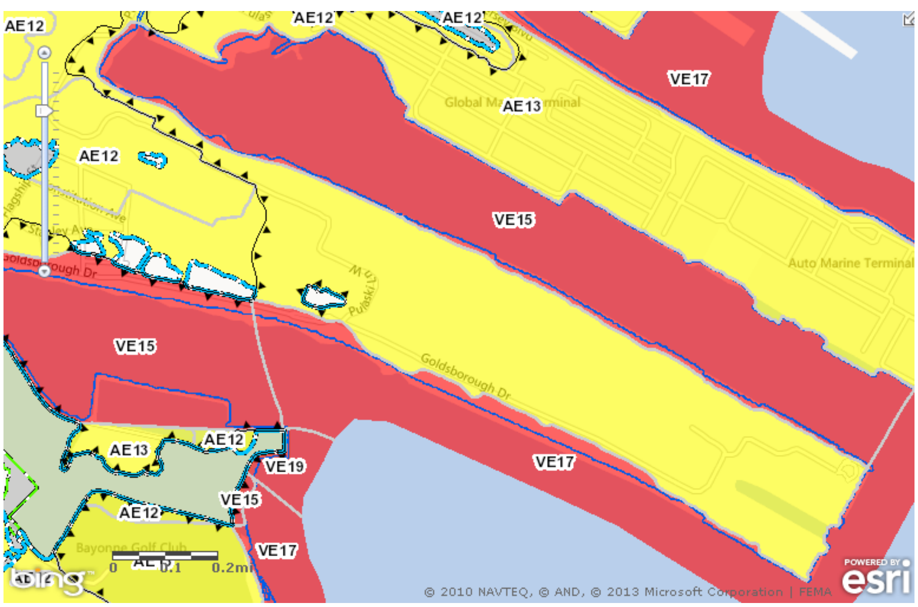

Figure 5: Existing flood map for Global Marine Terminal

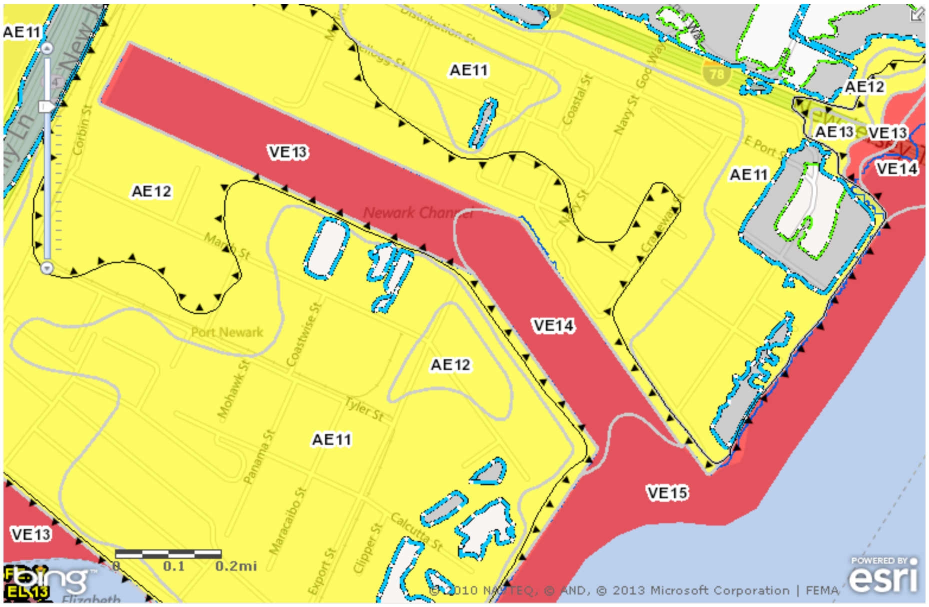

Figure 6: Existing flood map for Port Newark

Inundation of the port facilities ranged from nuisance flooding of several inches to damaging fast moving flood waters and waves on the order of several feet. Flood damage within the port itself was similar to that observed throughout the region. The combination of unprecedented water levels, a lack of knowledge about critical facility elevations, and to some extent, a false sense of security created by storms that failed to live up to expectations (e.g., 2011 Hurricane Irene), all contributed to the extensive flood damage within the ports during Sandy. Examples of the facility damages experienced in and around the port during Superstorm Sandy are presented in Figures 7 through 10**.**

Figure 7: Revetment damaged during Sandy

Figure 8: Wall damaged by waves and surge during Sandy

Figure 9: Piers damaged by uplift forces during Sandy

Figure 10: Inundation damage typical during Sandy

Existing Building Codes

While overall the major facilities of the Port of New York and New Jersey fared well during Sandy, a review of the existing building codes and guidelines was performed to identify any shortcomings, which could be addressed to enhance the resilience of the port to future storms. Since the Port of New York and New Jersey is shared between New York and New Jersey, the building codes used by both states were reviewed. In addition, New York City has a separate building code which applies to facilities constructed within New York City proper. In reviewing the building codes it became obvious that the existing codes provide little guidance for specialized structures, such as those found in a port facility.

New York and New Jersey are not alone in this oversight; a search for port specific sections in other state's building codes only identified a handful of existing code guidance. Most states adopt some version of the International Building Code, with amendments used to address specific local circumstances (most do not include amendments related to ports). Appendix G of the International Building Code generally addresses flood resistant design and construction and refers readers to ASCE 24 *Flood Resistant Design and Construction*. The following states were found to have port, pier, or wharf specific guidance in their building codes.

- **North Carolina:** North Carolina's building code contains a chapter on "Piers, Bulkheads, and Waterway Structures"; however the code specifically exempts "marine terminal or port facilities for berthing, mooring, docking, or servicing ships barges or tug boats that handle cargo of all types including bulks, liquids, fuels, and passengers." (http://ecodes.biz/ecodes_support/free_resources/ 2012NorthCarolina/Building/ 12NC_Building.html)

- **California**: California's building code contains a special section on "Marine Oil Terminals" which contains detailed specifications for the engineering, maintenance, and inspection of marine oil terminals. While intended for application to "facilities handling petroleum, liquid hydrocarbons, or petroleum products or any fractions or residues thereof" within the State of California, the completeness of the code has resulted in its more widespread adoption particularly for critical facilities. (http://www.slc.ca.gov/division_pages /mfd/motems/ motems_home_page.html)

- **Texas**: A single reference to piers and wharves is made in the section on seismic loading where it is stated that piers and wharves are to be treated like any other structure. (http://ia700306.us.archive.org/23/items/gov.tx.building/tx_building.pdf)

PANYNJ Guidelines

While it is somewhat disconcerting that none of the local building codes specifically addresses port facilities, the Port Authority of New York and New Jersey (PANYNJ, i.e., the bi-state agency responsible for operating and maintaining the port of New York and New Jersey) is one of several governmental agencies in New York and New Jersey granted an exemption from local building and fire codes. In spite of this exemption, the Port Authority has taken the public stance that its goal is to "meet(s) and, where appropriate, exceed(s) accepted local building and fire code standards with respect to construction, alteration and renovation to any building, structure and space at all Port Authority facilities". (http://www.panynj.gov/about/code-conformance.html)

The Port Authority generally enters into agreements with municipalities in which its facilities are located to ensure code conformance. In particular, all facilities within New York City are to comply with the New York City Building Code (NYCBC) (http://ia700801.us.archive.org/12/items/gov.law.nyc.building.2008/nyc. building.2008.pdf) and all structures and facilities within New York State must comply with the New York State Uniform Fire Prevention and Building Code (http://publicecodes.cyberregs.com/ st/ny/st/b200v10/index.htm). In New Jersey, the applicable standard is the New Jersey Uniform Construction Code (NJUCC) (http://www.state.nj.us/dca/ divisions/codes/codreg/ucc.html). Each of these local codes references recognized national standards that are discussed below. In addition to these codes, the Port Authority publishes its own Tenant Construction Review Manual (TCRM), which provides supplementary guidance and in some cases is more restrictive than the local codes (PANYNJ, 2013b).

Local Codes and Guidelines

The relevant sections of the New Jersey, New York State, and New York City building codes and the Port Authority's TCRM are discussed below.

- ***NYCBC***

The New York City Construction Codes consist of the 2008 Building Code, Plumbing Code, Mechanical Code, Fuel and Gas Code, Electrical Code and the NYC Energy Conservation Code (New York City, 2008). The majority of the codes relevant to storm resistant construction are contained in the 2008 Building Code and administrative provision 28-104.9.4, which mandates compliance with special flood hazard area requirements when the proposed construction is within a special flood hazard area. The 2008 Building Code is summarized below. Flood/wave resistant design is not addressed in the main body of the code, outside of Chapter 16 which simply refers the reader to Appendix G. Appendix G contains local modifications and interpretations of the standard National Flood Insurance Program (NFIP) flood resistant design methodology. American Society of Civil Engineers (ASCE) design standards for flood resistant construction (ASCE 24-05) and design load determination (ASCE 7-02) are referenced in several locations. Neither of those ASCE documents specifically addresses port facilities.

Table 2: Flood/Wave Resistant Design Sections of the NYCBC (2008)

Section	Topic
Chapter 16 STRUCTURAL DESIGN	
BC 1612	Flood Loads
Appendix G FLOOD RESISTANT CONSTRUCTION	
BCG104	Permits
BCG107	Variances
BCG304	Post-Firm Construction and Substantial Improvements
BCG308	Other Development
BCG402	Standards
BCG501	Modifications

- ***New York State Uniform Fire Prevention and Building Code***

The New York State Uniform Fire Prevention and Building Code contains three chapters with references to flood and/or wave loads. Chapter 8 deals with materials and refers readers to section 16. Likewise Chapter 18 dealing with soils and foundations also refers back to Chapter 16. Chapter 16 Structural Design details the loads to be used for specific conditions. Section 1612 is specific to flood loads and references the aforementioned ASCE technical standards 7 and 24.

Table 3: Flood/Wave resistant design sections of the NY State Building Code (2010)

Section	Topic
Chapter 8 INTERIOR FINISHES	
801.1.3	Applicability
Chapter 16 STRUCTURAL DESIGN	
1612	Flood Loads
Chapter 18 SOILS AND FOUNDATIONS	
1801	General

- ***NJUCC***

The International Building Code (IBC2009) forms the basis of the New Jersey State building sub-code, subject to the amendments laid out in NJCA 5:23-3.14 (New Jersey Consumer Affairs, 2013). The administrative code contains three specific amendments that contain references to wave/flood impacts but only one with a potentially significant impact to port facilities (IBC, 2012). Specifically, 3.14(b).27.i deletes several appendices in their entirety, including Appendix G, “Flood Resistant Design and Construction”. IBC2009 identifies the purpose of Appendix G as:

“to promote the public health, safety and general welfare and to minimize public and private losses due to flood conditions in specific flood hazard areas through the establishment of comprehensive regulations for management of flood hazard areas designed to:
1. Prevent unnecessary disruption of commerce, access and public service during times of flooding;
2. Manage the alteration of natural flood plains, stream channels and shorelines;
3. Manage filling, grading, dredging and other development which may increase flood damage or erosion potential;
4. Prevent or regulate the construction of flood barriers which will divert floodwaters or which can increase flood hazards; and
5. Contribute to improved construction techniques in the flood plain.”

IBC2009 contains several sections with potential relevance to ports and associated facilities, although no specific port design guidance is provided.

Table 4: Flood/Wave resistant design sections of the IBC (2009)

Section	Topic
Chapter 14 FLOOD WALLS	
1403.6	Flood resistance for high velocity wave action areas
Chapter 16 STRUCTURAL DESIGN	
1603.1.6	Flood design data.
1612.4	Design and construction.
1612.5	Flood hazard documentation.
1612.2	Flood Loads
Chapter 18 SOILS AND FOUNDATIONS	
1803.4	Grading and fill in flood hazard areas
APPENDIX G FLOOD-RESISTANT CONSTRUCTION (Excluded from NJUCC by NJAC 5:23-3.14)	
G103.7	Alterations in coastal areas.
G105.6	Considerations.
G301.2	Subdivision requirements.
G401.2	Flood hazard areas subject to high velocity wave action.
G601.1	Placement prohibited.

- ***TCRM***

The PANYNJ's Tenant Construction Review Manual (TCRM) lays out the technical criteria to be followed by tenants and their architects and engineers for projects to be undertaken at Port Authority facilities (PANYNJ, 2013b). The requirements discussed in the TRCM are in addition to local building codes and any requirements contained in the tenant's lease. Very few references are made to port specific construction requirements.

In Section 8 "Civil Engineering" specific requirements are given for storm and sanitary sewers in port facilities; however the guidance only addresses the loads imposed by containers and cargo handling equipment. Section 8 also provides port specific guidance on the citing of exterior water distribution systems. In Section 9 "Electrical", flood/wave protection is indirectly given as guidance. These requirements are summarized in the Table 5 below.

Table 5: Tenant Construction Review Manual

Section	Topic
Section 8 CIVIL - II Port Authority Design Criteria Standards	
C	Storm Sewer - Port/Commerce Facilities
ATTATCHMENT C3	
62.01	Ports-Marine Terminal Pavement Sections
ATTATCHMENT C3	
3.2	Elements of Design for Container Terminal & Intermodal Yards
3.6	Level of Protection (Return Period)
ATTATCHMENT C3	
BC 1704.9	Pier Foundations
1RCNY 1026-01	Flood Hazard Mitigation

National Guidelines

As discussed above, the applicable or potentially applicable building codes leave much to be desired in terms of the way in which they address, or fail to address, storm resistant port facility design and construction. There are several comprehensive guides that exist that specifically address flood/wave resistant construction, and several that are specifically focused on coastal and or port structures. These guides provide information well beyond that typically contained in local building codes and are in some cases cited by the building codes. A brief summary of some of the guides that are most relevant to port facilities is presented below.

- ***ASCE 24***

The American Society of Civil Engineers' ASCE 24, *Flood Resistant Design and Construction*, is a standard referenced in the International Building Code that was developed specifically for structures built within flood hazard areas (ASCE, 2005). ASCE 24 provides additional information and specificity beyond the minimum requirements laid out in the National Flood Insurance Program. ASCE 24 defines the requirements on the basis of the type of structure under consideration. Ports and most port structures would generally fall under "Category 2" which is the generic building category for all structures not falling into one of the other categories; however an argument could be made that ports and port structures are "essential facilities" and thus fall into Category IV which has more rigorous design standards. Some of the more relevant information for ports and port facilities contained in ASCE 24 are presented in the following list.

- Freeboard (elevation above the base flood elevation) requirements are based upon structure classification and flood zone type. Most port facilities lie in an A-zone. Accordingly the recommended freeboard ranges from 0 ft for temporary/storage facilities, to 1 ft for Category II structures, to 2-3 ft for Category 4 facilities.
- ASCE 7 "Minimum Design Loads for Buildings and Other Structures" is referenced for the calculation of flood loading.
- Specifications are provided for pile design, foundation design, and fill placement.
- Specifications are provided for the use of flood-resistant materials.
- Specifications are provided for the siting of critical utilities and mechanical equipment.

- ***ASCE 7***

ASCE 7, *Minimum Design Loads for Buildings and Other Structures*, provides detailed engineering requirements for dead, live, soil, flood, wind, snow, rain, ice, and earthquake loads, and their combinations (ASCE, 2002; ASCE, 2010). ASCE 7 is referenced by most building codes in the United States and is even utilized internationally. The structural loading requirements provided by the standard are intended for use by architects, structural, engineers, and those engaged in preparing and administering, local building codes. ASCE 7 does not address port facilities specifically (outside of seismic design); however the wave and flood loading provisions may be applied to the design of ancillary structures. Sections potentially relevant to port construction are identified in the table below. In the 2002 edition of ASCE 7, readers are referred to NAVFAC R-939, NAVFAC OM-25.1 (superseded by UFC 4-152-01), and NAVFAC P-355 (superseded by UFC 3-310-04) for a more complete treatment of piers and wharves.

Table 6: Summary of Relevant Sections of ASCE 7

Section	Topic
Chapter 2 COMBINATIONS OF LOADS	
2.3.3	Load Combinations Including Flood Load
2.4.2	Load Combinations Including Flood Load
Chapter 5 FLOOD LOADS	
5.3.1	Design Loads
5.3.2	Erosion and Scour
5.3.3	Loads on Breakaway Walls
5.4.1	Load basis
5.4.2	Hydrostatic Loads
5.4.3	Hydrodynamic Loads
5.4.4	Wave Loads
5.4.5	Impact Loads

Chapter 15 SEISMIC DESIGN REQUIREMENTS	
15.5.6	Piers and Wharves
C2 COMMENTARY COMBINATIONS OF LOADS	
C2.3.3	Load Combinations Including Flood Load
C2.4.2	Load Combinations Including Flood Load
C5 COMMENTARY FLOOD LOADS	
1612	Flood Loads

- ***Naval Facilities Engineering Command (NAVFAC) Design Manuals***

NAVFAC is the United States Navy's engineering command responsible for building and maintaining the Navy's facilities. There are a series of NAVFAC design guides that while focused on the construction of military harbors, contain information transferable to the design of commercial port facilities. A summary of the current NAVFAC military handbooks, design manuals and maintenance and operations manuals is provided in *NAVFAC Engineering Criteria*. Most of the NAVFAC design manuals refer to sections of the U.S. Army Corps of Engineers *Coastal Engineering Manual* (CEM).

While there are many guides which may provide useful information, the three containing potentially the most relevant information for a commercial port such as the Port of New York and New Jersey are: UFC 4-152-01 Design: Piers and Wharves, UFC 4-151-10 General Criteria for Waterfront Construction, UFC 4-150-06 Military Harbors and Coastal Facilities. The information in these manuals (United Facilities Criteria, 2005; 2010; 2012; 2013) and the corresponding sections of the CEM relevant to surge/wave resistant construction are summarized below.

Table 7: Summary of Relevant Sections of UFC 4-150-06 Military Harbors and Coastal Facilities

Section	Topic	CEM Reference
Chapter 2 HYDRODYNAMICS		
2-2	WATER WAVE MECHANICS	Section II-1
2-2.1	Selection of Design Waves	Section II-8
2-3	METEOROLOGY AND WAVE CLIMATE	Section II-2
2-4	ESTIMATION OF NEARSHORE WAVES	Section II-3
2-5	SURF ZONE HYDRODYNAMICS	Section II-4
2-5.1	Coastal Bottom Boundary Layers	Section III-6
2-6	WATER LEVELS AND LONG WAVES	Section IV-2
2-6.1	Water Wave Classification	Section II-5-2
2-6.2	Astronomical Tides	Section II-5-3
2-6.4	Storm Surge	Section II-5-5
2-6.5	Seiche	Section II-5-6
2-6.7	River Discharge and Flood Control Channel	Section II-7-6

	Discharge	
2-6.8	Extreme Water Levels	Section II-8-6-e
2-6.9	Numerical Modeling of Long Wave Hydrodynamics	Section II-5-7-f
2-7	HARBORS	Section II-7
2-11.2	Storm Surge and High Tide	Section II-5-5-a(3)
Chapter 3 SEDIMENT DYNAMICS		
3-5	FOUNDATIONS AND ANCHORING	Section VI-3-1
Chapter 5 PROJECT PLANNING		
5-3.1	Planning and Design Process	Section V-1
5-6.1.6.4	Piers and Wharves	UFC 4-152-01
Chapter 7 DESIGN OF MARINE IMPROVEMENT PROJECTS		
7-2	Types and Functions of Coastal Structures	Section VI-2
7-6.2	Vertical Front Structures	Section VI-7-3
7-6.5	Pile Structures	Section VI-7-6

Table 8: Summary of Relevant Sections of UFC 4-152-01 Design of Piers and Wharves

Section	Topic
Chapter 2 FACILITY PLANNING	
2-3.5	Pier and Wharf Deck Elevation
2-3.5.1	Overtopping
Chapter 3 LOAD REQUIREMENTS	
3-3.9	Wave Loading
3-4.4.1	Current and Waves

- ***Coastal Engineering Manual***

The Coastal Engineering Manual (CEM) is a comprehensive guidance document produced by the U.S. Army Corps of Engineers which details the science, tools, techniques, and methodologies relevant to construction within the coastal zone (USACE, 2002). The CEM is an updated version of the Shore Protection Manual which up until the release of the CEM was perhaps the most frequently used guidance document of its kind. The manual describes the basic principles of coastal processes, methods for computing coastal planning and design parameters, and guidance on how to formulate and conduct studies in support of coastal flooding, shore protection, and navigation projects.

The CEM is a living document with new sections added on topics such as navigation and harbor design, dredging and disposal, structure repair and rehabilitation, wetland and low-energy shore protection, risk analysis, field instrumentation, numerical simulation, the engineering process, and other topics as advances in the field warrant it.

Table 9: Summary of Relevant Sections of the Coastal Engineering Manual

Section	Topic
Part II HYDRODYNAMICS	
II-7	Harbor Hydrodynamics
Part V PROJECT PLANNING AND DESIGN	
V-2	Site Characterization
V-5	Navigation
Part VI DESIGN	
VI-3	Site Specific Design Conditions
VI-5	Fundamentals of Design
VI-6	Reliability Based Design of Coastal Structures

- ***FEMA Coastal Construction Manual***

The FEMA Coastal Construction Manual details the principles for planning, siting, designing, constructing, and maintaining residential buildings in coastal areas (FEMA, 2011). The manual is designed specifically for residential structures, however much of the information discussed within it is more broadly applicable. Specifically the discussions on coastal processes, building siting, and risk analysis are applicable in a port setting as well as for residential construction. In addition to the manual, FEMA also publishes a series of fact sheets and recovery advisories containing more targeted relevant information on array of topics ranging from the use of flood resistant materials to siting of electrical utilities.

Sea Level Rise

There were eleven weather and climate disasters in the United States in 2012 that caused more than $1 billion in damages each (NCDC, 2013, Website:http://www.ncdc.noaa.gov/news/ncdc-releases-2012-billion-dollar-weather-and-climate-disasters-information). The most damaging event was Hurricane Sandy, which caused approximately $65 billion in damages and claimed 159 lives. As reported in the National Climate Data Center's 2012 information release, Sandy's large size, with tropical storm force winds extending nearly 500 miles from the center, led to record storm surge, large-scale flooding, wind damage, and mass power outages along much of the East Coast. There appears to be a statistically significant trend of about 5 percent per year growth in the frequency of weather-related billion-dollar disasters (Smith and Katz, 2013).

Sandy highlighted the vulnerability of the Port of New York and New Jersey to storm surge and wave impacts. While storms such as Sandy are relatively rare, sea level rise increases the likelihood that storms capable of having similar impacts will occur in the future. The tide gauge at the Battery has measured a sea level rise of nearly one foot over the past century and, while not alarming in and of itself, if Sandy's water levels were reduced by a foot, the impact of the storm would have been significantly less. While the cause(s) of climate change has been disputed, there is consensus that globally water levels have risen considerably over the past century (IPCC, 2007).

The uncertainty surrounding the rate of future sea level rise has traditionally been a stumbling block for incorporating sea level rise into current construction and long-term planning. Even the recently revised FEMA floodplain maps for the New York region do not address sea level rise. Further, the Port Authority's design documents do not address the topic either, although there is an acknowledgement of its potential impacts and efforts to mitigate them by the agency.

There are many good examples of existing guidance that could be adopted or modified for use in the port by facility owners. The U.S. Army Corps of Engineers Engineering Circular 1165-2-212 details the procedure that the agency uses for its civil works projects (USACE, 2011). The methodology is well-described and requires the consideration of several sea level rise scenarios, but ultimately it provides leeway in the selection of the appropriate scenario depending on project details. Such a methodology could be readily adapted for use in the Port of New York and New Jersey and would enhance current design considerations.

Chapter 6 – Code Recommendations

Overall ports facilities are properly designed and constructed to withstand the forces of wind and waves generated by typical coastal storm or an allusion by an oceangoing containership. Sandy was considered an atypical event; however with the advent of sea level rise, there may be a higher occurrence of these types of severe storms in the future. Therefore, it seems prudent to consider potential upgrades to current guidelines for coastal infrastructure, particularly port infrastructure given its influence on international freight transportation and economic activity. Based on a review of existing building codes and the lessons learned for the interviews of port stakeholders, the following code recommendations are suggested for the port community's consideration.

Recommendation 1: The building codes of New York and New Jersey should be updated to include port specific sections. If the two states worked together, they could create uniform codes for the entire harbor region. These bi-state codes could apply to all public and private port facilities. Elements of Recommendations 2 through 8 could be included in the code to achieve greater uniformity. Even if the Port Authority of New York and New Jersey is not bound to abide by these state codes, although their current policy is to meet or exceed existing codes, new port facility building codes could provide essential minimum guidance for their facilities and all other facilities.

Recommendation 2: The facility owners in the Port of New York and New Jersey should adopt one or more of the documents listed in Chapter 5 as the primary source for all storm-related design for the Port of New York and New Jersey. It would be best if all adopted the same design document.

Recommendation 3: The states should adopt ASCE 24 for siting of critical utility and mechanical equipment. In conjunction conduct a survey of existing facilities to identify all critical utilities and mechanical equipment and their elevations.

Recommendation 4: The states should directly reference ASCE 24 for flood resistant design for all port facilities.

Recommendation 5: The Port Authority should add a section to their TCRM in Section 6.II devoted to port specific structural considerations (could reference one of the guides).

Recommendation 6: The Port Authority should add a Coastal Section to the TCRM specifically devoted to flood and wave resistant construction.

Recommendation 7: Update flood elevations should be provided in the Civil Guidelines to reflect the updated flood maps.

Recommendation 8: The facility owners in the Port of New York and New Jersey should adopt a reasonable and consistent methodology for incorporating sea level rise in their planned engineering upgrades. This methodology should be applied port-wide.

Chapter 7 – Disruptions & Resilience

Phases of Disruption and Recovery

Network industries are important enterprises in modern life that depend on specialized infrastructure and provide essential services to our society. There are four primary network industries in modern life. They are: power, water, communication, and transportation. These sectors are comprised of a mixture of public agencies and private businesses. They are identified by the National Research Council as "lifeline" sectors because of the critical nature of the relevant services they provide to support today's standards of living (Nash *et al*., 2009). Each of these sectors has both publicly-owned and privately-owned infrastructure. If their services are impaired because of damage to this infrastructure or their enterprise activities, then the community quickly suffers and our quality of life is negatively impacted.

The service capacity or output of each individual sector is determined by society's demand for their services. As the population has grown, the demand for water, power, communication, and transportation services has grown. Increasing demand has prompted these industries to increase their infrastructural and organizational capacity to meet the service requirement desired by the public. Correspondingly the infrastructure and sector organizations have become more complicated and technologically complex. The demands for service can influence government policies, which may have a greater influence than market forces in determined the individual industry's need for increasing the available service capability within their sector.

Although the industries initially emerged as single purpose sectors, their evolution and, in two cases (communication and transportation), globalization has resulted in their merging of outputs to allow for something greater than any one alone can provide. Hence, these sectors are increasingly interconnected and interdependent in their outputs (Figure 11).

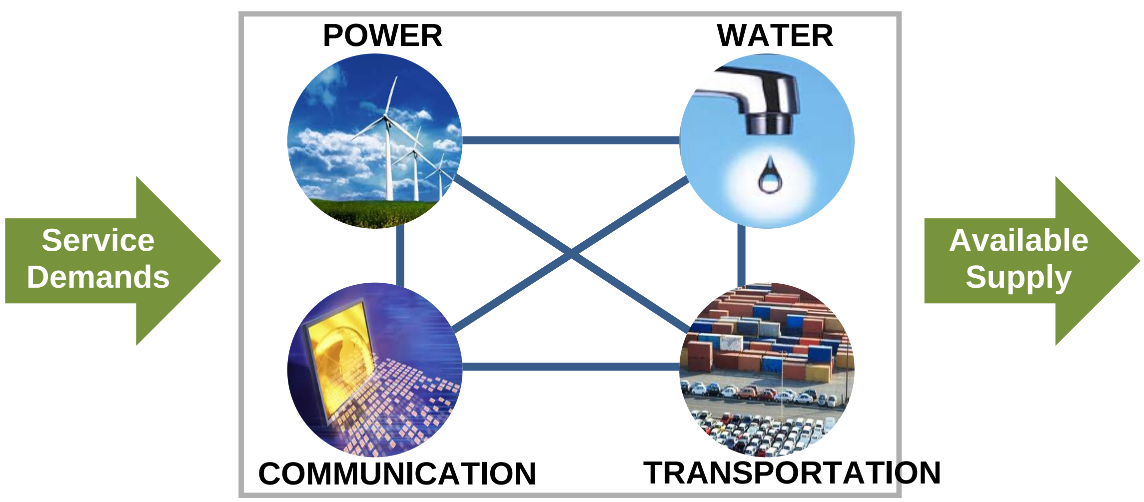

Figure 11: Network industry outputs

For example, the global logistics system that links the world economy is not only dependent on the mobility of transportation but on the real time communications provided by the internet and telecommunications. Both sectors depend on the availability of electric power to run their equipment or pump fuel. If there is a disruption, then the ability to ship cargo between markets is impaired. Further, these linkages are such that the four sectors are increasingly vulnerable to cascading failures during periods of extreme stress or disruption (Berle et al., 2011a; Berle et al., 2011b).

There are multiple examples of natural disasters and terrorist attacks causing significant disruptions to these sectors, particularly transportation systems. The economic harm of disruptions to the movement of international freight has been repeatedly documented and shown to be substantial to the national economy (Smith and Katz, 2013). There are four primary sources or drivers of disruptions (Mansouri et al., 2010):

- Natural events (floods, earthquakes, tornadoes, etc.)
- Human factors (accidents, terrorism, training, skills, behavior, etc.)
- Infrastructural failures (physical, mechanical, hydraulic, electrical/electronic, computational, etc.)
- Institutional failures (leadership, policies, protocols, procedures, guidelines, etc.)

A generalized scheme for conceptualizing a disruptive event is described as three progressive and distinct phases (Figure 12). The first phase is the pre-event phase and can be characterized by a baseline condition that is typically quantified by a system output metric. As part of standard emergency preparedness activities, an organization will make some level of physical and organizational arrangements during this phase to be ready for any foreseen problem. The second phase is the disruptive event itself. The third phase is the post-event phase. After the event occurs, there is an immediate response (i.e., an initial emergency and triage measures), which is followed by some form of recovery activity and adapting to the changed conditions.

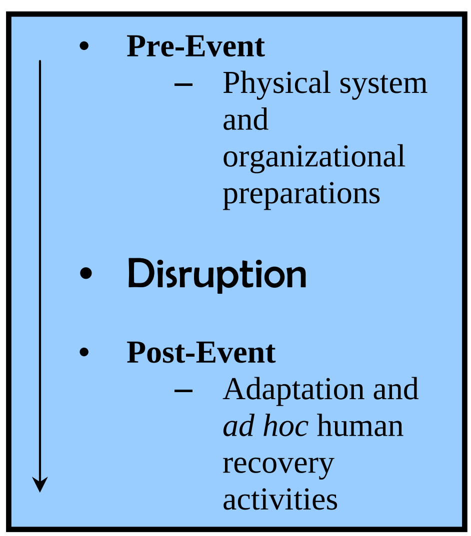

Figure 12: Three phase of a disruption event

The series of events is straight forward, but the reality of these disruptions can be catastrophic. Hurricane Sandy caused more than $50 to $70 billion in damages to the New York metropolitan region. Its disastrous effects closed the Port of New York and New Jersey for seven days, creating supply chain disruptions that rippled throughout the nation. Sandy was not a surprise. The New York/New Jersey has had experience with calamity, and yet "Super Storm" Sandy was still a major disaster with loss of life and widespread property damage. Preparedness as currently practiced is necessary but not sufficient to deal with the significant and cascading impacts of major disruptive events. Rapid and successful recovery from these events depends on creating resiliency enhancements to aid victims in their responses to such extreme events. It must be incorporated into the emergency planning process.

Character of Disruptions

There are several graphical methods that have been used to illustrate the impact of a disruption on system performance over time. The simplest is a picture showing output dropping dramatically after a disruption. The shock may cripple output for a brief period time. This can be the result of equipment damages, power loss or human upset and confusion, particularly when the victims try to re-orient themselves. This step function is depicted in Figure 13.

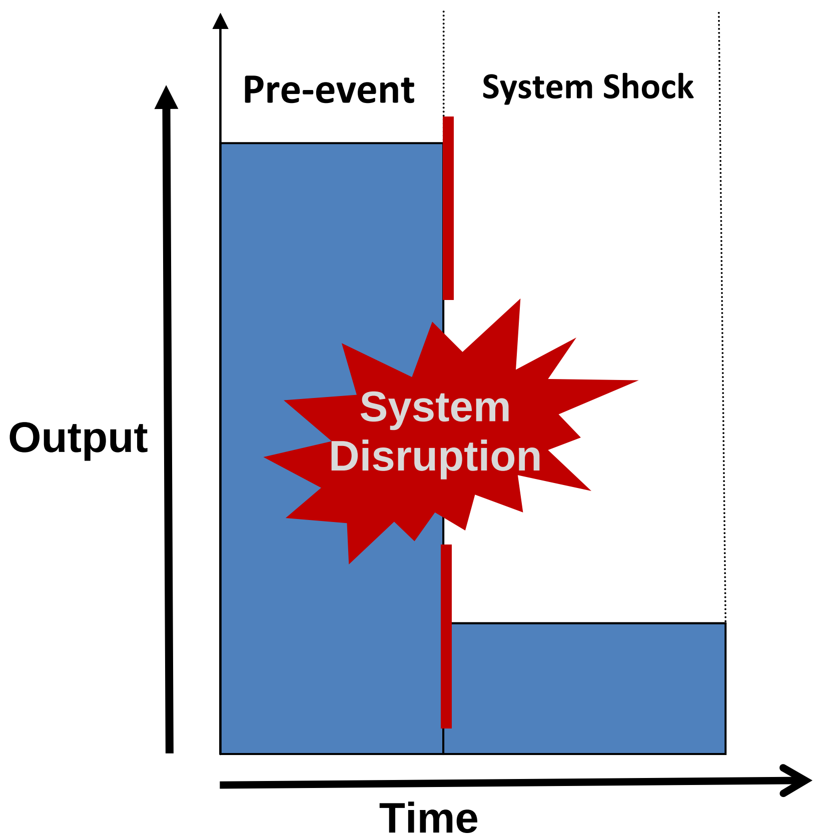

Figure 13: Simplified system disruption curve

Output declines proportionally to severity of the disruption and can be minimal to catastrophic. The performance failures can range from the simple loss of capacity and temporary system breakdown causing delivery failures to permanent destruction of assets (e.g., infrastructure and equipment) creating long-term diminished capacity reductions, or loss of life. The losses in one sector can lead to capacity losses in other sectors or even loss of life in the case of catastrophic system failures (e.g., lack of home heating oil during winter conditions, lack of 911 communications, etc.). During the period following Sandy's initial impact, all of these levels of system failures were observed.

There was cascading failures among the lifeline sectors. The storm's winds knockdown electrical power-lines and saltwater flooding damaged impacted electrical equipment; the result was the loss of power. No power impacted communications and transportation sectors. The loss of these services resulted in some areas have no clean water to drink. The previously mentioned National Research Council's report, which is entitled "*Sustainable Critical Infrastructure Systems*" (Nash *et al*., 2009, pg. 26), notes that:

> "Because these systems share rights-of-way and conduits above- and belowground, they are also geographically interdependent. These functional and geographical interdependencies have resulted in complex systems that regularly interact with one another, sometimes in unexpected and unwelcome ways. Because these interdependencies were achieved by default, not by plan, they create vulnerabilities *whereby a failure in one system can cascade into other systems* (emphasis added), creating more widespread consequences than those resulting from the one system originally experiencing the failure. For example, the failure to repair or replace a deteriorating water main could lead to a break in the main; the flooding of adjacent roads, homes, and businesses; the shutting off of water for drinking and fire suppression; the short-circuiting of underground cables; and the loss of power for a larger community. On a much larger scale, the failure of the levees in New Orleans in the aftermath of Hurricane Katrina in 2005 led to the flooding of large portions of the city, knocking out power, water supply, transportation, and wastewater systems for months and even years."

Pre-event Preparations

The phases of emergency management are prevention, mitigation, preparedness, response and recovery (FEMA, 1996; FEMA, 2012). Prevention and mitigation are activities to permanently protect facilities and reduce the risks of service failures. Preparedness is planning that takes place to be ready when an emergency occurs. Preparedness activities are a function of risk, where risk is the likelihood of an event and its consequences. The process of evaluating risk becomes more complicated as vulnerability increases and the consequences of failures become more complex.

The U.S. Department of Homeland Security (DHS, 2008) gives businesses a stepwise process for preparing an emergency plan prior to an event (http://www.dhs.gov/how-do-i/prepare-my-business-emergency). Under normal operations, the following preparedness activities may occur:

- Build sufficient capacity to meet anticipated demands
    - Infrastructural demands
    - Institutional demands

- Establish an agreement or charter, at least in principle, to a common corporate agenda.
- Identify and address economic, environmental and equity vulnerabilities and system requirements that may lead to system failures.

Typically industry has responded to these calls for preparedness by harden their infrastructure and vulnerable assets to protect service and by establishing emergency response teams. These activities may be sufficient for routine disaster but fail when the enterprise is impacted by extreme events, such as Sandy. There is a need to understand the elements of a system failure and to develop institutional safeguards that can be actuated during incidents. These may include developing detailed contingency plans for securing essential assets and human resources to restore services when local resources are stretched thin or are impaired.

Some organizations have prepared incident mitigation and contingency plans as a part of their corporate security and preparedness policy. The organizations that have followed through as an administrative matter are more likely to be forward thinking as to corporate vulnerability. They recognize the risks to potential business threats of future disruptive events. They may include specific areas where prior experience has demonstrated the need for addition steps beyond the routine steps mentioned above. These actions may include:

- Preparing a formal risk assessment
- Preparing a resilience assessment
- Enhancing system and infrastructure redundancy
- Developing robustness of physical, electrical, mechanical and cyber systems
- Stockpiling supplies and establishing open-end contracts for services, and
- Conducting training and emergency exercises.

Immediately After the Event

When a disruption occurs, there is often a brief period of shock, which is experienced by the victims, that is rapidly followed by a period of intense activity, particularly from emergency responders. The response phase may begin with a search and rescue effort but overall the focus will quickly turn to fulfilling the basic humanitarian needs of the impacted individuals or populations. Recovery begins after initial triage phase is completed and the immediate threat to human life has subsided. The primary goal of the recovery phase is to bring the effected area back to some degree of normalcy, even though there may still be some loss of productivity when compared to the pre-event level of performance or output. Figure 14 presents a diagram that represents this process.

Enhancing Output

Because there are often added resources made available following an extreme event or disruption to help with the restoration of services by public agencies and private organizations, there is an opportunity to enhance productivity with new technologies or other enhancements beyond the standard practice of seeking service restoration to the prior output levels. Government agencies set the bar at recovery (i.e., to re-establish the prior output or conditions) because using funding from taxpayers outside the region to upgrade performance may put another region at a competitive disadvantage and create a political backlash. Industry, however, may see the re-building process as an opportunity to upgrade by piggy-backing onto the inflowing government restoration investments.

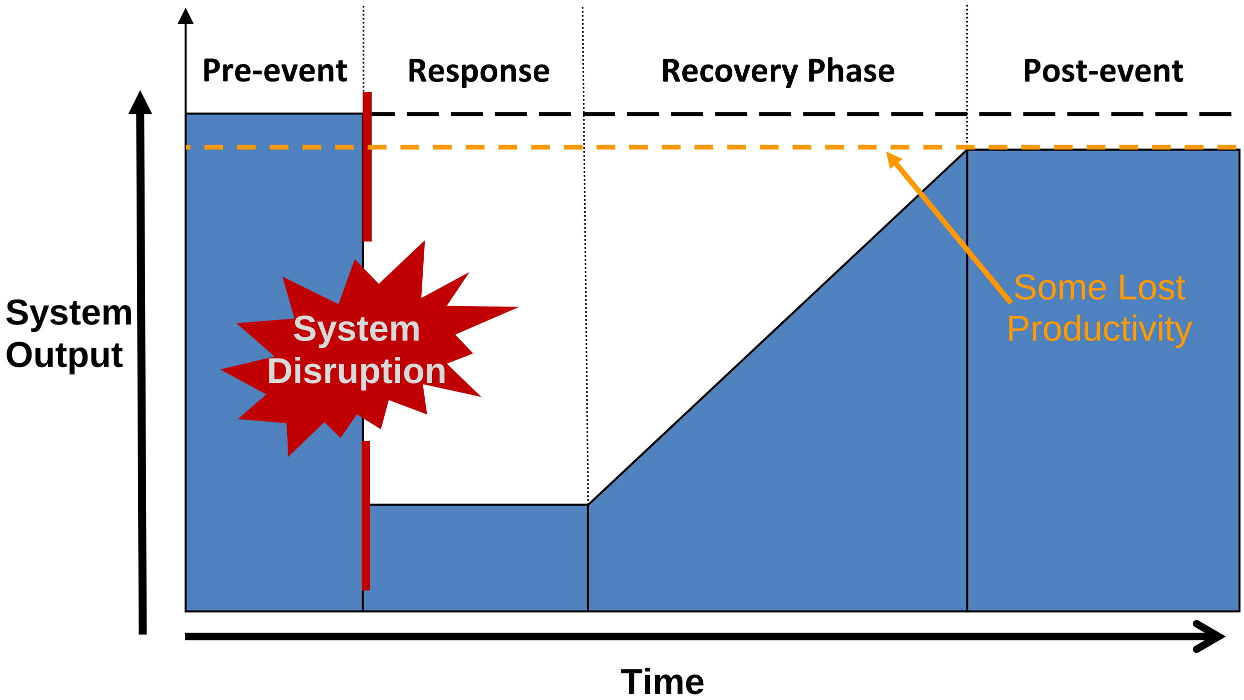

Figure 14: Recovery curve with some lost productivity

Particularly when there is a public–private partnerships, the private sector is often more aggressive than the public sector in the re-building process. They may insist in getting the greatest advantage achievable under the circumstances. Figure 15 depicts the disruption curve with this scenario of striving for improving infrastructure and facilities to achieve enhanced output following a disruption.

Post-Disruption Restoration

The ability to recover following a disruptive event depends on many factors. However from this study it appears that it is the human factors that are the most influential. The Port of New York and New Jersey's waterway system was opened and functional within seven days, which as many of the interviewees said is truly amazing considering the extend of the damages. As reported by Smythe (2013), this successful restorative effort was due, to a large extent, to the local expertise and coordination activities within the port community as exercised through the MTSRU. Specifically, she found that that it was the port partners' shared common culture and commitment that was the basis of a shared goal of getting the port open. Previous experiences with other catastrophic events (such as the attack of September 11th, Hurricane Irene, and the downed US Airways flight in the Hudson River) gave these port stakeholders prior experiences in acting together and helped other individuals to also work together in an efficient fashion to limit the time delay in re-opening the port. Beyond their collaboration, another key to their success was their ability to improvise before, during, and after the storm (Smythe, 2013).

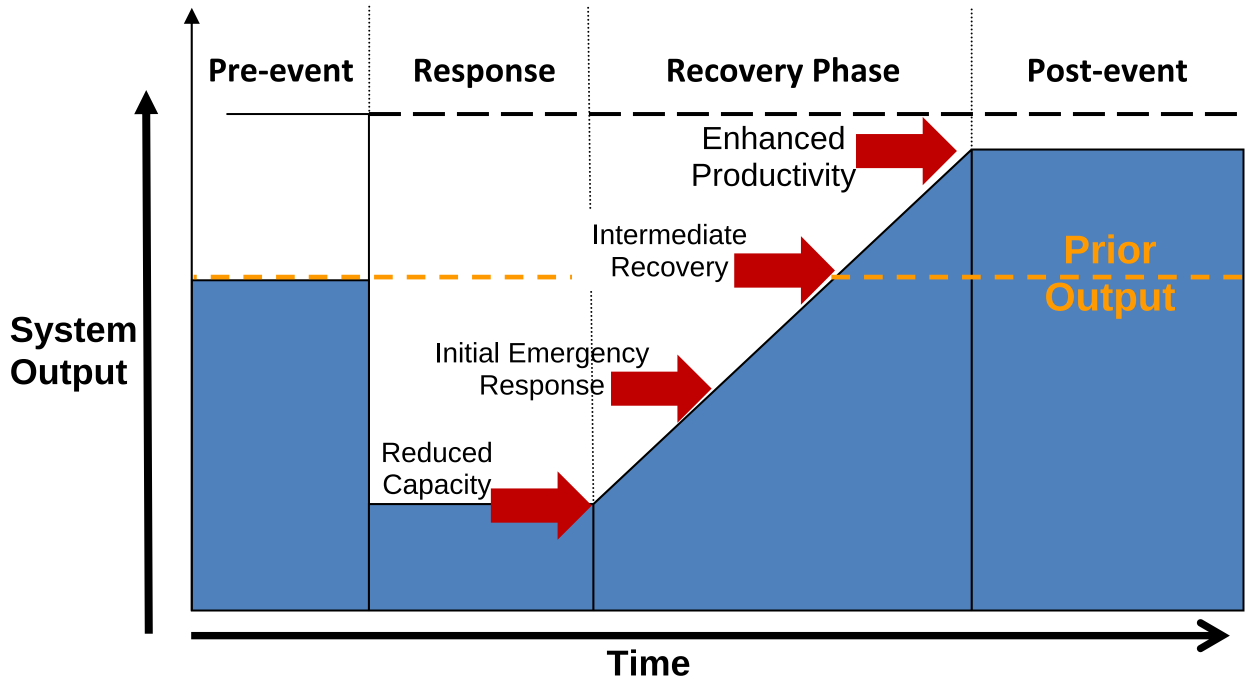

Figure 15: Recovery curve with enhanced productivity

Drawing upon these observations, there are several characteristics that seem to enhance port resilience and lead to an efficient recover process following a disruption. They include:

- Promoting the alignment of public, private, and political goals
- Agreeing to *shared outcomes* that:
    - Empowering known public-private champions
    - Identifying and acknowledging values and norms similarities
    - Achieving shared end-point(s) and recovery goals
- Standing-up command centers with clear chain of command and organizational collaboration based on pre-event agreements
- Allowing independent actors freedom to work outside of institutional boundaries.

Resiliency Processes

Finding a framework for enhancing resilience and incorporating that framework into current processes for emergency management has not been forthcoming even with years of effort in the homeland security community (Wakeman and Klein, 2013). Specific process recommendations for creating resilience or enhancing resilience in the port sector appear in the literature infrequently (Air *et al*., 2010; Chhetri *et al*., 2013). There have been papers in other areas that have made process recommendations for enhancing resilience in various industries or discipline areas (Little, 2002; Dalziell and McManus, 2004; Walker and Salt, 2006; Alderson *et al*., 2011).

Often in these papers the key ideas or concepts are repeated. Two papers (Christopher and Peck, 2004; Vugrin and Turnquist, 2012) illustrate the range of ideas that have been recommended to create or increase resilience. Christopher and Peck offered five principles for increasing resilience in supply chains that highlight several key themes previously mentioned. They included: (1) re-engineering -- to remove chokepoints, (2) develop a base strategy, (3) build collaboration, (4) enhance agility, and (5) create a management culture. From a different perspective, Vugrin and Turnquist presented similar ideas around the concept of capacity. They discuss three related capabilities with respect to improving network infrastructure resilience. To increase resilience of network industries, they recommended providing absorptive capacity (to withstand disruptions), adaptive capacity (to allow flows in the network to utilize alternate pathways), and restorative capacity (to enable rapid and cost effective recovery). These types of ideas and recommendations regarding a resilience process are similar but fragmented making development of a common stepwise process difficult to configure. However, the principles seem to be repeated; principles that were heard during the stakeholder interviews for this study.

Merging these principles and the descriptions of lessons learned by stakeholders as well as the observations presented by the interviewees, a simple stepwise process was formulated for the Port of New York and New Jersey. The various procedures were distilled to obtain a generalized resilience enhancement process, which may be applicable to other ports.

The outcome of the synthesis gives two pathways or processes to achieve increased resilience that are grounded in the physical environment and the human participants. These activities that can take place prior to a disruption (i.e., pre-event) or they can take place following the occurrence of an incident (post-event). These two timeframes are further divided into those issues that are: (1) primarily defined by infrastructure and organizational mandates and (2) those issues that are characterized by human behavior. The features of the generalized pre-event processes are presented below:

(1) Pre-event preparations for Physical Systems

- Harden facilities
- Remove choke points (that can cause obstacles or barriers)
- Building capacity (to enhance base service delivery)
- Consider building redundancy (to increase agility for use in emergency circumstances)

(2) Pre-event preparations for Human Systems

- Establish stakeholder groups of people with shared interests
- Prepare and ratify organizational charters that define goals and roles and responsibilities of participants to achieve those *stated and shared* goals
- Establish a communications plan to foster cooperation and collaboration
- Distribute contact information including virtual & paper lists including:
    - Land-line and cell numbers, and
    - Emails and physical addresses.

Following a disaster, there is an initial period of shock and disbelief that must be overcome in order for a reaction to be initiated; the response can be local leaders setting a course of action, an *ad hoc* organization to be established by the impacted parties, or waiting for outside assistance to arrive. The duration and severity of the disruptive shock will vary depending on the type of event (i.e., natural or human initiated) and amount of emergency resources required to stabilize the circumstances.

Beyond overcoming their fear that is generated by a severe disruptive event, the people involved will accelerate their reaction time if they having prior knowledge of each other's character and range of skills. This can be achieved by having had shared training and real-time emergency experiences. There are also training and exercise practices that may assist in enhancing the range of emergency responses and improving the assistance given to the victims of an incident. The suggested post-event processes are presented below:

(1) Post-event activities for Physical Systems

- Set-up Incident Command Center (formal management center)
- Survey and establish the range of impacts
- List and prioritize recovery efforts
- Allocate resources and emergency supplies.

(2) Post-event activities for Human Systems

- Establish a communications network among leaders and staff
- Allow *ad hoc* collaborations between public-private leaders during the unfolding of recovery, drawing upon trusted relationships
- Share information and seek to promote awareness of critical conditions
- Strive to highlight successes and overcome challenges to lift spirits

Human Factors/Social Capital

It was evident from the interviews that stakeholders felt that one of the keys to their success in reopening the port quickly was their ability to improvise and establish *ad hoc* processes that drew on their prior relationships, their shared experiences, and their trust in one another's professional expertise. In the jargon of safety and security, these issues are often termed "human factors". Human factors is an area of psychology that focuses on a range of different topics, including workplace safety, human error, product design, human capability, and human-computer interaction (Cherry, 2013). Smythe (2013) considers that the powerful relationships between port partners represent a form of "social capital", which she describes as "relationships between individuals, characterized by respect, trust, credibility, reciprocity, and networks."

There are many definitions of social capital used by different disciplines. The variety of definitions is because of social capital's highly context specific nature and its conceptual complexity (Dolfsma and Dannreuther, 2003). "Social capital" seems to be a better descriptor of the human behaviors that distinguish the stakeholders in the port's recovery than the term "human factors", although it is the preferred term for maritime security evaluations. Most of the interviewees had a common focus on social relations that had productive benefits. For this study, social capital is used and is defined as the capacity of people to solve problems from a shared institutional framework.

As reported in the interviews, the port partners' relationships are further defined as having shared values. Because of their shared values and institutional framework (i.e., the Marine Transportation System Recovery Unit), they were able to provide each other mutual access to information and resources. It is these relationships within the MTSRU that encouraged action in the face of uncertainty. It can be relied upon in times of crisis to breed resilience. W. Adger (Adger, 2003; Adger *et al.*, 2005) has reported social capital as a key to achieving resiliency following other coastal disasters.

Additionally, the community spirit demonstrated by the MTSRU seemed to create a magnetic attract to others that also volunteer their assistance to the cause. This shared spirit of community spread. Interviewees reported that their collaborations and shared commitment seemed to spawn outside interest, resource contributions, and person time contributions by third-parties from other states, those outside the area immediately impacted by the storm.

So the port opened to maritime activity -- but the landside continued to be damaged and mainly inoperable. There was no MTSRU for landside activities. What was missing was the same organizing principles that were working for the MTSRU on the marine portion of the port did not seem to work in congealing the transportation stakeholders for the terminal facilities and other intermodal portions of the supply chain. Further this sector seemed cut-off from other network sectors (including power) and their recovery activities. Clearly, the relevance of social capital or human factors in the achievement of system resilience deserves considerably more research.

Chapter 8 – Port Resilience Strategy

Physical Systems Can Fail

In general the port terminals and surrounding region faced cascading failures in the lifeline sectors starting with power. Because of the surge, many areas were flooded with saltwater that resulted in electrical service failures, including transformers exploding and power shorting out tripping circuit breakers. Electric power was lost.

As power was lost in homes, businesses, and industries, communications began to fail either because of flooding causing short circuits direct of phone equipment or because equipment had to switched to back-up generators for power. Subsequently these generators lost power because their generating capability was limited by their fuel availability to run their motor, which was often used up within 24-hours. Additional fuel was not available because there was no power at the oil distribution centers to run pump motors or truckers to deliver it. Many trucks were flowed (making them unusable) and available truckers were working to remove debris from the streets and damaged facilities.

As fuel became unavailable, transportation became increasingly uncertain or stopped. Subways and rail tunnels had been flooded. Autos were limited to fuel in local service stations, if they had power to pump the gas, and traffic was highly congested throughout the region. In addition local roads were blocked because of debris or downed power lines. Finally water became a problem in many areas because of contamination by overflowed wastewater systems, broken pipes, or back-up storm drains. Drinking water had to be imported into several neighborhoods in Staten Island, Brooklyn, Queens, and areas in New Jersey including Hoboken. Many of our regional physical systems that we depend on to provide lifeline services failed to be resilient when impacted by Hurricane Sandy.

In Summary*: Physical systems can fail even with our best planning, design and construction*.

Human Behavior is Critical

It appears from this study that the process of achieving post-disruption recovery is more a function of human behaviors than a function of the design of the concrete and re-bar specified in port infrastructure. In practice, after the Sandy hit the port region, although achieving resilience might have been aided by the MTSRU or the Port Authority creating a plan beforehand, it was the strength of the shared attitude among port stakeholders to overcome the adversity facing the port that manifests itself and turned the tide during the crisis. This positive attitude created a common intention among the stakeholders to accomplish a desired goal, specifically "re-open the port". Repeatedly the comments of the interviewees and their observations included the following human factor consideration, herein paraphrased:

> The speed and effectiveness of post-disruption resilience efforts directly corresponded to the strength of the pre-existing culture of cooperativeness and the depth of a *shared commitment* of the impacted stakeholders to achieving the common goal of re-opening the port.

In the case of post-Sandy recovery and restoration, it was the cooperativeness among port stakeholders, whether as public or private-partners, that was the catalysis that sparked the rapid implementation of restorative activities. The port community's actions appeared to embody a spirit of productive *collaboration* towards all the various victims of this catastrophic event. In one interview it was mentioned that:

> "…in this unusual moment, the port partners lacked any sense of destructive competition and expressed a share will to overcome their common affliction."

In summary: *The human spirit is the true source of disaster resilience.*

Chapter 9 – Summary & Conclusions

Today's international supply-chain has sophisticated infrastructure and equipment that provides extensive links to providers, suppliers, and customers, minimizing inefficiencies but simultaneously increasing vulnerability. Because of the enormous number of containers that a single post-Panamax ship discharges during a port call, ports require an expansive network of waterway and landside infrastructure. Disruptions to waterways and landside infrastructure not only threaten the continuity of operations but also have an adverse ripple effect throughout the economy. Disruptions may be local, such as waterway closures, or may be regional, such as the shutdown of several ports from a significant weather event, like Hurricane Sandy.

New York Harbor was directly in the path of the most damaging part of the storm causing significant impact on many of the facilities of the Port of New York and New Jersey. The U.S. Coast Guard closed the entire Port to all traffic before the storm hit on October 28th. The Coast Guard, Army Corps of Engineers, the Sandy Hook Pilots and others were quickly out on the water to survey the damage and to quickly re-open the Port. However, it was not fully reopened to vessel traffic until November 4th. Even though the waterways were open, numerous port terminals and maritime facilities did not resume their operations for several more weeks because of power failures and damages to the facilities and equipment. The impacts crippled the activities of the intermodal supply chain causing significant economic impacts at the start of the holiday shopping season.

This study was conducted to identify lessons learned that could assist in restoring the Port and its contributions to the supply chain to service more rapidly in the future. The study used interviews of key port stakeholders to gather information, to understand events, and to identify the circumstances that led to the Port's storm-related impacts and operational recovery. The project reviewed the existing design codes for infrastructure and attempted to identify how building codes could be improved. It also examine the activities and processes that enhanced port resiliency following the storm.

All interviews were conducted between January and September 2013. The participants include two federal agencies, two state agencies, a private pilot organization, an industrial association, and a private facility operator. There were several generalized principles that emerged from the interviews. They included:

(1) Safety of life is the prime consideration.
(2) Communications for decision-makers is critical. Make plans before hand to provide leadership across organizations with strong and redundant communication systems between the leadership team and the staff.
(3) The number and severity of natural disasters and terrorist attacks have increased in recent years. The current designs and procedures must be re-evaluated given the new conditions.
(4) Conduct drills and tabletop exercises. Exercises are needed to practice predetermined courses of action in an emergency.

While most of the waterside structures made it through the storm unscathed, there were many instances of wave and surge related damage to ancillary structures, equipment, and cargo throughout the port. Most of the major damage within the port was related to the inundation associated with the storm surge plus a high tide. While storms such as Sandy are relatively rare, sea level rise increases the likelihood that storms capable of having similar impacts will occur in the future. Hence, it is prudent to consider potential upgrades to current guidelines and codes for coastal infrastructure. Based on a review of existing building codes and the lessons learned for the interviews, the following code recommendations are suggested:

(1) The building codes of New York and New Jersey should be updated to include port specific sections that are uniform for the entire harbor region.
(2) Specifically the states should adopt ASCE 24 for siting of critical utility and mechanical equipment and directly reference it for flood resistant design for all port facilities.
(3) The Port Authority should add a section to their lease agreements devoted to port specific structural considerations.
(4) The facility owners in the Port of New York and New Jersey should adopt a reasonable and consistent methodology for incorporating sea level rise into their facility upgrades.

An attempt to identify port resiliency principles from the literature had limited success due to the lack of available after-action accounts in ports. However some the principles seem to be repeated by several authors -- principles that were heard during the stakeholder interviews. However some the principles seem to be repeated by several authors, principles that were heard during the stakeholder interviews conducted during this study. Merging these principles and the descriptions of lessons learned by stakeholders as well as the observations presented by the interviewees, a simple stepwise process was formulated for the Port. The various procedures were distilled to obtain a generalized resilience enhancement process, which may be applicable to other ports. The outcome of the synthesis gives two pathways or processes to achieve increased resilience that are grounded in the physical environment (i.e., infrastructure and technical procedures) and the human participants and their activities. These activities that can take place prior to a disruption (i.e., pre-event) or they can take place following the occurrence of an incident (post-event). These two timeframes are further divided into those issues that are: (1) primarily defined by infrastructure and organizational mandates and (2) those issues that are characterized by human behavior.

It was evident from the interviews that many stakeholders felt that one of the keys to their success in reopening the port quickly was their ability to improvise and establish *ad hoc* processes that drew on their prior relationships, their shared experiences, and their trust in one another's professional expertise. As reported in the interviews, the port partners' relationships are further defined as having shared values. Because of their shared values and institutional framework (i.e., the Marine Transportation System Recovery Unit), they were able to provide each other mutual access to information and resources. It is these relationships within the MTSRU that encouraged action in the face of uncertainty. It can be relied upon in times of crisis to breed resilience. Additionally, the community spirit demonstrated by the MTSRU seemed to create a magnetic attract to others that also volunteer their assistance to the cause. This shared spirit of community spread. Interviewees reported that their collaborations and shared commitment seemed to spawn outside interest, resource contributions, and person time contributions by third-parties.

So the port opened to maritime activity -- but the landside continued to be damaged and mainly inoperable. There was no MTSRU for landside activities. What was missing was the same organizing principles that were working for the MTSRU on the marine portion of the port did not seem to work in congealing the transportation stakeholders for the terminal facilities and other intermodal portions of the supply chain. Further this sector seemed cut-off from other network sectors (including power) and their recovery activities. Clearly, the relevance of social capital or human factors in the achievement of system resilience deserves considerably more research.

Chapter 10 - Future Research

The question of how to frame emergency management processes to fully address port resilience strategies in disaster response is still unanswered. The answer is partly a matter of risk management as has been suggested by knowledgeable officials (Bethann Rooney, PANYNJ, and Col (Ret.) John Boule, USACE) at the U.S. Coast Guard Resilient Ports Workshop, held at the USCG Academy on September 20, 2013. There is a great deal of literature on the subject that comes out of the port security activities that have been underway since the attacks of 9/11. However, the literature is somewhat limited and will require additional investigations and analyses particularly with respect to two critical issues presented in this report: 1) the tendency for lifeline sectors/network industries to experience cascading failures and 2) influence of social capital in contributing to system resilience.

Network Industry Cascading Failures

The issue of the interdependencies of network industries and the cascading failures that occurred during Sandy (i.e., loss of communications and power failures) is a phenomena that has been reported before with Hurricane Katrina and other major disruptions. The questions that emerge include what are the interrelationships between sectors, how are the interdependencies manifested, and what are the characteristics of their vulnerabilities that contribute to the phenomena of cascading failures? Clearly there are interdependencies between network industries that must be further investigated.

This study has provided a beginning for understanding the interdependencies between port infrastructure and a variety of other infrastructure areas. It describes examples for the port complex and presents code and other recommendations based on some of the experienced cross-sector impacts. Future research could explore this further with a comprehensive and systematic understanding of the interrelationships between port infrastructure and other infrastructure sectors. For example, a knowledge of dependencies and interdependencies is especially important given that the use of new technologies for remote controls and communication, which are becoming more prevalent. An inventory of the use of electric power and other infrastructures in port operations would be an important dimension of future research in order to anticipate what some of the likely areas of impacts of storms will likely be in the New York-New Jersey port in the future. This research is an important part of an overall risk assessment for the impact of storms and future sea level rise on ports.

Human Contributions to Resiliency

In addition to research on network infrastructure systems, there is a need for more research that is cross-cutting and attempts to align engineering methodologies and social science findings to enhance resilience practices. Future research along this theme is justified given the findings in this study and the work by others including T. Smythe (2013) on the importance of social capital in recovery of the Port of New York and New Jersey following Hurricane Sandy. New interdisciplinary research is needed to understand how social capital or human factors play into enhancing resilience in these network systems, and particularly marine transportation systems given their mix of public and private stakeholders.

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APPENDIX A
2013 Post-Sandy Interviews

Date	Agency/Organization	Interviewee
January 14	**PANYNJ**	Andrew Saporito Deputy Director, Development 225 Park Ave South New York, NY
January 31	**PANYNJ**	Robert Harley Manager, Newark-Elizabeth Facilities Port Newark Administration Bldg Newark, NJ
February 22	**USCG**	CDR Linda Sturgis Chief of Prevention Department Sector New York 212 Coast Guard Drive Staten Island, NY 10305
		LCDR Anne M. Morrissey Chief of Waterways Management Division Prevention Department
		LCDR Brian McSorley Deputy, Port Safety and Security Operations Prevention Department
February 22	**Sandy Hook Pilots**	Captain Andrew W. McGovern, MNI President New Jersey Sandy Hook Pilots Association 201 Edgewater Street Staten Island, NY
		Captain Dennis Wheeler New Jersey Sandy Hook Pilots Association
		Captain Rick Schoenlank New Jersey Sandy Hook Pilots Association

Date	Agency/Organization	Interviewee
March 22	**NJ Petroleum Council**	James E. Benton Executive Director 150 West State Street Trenton, NJ Scott J. Ross Associate Director
April 25	**NJ Homeland Security & Preparedness**	Joseph Picciano Deputy Director State of New Jersey Trenton, NJ Bradford C. Mason Assistant Deputy Director Steven Gutkin Chief Planning & Project Management Bureau
June 17	**PANYNJ**	Quentin Brathwaite Director, Storm Mitigation and Resilience 223 Park Avenue South, 4th Floor New York, NY 10006 Susanne DesRoches Sustainable Design Manager Engineering Department Two Gateway Center Newark, NJ 07102
June 25	**Union Dry Dock**	Robert Ferrie Vice President 901 Sinatra Drive Hoboken, NJ

Date	Agency/Organization	Interviewee
Sept 24	**USACE**	LTC John A. Knight Deputy Commander New York District US Army Corps of Engineers Joseph Seebode Deputy District Engineer New York District Corps of Engineers Jacob Javits Federal Building New York, NY 10278-0090

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